Inventory Parameter Management and Focused Continuous Improvement for Repetitive Batch Manufacturers.

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Synopsis.

What this thesis proposes is a methodology to assist repetitive batch manufacturers in the adoption of certain aspects of the Lean Production principles. The methodology concentrates on the reduction of inventory through the setting of appropriate batch sizes, taking account of the effect of sequence dependent set-ups and the identification and elimination of bottlenecks.

It uses a simple Pareto and modified EBQ based analysis technique to allocate items to period order day classes based on a combination of each item's annual usage value and set-up cost. The period order day classes the items are allocated to are determined by the constraint limits in the three measured dimensions, capacity, administration and finance.

The methodology overcomes the limitations associated with MRP in the area of sequence dependent set-ups, and provides a simple way of setting planning parameters taking this effect into account by concentrating on the reduction of inventory through the systematic identification and elimination of bottlenecks through set-up reduction processes, so allowing batch sizes to reduce.

It aims to help traditional repetitive batch manufacturers in a route to continual improvement by:

- Highlighting those areas where change would bring the greatest benefits.
- Modelling the effect of proposed changes.
- Quantifying the benefits that could be gained through implementing the proposed changes.
- Simplifying the effort required to perform the modelling process.

It concentrates on increasing flexibility through managed inventory reduction through rationally decreasing batch sizes, taking account of sequence dependent set-ups and the identification and elimination of bottlenecks.

This was achieved through the development of a software modelling tool, and validated through a case study approach.

Key Words: **Inventory Control, MRP Parameter Setting, Capacitated Batch Sizing, Repetitive Batch Manufacturing**.

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1 INTRODUCTION.

1.1 RESEARCH AREA.

In the increasingly competitive world of the 1990's, the ability to predict and control the behaviour of an inventory management system can have an important effect on the overall business performance of a manufacturing organisation. The earlier in the planning cycle that this predictive ability can be applied, the better the chance will be of taking effective remedial action.

One of the factors which has a major impact on the way in which an inventory management system performs is the way in which the inventory parameters are set. This thesis describes a methodology aimed at assisting repetitive batch manufacturers in this area and is split into two phases, phase 1 dealing with the planning system (MRP) parameter setting, and phase 2 dealing with the operational matching of the load to the available capacity.

The main emphasis of the research is to provide a means to assist traditional repetitive batch manufacturers in a route to continual improvement, by providing modelling tools, and by simplifying the effort required to control the business.

It aims to achieve this as follows:

1. With a new theoretical modelling tool, the K^+ Methodology, containing 4 different modelling methods.
2. With a comparison of the results of using each of the new 4 modelling methods with the Economic Batch Quantity formula and existing practices.
3. With the creation of novel modelling software, using average symbolic descriptive and normative modelling methods.
4. With the success of the approach being validated using the following five criteria: the insight gained, the sensitivity of the model, its usefulness to the decision making process, the acceptability of the suggestions, and level of commitment elicited from the users.

The research was applied and used a case study approach. Utilitarianism was the formal model of science used, and Interpretivism the philosophical stance. The starting point for the research was the K-Curve Methodology (KCM) *(Shah, Burcher, Relph 1990) (Shah 1992)*, which considers two dimensions, cost and the number of orders raised, however it is limited in applicability to purchased parts, being based on the Economic Order Quantity (EOQ) formula. The current literature then was examined for existing practices and historical precedences, and a new methodology created, the K^+ Methodology, by initially substituting a modified Economic Batch Quantity (EBQ) formula *(Harris 1913)* for the EOQ in the KCM. There then followed the recognition that set-up costs were variable, and sequence dependent, which led to the introduction and use of set-up groups and set-up reductions into the model. Comparisons between the different modelling scenarios were performed in three dimensions; capacity, administration and inventory value and the validation of the method was through working papers, published articles, seminar presentation, conference presentation, field trials with manufacturers.

The modelling process used has been developed to help to overcome one of the important criticisms of MRP, namely that MRP accepts the set-up times etc. as given and does not provide a mechanism for continual improvement.

The fundamental difference between this approach and others, such as the EBQ, Exchange Curve, or K-Curve, is firstly, that it considers the capacity load at the strategic parameter planning stage, and secondly, that this load is considered in terms of the set-up reductions possible through normal, good, scheduling practices. The first point is generally ignored by the tools available to assist in the strategic parameter setting stage, and the second point is generally only considered at an operational level by finite capacity planning tools.

Seven case studies were undertaken involving five participating companies, as follows:

- Boots Contract Manufacturing provided two case studies, the D95 Tablet factory concerned with the packaging of vitamin tablets and D106 Sterile Products concerned with the bottling of Optrex lotion.
- Rhône Poulenc Rorer, a pharmaceutical manufacturer provided one case study concerned with the packaging of tablets.
- FMCG provided a case study concerned with moulding plastic components.
- Caradon Terrain, a manufacturer of plastic plumbing systems, provided two case studies, one in the extrusion of guttering and pipes, and the other in assessing the feasibility of setting up a cell for underground components.

- Zeneca Pharmaceuticals provided one case study concerned with the packaging of tablets.

In order to conduct the case studies it was necessary to translate the methodology into a coherent, open ended and robust piece of symbolic modelling software, capable of coping with multi operation items with sequence dependent set-ups. This was designed to serve five purposes:

- To accurately translate the theoretical background into a working model.
- To obtain results from the modelling process which were consistent, repeatable, reliable, and in terms that were acceptable to the participating companies.
- To examine the applicability of the overall approach as a consulting tool capable of provoking creative and perceptive thought about the organisation and organisational problems.
- To assist in the problem solving process of choosing between alternative courses of action relevant to the problems faced.
- For the problem solving activity to have substance, with critical appraisals being made of the generated outcomes.

As well as this, thought had to be given to the type of modelling that would be used. The method chosen to satisfy the above criteria was average symbolic modelling, using PC based relational database technology, and developed using a fourth generation programming language. The system that was developed had to be open ended, dealing with relationships within the data which were not fixed, and able to communicate in both directions with a variety of host planning systems. Three key performance criteria were chosen to assess the relative merits of different strategies:

- The financial load in terms of average inventory value.
- The administrative load in terms of orders per annum.
- The capacity load in terms of set-up and run minutes per annum or per day.

In each of the seven case studies, each of the four modelling methods are compared with the current parameter settings and the EBQ. Many models were constructed using each of the modelling methods for each company, looking into the effects of implementing improvement programmes or changing the operational parameters.

The validation of the software took five forms, as follows:

- The publication of the proposed methodology in the form of working papers and in refereed journals to promote the wider dissemination of the ideas behind the methodology, and to invite a critical response from the academic and business communities.
- The presentation of the theoretical background internally within Aston University, at seminars at IBM and with the presentation of a paper at the 1996 IOM Conference.
- By the use of standard testing methods to ensure that the software performed to specification.
- By field trials with the participating companies to ensure that there was a real need.
- Once it was accepted by the interested parties that there was a need for the software, it was performing as specified, and that the specification was correct in its interpretation of the business problem, and on the utility value of the methodology relative to alternative methods.

The power of this methodology is not solely in the ability to calculate the business performance passively and then compare this against current performance measures, or in the ability to leap forward from MRP and provide true capacity constrained batch sizing, but the key to its success lies in the ability of the underlying modelling process to perform experiments which can help to predict the likely behaviour of the business in a variety of categories. It is the predictive ability of the modelling process (used in conjunction with its goal searching capability) that provides the key to the power of this approach.

The methodology was designed to help to answer these sorts of questions:

- Can the current inventory performance be improved upon by implementing an improved set of inventory parameters?
- What would be the effect on inventory and administration of decreasing all Set-Up times by 10% whilst loading the Work Centres to the same level?
- What would be the effect on inventory and capacity if our administrative system could cope with double the order workload?

- Where should we concentrate our Set-Up reduction programme?
- Is a Set-Up reduction programme what is required, or do our administration systems need improving first?
- Is the continuous improvement programme focused on the bottleneck resource(s)?
- How much money will be tied up in stock?
- If we can achieve a Single Minute Exchange of Dies (SMED) on a bottleneck resource will we still require a new machine?
- Which resources are bottlenecks?

1.2 Map of the Thesis.

The thesis is divided into seven chapters, as follows:

Chapter 1 is an introduction to the research area.

Chapter 2 is concerned with a description and analysis of the main manufacturing planning and control systems and philosophies. As the research is concerned with setting planning parameters it is important to understand the context in which the research is conducted. The investigation is conducted from a manufacturing planning and control perspective with the MRP approach analysed first, then the JIT approach then the integration of MRP and JIT, and finally discusses the various inventory planning parameter in general use.

Chapter 3 examines the historical background to, and derivation of, the methodology used in this research. The first section examines the Economic Order Quantity (EOQ) formula, Coverage Analysis, and the K-Curve Methodology (KCM). The second section examines the use and abuse of costs, examining the different methods used by the accountancy profession in deriving costs, and demonstrates by example the wide range of cost values that can be obtained for the same items using the different costing methods. The final section deals with the derivation of the K^+ methodology. It details the way in which each of the four methods used in the research are derived, considers the use of set-up costs and proposes the use of three key performance indicators as a way of comparing the relative performance of different scenarios.

Chapter 4 considers the philosophical approach taken to the research. Within the O.R. (Operations Research) and I.T. (Information Technology) research areas the accepted research paradigm has generally been the positivistic research model, with this approach dominating the literature. In recent years interpretive methods of research have become more common with approaches such as the Soft Systems Methodology being used. The way that these seemingly contradictory philosophies are presented is one of mutual incompatibility, you are either an interpretivistic or a positivistic researcher. However, these approaches are not irreconcilable, and it is possible to use both approaches in a complementary manner.

Chapter 5 fixes the approach used by the research to modelling within an accepted theoretical framework, describes the types of models that can be used and their applicability, and the different modelling techniques that can be used within the various model types. Having established the veracity of the theoretical approach used within this research, the next topic considered was how to ensure that a model, when constructed, is a valid model, and how to differentiate a valid from an invalid model.

Chapter 6 looks at the development of the computer software required to support the case studies. This was designed to serve five purposes, firstly to accurately translate the theoretical background into a working model, secondly to obtain results from the modelling process which were consistent, repeatable, reliable, and in terms that were acceptable to the participating companies, thirdly to examine the applicability of the overall approach as a consulting tool capable of provoking creative and perceptive thought about the organisation and organisational problems, fourthly to assist in the problem solving process of choosing between alternative courses of action relevant to the problems faced, and finally for the problem solving activity to have substance, with critical appraisals being made of the generated outcomes.

Chapter 7 considers the results of the seven case studies carried out at five participating companies. It contains a description of the performance measures used to measure the effectiveness of the various scenarios, an analysis of the individual case studies, a comparison of the results of the different modelling methods, and a resume of the overall results.

Chapter 8 discusses the overall conclusions and results of the research.

2 PLANNING AND CONTROL SYSTEMS AND PHILOSOPHIES.

2.1 INTRODUCTION TO PLANNING AND CONTROL SYSTEMS AND PHILOSOPHIES.

This chapter is concerned with a description and analysis of the main manufacturing planning and control systems and philosophies. As the research is concerned with setting planning parameters it is important to understand the context in which the research is conducted. The investigation is conducted from a manufacturing planning and control perspective with the MRP approach analysed first, then the JIT approach, and finally the integration of MRP and JIT. It then looks at the continual improvement process from a consultancy perspective, and finally discusses the various inventory planning parameters in general use.

There is an explicit recognition that although MRP and JIT are often portrayed as mutually incompatible competing philosophies in the literature, in practice many firms have a mixed environment that integrates the salient features of each approach in a complementary manner.

2.2 MRP.

2.2.1 Introduction.

MRP I (Materials Requirements Planning) started in the early 1960's in the USA as a computerised approach for the planning of materials acquisition and production, and is most commonly associated with a batch manufacturing environment. In the UK, computer based MRP is used by 96% of engineering firms employing more than 50 people, and over 50% of all manufacturing companies *(Luscombe 1993)*, and so can rightly claim to have achieved a high penetration in the marketplace.

The MRP philosophy has been used successfully in many different companies *(Bennett, Lewis, Oakley 1988)* over a wide variety of products when applied to what are essentially assembly situations, with early claims *(New 1976)* of up to a 30% reduction in component stocks and up to a 25% reduction in indirect employees. A more recent survey *(Wight 1986)* showed that 85% of the companies had performance improvements and 66% stating that MRP had equalled or exceeded their expectations. However, the implementation of MRP can be problematical for companies, in other surveys only 16 of the 33 companies in the sample claimed to have successful implementations*(Lawrence 1986)*, and only 11% of UK implementations were claimed to have realised their full potential with the rest only realising up to 10% of the available benefits *(Harrison 1993)*.

It has its basis in the planning of manufacturing based upon lead times for production or procurement, to produce a time-phased list of material requirements based on a stated level of demand for the saleable items over a number of periods (the planning horizon). It differed from the classic re-order point system in two important respects *(Hall 1989)*, firstly, that demand for components was calculated from the demand for the parent items, rather than being statistically forecasted, and secondly, that replenishment orders are time phased based on lead time and actual component demand.

The traditional manufacturing approach up to this time had been one whereby factories were generally divided functionally, and with co-ordination between functions simplified through the use of inter-process stocks. MRP represented a great leap forward in terms of the degree of lateral co-ordination across the functions, with an attendant reduction in stocks. It regarded the sharing of information as an essential instrument in achieving the co-ordination of the manufacturing activities.

MRP II (Manufacturing Resource Planning), as well as providing a check on available capacity against the load on that capacity that the plan would generate, was intended to achieve the co-ordination of the physical production with activities such as marketing, purchasing, accounting and distribution.

However, although the approach could in many ways be viewed as correct in the sense that it forced an explicit recognition of the key role that information plays in the manufacturing enterprise, the limitations in the MRP approach in areas such as high cost and low flexibility, constraints of the information processing technologies used, (batch rather than real time operation, inadequate filtering of unnecessary information, establishing access authorities to match personal responsibilities etc.) and a somewhat ad hoc imposition of the MRP philosophy (that is the use of both MRP I and MRP II) on existing organisational structures has led to productivity gains not being realised.

The MRP philosophy also ignored organisational issues, with companies having to change the way their businesses operated to suit the demands of MRP *(Harrison 1990)*. This did not address fundamental problems such as the benefits to be gained from the simplification and rationalisation of the manufacturing process, rather concentrating on making existing practices more efficient *(Bauer et al. 1994)* and so failing to highlight areas for potential improvement by the acceptance of set-up times, lead times, batch sizing rules etc. as given.

2.2.2 MRP In Use.

All that was required to make MRP I work, apart from a computer, was a time phased Master Production Schedule (to provide the demand), detailed Bills of Materials (product structure information), batching parameters (to derive lot sizes for manufacturing or procurement), inventory levels (to net off gross demand), and lead times for manufacturing and procurement (to establish when production should be started or orders placed). Manufacturing capacity was assumed infinite, time scales were coarsely defined in weekly buckets, and warehousing capacity was assumed limitless.

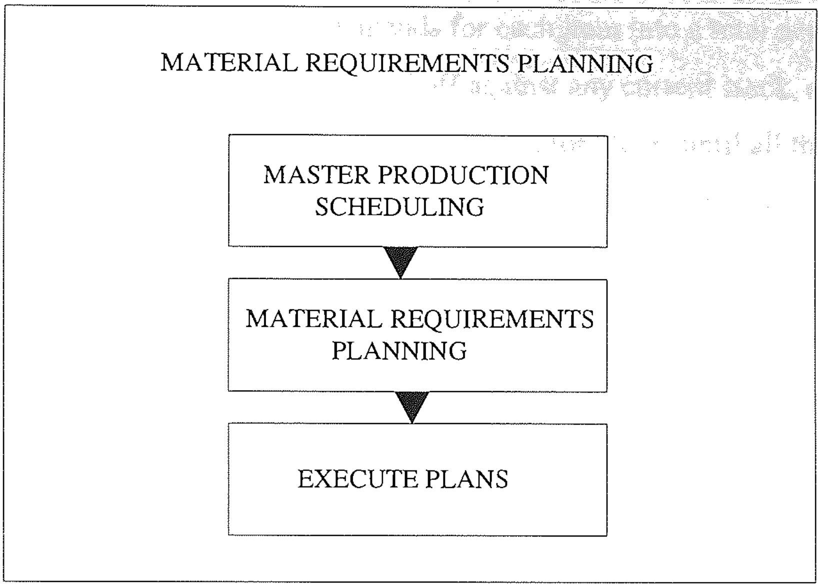

Figure 2.1 - Material Requirements Planning.

The input to MRP I is a time phased Master Production Schedule (MPS). This states the gross quantities and due dates required from production for each saleable item. It drives all the manufacturing and procurement activities. This is firstly netted off against any current stock and any future orders scheduled for receipt of each MPS item to provide a time phased statement of net demand. It is then converted into manufacturing (or purchase) orders which state what item is to be manufactured, how many are to be made (the batch size), and when they are to be made (the time phasing).

This also provides the component demand which triggers the detailed Requirements Planning (Bill of Material explosion) process. The order due date is stated in the MPS, the order start date is calculated by subtracting the manufacturing lead time from the order due date, and the lot size determined by the batching rules set for the item and the available inventory. It is assumed that all the materials required for the manufacturing order is needed to be in stock at the order start date. A Bill of Materials explosion (Requirements Planning) then takes place, using as its input the manufacturing orders created in the MPS, and details about the items such as lead times, low level code, and batching rules. The low level code defines the order in which the items are processed by MRP, and ensures that each item need only be considered once.

The Bill of Materials explosion is performed a level at a time (using the low level code) to ensure that the total demand for each item is considered prior to any manufacturing or purchase orders being planned.

This works by combining independent demands for each item into a total demand for each time bucket. This gross demand is then netted off against any current stock, and the Bill of Materials explosion is then performed for the next inventory level until all the manufactured and purchased parts are planned, and either purchase or manufacturing orders created, in line with the stated MPS demand.

As items are manufactured, issued to manufacturing orders, or received from suppliers, so the inventory and order records are updated. The planning cycle is then repeated when the next MPS is created. So, MRP I is primarily a works order based system, designed to supported batch production, using manufacturing lead times as the key tool to plan production.

Subsequently, the scope of the relatively straightforward MRP I system has been broadened to include Routings, Capacity Planning, Warehousing, Multi-Plant, Sales Order Processing, Forecasting, Sales Analysis, Repetitive Manufacturing, Shop Floor Control, Plant Maintenance, Product Costing, Inventory Accounting, Distribution Requirements Planning, and integrated Financial Ledger and Payroll modules.

MRP II, or Manufacturing Resource Planning is just an extension of the original MRP I principles, with the inclusion of a closed loop (re-iterative with feedback) Capacity Planning option, and increased depth in the planning cycle. The MRP II concept is contingent upon all the necessary master data for the manufacturing resources being accurately stored and updated, and the resources needed (e.g. labour and machine availabilities and usages) being calculated through a similar set of computations as that used for the materials explosion in MRP I. It was an attempt to provide an integrated manufacturing management system with all functions centrally co-ordinated *(Kerr 1991)*, with different parts of the enterprise obtaining information from a common database. It accepted the proliferation of manufacturing complexity and variety as givens, and used brute computational power to solve the problems.

The MRP II functions are easily shown in matrix form, with the matrix being divided horizontally into planning and execution activities. These are then divided vertically into demand, supply and capacity elements.

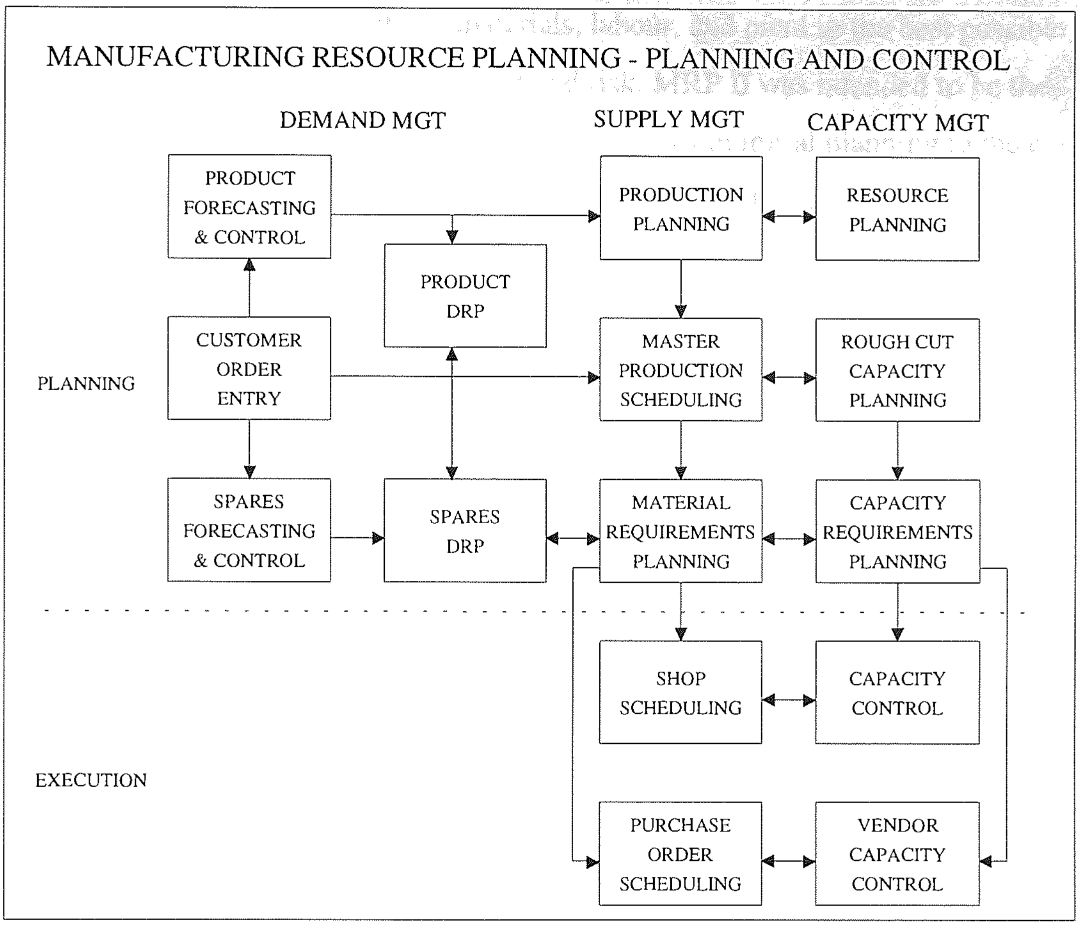

Figure 2.2 - Manufacturing Resource Planning.

The planning elements are essential to the success of the manufacturing strategy, and there has been an evolutionary process from the MRP I systems developed in the early 1960's to include highly developed and sophisticated functions such as:

Order Entry

Forecasting

Production Planning

Distribution Planning (DRP)

Capacity Planning

The original order launching emphasis of MRP I was refined in time to include "pegging" to provide visibility to the source of the requirements. This allowed better priority planning, so helping production to work on the most important jobs first.

The addition of capacity or resource planning options, and the ability to provide shop floor management were the features that gave rise to the change of name from Materials Requirements Planning (MRP I) to Manufacturing Resource Planning (MRP II).

The stated aim of MRP II is to utilise materials, labour, and plant in the best possible way to meet customer demand at minimum cost and risk. MRP II was intended to be the means of developing total control over manufacturing from initial planning to the control of priorities on the Shop Floor. It is apparent, however, that the main thrust of MRP II has continued to be the control of material by part. It is deterministic in its approach, assumes amongst other things, that the stock records, BOM and routing data are all accurate and synchronised, that the Master Production Schedule is both realistic and stable, that the lead times are fixed and independent of the lot size, and, initially at least, that capacity is infinite.

The next development of the MRP philosophy is in the area of Enterprise Resource Planning (ERP). ERP is an attempt to provide *(Luscombe 1993)* an integrated MRP II across several sites, so allowing enterprise wide integration of activities between business units. As such it is another evolution of the MRP concept whereby each site within a multi site environment controls its own individual MRP II, so allowing for greater ownership of data, but with enterprise wide co-ordination of activities between sites. This approach is not new, as an IBM salesman stated in conversation that in the 1970's IBM ran a similar system to co-ordinate the manufacture of the various parts of its mainframe computers across multiple sites. The system had an unfortunate effect of extending lead times through having to co-ordinate the running of the MRP system through the hierarchy of the sites to generate the demand for the components through each level, as the feasibility of the top level plan could not be guaranteed until the site at the lowest level had confirmed that it could achieve the plan. Where an unfeasible plan was generated at a site at a lower level, the plan for the site at the next level up on the hierarchy had to be revised, and so on. The integration of MRP in this way across multiple sites in a hierarchical manufacturing environment created the possibility of an almost infinite planning loop between the various MRP systems. From the available literature and discussions with software vendors it is not clear how this type of problem is avoided by ERP.

2.2.3 Uncertainty within MRP.

MRP systems are driven not only by the data, but also by a series of customisable parameters. The parameter settings as well as the accuracy of the data can have a great impact on the way the MRP system performs its calculations, and the overall stability, or nervousness, of the resulting manufacturing or purchase plans. Because MRP is designed to provide support for a dynamic manufacturing environment, and it is not always possible to forecast the future with complete certainty, a system which the parameter settings or data inaccuracies make volatile to change is going to be more difficult to manage than one which is more resilient.

The causes of uncertainty start at the top level with the generation of a Master Production Schedule. This is a combination of future demand obtained generally from a mixture of customer orders and forecasted demand. Depending on the manufacturing environment (e.g. whether make for stock or make to order), it is usual for the demand in the near future to be composed of a greater number of actual customer orders than that in the more distant future, so the further away into the future the demand is stated, the more likely that this is forecasted. Any forecast is a guess, it may be an excellent guess, but it is still a guess and subject to error. The scale of the error is dependent upon a variety of variables, some of which, depending on the characteristics of the marketplace and the veracity of the forecasting algorithms used, will also be subject to error. Indeed, customer orders themselves are not always inviolable, customers will change their demands for a variety of reasons, for example an unforeseen preference for a particular product in the marketplace could increase demand, or a substitute product could be launched which stifles demand for a particular item, or the demand can be brought forward or put back in time. So at the top level the MPS is composed of data which is not absolute and correct. Depending on the nature of the business it can be a good guide as to the future, but it is always subject to error.

The next level is that concerned with the calculation and time phasing of the production or purchase orders. This involves a variety of parameter and data values which affect whether or not an order will be placed, what quantity will be ordered, the order due date, and from where the order will be sourced (e.g. manufacture or purchase). Taking these in turn, the order quantity for a period is calculated by subtracting the available stock in that period from the demand. If the stock is less than the demand, an order will be raised. The quantity to be ordered will depend upon the Order Policy (e.g. Discrete or Fixed

Quantity), Quantity Modifiers (e.g. Minimum Quantity) and the Safety Stock Policy. The due date for the order will depend upon the Lead Time Offset for the part and any Safety Lead Time. This process is then cascaded to the next level, and so on until the lowest level item has its purchase order generated.

As MRP is deterministic in nature, being a calculating engine, it does not have the inbuilt intelligence to correctly use data which is subject to error or judgement. So the data at the top level, the MPS, is used by MRP as if it were totally correct. At the next level, the selection of the parameters and policy codes will materially affect the way in which MRP will service the requirements as stated in the MPS. Again, the demand data and the parameters are combined together in a set of calculations, the results of which are used by MRP as if they were correct in every detail, and not subject to error of any kind. For instance *(Mather 1988)*, parameters which are flexible in the business, such as batching rules, are fixed in the system, alternate BOM's and routes are not considered unless through manual intervention, and it doesn't have any means to judge the quality of its decisions, but merely follows set of rules.

If, as happens, a change is now made in the requirements for an MPS item in the short term future how will the MRP system satisfy the demand? If the system contains no slack and operates in a bucketless mode, the new order will create demand changes throughout the BOM of the MPS item.

A different problem, but equally difficult to solve without 100% control over the processing of transactions, occurs when transactions are either not processed, or are out of synchronisation. Transactions that are not processed fall into many categories, for instance the scrap of a component will make MRP think that no rescheduling of later orders is required to make up the shortfall, whilst the failure to book out a sample could result in a customer order being taken for which the stock does not exist. Transactions out of synchronisation, such as the booking of a component into stock after the finished item it was used in has been booked as completed can lead to negative stocks of the component where the finished item backflushes its components.

To successfully run MRP, the numbers it provides have to be believable *(Volmann, Berry, Whybark 1992)* and an error of as little as one piece can cause serious problems. The system has to be used to record the decisions made to solve problems, with the transactions processed to reflect the changes made. The BOM's, routes, timings, availabilities, calendars etc. must closely reflect the physical reality of the operating environment, and there should be no procedural inadequacies.

2.3 JUST IN TIME.

2.3.1 Introduction.

The Japanese have captured a sizeable share of world markets for many products because of the progress they have in manufacturing through *(Anderson, Sweeney, Williams 1992)* the development of new technologies, the Japanese style of management, and a different approach to material management and control than that traditionally adopted in the West.

Just In Time (JIT) is a phrase which has been used quite loosely, its meaning can range from an emphasis on inventory control and waste elimination, through pull systems and Kaizen (continuous improvement), to a complicated philosophy which transcends the organisation of work to encompass Japanese culture, or even the simple application of common sense. It was first described in detail in English in the early 1980's *(Schonberger 1982) (Hall 1983)*, and has been actively promoted in the UK by the Department of Trade and Industry under the Enterprise Initiative *(Jewitt 1992)*.

In the context of this chapter, JIT is taken to represent a philosophy, whose stated objective is to eliminate all sources of waste, including unnecessary inventory. In this sense, JIT was largely developed by Toyota *(Womack, Jones, Roos 1990)* over a fifteen year period starting in the early 1960's, with significant ground being covered by the mid 1970's.

One of the reasons for the take up of the JIT philosophy in the UK in the 1980's onward was the perceived superiority of JIT over more traditional manufacturing philosophies, with these improvements being achieved in environments with high product variety. JIT was claimed *(Parnaby 1985)* to provide up to 3 times the productivity, up to 5 times the stock turns, up to 5 times the sales per employee, shorter manufacturing lead times, quality improvements etc. However, there have been doubts expressed both from both inside and outside Toyota regarding the financial benefits of adopting a wholesale JIT approach. One recent report *(Oliver, Hunter 1994)* stated that although significant improvements in manufacturing efficiencies can be made through the use of Japanese methods, that translating these benefits into enhanced financial performances was problematical. This view echoes the sentiments expressed by Hiroshi Okuda, executive vice president of Toyota Japan, who was reported as saying *(Flint 1993)* that not one of the 8 Japanese car makers with plants in the United States made money on their North American operations.

The relevance of JIT to this research it twofold, firstly as a significant methodology or philosophy within manufacturing it requires mention in its own right, and secondly in the way that aspects of the JIT approach can be applied in context to a repetitive batch manufacturing environment.

2.3.2 The Development of JIT.

JIT as developed by Toyota, virtually bypassed MRP because the philosophy centred around extending the assembly line back through all the feeder operations, including the supplier network. The goal was to put raw material in one end, one piece at a time, and produce a car at the other end, a car at a time, with no interruption of flow along the way. The approach was to integrate, and so simplify manufacturing.

In a more philosophical sense the broader approach was the elimination of all forms of waste. This philosophy is summed up by Dr. Cho of Toyota in the January – February 1983 issue of Inventories and Production magazine, as follows:

> *Waste is ".... anything other than the minimum amount of equipment, materials, parts and workers (working time) which are absolutely essential to production ...."*

So a simple definition of JIT *(Wallace, Dougherty 1987)* is the achievement of excellence through the continuous elimination of waste, with the flow of materials being synchronised in time and space with the demands of production.

As part of this program to eliminate waste, quality improvement and programs to reduce defects were instituted to ensure that parts were made right first time. Products were designed for ease of manufacture and assembly, and simultaneous engineering was used to reduce the time from concept to market. The JIT approach tries, through intelligent product design and by considering the process issues at the design stage, to increase the product variety while not increasing the process variety.

The elimination of waste is one of the essential points of the JIT philosophy *(Parnaby 1988)* Inventory itself was considered a waste of money and space, since effort had to be expended first to store the material, then to retrieve it. An even greater waste was considered to be a computer program which tells an operator which material, when, and how much is needed. Finally, reactivity to real demand meant that set-up times were mercilessly attacked so that lot sizes corresponded to usable demand.

In Toyota's drive to reduce waste, other aspects were also considered, such as the need to schedule final assembly lines to avoid surging of components *(Monden 1983)*. This meant that instead of making trucks at the beginning of the month and cars at the end, there was a mixed model assembly of both vehicles every day so that the truck axle manufacturer would be continuously busy, as opposed to either working feverishly at the beginning of the month and being without work at the end, or building inventory.

As part of the simplification process, Toyota developed Kanban, a scheduling concept that works on the principle that each feeding operation replaces what is consumed by the next succeeding operation, no more, no less.

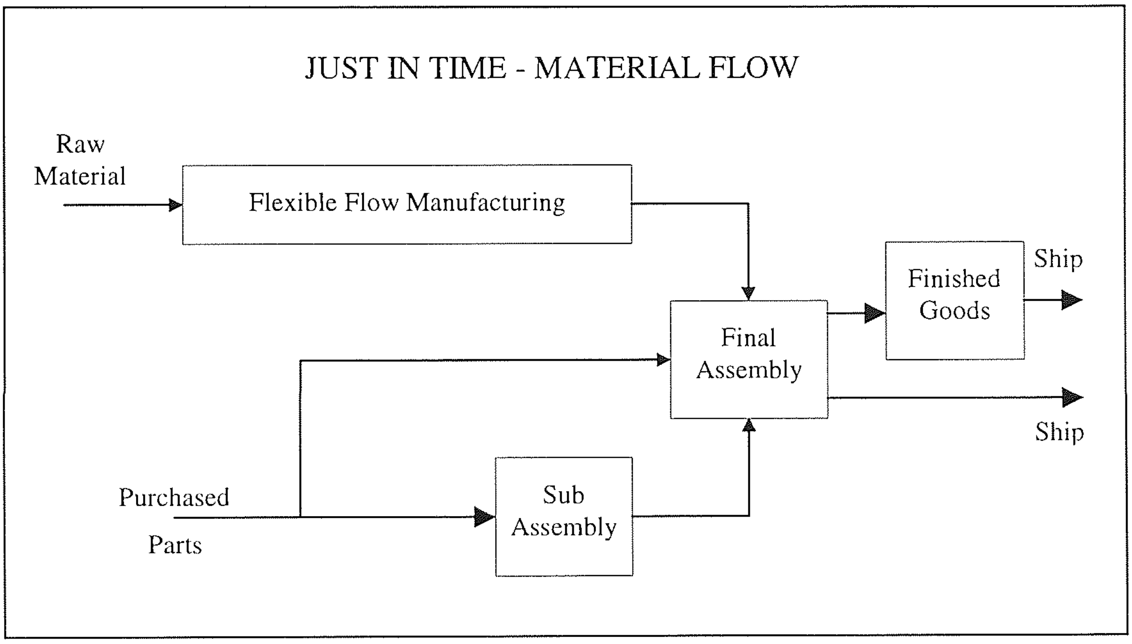

Figure 2.3 - Just in Time Material Flow.

The simpler "pull" environment does not require schedules, priority lists or pick lists, as the authority to make materials is generated from the consumer of that material with its pull card, or Kanban. So in a JIT environment, material is not "delivered". The using operation goes and gets (pulls) the material from the supplying cell. This pull then becomes the authorisation to make a pre-defined quantity of the same item just pulled.

The direction of this process simplification at Toyota is in direct contrast to the traditional MRP approach where the emphasis was to pre-define the manufacturing process and then attempt to manage the process with a computer system.

As a starting point, JIT has a production plan by product family. In JIT the production planning process is used to balance the production plan to the market forecast / customer orders by managing the manufacturing capacity through a combination of variable cell manning and levelled scheduling. Levelled scheduling is the process of smoothing out or levelling the production rate, and encompasses both the averaging of the production rate over a time period and the mixing of the different items being produced into a mixed model mode. The production plan becomes the input to both the detail JIT planning functions as well as the limits for the Final Assembly Schedule.

Figure 2.4 - Just in Time Planning and Control ***(Edwards, Wheeler 1989).***

The purpose of the production plan is to develop the Uniform Plant Load (UPL) for each product unit using a combination of the Bill of Materials and Bill of Resource (routings) *(Edwards, Wheeler 1989).* The Uniform Plant Load calculations determine the frequency in time that a product comes off a given line (cycle time). The cycle time along with the demand rate and lead time are the basis for the calculations of standard cost, cell manning, and supplier demand rates or capacity required.

The Final Assembly Schedule replaces the MRP II Master Production Schedule (MPS) process. In MRP II the MPS serves two functions (apart from being a time phased statement of demand), firstly to check the capacity availability, and secondly to check the product availability. In JIT the Final Assembly Schedule is used not just to check the capacity availability, but also to sequence and level the production. Whereas the emphasis in MRP II is on the demand and supply aspects, within JIT the emphasis is on planning and execution.

2.3.3 Critical Elements for JIT Implementation.

The success of the JIT philosophy depends on its implementation. In a survey of 105 JIT implementations, five critical groups of factors were identified *(Ramarapu, Mehra, Frolick 1995)* as being crucial to this implementation process. They are:

- Elimination of waste, including:
    - Reduction in waste
    - Batch size reduction
    - Lead time reduction
    - Automation
- Production strategy, including:
    - Set up reduction
    - Stable production
    - Preventative maintenance
    - Group technology
- Quality control and improvement, including:
    - Continuous quality improvement
    - Halt production line
    - Statistical process control
    - Quality circles
- Management commitment and employee participation, including:
    - Cross training / education
    - Team decision making
    - Management participation / commitment
    - Employee suggestions

- Vendor / supplier participation, including:
    - Quality parts
    - Reliable and prompt deliveries
    - Small batch size
    - Supplier communications
    - Long term contract
    - Supplier training
    - Single source supplier

The two most specific critical factors were identified as the *elimination of waste* and *production strategy*, followed by the other three. Within these factors, three of the activities fall under the area covered by this research, batch size reduction, lead time reduction, and set-up time reduction.

Set-up times have a great impact on the way that a business behaves in terms of inventory holding and manufacturing flexibility *(Ritzman, King, Krajewski 1984)*. One of the keys to manufacturing flexibility is in reducing the batch sizes. Smaller batches minimise inventory and make planning easier through reducing the unpredictability of capacity bottlenecks and therefore allow for the use of simple production control techniques, however, frequent set-ups are necessary to produce a variety of goods in small lots *(Shingo 1985)*.

A way of achieving frequent set-ups without increasing the capacity is through minimising the set-up times. Set-up times have traditionally been treated as a given *(Schonberger 1982) (Shingo 1985)* and therefore have not been subjected to the same level of scrutiny as large obvious costs such as direct labour, run time, scrap or rework. Set-up has two elements, internal and external. Internal set-ups consume capacity, and therefore affect output. To reduce the effective set-up time *(Shingo 1985)*, the necessity for the set-up either needs to be entirely removed (e.g. by using dedicated machines) or moved from internal to external set-ups. Also by identifying the bottleneck resources it is possible to focus on the most beneficial set-up to reduce first. Reductions in set-up times or cycle times on a bottleneck resource will show immediate benefits. Bottlenecks constrain business performance by adversely affecting cost through increased inventory, extended lead times and reduced throughput.

In summary:

> Batch size reduction requires the identification of bottlenecks and their elimination through a systematic set-up reduction programme allowing a decrease in Work in Progress which reduces the Lead Time.

The benefits of Lead Time reduction through smaller batch sizes are:

> The feasibility of increasing product variety without excessive cost penalties.
>
> Increased manufacturing flexibility.
>
> A lower cost base.
>
> Increased competitiveness.

2.3.4 Conclusions.

Within the JIT approach to manufacturing there is a great emphasis placed on ensuring that excellence can be routinely achieved. It is concerned with the conversion of discrete batch production into continuous flow processes through simplifying the planning and scheduling activities by redesigning the manufacturing operation. It requires three pre-requisites:

- That production is dedicated to a range of products with reasonably stable demand, and with a slight excess capacity.
- That the set-ups are reduced as much as possible so allowing small batch sizes to be produced economically. This allows for the mix of finished products to be varied according to the varying demand patterns.
- That disruptions to production are avoided through preventative maintenance and through the pursuit of zero defects.

The way in which JIT is applied is in direct contrast to the MRP II approach. In JIT the method adopted was one of continual process improvement and simplification, whereas in MRP II the approach was to pre-define the process and then manage it with the assistance of a computer. Advocates of JIT would say that MRP II statically reaffirms the current practices whilst JIT is a dynamic improvement process.

2.4 INTEGRATION OF MRP INTO JIT.

2.4.1 Introduction.

Within the available literature the MRP and JIT philosophies are often treated as mutually incompatible. This is not so in practice, there are very few companies which use either of the JIT or MRP philosophies exclusively.

In this mixed environment, how do these two philosophies coexist, and how can an enterprise migrate from MRP control to JIT control. With the reductions in lot sizes and lead times that a Just in Time environment creates, the operation of MRP as a planning tool needs significant revision.

2.4.2 Integration of MRP into JIT.

In a dual environment, where the manufacturing processes are partially managed by MRP, and partially converted to JIT, there needs to be a mixed Material Flow. That is, some parts of the manufacturing operations will be in a "push" environment, whilst others will be in a "pull" environment. Effective planning at the front end is essential to the success of both MRP and JIT environments, with both MRP and JIT using a production plan by

Figure 2.5 - Mixed MRP JIT Environment Material Flow *(Edwards, Wheeler 1989).*

In this mixed environment an MRP planning mode needs to be integrated with the JIT planning mode. Which mode a part is operating under needs to be recognised, so that the correct planning option is invoked. For MRP parts a further distinction is required to determine which parts are MPS controlled and which parts are MRP controlled. Within the JIT environment the flow of material through a shop or cell at any one point in time should be relatively constant, being determined by the number of "pull" cards or containers issued, so that elaborate tracking systems become both impractical and unnecessary.

Recognising firstly that the move from MRP to JIT is migratory in many cases, not revolutionary, the need for work flows that reflect the need for temporary stock holdings at the gateways between the different control philosophies must be recognised. MRP must not only be able to adapt to the evolutionary process improvements, it must also be able to intelligently track material in a changing environment. The material tracking must be capable of recognising whether a particular process is operating within MRP or JIT. Theoretically, within JIT, computerised material tracking is not required, as the "pull" card or container is the authorisation for material movements. Within MRP, there is a need to recognise whether the process is in a "job" shop environment, or a "rate" shop environment. Within a mixed JIT MRP environment, there will potentially be at least three methods of material tracking co-existing.

Manufacturing Environment	WIP Tracking Method
Job Shop MRP	Works Orders
Repetitive MRP	Works Orders (Lots) Weekly Schedules Backflushing at Gateways
JIT	Floor Stock

Table 2.1 - WIP Tracking Method by Manufacturing Environment.

The traditional Job Shop MRP approach is individual works orders at each count point, with material issued to works order prior to start, and finished items booked against the order.

In repetitive MRP, Works Orders are sometimes still used to track material, along with Schedules, which are effectively Works Orders for a specified period of time, usually a week. Alongside these approaches is that of "backflushing" or consuming components on booking the item being manufactured into stock.

In a JIT environment, although the record of material tracking is theoretically not necessary, it may be of value in highlighting potential imbalances, audit trails, and detecting Bill of Material errors. In this environment the Shop Floor control option is not required as the visibility of the processes controlled in this way makes the transactions unnecessary.

2.4.3 Conclusions.

For the migration from MRP to JIT, a first step could be to use Schedules instead of Works Orders. Using the Schedule approach, MRP nets off against floor stock at specific gateways, or count points. When an item crosses the gateway, it adds to the on hand quantity of article produced, and decrements the on hand balances of the components consumed, using the Bill of Material to control the "backflushing" process.

MATERIAL PLANNING AND CONTROL - MIGRATION STEPS

JOB ORDERS → SCHEDULES / RATES

ROUGH CUT CAPACITY PLANNING
DETAILED CAPACITY PLANNING → RESOURCE CALCULATIONS BY GROSS EXPLOSIONS

PLANNED ORDERS BY PART NUMBER → JIT PURCHASING

ORDER RELEASE → PULL SIGNALS

Figure 2.6 - Material Planning and Control - Migration Steps.

The second stage is to amend the MRP planning function to recognise JIT controlled parts, and be able to highlight capacity or resource constraints. As detailed material planning under JIT is performed at execution time using pull signals, MRP does not need to recognise intermediate parts or assemblies for JIT controlled items. Similarly, as Capacity Requirements Planning is not required under JIT, the need for Works Order control is eliminated.

Within MRP it is common for Purchase Orders and Works Orders to be managed on an order by order basis. JIT purchasing needs to plan on a commodity basis for capacity and rate purposes, the execution being controlled by the pull system.

When MRP plans for a weekly schedule, it also plans to receive a weeks worth of components. In a JIT environment, the components must be fed to the line as required.

2.5 INVENTORY ORDERING POLICIES.

2.5.1 Introduction.

Manufacturing enterprises have over the years developed a number of approaches to ordering for stock or manufacture. These different approaches fall into three basic categories *(BSI 5191 1975)*, those which operate using a fixed order size and flex the time interval between orders, those that operate on a fixed time interval between orders and flex the order size, and those which flex both the order size and the time interval.

Some of the methodologies that fit in with the three categories are:

Fixed Order Size	**Re-Order Point** **Kanban** **Two Bin** **EOQ / EBQ**
Fixed Time Interval	**Re-Order Cycle** **Period Order Quantity** **Group Period Order Quantity**
Variable Order Size and Time Interval	**Discrete (Lot for Lot)** **Least Unit Cost** **Part Period Balancing**

Table 2.2 - The Three Inventory Ordering Categories.

Each of the different ordering philosophies will tend to produce different overall inventory performances, in terms of the amount of stock held, and the number of orders raised, or deliveries received. These techniques (with the notable exception of Discrete) generally use an EOQ / EBQ approach to obtain either the order size or the time interval between orders. It is important to understand that different techniques exist, how they work, and the likely effects of using different approaches not only in terms of overall inventory performance, but also in terms of the resilience, or nervousness of the resulting system.

This section explains the types of inventory parameter settings available within a typical MRP system (plus Re-Order Point and Kanban which are not MRP based), and the differences in the way they calculate the order / manufacturing quantity. The EOQ / EBQ approach is not explained here, however, as a detailed description is given in chapter 3.

2.5.2 Re-Order Point Systems.

In Re-Order Point (ROP) systems the inventory for an item is drawn upon until a specific level, the Re-Order Point, is reached. When this happens, an order is triggered for a fixed Re-Order Quantity. The Re-Order Point is established using an average rate of demand for the item, any replenishment orders already placed, and the lead time for that item. Both demand for the item and the lead times may be subject to variability, and so are generally expressed in terms of a mean value and statistical distribution.

To accommodate variations in demand during the replenishment lead time, it is usual to provide additional cover in the form of Safety Stock. Safety Stock is also used to provide time cover in the event of the lead time being longer than normal. The amount of safety stock is generally set to a desired service level to give protection against a stock out arising during the replenishment lead time. To illustrate using an example:

If the lead time is constant and demand is variable, but is distributed normally about a mean, one method for calculating the Re-Order Level (ROL) could be *(Bennett, Lewis, Oakley 1988)*:

$$ROL = \bar{D}\,L + k\sigma\sqrt{L}$$

where	$\bar{D}$	average demand per unit time
	L	lead time
	k	the standard normal deviate
	σ	standard deviation in demand per unit time

2.5.3 Kanban.

Kanban is the visual control technique used in Just in Time manufacturing to pull work *(Schonberger 1982)* though the manufacturing or ordering process. It consists of 'containers' whose capacity is fixed, and when empty constitute a replenishment order. The system relies upon a Kanban being for a particular part and quantity, and the producing and consuming facilities being fixed. The number of Kanbans circulating for a particular part could be determined using the following formula:

$$N = \frac{D.LT.PV}{Q}$$

where	N	Number of Kanbans in system.
	D	Demand per unit of Time

LT	Lead Time
PV	Safety Stock Factor
Q	Kanban Quantity

2.5.4 Two-Bin.

The visual form of the Re-Order Level (ROL) system where stock is physically separated *(BSI 5191 1975) (Wallace, Dougherty 1987)* is normally referred to as the two-bin system. In the two bin system, the second bin is filled with the Re-Order Level (ROL) amount, with the remaining stock contained in the first bin. Issues are made from the first bin only until it is empty. When this happens, the replenishment order is placed for the Re-Order Quantity (ROQ), and stock issued from the second bin. When the ROQ is received, the second bin is topped up to the ROL and the rest of the items put in the first bin. Issues now take place from the first bin.

Instead of using two physical bins, this system can work equally well with a single bin with a suitable mark, or divider, to visually establish the ROL.

2.5.5 Re-Order Cycle System.

In this system, the inventory position is checked at fixed, regular, time intervals. An order is then placed for an amount, which when received, would restore the stock of the item, on average, to a pre-determined maximum level *(Schroeder 1985)*. The Re-Order Quantity (ROQ) is determined, at the end of each time interval, as the difference between the maximum inventory level, and the stock currently on hand plus any already on order and awaiting receipt. The ROQ is therefore a variable quantity and works by topping up the stock to the pre-determined maximum level.

The determination of the optimal value for the maximum inventory value results in an economic balance between the various cost elements. The re-order cycle system of inventory control offers the facility for grouping items with common fixed time intervals between review. It is therefore possible to place an order on a supplier containing a variety of items, so lessening costs in this part of the ordering cycle. The cyclical nature of the re-ordering process is in itself attractive to the supplier, as it is helpful in pre-planning production, even though the actual quantity is not known in advance.

2.5.6 Period Order Quantity.

A form of Re-Order Cycle system is Period Order Quantity. Period Order Quantity (POQ) uses the Economic Order Quantity equation to calculate the economic Time Between

Orders *(Berry 1972) (Wallace, Dougherty 1987)*. The Time Between Orders in weeks is the EOQ divided by the average weekly usage rate. Having established the TBO the order is then placed at that time interval, but for the exact requirements for the interval.

It therefore works as a periodic ordering system, with discrete (Lot for Lot) order quantities created for each time interval. This ordering policy is different to the Re-Order Cycle System in that there is no predetermined stock level, but the forward requirements are aggregated into a time bucket determined by the time between orders. In this system if there is no demand and the stock is zero, no order will be placed, in the Re-Order Cycle System an order will be placed to bring the stock up to the pre-determined maximum level.

2.5.7 Group Period Order Quantity.

Group Period Order Quantity *(Donaldson 1981) (Relph, Brown, Dupernex, Dance 1994)* is in many ways the same as Period Order Quantity. The difference between the two approaches is that whilst Period Order Quantity sets the ordering frequency at an individual item level, Group Period Order Quantity applies a set ordering cycle to a group of parts based on the Pareto Principle. The way the items are allocated into groups is by using the Annual Usage Value of the items to determine which item is allocated to which group.

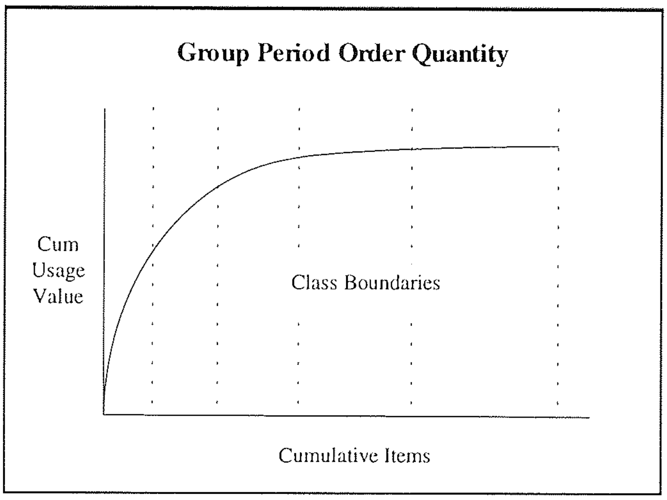

Figure 2.7 - Group Period Order Quantity Pareto Curve.

In order to set the class limits in terms of the Annual Usage Value, the class boundaries firstly need to be stated in terms of the number of periods' supply to be ordered within each class. There are, however, no clear guidelines on how many groups should be used, what the order cycles should be for each of the groups, and what the group boundaries should be.

2.5.8 Discrete.

In Discrete systems, an order is placed for exactly the net requirements for one or more time periods *(Wallace, Dougherty 1987)*. No Lot sizing is performed. This is also referred to as Lot for Lot *(Vollmann, Berry, Whybark 1992)*.

2.5.9 Least Unit Cost.

In Least Unit Cost (LUC) a lot size is calculated *(Vollmann, Berry, Whybark 1992)* that minimises unit carrying and ordering costs. This method uses an iterative process to determine the lot size by successively calculating the unit cost associated with lot sizes that cover the requirements for additional periods. It takes into account any set-up costs and supplier discounts as well as the inventory carrying costs. The Least Unit Cost and the lot size have been identified when unit costs no longer decrease with increasing quantity. This is in some ways creates similar problems to those associated with the EOQ formula, in that by accepting costs such as set-ups it can lead to an acceptance of the status quo.

It is, however, relatively easy to use and understand.

2.5.10 Part Period Balancing.

The Part Period Balancing (PPB) method is based *(Berry 1972) (Vollmann, Berry, Whybark 1992)* on the rationale that the sum of the set-up and inventory carrying costs for all lots within the planning horizon will be minimised if set-up and inventory carrying costs are as nearly equal as possible. Part Period Balancing attempts to do this by considering the inventory carrying costs for:

Period	1
Period	1 &2
Period	1, 2 & 3

and comparing these with the set-up or ordering costs.

The alternative which most nearly approximates to the set-up or ordering cost is that which is ordered. As additional weighting is attached to orders further out in the future, in periods of low demand, the lot size will reduce and the time interval between orders increase. In periods of high demand, the time interval will reduce, and the lot size increase.

Part Period Balancing therefore allows flexing of both the lot size and the time interval between replenishment.

2.5.11 Conclusions.

Choosing the correct inventory parameter set within MRP can have a great impact on the way the system performs, and the degree of comprehensibility of that performance by the system users. The use of an ordering policy with variable order sizes and time intervals tends to produce a nervous system. That is, every time the requirements changed, the corresponding orders changed, sometimes in a counter intuitive manner.

In a survey *(Haddock, Hubicki 1989)* into the use of ordering policies used, it was found that Period Order Quantity was the most widely used, followed by Discrete, and then Fixed Order Size. Dynamic techniques such as Least Unit Cost and Part Period Balancing were seldom used.

The reason for the widespread use of the Period Order Quantity ordering policy is due to its inherent simplicity, the way it can fit in with the standard weekly work cycle and its acceptance by users. It is easy to understand how the order sizes are derived, and these can be checked and verified manually if they seem to be incorrect.

Previous research *(Donaldson 1981) (Relph, Brown, Dupernex, Dance 1994)* has demonstrated both mathematically and empirically that when a Grouped Period Order Quantity approach is taken, then the number of classes, and the way in which the class boundaries are established can materially affect the overall inventory performance when measured in terms of orders raised and average stock holding. The technique for establishing the class boundaries is explained in chapter 3, detailing the K-Curve Methodology.

When analysing the criteria used by the various ordering policies in the context of manufactured items one significant factor emerges, none of them contain a factor to take account of the availability of manufacturing capacity. Each of the policy codes assumes that there is no capacity constraint, or that it should not be considered at the point in time that the parameter settings are made. The assumption that is being made is that the capacity load is an operational, rather than a tactical or strategic, concern, and that the solution is one concerned with short term capacity planning and sequencing. Certainly the short term planning and sequencing is a valid concern, but in many manufacturing enterprises capacity, rather than material supply, is the limiting factor. A method of generating an inventory parameter set that creates an achievable capacity load, as well as taking into account the financial and order workloads is a necessity, rather than a luxury, in today's highly competitive marketplace.

2.6 SUMMARY OF PLANNING AND CONTROL SYSTEMS AND PHILOSOPHIES.

In this chapter, MRP and Just in Time, the main planning and control systems and philosophies were examined, as was the way in which these systems can be used together in a mixed environment. Finally, an examination of the way in which planning parameters can affect the overall inventory performance was undertaken.

One further approach to production management is that offered by OPT which has made one major contribution to manufacturing management, the explicit recognition of the importance of identifying and either eliminating or managing bottlenecks, an approach used also within this research.

MRP, JIT and the mixed JIT/MRP environments were examined because the research is concerned with the effect of setting the planning parameters on overall inventory performance. Without understanding how these systems / philosophies work, it is not possible to design a tool to help in this important area.

Facilities exist within MRP to validate the load at execution time, as is the case with OPT, and a plethora of finite capacity scheduling tools which exist. As ordering parameters are central to the management of inventory within manufacturing, why at the time that the parameters are being set is there no recognition of the capacity load the parameter set will be likely to generate?

Two of the ways in which MRP can become an effective tool are by reducing the lead times and simplifying the processes *(Lunn 1994)*. What the research addresses is the gap in the MRP philosophy concerning the acceptance of set-up times and batch sizing rules etc. as givens, particularly the way in which MRP handles the planning of batches of items in an environment where a common machine set-up can be used for a group of items.

The research does this by, firstly, placing items with common set-ups into periodic ordering cycles so that the likelihood of the items being scheduled together is increased, and, secondly, by taking the orders generated by MRP and forming these into scheduling groups, so minimising the overall time spent on set-up during the execution phase.

By concentrating on reducing batch sizes (or avoiding expensive overtime or shift work) and simplifying the production and material control process through cyclic scheduling, and then focusing attention onto the bottleneck resources the research aims to increase the overall effectiveness of MRP.

3 THE DERIVATION OF THE K^+ METHODOLOGY.

3.1 INTRODUCTION.

In this chapter the historical background to, and derivation of, the methodology used in this research is examined. The examination starts off in 1913, by considering Ford Whitman Harris's Economic Order Quantity (EOQ) formula, which was a cornerstone of inventory management for many decades, but worked at an individual item level.

Coverage Analysis is then examined, a method proposed by Mr. J Murdoch the Head of Operational Research at Cranfield Aeronautical College for overcoming one of the limitations of the EOQ, that of being not constrained either by the total amount of inventory that could be held, or the total number of orders raised. This had the advantage of considering groups of items together, and neatly side stepping the issue of calculating detailed ordering and inventory holding costs for each item, by using a common ratio (K) for these costs across the group, and flexing the value of K to satisfy the order or inventory constraint limit.

The K-Curve Methodology (KCM) is then examined. This is very similar to Coverage Analysis in that it is based on the EOQ formula and considers items at a group, rather than individual, level. For each group of items a common ratio of the inventory holding and order raising costs is considered (K) and the items are placed into period order day classes based on the relative annual usage values of the items being considered.

The next section examines the use and abuse of costs. In a modelling exercise costs are invariably used when comparing the results of different scenarios. These costs are generally accepted as accurate and precise representations of fact. However, they may be neither. This section examines the different methods used by the accountancy profession in deriving costs, and demonstrates by example the wide range of cost values that can be obtained for the same items using the different costing methods.

The final section deals with the derivation of the K^+ methodology. It details the way in which each of the four methods used in the research is derived, considers the use of set-up costs and proposes the use of three key performance indicators as a way of comparing the relative performance of different scenarios.

3.2 THE ECONOMIC ORDER QUANTITY.

3.2.1 Introduction.

A paper describing the Economic Order Quantity *(EOQ)* formula was published in 1913 by Ford Whitman Harris *(Harris 1913)* and gained widespread use in industry through the efforts of a consultant called R. H. Wilson through the Harvard Business School *(Wilson 1934)*, and was a cornerstone of inventory management for many years.

The *EOQ* is an early attempt to apply the principles of scientific management to the problems associated with ordering stock. It assumes that the main concern for management when ordering inventory items is the minimisation of the costs associated with order raising and order holding, and that once these costs have been established that they can be successfully modelled through the use of a deterministic algorithm.

3.2.2 The Application Of The EOQ.

The *EOQ* is relevant to purchased items (the Economic Batch Quantity or *EBQ* formula being used for manufactured items) and is an equation which describes the relationship between the costs of placing an order, carrying inventory, and the order quantity, and involves the determination of the most economic order quantity - the quantity which minimises the total variable costs *(Wild 1980)*. It attempts to answer the two basic questions asked of any item for which inventory is to be held:

> When should an order be placed? and
>
> How much should be ordered?

Inventory can be broadly defined *(Moskowitz, Wright 1979)* as the quantity of goods, commodities, or other economic resources that are stored or idle at any given point in time. The economic resources vary in quantity over time due to a demand process which reduces the inventory level, and a replenishment process which increases the inventory level.

The first of these questions, when should an order be placed, is answered implicitly, the second question, how much should be ordered, explicitly.

The second of these questions, how much to order, involves selecting an order quantity which is a compromise between keeping small inventories by ordering frequently, but incurring higher ordering costs, and keeping larger inventories by ordering less often, but incurring higher inventory holding costs. The *EOQ* answers this question quantitatively by constructing a deterministic mathematical model that minimises the total sum cost of holding inventory and raising orders for a known future demand.

The inventory holding costs are considered *(Anderson, Sweeny, Williams 1985)* to be those which are dependent upon the size of the inventory, and is expressed in the following example as an inventory holding rate (annual percentage rate). The ordering costs are those incremental costs associated with the replenishment process.

The minimum cost solution can be easily determined providing that the assumptions made in deriving the equation are justified in practice, and the various costs can be established within reasonable limits. The way in which these questions are answered by the *EOQ* formula is as follows:

If 6,000 of an item are required in a year, with the item having a constant daily demand with no seasonality and no supply problems (instantaneous replenishment when the stock reaches zero), anything from one order of six thousand pieces to six thousand orders of one piece could be placed. If the item costs £1, a fixed cost of £15 per order, regardless of size, can be established, and an inventory holding rate of 20 percent per annum is used, the following results can be obtained for a sample of the different quantities that could be ordered:

Orders per Annum	Quantity per order	Average Stock £	Inventory Holding Cost	Ordering Costs	Total Cost
1	6000	3000	£600	£15	£615
2	3000	1500	£300	£30	£330
3	2000	1000	£200	£45	£245
4	1500	750	£150	£60	£210
6	1000	500	£100	£90	£190
12	500	250	£50	£180	£230
25	240	120	£24	£375	£399
50	120	60	£12	£750	£762

Table 3.1 - EOQ Total Cost by Order Quantity.

In choosing an order quantity, there is a trade off between the ordering frequency and the size of the inventory holding. Small order sizes lead to frequent deliveries and low inventory levels. Larger order sizes lead to larger inventories but a smaller number of deliveries. This trade-off between ordering frequency and inventory levels is illustrated in the above table.

Using the table of results above, when the ordering costs are plotted against the combinations of the order size, the following graph results:

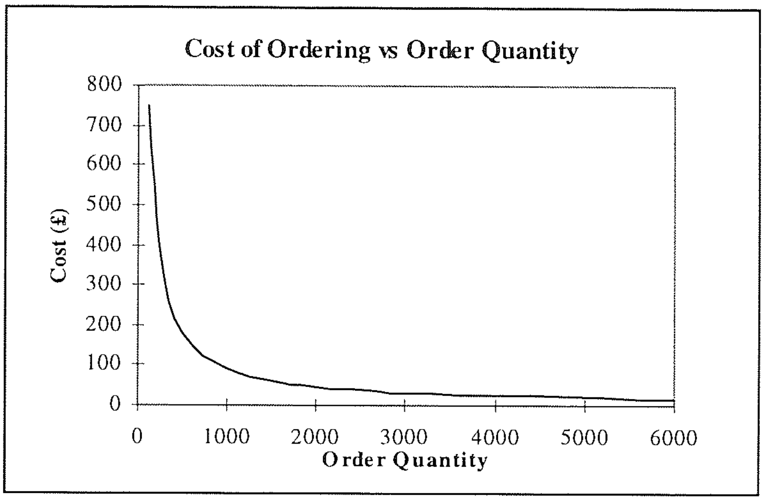

Figure 3.1 - Graph of Order Cost vs. Order Quantity.

In the above graph it can be clearly seen that as the order quantity increases (and the number of orders per annum thereby decreases) the cost of holding inventory decreases non linearly, asymptotically approaching zero.

If the cost of holding inventory is plotted against each of the combinations for the order quantity in the above table, the following straight line graph results:

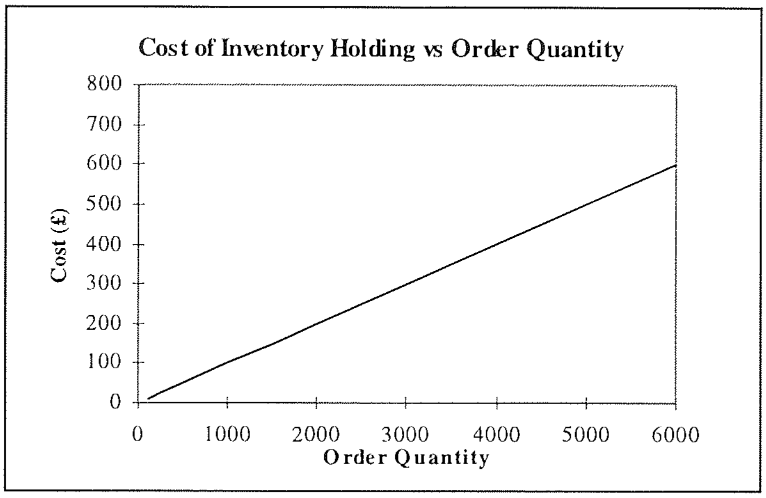

Figure 3.2 - Graph of Holding Cost vs. Order Quantity.

Again, the minimum cost solution will exist where the ordering costs per annum equal the annual inventory carrying cost. When the two graphs are superimposed this is easy to see:

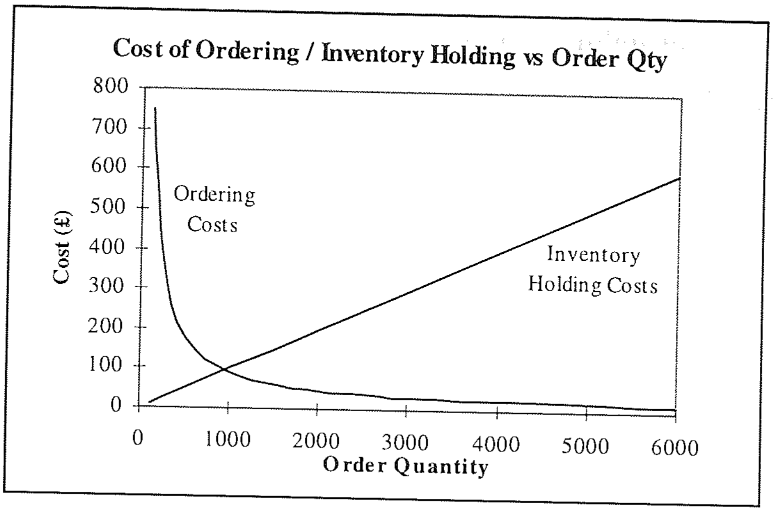

Figure 3.3 - Graph of Order Cost & Holding Cost vs. Order Quantity.

When the total cost graph is added, the *EOQ* is again shown by the lowest point of the resulting total cost curve, which is directly above the point of intersection of the previous two graphs:

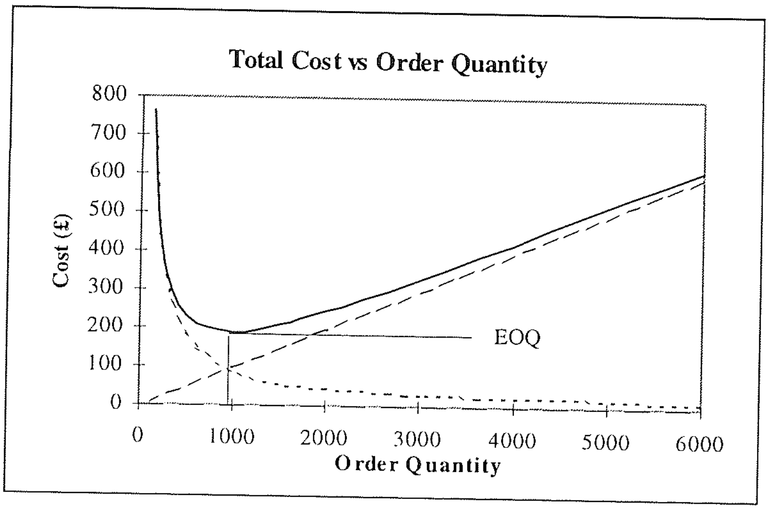

Figure 3.4 - Graph of Total Cost vs. Order Quantity.

It can also be seen that the total annual cost is also relatively flat around the minimum cost solution *(EOQ)*, which means that there is a relative insensitivity in the total cost to variations in the forecasted demand *(Woolsey, Swanson 1975)* or number of orders raised per annum. Also, as the slope of the total cost line is less steep to the right of the *EOQ* than to the left, increases in order quantities above the *EOQ* have less effect on the total cost than decreases in order quantity. This is because the slope of the curve representing the cost of ordering decreases as the order quantity increases, whilst the slope of the line representing the inventory holding costs is constant.

This can be illustrated for the item previously used by the following table, where the order quantity is varied from 800 units to 1,100 units(+/- 16%), and the calculated total annual cost varies by only 1.45% from a low of £189.74 to a high of £192.50

Holding Rate	20%				
Cost per Item	£1.00				
Order Cost	£15.00				
Quantity	6000				
Order Quantity	948	800	900	1000	1100
Orders / Year	6.3	7.5	6.7	6.0	5.5
Order Cost	£94.94	£112.50	£100.00	£90.00	£81.82
Holding Cost	£94.80	£80.00	£90.00	£100.00	£110.00
Total Cost / Year	£189.74	£192.50	£190.00	£190.00	£191.82

Table 3.2 - Change in EOQ Total Cost with 16% Variation in Order Size.

This means that inventory management performance is relatively insensitive to small changes in the order quantity around the minimum cost solution. It is possible, therefore, to adopt a batch size which differs from the 'optimal' without incurring substantially increased annual costs.

The theoretical inventory performance over time can be expressed by the following graph. The dotted horizontal line represents the average stock holding of half the order quantity.

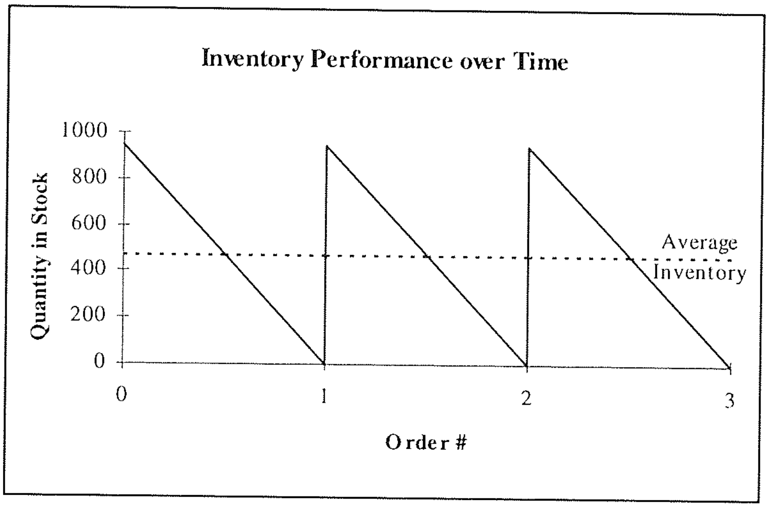

Figure 3.5 - EOQ Inventory Levels *(Schroeder 1985)*

It has already been stated that the *EOQ* does not explicitly answer the first of the questions posed at the beginning of this section, 'When should an order be placed?'. But it must answer this question, if only by implication, for otherwise how could the delivery be arranged to arrive at the exact moment that the stock reaches zero without having a way of being certain that the order is placed such that the suppliers' lead time is not violated. This is not to say that the lead time need be fixed, it need not be, just that the way in which it is calculated is known and used. Only then it is possible to place the order such that the delivery is synchronised with the stock reaching zero.

3.2.3 Economic Order Quantity *(EOQ)* Equation.

The **annual ordering cost** *(OC)* is the cost per order multiplied by the number of orders per annum:

$$OC = \frac{Co.A}{OQ}$$

where		
	A	Annual Usage
	Co	Cost of ordering and delivery per occasion
	OQ	Order Quantity

As A is the annual demand and the item is ordered in lots of OQ, A/OQ orders are placed annually and the annual ordering cost is calculated by multiplying this figure by Co, the cost of ordering and delivery per occasion.

The **annual inventory holding cost** *(IC)* is the average inventory value multiplied by the inventory holding rate per annum:

$$IC = \frac{i.Cm.OQ}{2}$$

where		
	Cm	Item Cost
	OQ	Order Quantity
	i	Annual stockholding interest rate

If the item is ordered in lots of OQ, the average inventory quantity will be $OQ/2$ as a maximum of OQ units will be stocked as the lot is received, and as the stock decreases at a constant rate, the average stock quantity is half the lot size. By multiplying the item unit cost Cm by the annual stockholding interest rate i, the holding cost per unit per annum is established. The annual inventory holding cost IC is then established by multiplying the average inventory quantity by the holding cost per unit per annum.

The **total inventory cost per annum** is the inventory carrying costs per annum plus the ordering costs per annum.

$$
\begin{aligned}
TC &= IC + OC \\
&= \frac{i.Cm.OQ}{2} + \frac{Co.A}{OQ}
\end{aligned}
$$

The Economic Order Quantity *(EOQ)* equation finds the value of the order quantity *OQ* which minimises the total cost TC.

There are two methods for doing this, firstly by calculus:

The total cost equation, *TC*, is differentiated with respect to the order quantity *OQ*, and solved by setting the resulting equation equal to zero, as follows:

$$
\begin{aligned}
TC &= OC + IC \\
&= \frac{Co.A}{OQ} + \frac{i.Cm.OQ}{2} \\
\frac{dTC}{dOQ} &= -\frac{Co.A}{OQ^2} + \frac{i.Cm}{2} = 0 \\
\frac{Co.A}{OQ^2} &= \frac{i.Cm}{2} \\
OQ^2 &= \frac{2.Co.A}{i.Cm} \\
OQ &= \sqrt{\frac{2.Co.A}{i.Cm}}
\end{aligned}
$$

Therefore the *EOQ* equation is:

$$EOQ = \sqrt{\frac{2.Co.A}{i.Cm}}$$

where	A	Annual Usage
	Co	Cost of ordering and delivery per occasion
	i	Annual stockholding interest rate
	Cm	Item Cost

The second method of solving the *EOQ* is by finding the point of intersection of the two lines, as follows:

The equation for the annual inventory holding cost *IC* for any order quantity *OQ* is:

$$IC = \frac{i.Cm.OQ}{2}$$

The equation for the annual ordering cost *OC* for any order quantity *OQ* is:

$$OC = \frac{Co.A}{OQ}$$

The minimum cost solution exists where these are equal IC equals OC.

$$IC = OC$$
$$\frac{i.Cm.OQ}{2} = \frac{Co.A}{OQ}$$
$$OQ^2 = \frac{2.Co.A}{i.Cm}$$
$$OQ = \sqrt{\frac{2.Co.A}{i.Cm}}$$

Giving the same equation as before.

Therefore for the item already discussed, with:

A	6,000
Co	£15
i	20%
Cm	£1

the EOQ is calculated as follows:

$$EOQ = \sqrt{\frac{2 \times 6000 \times £15}{0.20 \times £1.00}}$$
$$= 948$$

The Economic Order Quantity is therefore calculated as 948, as before.

3.2.4 Economic Ordering Or Delivery Frequency *(F)*.

As well as calculating the 'optimal' order quantity, the EOQ equation can also be used to develop the economic ordering or delivery Frequency (F).

The economic ordering or delivery Frequency *(F)* is the result of dividing the periodic usage by the Economic Order Quantity to provide a measure of the number of times per period that a order would need to be placed to support the constant demand for the item.

The economic ordering or delivery Frequency (F) can be expressed thus:

$$F = \frac{A}{EOQ}$$

where		
	EOQ	The Economic Order Quantity
	A	Period (e.g. Annual) Usage

Therefore for the item already discussed, with:

A	6,000
EOQ	948

the economic ordering or delivery Frequency *(F)* is calculated as follows:

$$F = \frac{6000}{948}$$
$$= 6.3$$

The number of orders per year is therefore calculated at 6.3, as before.

3.2.5 The Economic Time Between Orders *(TBO)*.

As well as calculating the economic ordering or delivery Frequency *(F)*, the *EOQ* equation can also be used to develop the economic Time Between Orders *(TBO)*, which is a measure of the elapsed time between the receipt of one delivery for the item concerned and the receipt of the next delivery for the same item.

The economic Time Between Orders *(TBO)* is the result of dividing the Economic Order Quantity *(EOQ)* by the daily demand (the annual usage divided by the number of working days per year), and can be expressed thus:

$$TBO = \frac{EOQ.DY}{A}$$

where		
	EOQ	Economic Order Quantity
	DY	Days per Year
	A	Annual Usage

Therefore for the item already discussed, with:

EOQ	948
DY	250
A	6,000

the economic Time Between Orders *(TBO)* in days is calculated as follows:

$$TBO = \frac{948 * 250}{6000}$$
$$= 39.5$$

The number of working days between deliveries is therefore calculated at 39.5.

3.2.6 Assumptions Made By The EOQ Equation.

The assumptions made by this equation are:

- the minimum cost is the most relevant criteria.
- the input data is reliable.
- the demand rate is known and remains constant into the indefinite future.
- the lead time for replenishment is known.
- no stock outs are allowed, and, since lead time and demand are constant inventory can always be replenished exactly when it reaches zero.
- purchased items are delivered as a batch and placed into inventory all at one time.
- the items delivered are 100% defect free.
- the unit cost price is known and remains fixed.
- the supplier has an unlimited production capacity.
- there is unlimited inventory capacity.
- the annual stockholding interest rate can be meaningfully calculated.
- the annual stockholding interest rate is fixed.
- the inventory holding costs are independent of the storage space used.
- the cost of ordering and delivery per occasion can be meaningfully calculated.
- the cost of ordering and delivery per occasion is fixed and independent of the number of items being ordered.
- the item to be ordered is a single product, with no interaction with other products as the *EOQ* contains no term to represent the number of items in the inventory.
- the item to be ordered is not perishable, that is, the utility of the item does not deteriorate over time.
- item substitution does not take place.

- items are paid for on receipt, that is, there is no delay between the receipt of the goods and the actual payment being made.

It is generally agreed, however that although the EOQ derived by this algorithm may be incorrect for any particular item, that *'the ratio of the value of the EOQ for one stocked item to another is always relevant' (Bennett, Lewis, Oakley 1988)*. Despite the assumptions implicit in the approach, the *EOQ* equation is still the best known and most fundamental inventory model, and can provide useful ordering guidelines even in operating conditions which deviate from those reflected in the above list of assumptions. The financial 'penalty' for rounding to a convenient quantity *(Thomas 1973)* or to a quantity corresponding to a given period of time is therefore small so the phasing of deliveries into periodic ordering cycles based on the *EOQ* calculation can lead to administration benefits and operational simplicities *(Burbidge 1962)* which outweigh the 'penalties' attached to the order quantities deviating from the 'optimal'. It also has the advantage over using straight *EOQ* quantities that where the demand rate over time fluctuates, the order quantity will flex from period to period to reflect the actual demand, and so improve the inventory performance *(Vollman, Berry, Whybark 1991)* through not carrying excess stock.

Its use, however, can lead to the precision of the answer to the *EOQ* calculation being confused with the accuracy of the answer, and also lead to an institutionalisation of the figures used in the calculation. An example of this institutionalisation is the de-stocking that has resulted from the adoption of Just in Time *(JIT)* which challenged the integrity of the assumptions which were prevalent through the rigid use of the *EOQ*. There is, however, nothing within the *EOQ* formula which says that the answer calculated under a given set of circumstances is inviolable. It actually invites a modelling approach by promising to come up with different ordering guidelines when circumstances change. Perhaps its use in the past (pre personal computer and pocket calculator) to determine 'accurate' order quantities by item tended to be on a one pass approach because of the time required to recalculate the model manually.

3.2.7 Conclusions.

F. W. Harris never claimed that the raw *EOQ* results could or should be used without either an understanding of the simplifying assumptions made, or the application of trained judgement. He advocated it as providing a 'theoretically correct result' and its use as a check to avoid making costly mistakes on batch sizes. It was intended as a practical tool to be used intelligently, not as a panacea to be used indiscriminately.

The second paragraph of his 1913 article states *'The writer has seen the practical workings of a first class stock system and does not wish to be understood as claiming any mathematical formula should be depended upon for the amount of stock that should be carried or put through on an order. This is a matter that calls, in each case, for trained judgement. There are many other factors of even more importance than those given in this discussion' (Harris 1913).*

The final paragraph of his 1913 paper begins with *'In conclusion, it may be well to say that the method given is not rigorously accurate ....'* and ends with the following words *'The general theory as developed here is reasonably correct and will be found to give good results.' (Harris 1913).*

3.3 COVERAGE ANALYSIS.

3.3.1 Introduction.

Coverage Analysis is a technique developed by J. Murdoch *(Murdoch 1965)* for purchased and manufactured items and is based on the Economic Order Quantity *(EOQ)* and Economic Batch Quantity *(EBQ)* equations *(Harris 1913)*. It considers the theoretical inventory requirements, that is, it calculates an average theoretical stockholding position based on the resulting inventory planning parameters, and ignores the current stock position. The coverage of an item is defined as the ratio of the average stock level value (inclusive of policy stock) to the annual usage value.

3.3.2 The Application of Coverage Analysis.

Coverage Analysis is applied in two different ways, firstly, where each item may have a different order quantity and ordering frequency *(Robinson 1963)*, and secondly, where items are grouped into periodic ordering classes *(Lewis 1981)* where each item within a class is ordered on the same frequency. For the purposes of simplicity, only the first method is described in detail.

The first method starts off by establishing groups of parts with a common ratio *(K)* of ordering and delivery costs to the inventory holding rate, and from this uses the ratio *(K)* within the *EOQ (or EBQ)* to flex the number of orders raised and the average inventory holding value, using the principles behind the inventory vs. orders exchange curve.

Within each of these groups of parts, the current number of orders per year can then be established from the existing ordering parameters, and used as a control, and to calculate the initial value of K. The next step is to calculate an initial 'rational' ordering policy based on the initial value of K and the annual usage value of each of the items within the group.

The initial rational ordering policy and value of K can then be flexed to move the items up and down the exchange curve to establish a new rational inventory and ordering position. The exchange curve clearly illustrates that inventory is reduced by increasing the number of orders raised, and vice versa.

For example, if the inventory were to be halved, the number of orders would have to be doubled. If the value of K were reduced by 25% to 75% of the initial value, then, for each of the items being considered, the number of orders raised would increase by $\frac{1}{0.75}$ and the average inventory value decrease to 0.75 of the initial value. The increase in the number of orders would lead to an increase in clerical ordering workload and delivery workload, or amount of time spent on set-ups.

A marginal cost viewpoint can then be used to determine whether the cost savings due to the inventory reduction are outweighed by the increase in costs associated with the extra order raising activities or machine set-ups.

Using the above principles, it is relatively easy to establish an ordering policy which fits in with the enterprise objectives by flexing the initial value of K to achieve the desired proportional increase (or decrease) in stock.

For manufactured items the recommendations *(Robinson 1963)* are that a different control value of K be established for ranges of set-up costs, and that 5 or 6 ranges have been found to be sufficient in most manufacturing organisations. For purchased items the recommendations are that a single value of K is sufficient except where items can be demonstrated to have exceptional holding costs (e.g. cold storage).

3.3.3 Coverage Analysis Theory.

The starting point for Coverage Analysis is the *EOQ* equation, which provides an order quantity which minimises the total cost of a stocked item, as follows:

$$EOQ = \sqrt{\frac{2.A.Co}{i.Cm}}$$

where	A	Annual Usage
	Co	Cost of ordering and delivery per occasion
	i	Annual stockholding interest rate
	Cm	Item Cost

There has been considerable difficulty and debate over how to establish meaningful values for the annual stockholding interest rate *(i)* and the cost of ordering and delivery per occasion *(Co)*. The cost of ordering, for example, could be taken as the total annual cost of the purchasing department divided by the number of orders raised per annum, or as the marginal cost of raising the additional order. This apportionment can create philosophical as well as practical difficulties, as is illustrated in the section on Product Costing and Accounting.

However, the difficulties in assessing the relevant values of i and Co are reduced by the use of Coverage Analysis. Where the ratio of Co to i is reasonably constant for a group of items, the EOQ formula

$$EOQ = \sqrt{\frac{2.A.Co}{i.Cm}}$$

can be simplified as follows:

$$EOQ = K\sqrt{\frac{A}{Cm}}$$

where:

$$K = \sqrt{\frac{2.Co}{i}}$$

The number of orders placed per year *(or ordering frequency F)* can be found by dividing the *annual usage* by the quantity per order *(EOQ)*, as follows:

$$F = \frac{A}{EOQ}$$

If the modified EOQ equation is substituted in the above

$$F = \frac{A}{K\sqrt{\frac{A}{Cm}}}$$
$$= \frac{1}{K}\sqrt{A.Cm}$$

This means that the number of orders placed per year *(F)* is equal *1/K* times the square root of the annual usage value of the item *(A.Cm)*. The total number of orders placed per year for a group of items with a common ratio of the K factor is:

$$\sum F = \frac{1}{K}\sum\sqrt{A.Cm}$$

This can be re-arranged to establish a value of K that the organisation currently operates under, as follows:

$$K = \frac{\sum\sqrt{A.Cm}}{\sum F}$$

By establishing a initial, achievable, value of *K*, the Coverage Analysis technique will produce, as a starting point, order quantities which are rational and within the current capabilities of the enterprise, as the value of *K* is based on the existing number of orders raised.

This initial value of *K* can then be used to establish the initial ordering policy for each item within the group by re substitution, and then flexed to obtain an acceptable solution.

To illustrate the technique, take the following 5 items:

Item	Annual Usage	Unit Cost	Annual Usage Value	Orders per Year	$\sqrt{A.Cm}$	Average Stock £
1	600	£3	£1,800	5.0	42.43	£180
2	900	£10	£9,000	5.0	94.87	£900
3	2,400	£5	£12,000	20.0	109.54	£300
4	12,000	£5	60,000	40.0	244.95	£750
5	18,000	£1	18,000	40.0	134.16	£225
			Totals	110.0	625.95	£2,355

Table 3.3 - Calculation of initial value of *K*.

The initial value of *K* is calculated as 5.69 (the total of $\sqrt{A.Cm}$ / total of Orders per Year (626/110)). The average stockholding value that the current policy would generate is £2,355, and this would require 110 orders.

If the initial value of *K* (5.69) was then used to formulate a consistent ordering policy, the following ordering frequencies would result. The average stockholding value that this policy would generate is £1,781, a reduction of £574 or 24%, and this would still require 110 orders.

Item	Annual Usage	Unit Cost	Annual Usage Value	Orders per Year	$\sqrt{A.Cm}$	Average Stock £
1	600	£3	£1,800	7.5	42.43	£121
2	900	£10	£9,000	16.7	94.87	£270
3	2,400	£5	£12,000	19.3	109.54	£312
4	12,000	£5	£60,000	43.0	244.95	£697
5	18,000	£1	£18,000	23.6	134.16	£382
			Totals	110.0	626	£1,781

Table 3.4 - Calculation of consistent ordering policy for initial value of *K*.

Any further policy can now be established by stating either the desired number of orders per year or the average stock value. If the desired orders per year was stated to be 165, then each of the item level orders per year would be multiplied by 1.5 (165/110) to establish the revised ordering frequency, and the average stock valuation divided by 1.5 to establish the revised average stock value.

The same exercise can be performed for a stated average stock valuation, where if this was stated to be £1,200, then each of the individual average stock valuations would need to be multiplied by 0.67 (1200/1781) and each of the item level orders per year would be divided by 0.67 to establish the revised ordering frequency.

3.3.4 Conclusions.

Coverage Analysis is an elegant method of considering the overall order and inventory load that an inventory ordering policy will generate. It retains some of the disadvantages of the *EOQ / EBQ* approach, but avoids a major pitfall, the difficulty of calculating the Ordering Cost and the Inventory Holding Rate.

As a starting point the initial value of K produces a result which is demonstrably within the current capabilities of the enterprise, as it is based on the existing number of orders that current parameters would produce. The result produced for any value of K will also be a least cost solution as measured by the *EOQ / EBQ* equation, but subject to the constraint imposed by the value of K.

When applied to items grouped into common periodic order cycles, the approach *(Lewis 1981)* is the same as described previously except that the items are placed into the ordering classes based on annual usage value. The number of orders per annum per class is then modified by the ratio of the total derived number of orders to the total current number of orders to provide a match on the number of orders raised.

N.B. Some confusion may unintentionally arise due to the use of the letter K as used within Coverage Analysis and the letter K as used later in this thesis within the K Curve Methodology. Whilst it may be confusing for the same symbol to represent two similar, but different ratios, the symbology as used by the original authors is retained for the sake of compatibility.

3.4 THE K-CURVE METHODOLOGY (KCM).

3.4.1 Introduction.

The K-Curve Methodology *(KCM)* was initially developed by IBM in collaboration with Aston University *(Shah, Burcher, Relph 1990) (Shah 1992)* and later with Sunderland University *(Relph, Brown, Dupernex, Dance 1994)*, and is basically a method of modelling the effects of ordering, or having delivered, different groups of items at different frequencies and is an extension of the principles behind the Economic Order Quantity (EOQ) formula.

The EOQ *(Harris 1913) (Wilson 1934)* was the tool used extensively from 1913 up to the mid-1970's to establish 'scientific' batch sizes for the purchasing of materials and components.

The *KCM* provides predictions on the average inventory investment resulting from the inventory ordering policies, as well as the number of deliveries or orders that the system will have to accommodate. The basic premise that the methodology works on is that of splitting the number of items that have to be ordered into a number of classes on a different ordering or delivery frequency, using a Group Period Order Quantity (GPOQ) approach. This is based on Pareto or ABC analysis *(Figure 3.6)*, using the Annual Usage Value *(unit cost x annual quantity)* of each part being considered.

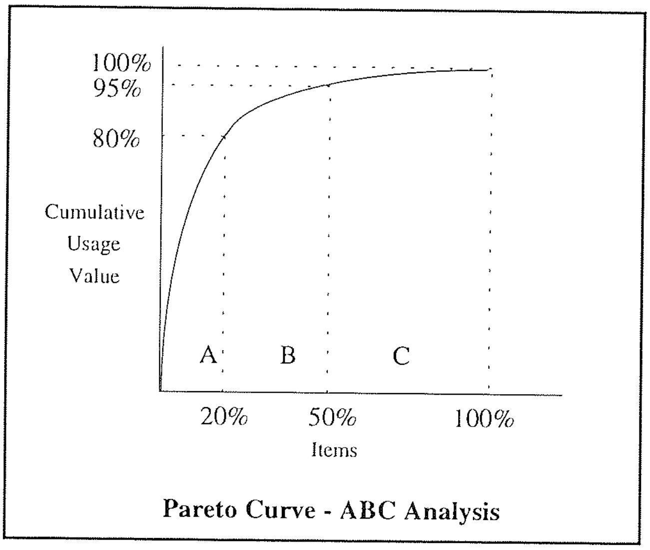

Figure 3.6 - Pareto Curve - ABC Analysis.

The items within each class are determined using a modified EOQ calculation. The EOQ formula operates at an individual item level, and sets out to balance the costs of holding inventory against the costs of ordering. As a result of the EOQ, each part could have a different order size, and a different delivery cycle. It assumes many things, such as the costs could be established, but one of the main assumptions was that there were no constraints within the business which could serve to limit the inventory held, or the total number of orders raised.

In an effort to inject some realism into the EOQ, the Optimal Policy Curve (*Starr, Miller 1962*) was developed, which firstly took account of business constraints such as the amount of money that could be tied up in stock or the number of orders that the business could process, and secondly operated at a macro level. That is, it considers the performance of the whole group of items, rather than the performance of individual items, as per the EOQ approach.

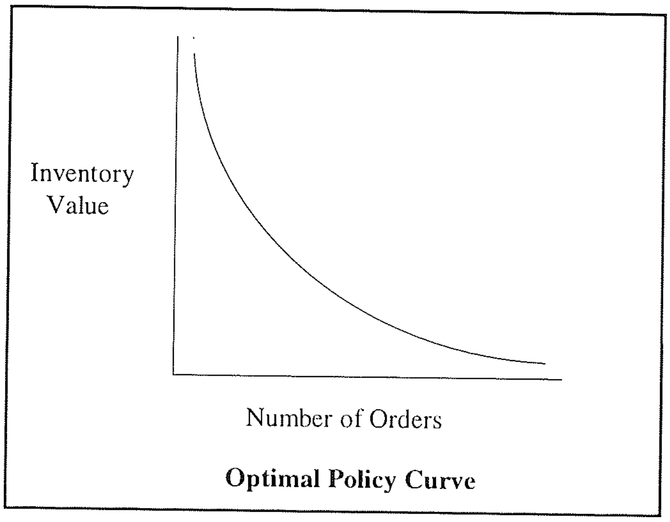

Figure 3.7 - The Optimal Policy Curve.

The first principle behind the Optimal Policy Curve is that there can be more than one optimal solution to your inventory management, and by "exchanging" orders for inventory, it is possible to create any number of ordering policies *(Figure 3.7)*. The second principle that the Optimal Policy Curve works under is that, for a group of items, there is a constant product of the total number of orders and the total inventory value which holds true for any value of the ratio of the inventory holding cost to the order raising cost. Each policy will be optimal for a particular constraint, and each item may still have a different order size and delivery cycle. A similar approach to the Optimal Policy Curve, but significantly easier mathematically, was the Coverage Analysis *(Murdoch 1965)* technique described previously.

The *KCM* takes the basic principles behind the EOQ and the Optimal Policy Curve and applies them in a Periodic Order Cycle environment with separate groups of parts. *KCM* also has the advantage over EOQ and the Optimal Policy Curve of not needing to consider individual costs of ordering, but rather (like Coverage Analysis) the overall ratio of these costs for the items being considered

It is possible with the *KCM* to model the inventory performance of an item when its Annual Usage Value is known, by setting the overall cost ratio to a particular value, and thereby determining an economic Ordering or Delivery Frequency. Changing the value of the overall cost ratio will merely give rise to another economic Ordering or Delivery Frequency, and by choosing a series of delivery frequencies, the parts that fit into each grouping can be established. Each part, therefore, will be slotted into one of the set ordering or delivery frequencies chosen for the modelling process (e.g. 5, 10, 20, 40, 80, or 160 days supply).

From this it is possible to determine an average inventory holding for all the parts being considered, and the administrative effort (the number of orders) that would be required to sustain the inventory at the stated level.

3.4.2 The Mathematical Process.

The K-Curve Methodology *(KCM)* takes as its starting point the Economic Order Quantity (EOQ) equation:

$$EOQ = \sqrt{\frac{2.A.Co}{i.Cm}}$$

where		
	A	Annual Usage
	Co	Cost of ordering and delivery per occasion
	i	Annual stockholding interest rate
	Cm	Item Cost

This can be rearranged to calculate the Economic Ordering or Delivery Frequency *(F)*, in the following manner:

$$F = \frac{A}{EOQ}$$

where		
	EOQ	The Economic Order Quantity
	A	Annual Usage

Therefore:

$$F^2 = \frac{A^2}{EOQ^2}$$

If the Economic Order Quantity *(EOQ)* is re-substituted from the *EOQ* equation, this gives:

$$F^2 = \frac{A.i.Cm}{2.Co}$$

$$F^2 = \frac{i}{2.Co}(A.Cm)$$

This can be further re-arranged in terms of the Annual Usage Value, as follows:

$$A.Cm = \left(\frac{2.Co}{i}\right)F^2$$

Therefore the Annual Usage Value *(Annual Usage * Item Cost)* is related to the square of the Ordering or Delivery Frequency *(F)* by a factor which could be called *K*. *K* is the ratio of the Ordering or Delivery Cost *(Co)* to the Annual Stockholding Interest Rate *(i)*.

$$K = \frac{2Co}{i}$$

From which can be derived the following equation:

$$A.Cm = K.F^2$$

The K-Curve Methodology works on the premise that although the Cost of Ordering or Delivery *(Co)* and the Stockholding Interest Rate *(i)* are both difficult to determine, it is still possible to try out the effect of changing the Cost Ratio *(K)* on the Ordering Frequency *(F)*. So, for a known Annual Usage Value of an item, and a starting value of the Cost Ratio *(K)*, an "economic" Ordering Frequency can be established, as follows:

$$F = \sqrt{\frac{A.Cm}{K}}$$

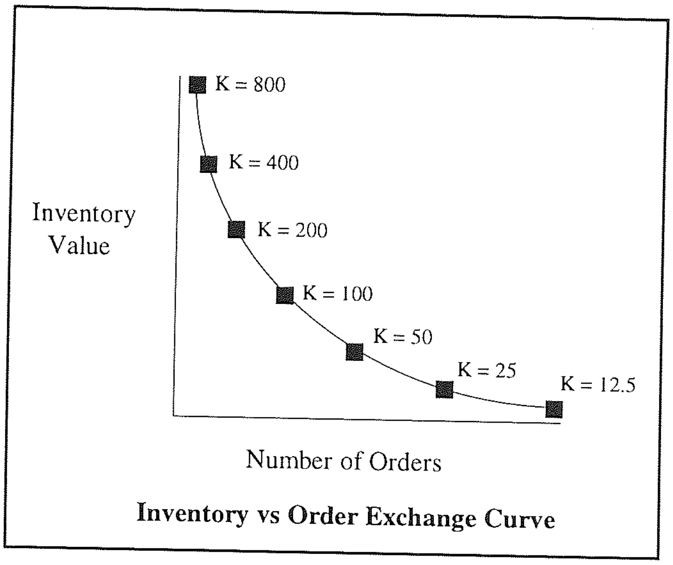

Figure 3.8 - Inventory vs. Orders Exchange Curve for Different K Values.

A different value of *K* will suggest a different ordering frequency *(Figure 3.8)*. It is assumed that all the parts being considered *(e.g. Raw Materials)* have the same value for the Cost Ratio *K*.

Since the Cost Ratio (K) is not known precisely, it can be flexed and corresponding results in terms of the number of orders and average inventory investment for each value of *K* can be determined.

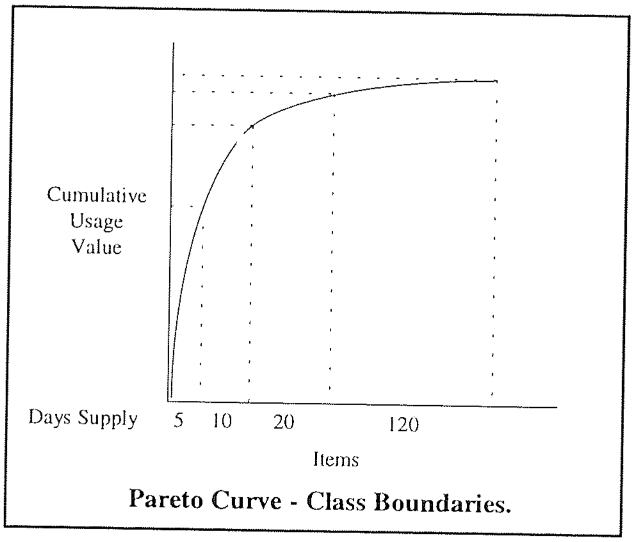

Figure 3.9 - Pareto Curve - Class Boundaries.

The class limits for each of the Ordering Frequencies for the stated value of the Cost Ratio *(K)* are determined using Annual Usage Values *(Figure 3.9)*. Having established the "economic" Ordering Frequency for each of the parts, they are then allocated to the classes.

By substituting different values of *K* into the formula it is possible to predict the total inventory performance in terms of both the number of orders and the average inventory value that the policy would generate. Each value of *K* would generate a different optimum solution in terms of the number of orders and average inventory value.

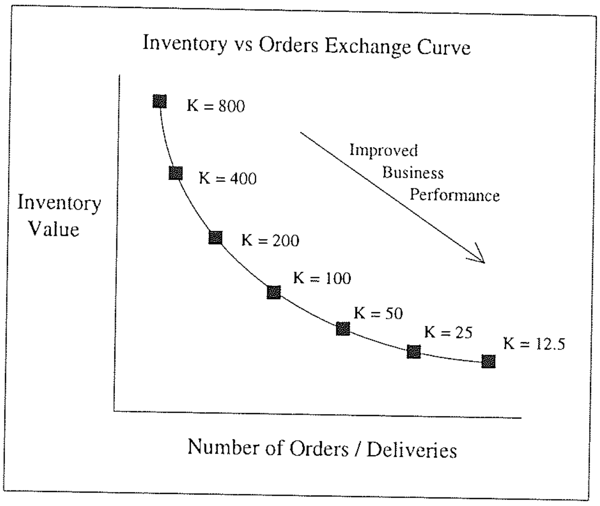

Figure 3.10 - Modified Exchange Curve - K-Curve.

The value of *K* established for a business should tend to decrease with time, as continual process improvements are introduced, increasing the number of orders/deliveries processed, and is in effect a reflection of the speed of the business. The ability to operate using lower values of *K* is a reflection *(Figure 3.10)* of improved business and manufacturing processes.

3.4.3 Worked Examples.

To clarify this approach, the same five items used to explain Coverage Analysis can be considered:

Item	Annual Usage	Unit Cost	Annual Usage Value
1	600	£3	£1,800
2	900	£10	£9,000
3	2,400	£5	£12,000
4	12,000	£5	£60,000
5	18,000	£1	£18,000

Table 3.5 - Cost and Usage Details of Example Items.

Setting different values of *K* suggests different values for the Ordering or Delivery Frequency (*F*):

		K = 50	K = 100	K = 200	K = 400
Item	AUV	Ordering or Delivery Frequency			
1	£1,800	6.00	4.24	3.00	2.12
2	£9,000	13.42	9.49	6.71	4.74
3	£12,000	15.49	10.95	7.75	5.48
4	£60,000	34.64	24.49	17.32	12.25
5	£18,000	18.97	13.42	9.49	6.71

Table 3.6 - Results for K=50, 100, 200 and 400.

As can be seen, as the value of *K* (the ratio of the Ordering or Delivery Cost to the Annual Stockholding Interest Rate) decreases, so the Ordering or Delivery Frequency increases. What this actually means is that inventory is being traded for orders in the same way as the Exchange Curve. The number of orders per year times the order size for each of the items always equals the Annual Usage Value (*AUV*). If all the different economic orders were plotted for Item 1, for values of *K* from 12.5 to 400, the resultant curve would look like:

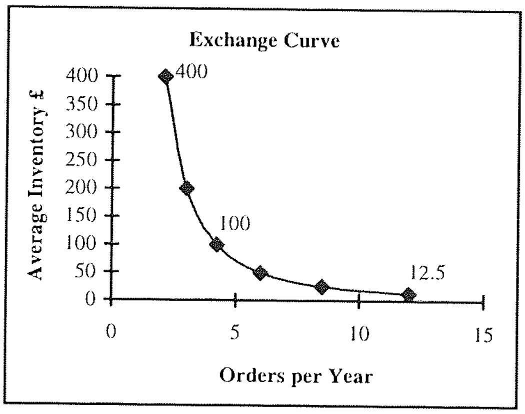

Figure 3.11 - Inventory vs. Orders Exchange Curve - Item 1 for K=12.5 to K=400

The next stage in this approach is to set the Ordering or Delivery Frequency (*F*) at certain pre-determined values, so that groups of items with similar Annual Usage Values can be ordered on similar periodic bases (e.g. daily, weekly, monthly). By flexing the value of *K* to be modelled, the parts which fall into each group will be determined, based on the Annual Usage Value. The determination of the class limits is totally independent of any items that may fit inside the classes. It purely needs the values for Cost Ratio (*K*), and the Ordering or Delivery Frequency (*F*) to be both stated.

In the example, the Ordering or Delivery Frequency (*F*) has been set to 50 times a year (weekly), 12 times a year (monthly), and once a year (annually), and gives the following resultant Annual Usage Values for each different value of *K*:

	K = 25	K = 50	K = 100	K = 200	K = 400	K = 800
F = 50	£62,500	£125,000	£250,000	£500,000	£1,000,000	£2,000,000
F = 12	£3,600	£7,200	£14,400	£28,800	£57,600	£115,200
F = 1	£25	£50	£100	£200	£400	£800

Table 3.7 - Using Different Values of K to Flex the AUV by Delivery Frequency.

Having established the class boundaries in terms of the Annual Usage Values for the individual ordering or delivery frequencies the next step is to allocate the individual inventory items to these frequencies in a rational manner. The way this is done is to use a Group Period Order Quantity approach.

Using the knowledge that as the Economic Order Quantity curve is relatively flat around the optimum policy, it is possible to be sub-optimal around this point either in terms of overall inventory or orders, and still be close to the optimum value in terms of overall inventory performance.

The way the Class Limits are calculated is easily demonstrated using the values previously derived. It basically consists of re-plotting the values of the order cycle in days vs. AUV curve, using logarithms to produce a straight line graph, as follows:

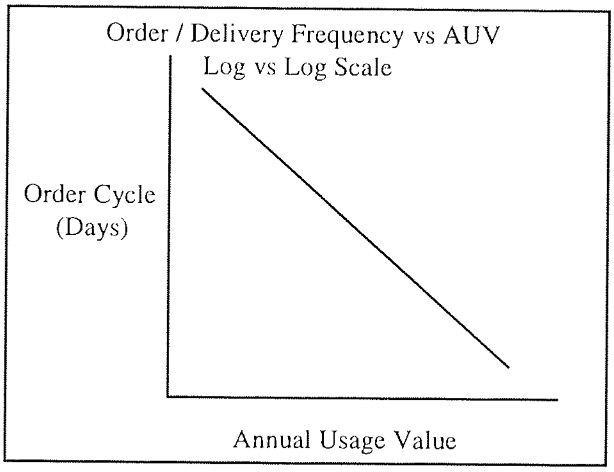

Figure 3.12 - Order Frequency vs. Annual Usage Value using Log scales.

Using the logarithms, perform a linear interpolation to find the mid point *(Figure 3.13)* between each of the stated classes, and anti log the result to provide the class boundary. Mid points are used because the net differences of the positive and negative errors against ordering each item optimally are minimised, as it is likely that the annual usage value will be evenly distributed around the mid point for the class. Items within the class boundaries with Annual Usage Values above the class mid point will be ordered more frequently than the optimum value suggested by the EOQ equation, with the benefit of lower inventory levels. Those below the class mid point will conversely be ordered less frequently than the optimum, with correspondingly higher inventory levels.

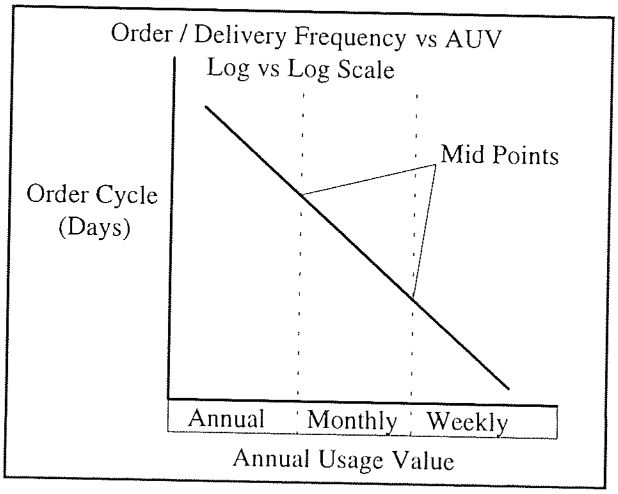

Figure 3.13 - Calculation of Class Boundaries using Mid Point Log Values.

Taking as a worked example the values previously calculated for *K* equal to 50, the following class boundaries are established:

	K = 50	Log	Mid Point	Anti Log
F = 50	£125,000	5.0969	4.4771	£30,000
F = 12	£7,200	3.8573	2.7781	£600
F = 1	£50	1.6989		

Table 3.8 - Calculation of Class Boundaries.

The class limits expressed in terms of the Annual Usage Value for each item for *K* equal to 50, with weekly, monthly, and annual orders will be therefore set to weekly £30,000+, monthly £29,999.99 to £600, and annual to less than £600.

Having set the class limits it is now possible to allocate items to the classes for the particular value of the Cost Ratio (*K*), based on their Annual Usage Values. Having allocated the items to the classes, the total number of orders per year (*OPY*) can be established from the number of items within each class and the delivery Frequency per annum for the class, as follows:

$$OPY = IPC.F$$

where IPC number of items within the class
F delivery frequency per annum

The average inventory holding can also be calculated by summing the annual usage values for all the items within the class, and dividing this by twice the total number of orders per year for the class. The Average Inventory Holding (*AIH*) for each class is calculated in the following manner:

$$AIH = \frac{AUV}{2OPY}$$

where AUV total Annual Usage Value for items in class
OPY total number of Orders or Deliveries per annum for the class

So, for a particular value of *K* and a particular set of class limits, it is possible to predict the total number of orders and the average inventory that the policy creates. By performing the calculations with different values of the cost ratio *(K)*, it is possible to construct an overall exchange curve for the items being considered:

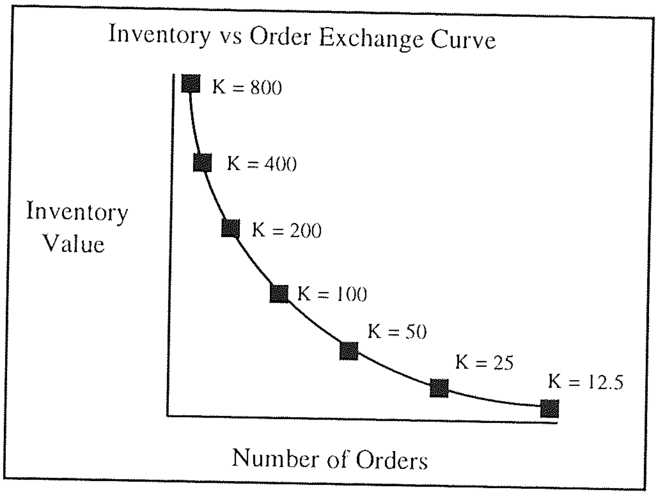

Figure 3.14 - Inventory vs. Orders Exchange Curve for K=12.5 to K=800.

The curve represents all the optimal policies between the stated values of the cost ratio *(K)*, for the period order day classes. In the example above *(Figure 3.14)* this is from *K* = 12.5 to *K* = 800 inclusive.

Using the overall exchange curve it is possible to predict the number of orders and the average inventory value that a particular value of *K* will provide, with the prescribed class limits, for the items being considered. It is also possible to predict the minimum number of orders or deliveries, and the cost ratio, that would have to be achieved in order to satisfy a particular inventory limitation. Likewise, it is possible to predict the minimum average inventory, and the cost ratio, that would be needed to satisfy a limitation on the number of orders or deliveries that a business could handle. The current number of orders or deliveries, and the current average inventory value could also be plotted as a point to establish the rationality of the current ordering policy.

In the example below *(Figure 3.15)*, any position on the curve between points X and Y would save the company money.

How much is difficult to say, as all the costs are not known.

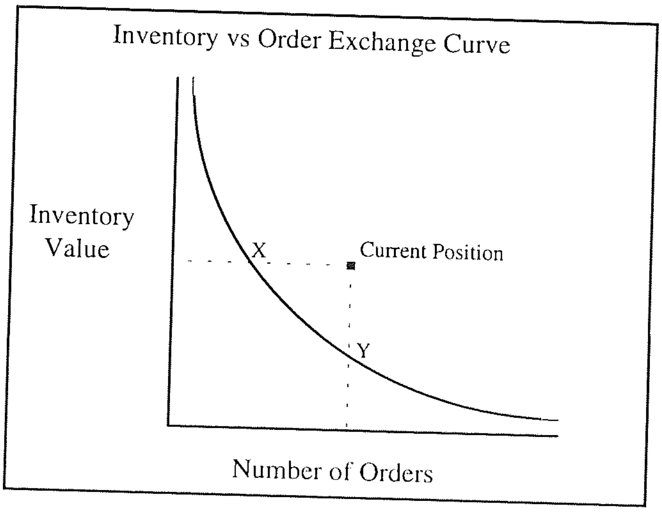

Figure 3.15 - Exchange Curve vs. Current Position.

The way the value of the cost ratio *(K)*, and thereby the class limits, is established for a particular business is through a heuristic search process. This is not to say that it is random, but that it is by reference to the current situation of the enterprise being examined together with benchmarking against current best practice in the particular industry.

If the current inventory ordering policy lies above the exchange curve, then clearly it is possible to improve on the current policy. As a starting point, an ongoing enterprise already demonstrates that it can operate historically with a current level of orders or deliveries. By taking this figure on the graph, and moving vertically to point Y, it is possible to establish an optimum inventory level achievable with the same number of orders.

It is possible also to establish the saving in inventory value.

This is the difference between points A and B below:

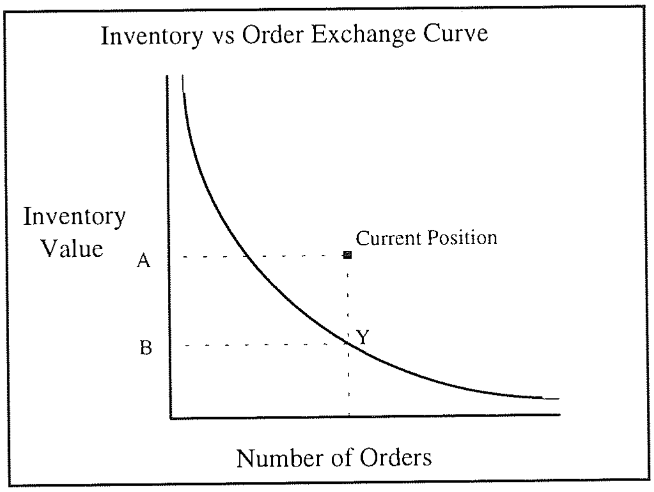

Figure 3.16 - Exchange Curve Inventory Value Saving vs. Current Position.

This also serves to establish a value for the cost ratio, K, that it is possible for the enterprise to work at under prevailing operating conditions, with no improvement in working practices. In other words that the current systems, organisational structure, work flows, manning levels, accounting practices etc. remain in place.

Likewise it is possible to take, as a starting point, the current inventory levels carried by the enterprise. By taking this figure on the graph and moving horizontally to point X it is possible to predict the number of orders that an optimum policy would create using the same level of inventory as the current policy. It is possible also to establish the reduction in the number of orders. This is the difference between points C and D below:

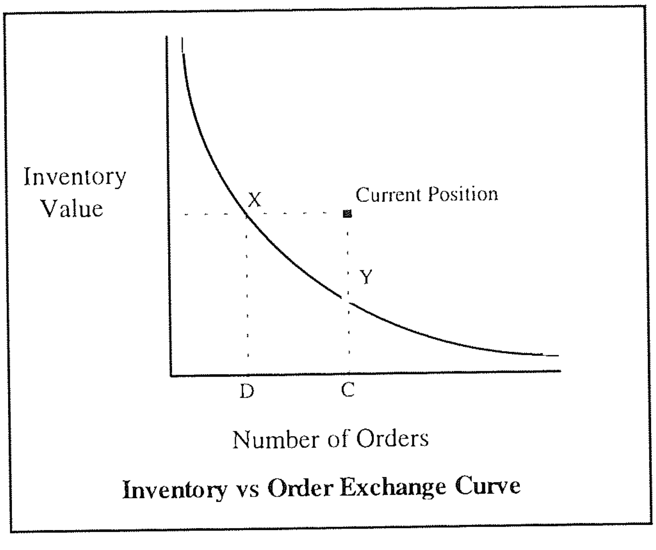

Figure 3.17 - Exchange Curve Annual Orders Saving vs. Current Position.

Again, this establishes another value of the cost ratio, K, that the business can also currently operate to. It is also fair to say that the business can operate within a band of cost ratios, with the band width being defined by points X and Y *(Figure 3.17)*.

Another approach is to establish the level at which the enterprise would like to hold either the orders or inventory, and thereby establish a value for the cost ratio (*K*). It is then possible to explore the ramifications on the business of operating to this ratio.

For instance a cost ratio (*K*) of 50 on its own implies only the ratio of the cost of ordering or delivery to the inventory holding rate. But every enterprise creates a business plan, where the future rate of interest is budgeted to be within a certain range. If, for example, this were 8 percent to 12 percent, it is possible, using the budgeted assumptions, to fix a range for the costs of ordering and delivery, and see if it then is possible for the enterprise to operate within this range, as follows:

$$\begin{aligned} K &= \frac{2Co}{i} \\ 50 &= \frac{2Co}{0.08} \\ Co &= \frac{50*0.08}{2} \\ &= £2.00 \end{aligned} \qquad\qquad \begin{aligned} K &= \frac{2Co}{i} \\ 50 &= \frac{2Co}{0.12} \\ Co &= \frac{50*0.12}{2} \\ &= £3.00 \end{aligned}$$

In the above example, for the enterprise to be able to operate at the desired number of orders or deliveries and inventory level, at a *K* value of 50, and with an inventory holding rate between 8 percent and 12 percent per annum, it would have to be able to operate with a cost of ordering or delivery between £2.00 (for 8%) and £3.00 (for 12%). From these figures a total cost of ordering or delivery can be calculated for the enterprise, as follows:

$$TOC = n.Co$$

where	n	Number of items being considered
	Co	Cost of ordering or delivery per occasion

In this way it is possible to turn round the traditional *EOQ* arguments over determining costs into a "can the enterprise operate at this level" discussion, using either the Total or Individual Cost of Ordering or Delivery per occasion. Having established a value for the Cost Ratio (*K*) for the particular items to be classified, it has to be realised that this will not remain fixed. It will tend to slowly increase as time passes due to the effects of inflation, but this should be more than compensated for by improvements made to the processes leading to a decrease.

The assumptions made by the K-Curve philosophy are:

- the EOQ assumptions are valid for the purposes of the *KCM* model
- the demand remains constant
- the ratio of the costs (*K*) remains constant
- there is unlimited production capacity
- there is unlimited inventory capacity
- the cost of ordering and delivery per occasion is the same for all items
- a meaningful value can be obtained for the Cost Ratio (*K*)

Without these assumptions it is not possible to establish a value for the business of the Cost Ratio (*K*), or to allocate items into product classes using this fixed ratio.

3.4.4 Conclusions.

Although the assumptions inherent in the methodology may be questionable in a laboratory setting, in a practical setting the output from the *KCM* modelling process has been shown to be acceptable to the users of the methodology. It is not seen by the users as a correct solution to be followed without thought, but as a theoretical model to be interpreted, and used within the context of the current and future operating constraints.

What *KCM* has provided is a quick method of obtaining realistic estimates of the value of base inventory and order workload that a set of inventory parameters would be likely to generate given the assumptions inherent in the users data and the modelling process. The key to the success of the methodology is the way in which the period order day class boundaries are fixed *(Relph, Brown, Dupernex, Dance, 1994)*, and the value of *K* established for the particular business, which then allows the inventory holding and resourcing decisions to be expressed in business case form.

After contacting several mature users of the *KCM,* and discussing the way in which it has been applied by IBM Consulting, it is apparent that none of the users of the methodology have blindly applied the raw recommendations within their enterprises, all of them have had to use their knowledge of their businesses and critical judgements in interpreting the results to the benefit of their businesses.

3.5 ACCOUNTANCY AND COSTING.

3.5.1 Introduction.

The determination of costs and benefits is a necessary part of any modelling exercise, and these are invariably presented to a great degree of precision, but exactly how accurate are they? The answer to this depends on the use to which the figures are to be put, and what assumptions can be made about the trading conditions the company operates under. Where the actual volume and timing of manufacture differ materially from the forecasted figures used to assemble the costs of the various items, it could be thought that the costs are not wholly correct. However, if the actual volume and timing of manufacture correlate more closely with the operating conditions, the costs still may not be wholly accurate. This is because of the basis under which costs are built up by the management accountants.

As a simple example, if a can of dog food were purchased from a supermarket for 50p, what is the cost of the item? It is not just the 50p purchase price. Certainly 50p is the purchase price, however how much did it cost to get to and from the supermarket? If this journey was by car, how much petrol was used and what was the cost of the petrol, what are the fixed costs of the car (insurance and road fund licence) and what proportion of those costs were incurred in going to the supermarket, what are the other semi fixed costs (servicing and replacement parts) and how should these be allocated to the supermarket trip, what is the annual depreciation of the car, how long did it take to drive to the supermarket, purchase the dog food, and return home, and what is a valid rate of pay per hour for the car driver? Were other items purchased at the same time, and was the journey used for another purpose, perhaps to collect a child from school? What process was followed to establish the need for the dog food, how long did this take, how often is this done, and how many times does this result in the need to buy? What else takes place that has not been considered, do these events always take place, or can other courses of action be followed to achieve the desired result?

With this simple example it is clear to see that the establishment of costs is not and can not be an exact science. It is an approximation based on the available information and assumptions as to how future events will unfurl.

Cost information is ubiquitous, permeating every aspect of a business, and so is of great commercial significance to an enterprise. Originally, costing systems were devised so that unit costs could be established as accurately as possible, however the development of company law and Statements of Standard Accounting Practice (SSAP's) have meant that the usefulness in decision making has been subordinated to auditability *(Kaplan Johnson 1987)*, with costing systems being developed to satisfy financial accounting requirements as simply and cheaply as possible *(Dugdale 1990)*. The way in which costs have traditionally been derived have to a large extent been driven by the legal requirement on Financial accountants to report stock valuations in annual accounts on an absorption basis as stated in SSAP 9 (Stocks and Works in Progress 1975) *(Lucy 1988) (Glautier, Underdown 1988)*. This has had the effect of the absorption costing method being generally adopted for valuation purposes, it being easier and more consistent for one set of costs to be used within a company, rather than go to the expense of keeping multiple methods current. Another effect of this subordination of the costing function to the requirements of financial accounting *(Kaplan, Johnson 1987)* was that only production overheads were absorbed into product costs, rather than including selling or administration costs.

As the research is based on a modified EBQ formula, which relies heavily on cost data, this section is concerned with the some of methods used for evaluating the costs of manufacturing products (Product Costing), and using the costs over a period of time (Standard Costing).

3.5.2 Introduction to Product Costing.

This covers a wide area, the extremes of which are represented by Job Order Costing and Process Costing. However, for repetitive batch manufacturing, the following three methods are more generally used for costing purposes:

- Absorption Costing
- Marginal Costing
- Activity Based Costing (ABC)

The determination of the unit cost poses two problems, firstly, the identification of the cost categories to be used and, secondly, how to apply these costs to the products as they pass through the manufacturing processes. The cost categories need to cover the purchasing and conversion activities required to manufacture the products. The manufacturing costs are classically divided into three categories, two direct cost classifications and one indirect cost classification:

- Direct material costs.
- Direct labour costs.
- Factory Overhead costs.

However, can it reasonably be assumed that even the cost of direct materials is fixed? Or can these vary? Is it the purchase price of the materials themselves that should be considered, or the cost of ownership? What about the quality of the materials supplied, is this subject to variability, or uniform? How does any variability in material quality affect the true cost of purchase? Does the supplier always deliver the materials in the quantity required, and on the date required, or not? If not, how does this delivery variability affect the true cost of purchase? Is the production method standard, or are alternative routings used? Is the material usage the same for each manufacturing method, or is there a variability? How is this material usage variability expressed in the cost figure?

Direct labour costs are also treated as though they are fixed, but again, these are subject to variability, both in the setting-up the product for manufacture, and during the manufacturing process itself. Is the time taken by an individual to perform a task fixed? Or is it variable? If different individuals perform the task, do they undertake it in exactly the same way, or does the method vary from person to person in a manner that affects the time taken to complete the task? Are all the individuals who can perform the task on the same rate of pay, or not? Is the production method standard, or are alternative routings used? Is the direct labour usage the same for each manufacturing method, or is there a variability? How is this variability measured, and expressed in the cost figure?

Likewise, the way in which the factory overhead costs are allocated to a product will materially affect the cost.

The importance of the costing system is in the nature of the decisions made in the light of the resulting margin, so the accuracy of the costing system chosen will materially affect the commercial decisions of the company. As product life cycles contract, so more of the cost of a product is committed to origination costs *(Sakurai 1989)*, such as research and development activities, so giving the management accountants less time to confirm the correctness of the costs, and so to correct errors or omissions. Product costing cannot, therefore, be viewed as an exercise unrelated to other issues facing management.

Where poor costing gives rise to understated margins, there will be less interest in investment in the product, however, if the margin is overstated the effort in promoting the product will have sales and marketing effort invested giving rise to inadequate returns.

Over the past 30 years the typical cost profile in manufacturing has changed dramatically due to the shift to automation resulting in a greater proportion of overhead costs *(Clarke 1995)* and the relative decline in labour:

Figure 3.18 - Changing Cost Structures ***(Morrow 1992).***

The average proportion made up of direct labour has been in decline *(Bromwich, Bhimani 1989),* as technology and automation have been widely adopted and the development and life cycles of products shortened, and is now thought to lie between about 5% *(Horngren, Sundem 1990) (Ralston 1994)* and 15% in the United Kingdom *(Morrow 1992).* At the same time manufacturing overheads have risen *(Bellis-Jones, Develin 1992)* by almost 50% to account for an average of 25% of sales revenue. A result of the relative decline in labour and the increase in overhead costs is that labour accounting becomes less important.

There is also a change in emphasis from one of cost control to cost planning, with the control of costs at the planning stage receiving greater significance, as by the time it comes to produce an item, it is too late to effectively control costs.

With the emphasis of those firms achieving World Class Manufacturing (WCM) moving to one of making high quality items at low cost which are delivered promptly, providing customer satisfaction and high performance, the traditional manufacturing philosophy on quality is being challenged:

Traditional Management view	WCM philosophy
	product

Table 3.9 - Differing views on quality ***(Clarke 1995).***

This move to WCM has highlighted deficiencies in the traditional approach to management accounting in the following areas *(Clarke 1995)*:

- It fails address the way in which an enterprise progresses towards WCM.
- Product Costs in multi product companies are incorrect due to inappropriate use of overhead absorption methods.
- A narrow internal orientation hampers strategic decision making.

One of the ways in which enterprises have attempted to achieve WCM is through investment in automation and advanced manufacturing technology (AMT) with the aim of achieving better product design, production flexibility, enhanced reliability, and quicker response to the customer. From an accounting viewpoint, the move to increased automation has resulted in a decline in direct labour costs and an increase in the relative proportion of overhead costs.

Another way of achieving WCM is through the introduction of Just in Time (JIT) systems, which attempt to dramatically cut lead times from the supplier, within the factory, and to the customer by eradicating non value added activities, leading also to reductions in stock levels and the elimination of waste. With the reduction in inventories under JIT, stock valuation is a less important issue, and the need for detailed management accounting for finished goods, work in progress and purchased items is therefore reduced. JIT, with its emphasis on Total Quality, and new technology, both lead to fewer defects and less inherent wastage, so diminishing the importance of the material usage variances. As suppliers are integrated into the business, and supplier reliability and component quality become the key issues in the relationship, and price a less potent issue, the material price variances become less important and the cost of quality assumes a pre-eminence.

Strong arguments to change *(Kaplan, Johnson 1987)* are put forward which focus on the inappropriateness of current management accounting. In WCM less direct labour is used, with a greater proportion of cost being in overheads. An emphasis on labour based overhead recovery is said to produce distorted product costs. It is said to produce results that can lead to decisions being taken which are positively harmful to their enterprises. However it has also been concluded *(Bromwich, Bhimani 1989)* that the evidence and arguments put forward by advocates for change in the approach to management accounting are not sufficient to justify wholesale changes in accounting practice and that reforms cannot be advocated.

3.5.3 Absorption Costing.

Absorption Costing bases the product cost on three categories previously mentioned (direct labour, direct material and factory overhead). It traditionally recovers the costs of overheads by using apportionment based usually on the use of direct machine or labour hours.

Direct materials, labour and expenses can usually be identified to the cost unit with relative ease, but indirect overheads are allocated through allocation, apportionment and absorption.

The advantages claimed for absorption costing are:

- SSAP 9 (Stocks and Works in Progress 1975) recommended the use of absorption costing for financial accounts.
- Production cannot be achieved without incurring fixed costs, and so these should be included in stock valuations.
- Where stock building is necessary (e.g. maturation of spirits) the inclusion of the fixed costs in stock valuations is necessary to avoid 'losses' occurring in early periods offset eventually by excessive 'profits' when the goods are sold.
- The conceptual simplicity of the system.
- Since production cannot be achieved without incurring fixed costs, such costs are related to production. Absorption costing merely reflects this relationship

by providing a 'fair' method of apportioning the share of overheads that should be borne by each product.

- Pricing decisions based on total costs can 'avoid' the danger of incomplete recovery of overheads.
- If a product cannot sell profitably at a price based on the fully absorbed cost, it should probably not be made.

The disadvantages claimed for the method are:

- The use of volume based drivers to allocate manufacturing overheads to products. Many overheads such as rent and audit fees *(Harper 1993)* are completely independent of whether an individual product is made or not.
- It is not appropriate where overhead costs relate to transaction based costs such as set-ups or quality.
- The focus is on the past.
- Since overhead apportionment's are often arbitrary, different cost accountants often arrive at different cost-unit costs. Its calculation depends upon the apportionment of all expenses that cannot be traced back directly to a cost centre or product. This apportionment, although reasonable, must be arbitrary. The consequence of this is that decisions are made on the basis of figures which depend for their validity on the costing conventions adopted in the cost build up.
- It can institutionalise non value added activities into the total cost.
- Relatively minor volume variations against the budgeted figures used for the costing exercise can lead to substantial under or over recovery of overheads, so affecting profitability.
- The overhead apportionment is generally assigned on a volume based recovery basis. This is not acceptable where a large proportion of the overheads are unrelated to volume.
- All costs are absorbed into the products.

3.5.4 Marginal Costing.

Marginal Costing is a method of charging the variable production costs to cost units. It is based on the view *(Harper 1993)* that in many practical short term situations the cost of any given activity is the cost that that activity generates - and no more. The variable costs are the sum of all the direct unit costs plus the variable overhead cost per unit incurred by the cost unit. The contribution per unit is the amount that the sale of each unit contributes to recovering the fixed costs.

The principle that marginal costing operates under is that it recognises that the behaviour of the costs is influenced by the level of activity. The total fixed costs tend to remain constant irrespective of the levels of production, whereas the total variable costs tend to increase or decrease in line with the production or sales activity.

The advantages of marginal costing are:

- Ease of use.
- No attempt is made to relate fixed costs, incurred on a time basis, with products, since these costs are independent of production.
- Does not require the apportionment of overheads.
- Under or over absorption of overheads is avoided.
- Fixed costs are incurred on a time basis.
- Fictitious profit cannot arise due to fixed costs being absorbed and capitalised in unsaleable stock.
- Contribution is a correct measure of the effect of making and selling a product.
- It is easier to evaluate the profit performance of different product lines.
- The impact of pricing decisions on the contribution margin can be easily measured.

The disadvantages of marginal costing are:

- It cannot be used for external accounting purposes as SSAP 2 (Disclosure of Accounting Policies) requires *(Glautier, Underdown 1988)* that 'revenues and costs are matched with one another so far as their relationship can be established or justifiably assumed'.

- It may be difficult to segregate the fixed and variable elements of the overheads.
- It can lead to bad pricing decisions which result in selling prices being set such that the overhead costs are not fully recovered.

3.5.5 Activity Based Costing.

The main difference between absorption accounting practice and ABC lies in the way overhead costs are apportioned to products. Absorption accounting relates the resources consumed on a volume basis. But, as there are costs which are not volume related, the approach adopted by ABC is one where overhead costs can be related to products on a product basis (either by volume or batch), customer basis, or facility sustaining basis.

Its primary purpose is to analyse indirect costs, to understand the cost and operational relationships, and to make the information usable, and is based *(Bellis-Jones, Develin 1992)* on the following principles:

- Costs represent the expenditure incurred in acquiring **resources**;
- **Activities** use or consume **resources**;
- The amount of **activity** consumed, and therefore the cost, is dictated by the appropriate **cost driver**;
- **Activity costs** are linked to **objects** by means of the appropriate **cost driver**.

ABC aims to produce a 'correct' product cost, and is a cost and operations analysis based on the assembly of financial and non financial operating data. For it to be effective, a majority of all costs incurred by a significant unit of a business must be systematically analysed.

Although the absorption method of costing can be seen to be deficient in a number of areas, an analysis of an ABC system *(Datar, Gupta 1994)* concluded that *'better specified costing systems may actually increase measurement errors and hence errors in product costs'*.

The advantages of ABC are:

- It provides greater understanding of the overhead costs.

- It helps in controlling and managing costs by better understanding the cost drivers.
- It establishes direct relationships between service providers and consumers.
- It directs management attention to the activities which consume resources.
- The indirect costs are more accurately applied to products.
- Unused resources are exposed rather than absorbed.
- Product and service costs are more accurate *(Jayson 1994).*
- It focuses on activities that add value.
- It allows the better understanding of the costs of variety, complexity and change to be used in focusing the continual improvement process.

The disadvantages of ABC are:

- The reluctance of accountants to change.
- It can be very complex and expensive to implement, requiring organisational changes.
- Where there is a high direct labour content, with low variety, complexity variability and change in the customer or product base it is unlikely to produce product costs which significantly differ to those produced by absorption costing *(Cooper 1988).*
- The result may be more 'inaccurate' *(Datar, Gupta 1994).*
- Existing software (such as MRP) is not designed to support multiple cost drivers.
- The subjectivity in choosing the cost drivers.
- Verifiability of the cost drivers.
- For Financial Accounts:
    1. Where cost drivers relate to non production bases, these would have to be excluded from stock valuations.
    2. How to define and dispose of excess capacity costs.

3.5.6 Standard Costing.

Standard costing is the technique which relies upon the comparison of the actual levels of costs and sales achieved to be compared with the predetermined (or budgeted) levels to allow for the investigation of variances.

The predetermined costs are called Standard Costs. Standard Costs are the costs judged to be incurred under a set of defined working conditions. Standard minutes (or hours) is the measure of the time taken to complete a certain volume of work under the defined conditions, which may never actually exist in practice.

Standard costs can be established using any of the methods previously described, or can use, for example, a theoretical average material cost over the period for which the standard is to be current. Similarly, the routing information may not relate to a particular method of manufacture, but can be a composite based upon the various routes which the item is likely to use during the currency of the standard.

It establishes *(Perks, Graham 1984)* quantity and price targets for inputs of labour, materials and overheads prior to production, set by reference to product specifications, expected costs, and anticipated production volumes and efficiencies based on estimates of what is attainable under normal operating conditions. It was developed to help in the planning and control of operations while providing costs which could be used for calculating the cost of sales and closing stocks.

3.5.7 Conclusions.

Within this section it has been demonstrated that although product costs are presented by the accountancy profession to a great degree of precision, that the accuracy of the costs is debatable, whichever of the costing methods discussed is used.

Accountants and accounting policies have a far reaching effect on the performance of an enterprise, and the way in which the cost of a manufactured item is derived can profoundly affect the product portfolio in terms of whether the product if retained in the portfolio, and if so, whether it is made or purchased.

What is of concern is the range of product costs that the different methods can derive for a particular item, and the way in which a product cost, once calculated, is treated as 'correct'. This is easy to demonstrate with absorption costing, but even using ABC there has to be a debate about the costs used. For instance, how much does a computer transaction cost, how much does a set-up cost, what time and by implication cost should be used for a set-up if this is sequence dependent, if alternative routes are available, which one should be used for costing purposes, etc.

Realising that costs are not accurate, but are presented to a great degree of precision leads to the inevitable conclusion that they must be used with caution. The variability in the costs of a particular item are generally neither calculated nor discussed, the cost of item never normally being expressed in terms such as £1.23456 ± £0.10p with 99% probability.

The implications for the research, which is based on the use of a modified EBQ formula, is that the results of any modelling exercise using item, ordering and set-up costs cannot be viewed as wholly accurate. This is because, no matter which of the three costing methods is used, the cost base is open to question, being based on average figures for material, labour and overhead usage. At an individual product level, and over a short time-scale, the difference between the figures used for costing purposes and those observed could well be large, due to the probabilistic nature of the data. However, over a longer timescale, and with more products being considered, the observed figures should more closely align with the costing figures, and the accuracy of the modelling improve.

By taking a longer timescale, and limiting the choice of modelling technique to one which uses an overall, rather than detailed approach, it is possible to take advantage of the predictive quality of the figures used as a basis for costing to anticipate the likely future performance of an enterprise with a reasonable degree of accuracy, even without knowing the statistical variability of the figures being used.

3.6 THE K^+ METHODOLOGY.

3.6.1 Introduction.

Taking the K-Curve Methodology (KCM) as applied to purchased parts as a starting point, this provides *(Shah 1992)* an elegant and simple way of minimising the overall costs for a group of purchased parts to be ordered on a periodic basis. Each part is assumed to be independent of every other part, and can be ordered on a different ordering cycle without either incurring any cost penalty or accruing any cost benefit. Obviously there are instances where this is not so, but for the majority of parts, this rule of thumb approach provides a better answer than other methods. Better because, firstly, it is quick to do as it requires very little data for each item and the modelling is relatively simple, secondly, once the items have been allocated to period order classes it provides realistic estimates of base inventory and order load, thirdly, that by concentrating on just two dimensions, the number of orders raised and the theoretical base inventory value, the results are easily understandable by the users, and fourthly, that it is a simple matter to estimate the order load required to support a required inventory level, or vice versa.

However, for manufactured parts, the assumption that the ordering (or, more properly, set-up) costs are the same for each item, can be shown to be fallacious in a large number of cases. Only where the set-up costs are the same for the group of items being considered may it be appropriate to use the KCM approach, and even then KCM lacks any insight into the capacity utilisation that the policy would generate, continuing to work in only two dimensions, the average base inventory value and number of orders raised per year.

For manufactured parts, the KCM fails to take account of three important factors, firstly that the capacity used to support a particular ordering policy is of prime importance, secondly that set-up costs vary between items and so the use of the common ratio K is inappropriate, and thirdly that set-up costs of an item cannot always be thought of as fixed, but may vary according to the previous item on the machine.

The challenge is therefore to develop a methodology which retains the simplicity of the KCM approach, and avoids the factors that makes the KCM inappropriate for use with manufactured parts. This chapter explains a proposed methodology for dealing with this in a unified manner.

3.6.2 Investigation of the EBQ.

The Economic Order Quantity (EOQ) has been already been explored in detail, and is similar in most respects to the Economic Batch Quantity (EBQ), which is applicable to manufactured parts. The *EBQ* was put forward by Ford W. Harris *(Harris 1913)* as a general solution to a general problem which produced a theoretically correct result for determining an economical ordering quantity for manufactured items. The simple square root formula for determining the optimal ordering quantity follows directly from the assumption that the rate of demand is constant and the balancing of the inventory holding costs against the ordering, or set-up, costs.

It requires certain values or costs to be calculated or estimated for each item:

- The cost price of each item
- The carrying cost per unit of time
- The ordering / set-up cost per occasion
- The usage quantity per unit of time

The correctness or otherwise of these costs or values will directly influence the validity of the answer provided by the *EBQ* formula, however it is immediately noticeable that the *EBQ* contains no reference to the capacity used to support the optimal ordering policy. As it operates at an individual item level it also fails to consider any constraints on the factors it does consider which may exist.

When modified to take account of set-up costs the *EOQ* formula becomes the *EBQ* formula:

$$EBQ = \sqrt{\frac{2A\,(Co + Su)}{i.Cm}}$$

where	A	Annual Usage
	Co	Cost of internal ordering per occasion
	Su	Set-Up Cost per occasion
	i	Annual Stockholding Interest Rate
	Cm	Item Cost

3.6.3 Derivation of the KCM for Manufactured Items (K-Plus).

Taking as a starting point the *EBQ* formula, this can be rearranged in terms of the Annual Usage Value (AUV) to see whether a similar constant ratio, K, can be found for manufactured items as was found for purchased items, as follows:

$$EBQ = \sqrt{\frac{2A\,(Co + Su)}{i.Cm}}$$

$$F = \frac{A}{EBQ}$$

$$F^2 = \frac{A^2}{EBQ^2}$$

$$F^2 = \frac{A.i.Cm}{2(Co + Su)}$$

$$F^2 = \frac{i}{2(Co + Su)}(A.Cm)$$

$$A.Cm = (\frac{2(Co + Su)}{i})F^2$$

$$AUV = (\frac{2(Co + Su)}{i})F^2$$

where F Number of Orders per Annum

Unlike the K-Curve Methodology, where a value of K can be argued to be a common cost ratio applicable to a large group of parts, within the K^+ Methodology the value of K^+ can easily be shown to be different, as follows:

$$K^+ = \frac{2(Co + Su)}{i}$$

This is because it is difficult to argue convincingly that set-up costs *(Su)* are the same for all the parts being considered, when they could easily be demonstrated to be different in a large number of real life examples.

Taking the original formula, research *(Shah, Burcher, Relph 1990) (Relph, Brown, Dupernex, Dance, 1994)* has already proven that, when taken at the macro level, the ratio of the ordering cost to the inventory holding rate can be considered constant for a range of purchased parts. This is the basic premise of the K-Curve Methodology.

For manufactured parts, it can be argued with equal validity, that if the set-up costs were zero, that is, only considering internal ordering costs, a constant value for K^+ could be derived for the group of parts being considered. An example of this could be an assembly operation where toy cars are automatically packed in boxes. As all the cars are packaged in the same outer, a change of model does not require a change of packaging, and so the set-up cost is zero. It can also be argued that, having established a value of K^+ assuming that set-up costs are zero, an educated estimate of the inventory holding rate (i), or range of values that the rate was likely to be within, could likewise be established for the part of the enterprise being considered. Having established these values, a value, or range of values, for the cost of internal ordering or delivery per occasion (Co) can likewise be inferred.

To illustrate this with a worked example, if the initial value of K^+ chosen for all parts is equal to 150 (the method for determining this value will be shown in a later section), the set-up cost (Su) is zero, and the inventory holding rate (i) is 10%, then the cost of internal ordering per occasion can be calculated as £7.50 by substituting the other values into the formula, as follows:

$$\begin{aligned} K^+ &= \frac{2(Co+Su)}{i} \\ &= \frac{2(Co+0)}{i} \\ &= \frac{2Co}{i} \\ Co &= \frac{K^+.i}{2} \\ Co &= \frac{150*0.1}{2} \\ &= 7.5 \end{aligned}$$

If it is assumed that the set-up cost per occasion (Su) can be determined for a particular part and, for the sake of illustration, that a figure of £2.50 is correct for the part being considered. Then, if the initial value of K^+ chosen for all parts is 150, the inventory holding rate (i) is 10%, and the cost of delivery or ordering per occasion (Co) is £7.50, the new value of K^+ under which the particular part is operating can now be calculated as being 200, as follows:

$$\begin{aligned} (New)K^+ &= \frac{2(Co+Su)}{i} \\ &= \frac{2(7.5+2.5)}{0.1} \\ &= 200 \end{aligned}$$

Using this new value of K^+, it is now possible to calculate the appropriate class boundaries in terms of AUV, and to place the part in the correct ordering cycle according to the AUV value for the part.

Using the process described above, it is possible to use the underlying initial value of K^+ to place items into lower or higher period order day classes. By increasing the initial value of K^+, so the value of the class boundaries increases, and items will be scheduled less frequently. If K^+ is decreased, so the value of the class boundaries decreases, and items will be scheduled more frequently.

In order to control the spread of the period order day classes used, it is necessary to be able to modify the set-up cost. This is achieved as follows, using an improvement factor *(v)*:

$$K^+ = \frac{2.(Co + (Su.v))}{i}$$

The improvement factor *(v)* also ensures that it is possible to allocate items into low period order day classes (e.g. 5 days) when there are high set-up costs and available capacity, so circumventing a shortcoming in the original EBQ.

It is possible, using these three modifiers *(K^+, v and i)* to focus the attention of the modelling process onto the degree of fit possible against the three constraints (Financial, Administrative, and Capacity), and away from the detailed discussions on the veracity of the underlying costs (always a topic of much debate).

3.6.4 The Treatment of Set-Up Costs.

What now needs to be considered is the way in which the set-up costs are treated. As has been previously stated, set-up costs are not always fixed. A set-up time is generally only an average time that the set-up would be expected to take. If this were stated at 30 minutes, it could take anywhere from, say, 27 minutes to 33 minutes to accomplish and still be thought of as acceptable to the business concerned.

The case of the toy packing line example used earlier can now be further examined. Now if the same outer packing was not used for each model car, but was available in three sizes, one for small cars one for medium size cars and one for large cars, and it took the operator 30 minutes to change the machine to use the different packaging, how long is the set-up time? In this case, any change of model size would necessitate a set-up taking an average of 30 minutes.

What would happen if the cars were sold in 2 different markets, Market A and Market B, each requiring a language specific leaflet to be inserted, if this set-up took an average of 10 minutes to accomplish?

If a change of leaflet only is required, the set-up time is 10 minutes, if a change of size or size and leaflet is required the set-up time is 30 minutes. So, the situation is now one where the set-up is not fixed, but is dependent upon the previous item. The time taken to change from one item to another is given in the following table:

	Small A	Small B	Med A	Med B	Large A	Large B
Small A	0	10	30	30	30	30
Small B	10	0	30	30	30	30
Med A	30	30	0	10	30	30
Med B	30	30	10	0	30	30
Large A	30	30	30	30	0	10
Large B	30	30	30	30	10	0

Table 3.10 - Example of Sequence Dependent Set-Up.

If a small car for market A follows another small car for market A, the set-up time is zero. However, if a small car for market A follows a small car for market B, the set-up time is 10 minutes, and if a small car for market A follows any medium or large car for any market, the set-up time is 30 minutes. If the cost of setting the line has been calculated at £5 for the leaflet change and £15 for the model size change, which of the costs should be used as the set-up cost?

If an EBQ approach was used, there could be no assumption that a batch of small cars for market A would be scheduled directly before (or after) a batch of small cars for market B. This is because the calculation of the EBQ for each of the items is totally independent, and each of the items will have a unique batch size and scheduling frequency. So the assumption that would have to be used would be that a model size changeover would be required for each item, at a cost of £15.

If, however, the manufacturing frequencies are arranged such that it is possible to schedule a batch of small cars for market A directly before (or after) a batch of small cars for market B, then it could be reasonably assumed that the batch of small cars for market

A would cost £15 to set-up, and that the batch of small cars for market B would only cost £5 to set-up. Likewise the total set-up time for the two batches would be reduced by 20 minutes, the difference between the time taken to change a leaflet and a model size.

One method of achieving this is to use a grouped periodic ordering policy, with a geometric progression (e.g. 5, 10, 20, 40, 80, 160 days supply) for the period order day classes. In the above example, if the small cars for markets A and B were scheduled every 5 days, the cars for market B could be loaded onto the line after those for market A and only incur a £5 set-up. It is possible, using a geometric progression for the periodic order day classes, to allocate the items to any of classes and still be able to benefit from potential set-up reductions.

Having established that there are different set-up costs that could be used at an individual item level, and that there may be a choice of costs to choose from, four different methods of using the set-up costs and times within the EBQ equation can be investigated, as follows:

1. No Set-Up.
2. Individual Item Set-Up.
3. Group Item Set-Up.
4. Group Total Set-Up.

The *No Set-Up* option takes no account of any set-up costs, just the internal ordering cost, however, as a geometric progression is used for the period order day classes, reductions in set-up times can be planned for.

The *Individual Item Set-Up* option allocates the major set-up cost to each item. In the case of the cars example, this would be the £15 set-up cost, and as a geometric progression is used for the period order day classes, reductions in set-up times can also be planned for.

The *Group Item Set-Up* option allocates set-up costs and times within each set-up group according to the annual usage value *(AUV)* of each of the items within the set-up group. In the case of the cars example, if the small cars for market A had an AUV of £100,000 and those for market B had an AUV of £50,000, the small cars for market A would be allocated the £15 set-up cost and the 30 minute set-up time, and those for market B the £5 set-up up cost and the 10 minute set-up time.

The *Group Total Set-Up* option considers all the items within a set-up group at the same time, by looking at the total set-up group AUV, £150,000 in the case of the small cars, and the total set-up cost and time calculated as per the *Group Item Set-Up* option, in this case £20 and 40 minutes.

3.6.5 Method 1 - No Set-Up.

This option takes no account of any set-up costs, just the internal ordering cost, however, as a geometric progression is used for the period order day classes, reductions in set-up times can be planned for.

For the sake of illustration, the optimal 8 *(Relph, Brown, Dupernex, Dance, 1994)* class series of 1, 2, 4, 8, 16, 32, 64, and 128 days supply is used. In a year with 256 working days the delivery frequencies work out as follows:

Days Supply	1	2	4	8	16	32	64	128
Frequency	256	128	64	32	16	8	4	2

Table 3.11 - Optimal 8 Class Period Order Day Series.

To calculate the upper class boundaries in terms of the annual usage value for an initial value of K^+ of 150, the K-Curve formula is used, as follows:

$$AUV = K^+ . F^2$$

Firstly, the AUV is calculated for each desired frequency, then the upper class boundaries are calculated by converting the AUV to logarithms and then using linear interpolation to find the mid point, as follows:

Days	F	AUV	log AUV	mid point log	Class Boundaries
1	256	£9,830,400	6.9925712		
2	128	£2,457,600	6.3905112	6.6915412	£4,915,200
4	64	£614,400	5.7884512	6.0894812	£1,228,800
8	32	£153,600	5.1863912	5.4874212	£307,200
16	16	£38,400	4.5843312	4.8853612	£76,800
32	8	£9,600	3.9822712	4.2833012	£19,200
64	4	£2,400	3.3802112	3.6812412	£4,800
128	2	£600	2.7781512	3.0791812	£1,200

Table 3.12 - Calculation of the Class Boundaries with $K^+ = 150$.

Using these upper class boundaries it is possible to place items (where set-up costs are zero) into the correct ordering or delivery frequency, using the annual usage value *(AUV)* of the parts. If the item being considered had an annual usage value of £350,000, it would have fallen into the 4 days supply class using this method.

The relevant set-up times can be established by allocating the major set-up time to the item with the highest AUV within each set-up group. This process can be repeated for each level of the hierarchy within each set-up group.

This approach requires the following assumptions and pieces of data:

- An initial value of K^+ can be established for the group of parts being considered.
- An annual usage value (AUV) can be established for each item.
- Set-up times can be established for each item, and at each level within the hierarchy of a set-up group.
- A geometric progression order series is used.

3.6.6 Method 2 - Individual Item Set-Up.

This option allocates the major set-up cost to each item, and as a geometric progression is used for the period order day classes, reductions in set-up times can also be planned for.

Taking as a starting point the initial value of K^+ of 150 used to illustrate *Method 1 - No Set-Up,* and assuming that an inventory holding rate *(i)* of 10 % can be established, then it is possible to calculate the order cost *(Co)* as £7.50, as follows:

$$
\begin{aligned}
(Initial)K^+ &= \frac{2.Co}{i} \\
Co &= \frac{K^+.i}{2} \\
&= \frac{150 * 0.1}{2} \\
&= 7.50
\end{aligned}
$$

If the major set-up cost of the item being considered is £2.50, then the new value of K^+ to be used to allocate the item to a period order day class can be calculated as 200, as follows:

$$
\begin{aligned}
(New)K^+ &= \frac{2(Co + Su)}{i} \\
&= \frac{2(7.5 + 2.5)}{0.1} \\
&= 200
\end{aligned}
$$

The upper class boundaries for the item being considered, where K^+ is equal to 200, can now be calculated using exactly the same method as before:

Days	F	AUV	log AUV	mid point log	Class Boundaries
1	256	£13,107,200	7.1175099		
2	128	£3,276,800	6.5154499	6.8164800	£6,553,600
4	64	£819,200	5.9133899	6.2144200	£1,638,400
8	32	£204,800	5.3113299	5.6123600	£409,600
16	16	£51,200	4.7092699	5.0103000	£102,400
32	8	£12,800	4.1072100	4.4082400	£25,600
64	4	£3,200	3.5051500	3.8061800	£6,400
128	2	£800	2.9030900	3.2041200	£1,600

Table 3.13 - Calculation of the Class Boundaries with K^+ = 200.

Using these new class boundaries, the item can then be placed in the correct ordering frequency, using the annual usage value (*AUV*).

If the item being considered had an annual usage value of £350,000, without considering set-up costs it would have fallen into the 4 days supply class. The effect of considering the set-up cost means that this item now falls into the 8 days supply class.

This method is applicable at the item level, and different sets of class boundaries will be established for items with the same original value of K but different set-up costs.

The relevant set-up times can be established by allocating the major set-up time to the item with the highest AUV within each set-up group. This process can be repeated for each level of the hierarchy within each set-up group.

This approach requires the following assumptions and pieces of data:

- The underlying initial value of K^+ be established for the group of parts being considered.
- A sensible value for inventory carrying rate *(i)* can be agreed.
- The underlying cost of ordering or delivery per occasion *(Co)* can therefore be calculated.
- A major set-up cost per occasion *(Su)* can be established for each relevant item.
- Set-up times can be established for each item, and at each level within the hierarchy of a set-up group.
- An annual usage value (AUV) can be established for each item.
- A geometric progression order series is used.

3.6.7 Method 3 - Group Item Set-Up.

This option allocates set-up costs and times within each set-up group according to the annual usage value *(AUV)* of each of the items within the set-up group. This approach is an extension of the *Method 2 - Individual Item Set-Up* method described previously. In this method the case of a group of items which use the same basic machine set-up, but which incurs an incremental set-up when changing between the items within the group, and each item within the group retains its natural ordering frequency (i.e. that calculated from the K^+ formula) is considered. It takes account of set-up reductions which can result from a more intelligent approach to scheduling and sequencing.

An example of this could be a manufacturer of plastic curtain rail. This could be produced in a variety of colours. To set-up the moulding machine for the particular size and colour of curtain rail could cost, for the sake of argument, £4. To change the colour of the rail with the machine already set-up would cost less than a full set-up, say a cost of £2 for this intermediate set-up.

For the sake of illustration, the optimal 8 class geometric series is used as before, and the underlying initial value of K^+ for the items being considered is again assumed to be 150 and the holding interest rate and therefore order-raising cost assumed to be 10% and £7.50 respectively.

The annual usage value of the items being considered is as follows:

Item	AUV
A	£350,000
B	£200,000
C	£80,000
D	£5,000

Table 3.14 - AUV of Items used in Example.

By using a geometric progression it is possible to make use of the fact that if the item with the highest annual usage value within the group, and therefore the highest ordering frequency, is used to 'drive' the group, all the other items within the group will either have an identical or lower ordering frequency, and will therefore only be made when the driver is made. This allows all the other items within the group to only incur the intermediate set-up cost.

If the item with the highest annual usage value is now considered, and, using the same method as that used for an individual item, the new value of K^+ to which this item is operating can be calculated, as follows:

$$\begin{aligned}(New)K^+ &= \frac{2(Co+Su)}{i} \\ &= \frac{2(7.5+4)}{0.1} \\ &= 230\end{aligned}$$

The upper class boundaries for this new value of K^+ can be calculated as before, as follows:

Days	F	AUV	log AUV	mid point log	Class Boundaries
1	256	£15,073,280	7.1782078		
2	128	£3,768,320	6.5761478	6.8771778	£7,536,640
4	64	£942,080	5.9740879	6.2751178	£1,884,160
8	32	£235,520	5.3720278	5.6730578	£471,040
16	16	£58,880	4.7699678	5.0709978	£117,760
32	8	£14,720	4.1679080	4.4689378	£29,440
64	4	£3,680	3.5658478	3.8668778	£7,360
128	2	£920	2.9637878	3.2648178	£1,840

Table 3.15 - Calculation of Class Boundaries with $K^+ = 230$.

The item with the highest *AUV*, Item A (£350,000), will now fall into the 8 days supply class.

For the other items, the value of K^+ to which they operate is found by substituting the intermediate set-up cost of £2 into the K^+ formula, as follows:

$$\begin{aligned}K^+ &= \frac{2(Co+Si)}{i} \\ &= \frac{2(7.5+2)}{0.1} \\ &= 190\end{aligned}$$

where Si = Intermediate Set-Up Cost per occasion

The upper class boundaries are established for $K^+ = 190$, as follows:

Days	F	AUV	log AUV	mid point log	Class Boundaries
1	256	£12,451,840	7.0952335		
2	128	£3,112,960	6.4931740	6.7942035	£6,225,920
4	64	£,778,240	5.8911135	6.1921435	£1,556,480
8	32	£194,560	5.2890536	5.5900835	£389,120
16	16	£48,640	4.6869936	4.9880236	£97,280
32	8	£12,160	4.0849336	4.3859636	£24,320
64	4	£3,040	3.4828736	3.7839036	£6,080
128	2	£760	2.8808136	3.1818436	£1,520

Table 3.16 - Calculation of Class Boundaries with $K^+ = 190$.

The number of days supply can now be determined for each of the remaining items in the group. The results of applying this group approach are shown in the following table:

Item	AUV	K^+ Value	Days Supply
A	£350,000	230	8
B	£200,000	190	8
C	£80,000	190	16
D	£5,000	190	64

Table 3.17 - K^+ and Period Order Day Classes by Item.

As can be seen from the above table, theoretically it is possible to arrange for each of the items to be made when the 'driver' item, Item A, is manufactured.

In some situations, for example where, for a 'non-driver', there is an AUV close to the value of the 'driver' AUV and the incremental set-up cost is close to that of the set-up cost of the 'driver', it is possible that certain of these 'non-driver' items may fall into a lower days' supply class than the 'driver' item. If this happens, the days' supply class for the 'non-driver' should be set to that of the 'driver' item.

Where the incremental set-up costs are zero, the underlying initial value of K^+ can be used directly to determine the correct class for all the items within the group, with the exception of the 'driver' item.

This method is applicable to a group of items, with common set-ups. The highest AUV item is selected as that which will incur a full set-up, as it will be manufactured most frequently. The value of K^+, to which this item is operating, is established as before, the upper class boundaries calculated, and the days' supply class established. All the other items within the common group set-up incur the cost of the intermediate set-up, and a common value of K^+ is established for this group, upper class boundaries calculated, and each item placed in the correct days' supply class.

This approach requires the following assumptions and pieces of data:

- The underlying initial value of K^+ be established for the group of parts being considered.
- A sensible value for inventory carrying rate *(i)* can be agreed.
- The underlying cost of internal ordering per occasion *(Co)* can therefore be calculated.
- Groups of items with similar set-up characteristics can be identified.
- Each of the items within the group is to be manufactured in its natural ordering cycle.
- A set-up cost per occasion *(Su)* can be established for each relevant item.
- An intermediate set-up cost per occasion *(Si)* can be established for each relevant item.
- An annual usage value (AUV) can be established for each item.
- A geometric progression order series is used.

3.6.8 Method 4 - Group Total Set-Up.

This approach is an extension of *Method 3 - Group Item Set-Up* with groups of items with common set-up characteristics, all being produced on the same ordering cycle. In this, the case of a group of items which use the same basic machine set-up, but incur an incremental set-up when changing between the items within the group, and the group of items is to be scheduled on a common ordering frequency, with each item being made on every group order cycle, is considered.

As an example, the same items are used as before, i.e.

Item	AUV
A	£350,000
B	£200,000
C	£80,000
D	£5,000

Table 3.18 - AUV of Items used in Example.

and the same assumptions are made i.e. an 8 class geometric series is being used, assuming the underlying initial value of K^+ is 150, the holding interest rate *(i)* is 10% and therefore the order raising cost *(Co)* is £7.50, the major set-up cost is £4 and the intermediate set-up cost is £2.

This method works on the premise that if all the items in the group consisting of *n* members were scheduled on each occasion, the schedule group would incur *1* major set-up, and *n-1* intermediate set-ups each time it was scheduled. So the total set-up cost for the scheduling group could be established. The *AUV* used would then be the sum of all the *AUV*s for the items within the schedule group, and the days' supply class established accordingly.

If the set-up cost for the schedule group consisting of *n* items can be taken as being *1* major set-up cost *(Su)* plus *n-1* intermediate set-up costs *(Si)*, then it is possible to calculate the value of K^+ to which the schedule group is operating, as follows:

$$
\begin{aligned}
K^+ &= \frac{2(Co+Sg)}{i} \\
&= \frac{2(Co+Su+(n-1)Si)}{i} \\
&= \frac{2(7.5+4+(4-1)2)}{0.1} \\
&= \frac{2(7.5+4+6)}{0.1} \\
&= 350
\end{aligned}
$$

The upper class boundaries are established for K^+ = *350*, as follows:

Days	F	AUV	log AUV	mid point log	Class Boundaries
1	256	£22,937,600	7.3605480		
2	128	£5,734,400	6.7584880	7.0595180	£11,468,800
4	64	£1,433,600	6.1564280	6.4574580	£2,867,200
8	32	£358,400	5.5543680	5.8553980	£716,800
16	16	£89,600	4.9523080	5.2533380	£179,200
32	8	£22,400	4.3502480	4.6512780	£44,800
64	4	£5,600	3.7481880	4.0492180	£11,200
128	2	£1,400	3.1461280	3.4471580	£2,800

Table 3.19 - Calculation of Class Boundaries with $K^+ = 350$.

The AUV of the schedule group being considered is £635,000, so the whole group will be scheduled every 8 days.

This approach requires the following assumptions and pieces of data:

- The underlying initial value of K^+ can be established for the group of parts being considered.
- A sensible value for inventory carrying rate *(i)* can be agreed.
- The underlying cost of ordering or delivery per occasion *(Co)* can therefore be calculated.
- Groups of items with similar set-up characteristics can be identified.
- The group of items is to be manufactured in its natural ordering cycle.
- A set-up cost per occasion *(Su)* can be established for each relevant item.

- An intermediate set-up cost per occasion *(Si)* can be established for each relevant item.
- An annual usage value (AUV) can be established for each item.
- Any ordering series can be used, not just geometric progressions.

3.7 CONCLUSIONS.

In this chapter the historical background of the methodology was examined by looking at the EOQ, Coverage Analysis, and the K Curve Methodology. The way in which costs are derived was then examined and it was concluded that they must be used with a sense of caution with regard to the accuracy of the results. Finally a methodology was proposed for the allocation of manufactured items into period order day classes which aimed to take account of the three key inventory performance constraints, the overall administrative, financial, and capacity loads that the policy would generate.

Four different ways of using set-up costs to allocate items to period order day classes have been defined in this chapter. Each of these has been used as the basis for a segment of the software used to conduct the research. Intuitively, the *Group Item Set-Up* and *Group Total Set-Up* methods would appear to provide the best approach, as they both take full account of set-up reductions within set-up groups, the validity of this supposition will be tested later.

Each method directly allocates an item into a period order day class using a modified EBQ formula. From this, the number of orders per annum and the base average inventory value can be directly calculated for each item, and accumulated for the group of items being considered without requiring any further information. In order to take account of the capacity required to support a particular policy, routing information is also required. This can then be used to calculate the total annual run and set-up minutes for each item and accumulated to provide an overall capacity load. The run minutes are calculated for each item from the line speed and the annual demand, and the set-up minutes are calculated from the relevant set-up time and the number of orders per annum.

Having calculated the total load in terms of finance (average inventory value), administration (orders per year) and capacity (workcentre load) it is possible to identify potential constraints by comparison with the stated limits in each area. Comparisons with the load that the current policy would generate can also be made to further validate and quantify the operational constraints that it is currently possible for the enterprise to operate under. The modelling is greatly simplified by concentrating on the theoretical load that the inventory policy would generate, and ignoring the effects of any current or planned inventory overage such as safety stock.

Having clearly defined the starting position both in terms of the theoretical limits, and load that the current policy will generate, comparisons against other solutions can be performed and the effect of implementing any proposed changes to the operational parameters (run times, set-up times etc.) can then be modelled to assess their viability.

Having derived an inventory policy that broadly satisfies the limits within which the enterprise wishes to operate, other operational considerations particular to individual items (e.g. space) can be considered, and the parameters generated by the modelling modified accordingly. The output from this phase is the setting of the order policy codes, validated in three dimensions, for the planning system (typically MRP).

The modelling process used has been developed to help to overcome one of the important criticisms of MRP, namely that MRP accepts the set-up times etc. as given and does not provide a mechanism for continual improvement.

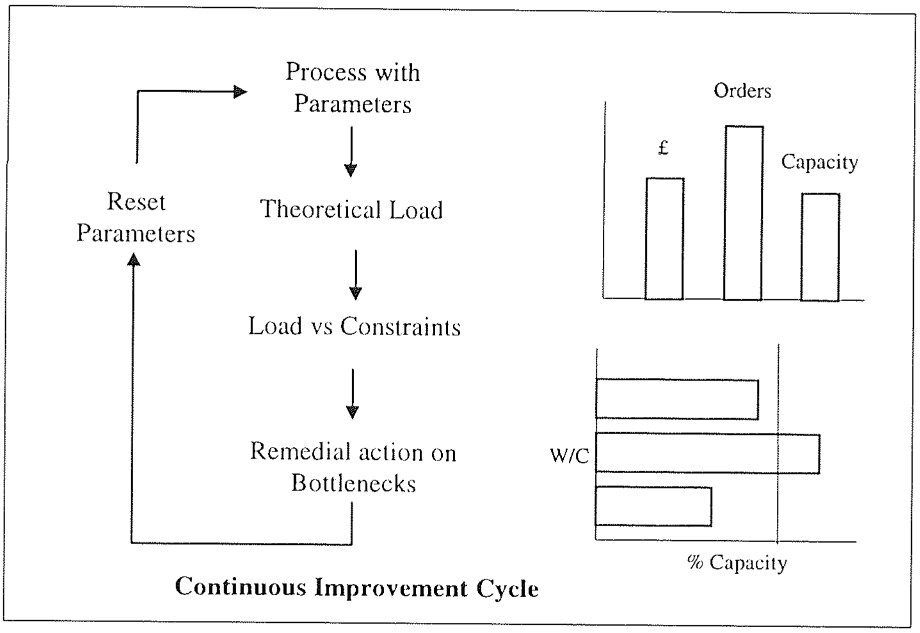

Figure 3.19 - The Continuous Improvement Cycle.

The facilities provided within the modelling process address this issue, as follows:

1. By providing the feedback on the constraint load vs. constraint limits in the three measured dimensions.
2. By scenario modelling the effects of changing the limits of the constraints.
3. By scenario modelling the effects of changing operational parameters (set-up times etc.).

4. By assisting multi dimensional goal searching, and finally, by automatic goal searching for the 'best fit' when constrained in one of the three dimensions.

The power of this methodology is not solely in the ability to calculate the business performance passively and then compare this against current performance measures, or in the ability to leap forward from MRP and provide true capacity based batch sizing, but the key to its success lies in the ability of the underlying modelling process to perform experiments which can help to predict the likely behaviour of the business in a variety of categories. It is the predictive ability of the modelling process (used in conjunction with its goal searching capability) that provides the key to the power of this approach.

The methodology has the ability to help to answer these sorts of questions:

- Can the current inventory performance be improved upon by implementing an improved set of inventory parameters?
- What would be the effect on inventory and administration of decreasing all Set-Up times by 10% whilst loading the Work Centres to the same level?
- What would be the effect on inventory and capacity if our administrative system could cope with double the order workload?
- Where should the Set-Up reduction programme be concentrated?
- Is a Set-Up reduction programme what is required, or do our administration systems need improving first?
- Is the continuous improvement programme focused on the bottleneck resource(s)?
- How much money will be tied up in stock?
- If a Single Minute Exchange of Dies (SMED) on a bottleneck resource can be achieved, will a new machine still be required?
- Which resources are bottlenecks?

4 THE PHILOSOPHICAL BACKGROUND - POSITIVISM AND INTERPRETIVISM.

4.1 Introduction.

Within the O.R. (Operations Research) and I.T. (Information Technology) research areas the accepted research viewpoint has generally been the positivistic research model, with this approach dominating the literature. In recent years interpretive methods of research have become more common with approaches such as the Soft Systems Methodology *(Checkland 1981) (Checkland, Scholes 1990)* being used. The way that these seemingly contradictory philosophies are presented *(Orlikowski, Baroudi 1991)* is one of mutual incompatibility, in that research is either conducted from an interpretivistic or a positivistic viewpoint. However, these approaches are not opposed and irreconcilable *(Lee 1991)*, and it is possible to use both approaches in a complementary manner. In order to do this it is necessary to understand, firstly, what the two philosophies mean in terms of the approach taken to research and, secondly, the way in which the results of the research are treated.

The research makes use of both these seemingly contradictory philosophies, in that the initial modelling is based on a positivistic approach, where 'optimal' results are provided from the modelling process which could seemingly be implemented without question to produce an improvement in business performance. However, the way in which the results of the modelling process are presented is interpretative, in that they are not treated as providing a 'correct' solution but rather as, firstly, representing a set of discussion points or guidelines to the likely state of affairs that could arise from implementing the recommendations and, secondly, opening an extended dialogue concerning the appropriateness of the different strategy options and, thirdly providing a usable, rather than representative, method of representing changing circumstances.

The reason for adopting this dual approach is pragmatic, as what is known is always an approximation, and understanding is only elicited from talking and debating, reasoning about definitions and examples, and from investigation of the object of research *(Gadamer 1980)*. Managers today need skill and judgement in handling a variety of unpredictable events in a way that is coherent with the ethos or culture of the business enterprise. However these events are open to different interpretations which means that a methodology that can assist in understanding this interpretative process by providing both tools and a framework for discourse could prove to be a powerful catalyst for the critical examination of current practices.

4.2 Different Approaches To Decision Making.

The rationalist approach to decision making, which can be traced back to Plato and Aristotle, can be explained by considering the question *'What do you do when faced with some problem whose solution you care about?'*.

What the rationalist does is to use the scientific method which *'can be described as involving the following operations: (a) observation of the phenomenon that, henceforth, is taken as a problem to be explained; (b) proposition of an explanatory hypothesis in the form of a deterministic system that can generate a phenomenon isomorphic with the one observed; (c) proposition of a computed state or process in the system specified by the hypothesis as a predicted phenomenon to be observed; and (d) observation of the predicted phenomenon.' (Maturana, 1978 p28).*

This can be put more simply as a process of choosing alternatives and involving three steps *(Simon 1976):*

1. Listing the alternative strategies.
2. Determining all the consequences of following each of the alternative strategies.
3. Comparatively evaluating the consequences.

These steps, however, involve the acceptance of the duality of the objective physical world co-existing with the subjective world of an individuals thoughts and feelings. This acceptance assumes *(Winograd, Flores, 1986)* that:

1. One inhabits a real world in which ones actions take place and this real world is made up of objects bearing properties.
2. There are objective facts pertaining to that world that are independent of the interpretation or presence of any individual.
3. The facts about the real world are registered in ones thoughts and feelings through perception.

4. Thoughts and intentions about action can somehow cause physical motion of ones body.

In modelling, the rationalist approach depends heavily on the correspondence of the model to the state of affairs which it is trying to represent. The technique is based on developing a formal model of the system being considered, a set of rules which describe the systems behaviour and an objective means of assigning weight and value to the resulting effects, so that alternatives can be compared, and the optimal solution chosen.

Although this approach is widely adopted it is not without its pitfalls. A classic example of the dangers inherent in this formal approach is that of IBM UK in the late 1980's where a marketing model was constructed based on a competitive strategy analysis using highly structured quantitative data. This system attempted to develop a new understanding of its markets and competitors. It failed to do this and '*it was not until the early 1990's that IBM UK recognised that this scientistic regime of analysis could limit or even distort understanding*' *(Wilson, 1995).*

However, it is in practice, impossible to know all the alternatives or all the consequences so any model must operate with a bounded rationality. This means that it is possible to characterise rational decision making as *(Winograd, Flores, 1986)* a heuristic search among alternatives in a problem space of possible courses of action with a view to achieving a preferred set of consequences. It is a process of bounded rationality whereby choices are made by applying formal rules to incomplete information in a precise manner.

This rationalist or scientific approach philosophically relies upon the idea that one inhabits a real world in which ones actions take place, that this real world contains objective facts which are independent of the interpretation or existence of any person, and that perception is the process by which these facts are retained in ones thoughts.

This approach is clearly brought into question by attempting to answer the philosophical question of whether anything actually exists outside of ones subjective consciousness. A subjective stance would argue that thoughts and feelings constitute a primal reality, and an objective stance would argue for the primal reality of objective physicality. This type of debate has kept philosophers employed for many hundreds of years and is too abstract to be debated to any formal conclusion other than that of respect for postulants of either philosophical stance. What these opposing viewpoints do manage to illustrate, is the diversity of views that are credible, and that it is sometimes impossible to find a 'correct' answer, and that the correctness of the answer is dependent on both objectivity and subjectivity on the part of the researcher, and of the subjects of the research.

A different approach was postulated by Heidegger, who argued *(Dreyfus 1985)* that:

- The interpreted and the interpreter cannot exist without each other. This means that there is no neutral viewpoint and that understanding is never objective or complete.
- This leads to the idea that as ones primary access to the world is through practical involvement, that practical understanding is more important than a detached theoretical viewpoint.
- Connected to both these points is the issue of mental representations, where it has been thought that in order to perceive and relate one needs to have a corresponding mental representation of what one is relating to or perceiving. This may be true of contemplative activities, but is highly questionable when actions are considered. An example of this given by Heidegger is the use of a hammer to drive a nail into a piece of wood. In order to use the hammer, there does not need to be an explicit mental representation of the hammer, the act only requires a familiarity with hammering, not the hammer itself.
- And, finally, that meaning is to be found within a social context.

Interpretative research takes this position, namely that ones knowledge of reality is a social construction, that there is no objective reality that can be discovered and replicated by others, and that theories concerning reality are used as ways of making sense of the world, with shared meanings arising from inter subjectivity. The main work which provides the philosophical basis for the interpretative stance for this type of research is that on the Soft Systems Methodology *(Checkland 1981) (Checkland, Scholes 1990)*. SSM incorporates a philosophy of organisational intervention *(Walsham 1994)* that sees different individuals and groups as constructing interpretations of the world, the interpretations having no absolute or universal status. The intervention being designed to reconcile these interpretations in such a way that organised action can be achieved.

The approach of positivist researchers is that it can be assumed that objective data exists, that this can be collected and used to test prior hypotheses.

4.3 The Implications of the Theoretical Considerations for this Research.

The methodology described and used during the research was, within a limited area of research, designed to, firstly, be a tool based problem solving system capable of provoking creative and perceptive thought about the organisation and organisational problems, secondly, be an assistance to the problem solving process of choosing between alternative courses of action relevant to the problems faced, thirdly, for the problem solving process to include critical appraisals of the generated outcomes, fourthly, for the problem solving process to have substance, and finally, for problem solving to be enjoyable satisfying and empowering to the participants.

5 MODEL VALIDATION.

5.1 Introduction.

This chapter aims to fix the philosophical approach used by the research to modelling within an accepted theoretical framework, and to describe the types of models that can be used and their applicability, and the different modelling techniques that can be used within the various model types. Having established the veracity of the theoretical approach used within this research, the next topic to be discussed is how to ensure that a model, when constructed, is a valid model, and how to differentiate a valid from an invalid model.

The questions being addressed in this chapter are:

- Having decided on a particular modelling method, how can the validity of the chosen method to the particular context be accepted as a valid approach. For instance if in a particular context a Symbolic, Descriptive, Discrete Event Simulation is the chosen method, why should this be preferred over other methods, and what competence does this bring that alternative methods omit.
- Once the modelling method is accepted as valid, how can the validity of the inputs to, processes and outputs from the modelling process be assessed, and how universal or contextual is this acceptance.

The conclusion drawn is that there is no universal scientific method or formal criteria that can guarantee the validity of any formal model, and that scientists (or researchers) do not have a unique definition of knowledge validity, and that the validation of any model involves not only relations with the objects being modelled but also social relationships as well.

In this chapter, the word *model* is used in context to describe different aspects or attributes of the modelling process. Each of these model attributes is distinct, and has a different set of values. A model *type* is used to describe the way in which the model is going to represent the subject, and a model *category* is used to describe the way in which the model incorporates the fourth dimension, time.

The *formal model of science* used in this research is the Utilitarian model. This accepts that the truth of what is discovered is based on the usefulness of the knowledge acquired and its successful use. The types of modelling used in the research are Descriptive and

Normative Symbolic modelling, that is, mathematical modelling which either predicts outcomes (Descriptive) or prescribes a set of circumstances that will enable stated goals to be achieved (Normative). The modelling technique used is Average Modelling, which is an overall approach, without a timing element.

5.2 What is a Model.

The word *model* brings to mind several preconceived mental images, perhaps of small plastic pieces of an aircraft, car or ship, perhaps a scale representation of a proposed or existing building. With the onward march of technology, a migration is occurring from the predominant use of live or constructive simulations or models to the increased use of virtual simulations. This shift is supported by rapid improvements in the sophistication of information processing and display technologies, and is largely characterised by the use of modelling or simulation tools in stand-alone and system specific applications.

There are three basic types of model, the iconic, the analogue and the symbolic *(Dennis, Dennis 1991)*. The iconic model is a physical representation such as a model aircraft or building. The analogue model is another physical representation, but without the same physical appearance as the object being described, such as a speedometer, graph, or flow chart. The symbolic (or mathematical) model is an attempt to represent the object through mathematical statements.

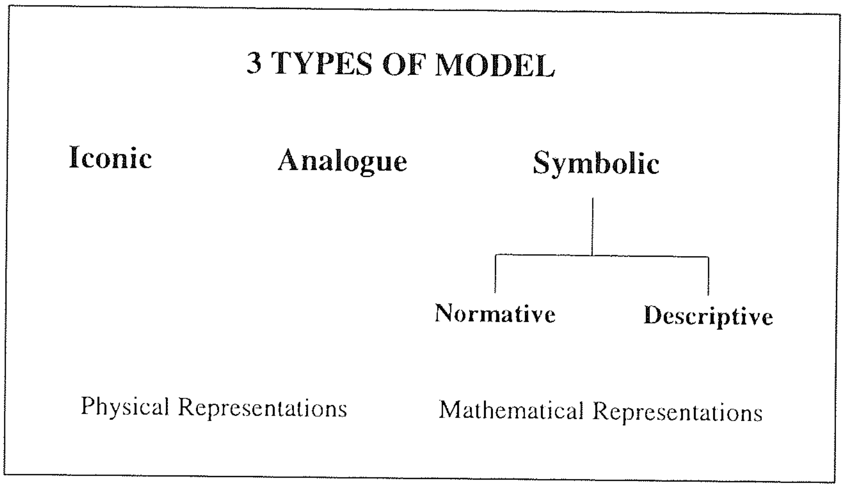

Figure 5.1 - The Three Model Types.

There are two types of symbolic models, descriptive and normative*(Dennis, Dennis 1991)*. Descriptive models represent the relationships, and identify the outcomes, but do not indicate actions to be followed. A simple example of this could be a model which has as its inputs the cost of the grocery items required for this weeks shop, and the quantity required of each item, which could calculate the total cost for the weeks shop. If too much was spent, items would have to removed and the model rerun until the available funds were not exceeded. Normative models are optimisation models, are prescriptive, and define the actions required to achieve a specified goal. The former simple model could be extended and constrained by a factor such as the total cost not exceeding a specified figure, with a method for ascertaining the purchase preferences, and so automatically including or excluding items so that the cost of the groceries is not above the available funds. This research is concerned with both types, descriptive and normative.

In modelling, many different problems exist; the problem of one individual with a single choice differs markedly from the problem of social choice that involves many individuals with interests that are often conflicting.

In the context of the research, which is purely concerned with symbolic modelling, a model can be thought of as *'an abstraction of an object or real world phenomenon' (Dennis, Dennis 1991)* or a simplification representing the key properties of the object being represented. It is an attempt to logically represent a problem (system, phenomenon or process) through equations and by the use of mathematical symbols. A simulation can be thought of as a method for implementing a model over time, and a technique for testing or analysing where real world and conceptual systems are reproduced by a model.

A model has three components, Inputs, Processes and Outputs. Inputs are those elements which feed the Processes, Processes are the elements required to convert the Inputs into Outputs, and Outputs are the results of the modelling process.

5.3 The Formal Models of Science.

FORMAL MODELS OF SCIENCE

Logical Empiricism	**Falsification**	**Utilitariansm**
Proving Theories True	Proving Theories False	Does the Theory work in Practice

Figure 5.2 - The Three Formal Models of Science.

There are three main formal models used in science, logical empiricism (trying to prove theories true), falsification (trying to prove theories false) and the utilitarian model (does the theory work in practice).

Logical empiricism, or the scientific method, was developed by the Vienna Circle in 1929 *(Dery, Landry, Banville 1993)*, and is a doctrine whereby experimentation allows the discovery of the properties of the real world and the laws that govern it. The following definition of the scientific method *(Morse 1956)* illustrates the influence of the Vienna Circle:

1. *Observation of phenomenon*
2. *Constructing a mathematical model, a quantitative hypothesis.*
3. *Controlled experiments to test the model.*
4. *Developing a theory from the model, after a continued alternation of model improving and further experimentation.*
5. *Control of the phenomenon by means of the theory, a mathematical model that can predict quantitatively what will happen in various specific circumstances.*

The same doctrine is put forward *(Beer 1968 p15)* in a description of the scientific method *'First of all things are measured. Secondly, only things that result in the same measurement many times by many observers count as facts. Thirdly, hypotheses are formed to account for the facts being as they are, and these hypotheses are tested in every way that anyone can think of. Next, a hypothesis that does not break down after* *continuous testing over the years acquires the status of a law. Finally, theories are constructed and again tested to account for the laws'.*

So, for logical empiricists, a model is only valid if it originates from factual observations, and if the method of observing the phenomenon can be translated into logical mathematical terms. However the notion that a unique and universal scientific method is relevant to problem solving is seriously flawed. Firstly there is the problem with the notion of the unbiased observer, secondly that observational terms are contextual, not universal, thirdly it ignores the social dimension, fourthly that a theory can be invalidated by a single contrary observation, and finally that it is not possible to be certain of the truth of a generalisation based on direct induction from a small sample.

These five problems, but most importantly that of induction, led to criticisms of this approach *(Popper 1972) (Chalmers 1982)*, and to the doctrine of falsification, which was postulated by Karl Popper. It contends that new or revised theories are construed as speculative or tentative conjectures by the human intellect in order to overcome problems associated with previous theories. Once the new theories are proposed they are then subjected to rigorous testing through observation and experimentation. Those theories which fail the observational and experimental testing are discarded, and replaced by further theories. So progress is made through a process of natural selection where only those theories which are not falsified remain, and those theories are only thought of as the best available, rather than the final truth.

Falsification relies upon hypotheses being falsifiable, such as *'November 12th always falls on a weekday'* rather than unfalsifiable, such as *'November 12th always falls either on a weekday or a weekend'*. Falsification, however, relies upon observational evidence, so it is not possible to conclusively falsify theories as the observations may themselves be shown to be false. Most hypotheses are not concerned with a single item, but with a complex set of interconnected statements.

The doctrine of falsification was put forward *(Raitt 1974 p4)* as appropriate for model validation *'Models in the management sciences are equivalent to the physical scientists' hypothesis. They are intended as a representation of reality .... the key to a model's validity lies in the tests to which we subject it. Have we tried to refute our model during the validation phase by subjecting it to severe empirical tests? If so, we are entitled to call* *our work scientific and respond accordingly to those who doubt that there is a true science of management'.*

This complexity leads to difficulties of causality where theories are being tested which rely upon auxiliary assumptions. So the lack of a secure base for observation, together with problems associated with causality, rules out conclusive falsification.

The utilitarian model (or instrumentalism) is pragmatic, in that the truth of knowledge is an attribute of its practical character and its concrete usefulness. Truth is therefore based on the usefulness of knowledge and its success in action. By taking this philosophical viewpoint it is possible to justify the retention of theories which are useful in a practical sense, but which are capable of being theoretically refuted, so allowing researchers to develop belief systems whose usefulness is not universal, but rather dependent on context. This explicitly recognises three differences *(Gault 1984)* between technological activities (such as modelling) and true scientific activities:

- The scientific search for absolute truth, whatever that means, is not the concern of a modelling activity such as that used in this research.
- Whereas scientists attempt to build models to develop theories of greater significance and explanatory power, within this research the model is only of local, rather than universal significance.
- Within Operations it is rarely possible to perform the equivalent of a scientific experiment.

It is no longer important to know if the model mirrors reality, what is important is to know how useful the model is in solving the problems for which it was built. This has been put forward *(Raitt 1979 p835)* as an appropriate method for model validation *'A model is constructed for practical application in a particular situation. It is wholly instrumental. We do not ask if it is true, only if it works - we validate not verify'*, and is the viewpoint used for validating the model used in this research.

It must, however, be recognised that there is no universal scientific method or approach which can guarantee the validity of any model. The concept of validity varies between periods, applications and factions. The absence of a consensus is a characteristic of the social relations that are present through co-operation and competition between scientists. Model validation involves not only the relationships of the objects to be modelled, but also social relationships. These social relationships shape the way in which problems are approached, depending upon the prevailing paradigm within the institution or group. This touches on another aspect, that of credibility and confidence *(Gass 1993)*, the credibility and confidence that the decision maker has in the model's ability to produce meaningful and useful information. Validating a model is therefore a process that goes beyond solely accepting or rejecting the technical aspects of the model to understanding the beliefs surrounding the model *(Smith 1993)*.

5.4 Different Categories of Modelling.

In the context of the research, symbolic modelling falls into four categories:

Average Modelling.

Steady State Modelling.

Dynamic Modelling.

Discrete Event Simulation.

Average modelling is a representation of the system being investigated at a particular time, or one in which time plays no part, and whose output is determined explicitly by the inputs to the model and contains no probabilistic elements. An example of this could be an annual budget. This is a simple form of modelling, and can be used to provide a close approximation of the level of activity that a series of inputs would create when subject to a set of rules. It is particularly useful when an idea of scale is required quickly.

Steady state modelling is a representation of the system being investigated at more than one particular time, and whose output is determined explicitly by the inputs to the model and contains no probabilistic elements. An example of this could be an annual budget, divided into monthly buckets. This is slightly more complex than Average modelling, and can be thought of as (in the example given) as a series of 12 monthly Average models.

Dynamic modelling is suitable for systems where the variables are in a state of continuous change.

Discrete event simulation is concerned with modelling a system as it changes over time. It uses a technique *(Law, Kelton 1991)* whereby the way a system evolves over time is represented by instantaneous changes of state at a point where events occur. It uses a next event time advance mechanism whereby the simulation clock is initially set to zero and the times of the occurrences of future events calculated. The simulation clock is then advanced to the time occurrence of the first (i.e. most imminent) of the future events and the system updated to take account of the occurrence of that event, and the times of future events updated. The simulation clock is then advanced to the time of the new first future event and the system updated. This sequence of events is repeated until the condition to stop running the simulation is reached. As changes of state only occur at event times, the time intervals between each not being fixed, the periods of no change can be jumped over, so speeding up the simulation. Discrete event simulation, however attractive conceptually, does require a high level of integrity in the data and understanding of the system dynamics.

The above categories of symbolic modelling can all be either Normative or Descriptive.

5.5 What is meant by Model Validation.

Validation of any model raises numerous questions, the most fundamental of which is what is a model and what differentiates a valid model from on that is not valid *(Landry, Malouin, Oral 1983)*. How is it decided that one model is valid and another one not, and does this mean that a valid model is only one that is irrefutable or incontestable, and that there is only one possible modelling solution to a particular problem? What is it that is being validated, the problem statement, the conceptual model, the formal model, the solution, or the data, or all or some of them, and what are the measurement criteria to be used with respect to the area being validated, and how does this affect the confidence of the decision maker in making use of the output from the model. How do ideas of usefulness, usability, representativeness and cost affect the validation process, and how should the relative importance of these be incorporated into a validation process.

Model validity has been (and still is, unfortunately) thought of purely in terms of representativeness, which is the scientific viewpoint and bases the validity of a model on the degree of correspondence to the problem domain and as such is an exceedingly narrow view of validity. Representativeness in itself is meaningless unless combined with the concept of usefulness.

This duality of the managerial perspective to modelling between the aims of representation and validity appears to present a paradox of aims. However, model building to be successful must incorporate validation, and involve the active participation of the actual and potential users to ensure that the context of the problem to be addressed is understood, and to ensure the usefulness of the model. It is clear that a model needs to be both useful and usable in order for it to be accepted by those whom it is intended to assist, the user, rather than just being thought of as an interesting intellectual and technological challenge by the model builder.

This idea of usefulness and usability has a profound effect on the concept of validation, and it has been stated that *'Models used to aid decisions and policy analysis should be judged on their utility in aiding decisions relative to alternative procedures, rather than on the same basis as models are used in science' (House, Ball, 1980)*. Furthermore, models developed using the concept of representativeness have been found to be difficult to justify *(Landry, Malouin, Oral, 1983)* in a real situation with actual decision makers as the decision makers' interest lies in the usefulness and usability of the model, constrained by cost limits.

When validating a model in an industrial situation, various authors have suggested some of the following practical factors to be considered, such as:

- What is the purpose of the model, what perceived problem is the modelling process to address?
- How much money can be spent developing the model?
- What are the time constraints for developing the model?
- What are the time constraints for running the model, is it to be used interactively, or is an answer a day or week later acceptable to the user?
- In order to relate the modelling process to a decision making process, what is the required level of accuracy in the model that is acceptable for the decision making process to be successfully carried out, and how can this be measured?
- Who is going to assess the output from the model, and in what manner can the assessor(s) best interpret the results of the modelling process?
- What are the model boundaries. What can be ignored and what must be included by the modelling process?
- Having identified the required outputs from the modelling process, what questions (modelling rules) need to be asked in order to make a decision to alleviate the perceived problem, and how can this be agreed by the interested parties?

- What data is required in order to satisfy the modelling process, and what is the level of accuracy of the data, and how may this affect the results of modelling process?
- How sensitive is the model to changing circumstances?
- Do the results look reasonable or logical based on experience?

In most contexts, once a perceived problem has been identified as requiring analysis, there will normally be some kind of cost and time constraint imposed on the modeller. To have a perfect answer a month late tends not to be acceptable, whereas having produced a model to the time scales required by the decision makers, which can demonstrate the unsuitability of certain courses of action and show a preference for others, can be highly beneficial to the decision making process. Similarly, unlimited resources are generally not available to a modeller, so the cost of developing a model in relation to the scale of the perceived problem will have a profound affect on the willingness of an enterprise to use a particular technique, and the depth to which the technique is used, especially when a wide range of managerial decisions can often be made without recourse to sophisticated models. The utility value of the model may well be questioned, as how well does a model which makes certain simplifying assumptions about a complex environment truly provide a representation of reality, the ability to predict the weather accurately into the future is illustrative of this point. Finally, the decision makers, who may well not be the model makers, may not understand or accept the results, for reasons which may be beyond the scope of the model. For instance, a model could show that it may be beneficial to close a local Hospital, and merge and upgrade services with another one near by. The cost savings and increase of facilities in patient care will mean nothing when compared with the political will of the local population to save their Hospital.

Modelling only provides a tool for assisting managers to make better informed decisions. It assists by offering a framework to make decisions by helping to define and conceptualise the problem being investigated, and interpret the results. The validation process is not only concerned with the correctness of the answer, but also with the confidence that the manager has not only with the model, but in the abilities of modeller to understand and be sympathetic to the managerial perspective which may be further influenced by technological, social, political, environmental, or economic issues.

5.6 Credibility of Models and Simulations.

A model is (normally) created to provide advice or analyse a problem, as a tool to minimise risk to cost, schedule, supportability and performance for the user. It is this point of view (the minimisation of risk) that is used to communicate the value added by modelling and simulations. When the model maker discusses the results of a modelling process with a user, they must be in a position to substantiate the credibility of the underlying information.

By its very nature, a model is an abstraction of the real world. Items are included and excluded, based on an assessment of the relevance to the performance of the model of specific factors. The perceived relevance is also balanced against the cost and complexity of including the factor and modelling its effects. As a result, model builders and users have to make assumptions about the relevance of specific factors in the modelling process, by assessing the value that would be added by their inclusion, and the complexity of effort involved in including them. These assessments are also affected by how well the factor and its impact on the model domain are understood. Initial representations of a system are generally based on what is known at the time, the related technologies and phenomenologies, and tend to change over time as further knowledge is gained.

Since the results of simulations and models are analysed to support decisions, how can the decision maker be assured that the results obtained from the modelling process are credible? This can be done through ensuring that the model is subjected to verification, validation and accreditation, as a continual process, and as a part of the development, use and maintenance of the model. This can be achieved by involving all the interested parties (sponsor, developer, requester and user) who have a vested interest in insuring that credible and supportable decisions result from the use of the model at the outset, and involving them in the development process.

Verification is the process of determining that a model implementation accurately represents the developers conceptual description and specifications. Verification answers the question '*Is it what was intended?*', is applied at each stage of the model life cycle, and requires identification and examination of the explicit and implicit assumptions and logic flows, and data validation. The concept in itself is simple, but debugging a complex suite of computer programs is a difficult and arduous task.

Validation is the process of determining the manner and degree to which a model is an accurate representation of the real world from the perspective of the intended user of the model, together with the confidence that should be placed on this assessment. The thinking behind this is that if a model is valid then the decisions made with the model should be similar to those that would be made by physically experimenting with the real system. As far as this research is concerned validation is concerned with determining whether the conceptual simulation model is a reasonable representation of the system being studied, or not, which implies that the aim of a validation process is not to end up with a perfect model, but a model which is good enough to satisfy the goals of the modelling exercise. Validation answers the question *'How well does the model represent what it claims to represent?'*, is applied throughout the development life cycle, addresses the fidelity and resolution of the model, and ensures that all aspects of the real world which should be represented are accounted for in sufficient detail to establish causal relationships. It cannot be assumed to result in a perfect model since the only perfect model is the system itself and is only required to be good enough, which is dependent upon the goals of the model *(Kleijnen 1995)*. Model validating activities are grouped *(Landry, Malouin, Oral 1983)* into four interrelated and iterative stages, the problem situation, the conceptual model, the formal model and the solution and recommendations.

Figure 5.3 - The Model Validating Process ***(Landry, Malouin, Oral 1983).***

The problem situation is that part of the real world that contains the problem to be investigated. The conceptual model is the way in which the problem to be investigated is perceived and presented by the individuals involved in the modelling exercise. The formal model is the translation of the conceptual model into mathematical relationships and / or computer programs. The solution is the output from the modelling process, and is the basis for the recommendations. During this process the conceptual validation, logical validation and verification, experimental validation, operational validation and data validation also take place.

Accreditation is the acceptance that a model is acceptable for use for a specific purpose. Accreditation answers the question *'Should I sanction the use of this model?'*, is based on a set of acceptability criteria that a particular model must meet in order to be accepted, and is a user judgement based upon technical evidence and the audit trail resulting from the verification and validation processes.

5.7 Conclusions.

As decisions become more complex and unstructured there is less likelihood of finding optimal solutions. A significant factor which affects the behaviour of the decision makers is the manner in which the information concerning the task in hand in presented. Research has shown *(Hogarth 1980)* that human judgement is selective, sequential, constrained by limited human memory capacity, and impacted by limited powers of computation, and so subject to bias and error. Decision maker expectations and anticipations play a major role in what information is solicited and acquired, more recent information can be erroneously given greater attention than earlier information, and the mode of presentation of information such as the simultaneous presentation of qualitative and quantitative data causes difficulties.

By adopting the modelling strategy as used within this research, with an emphasis on providing an appropriate level of information from the model, combined with an ongoing dialogue with the decision makers in a series of extended re-iterations, the decision outcome is more likely to be of high quality.

Modelling has proven a useful technique *(Dreyfus, Dreyfus 1986)* in a number of areas, such as:

- Handling problems which contain an underlying structure or rationale. Many problems encountered in production, scheduling or distribution are too complex for good intuitive decision making, and are sufficiently structured to be reasonably described mathematically and 'solved' through the use of computers.

- Those areas where no previous experience exists, so called novel problems. In these cases modelling is the only choice short of actually performing the activity for real. In the case of building a new aircraft (or changing the layout of a factory) this may be an unacceptable risk for the test pilot (or shareholders).

- Where although the problem may not be new, the decision maker lacks sufficient experience, the understanding and insight provided by the modelling process could allow the decision maker to make a superior and better informed choice.

- Situations where the problems are unstructured and a certain amount of intuitive expertise exists, such as ascertaining the optimum sequence to perform jobs in a job shop environment. Models of this sort may not deal with the problem as well as an expert, but they do make possible the generation of decisions that are acceptable, routine, fast, and economical, and free the expert for more important problems.

It requires careful investigation of the way in which the model is to be used, the issues to be investigated and the measures of performance that are to be applied. Models are generally designed for a specific purpose and therefore do not possess universal validity. If the issues to be investigated are not clear, or have not been explicitly stated, then the level of detail required from the model cannot be correctly determined.

How the solution validity is measured depends upon whether the solution is implicit or explicit and whether the solution is considered as optimal or satisficing. The quality of the solutions from any modelling exercise could be measured *(Oral, Kettani 1993)* in the following ways:

- The quality of insight gained into the perceived problem. How does the model increase the level of understanding of the system by both the model builders and model users.

- The level of sensitivity of the model to data or parameter changes. For instance, what would be the result of making a small change to the data values input to the model.

- The level of usefulness to the decision making process. Does the model address the salient points.
- The acceptability level of the suggestions. Are the suggestions unfeasible or contrary to the ethos of the enterprise. For instance, in a recent television program John Harvey-Jones suggested various ways to make Morgan cars more profitable through increased levels of production through automation. This somewhat missed the point that it was *because* of the way the car was constructed that people bought Morgan cars, not *in spite* of it.
- The level of commitment elicited from the users. This is concerned with the level of understanding achieved and the insight gained, the degree in which communication has been enhanced between the various stakeholders, the extent to which the relevant people have been motivated to use the model to resolve the perceived problem.

The above five criteria will be used to assess the validity of the modelling exercises carried out with the participating companies.

6 SOFTWARE DEVELOPMENT.

6.1 INTRODUCTION TO THE SOFTWARE DEVELOPMENT.

6.1.1 Introduction.

In order to conduct the case studies it was necessary to translate the methodologies discussed earlier into a coherent, open ended and robust piece of symbolic modelling software, capable of coping with multi operation items with sequence dependent set-ups. As well as this, thought had to be given to the type of modelling that would be used. The first question to answer is which of the following symbolic modelling approaches would be most appropriate:

Average Modelling.

Steady State Modelling.

Dynamic Modelling.

Discrete Event Simulation.

Taking into account the way in which the software was to be used, and the lack of reliability inherent in the data (cost prices, annual usage quantities, set-up costs and times etc.) ruled out choosing a modelling method that required more precise data such as discrete event simulation or dynamic modelling, as it would not be possible to attempt to validate the correctness or otherwise of results obtained using one of these methods.

As the approach was based on the EBQ, consideration had to be given to the limitations of the formula. One of these is that there is a steady, non fluctuating demand. This assumption is used by the EBQ when calculating the inventory holding cost. Now, as the software to be developed used the same assumption, why initially take account of time phasing, as each time 'bucket' should, theoretically, contain the same demand and so there would be no benefit in adding a feature to take account of this, only an extra complexity. Also, if time phasing was an issue, the modelling would have to take account of existing stock in the system and safety stock policies in order to reasonably predict when manufacturing orders would be placed, and the quantity that would be required. And finally, if the demand fluctuated, how would the supply actually be met, would existing stock suffice, would the demand be levelled and made earlier than required, would the capacity be increased in line with the demand, or would the demand be out sourced, or a combination of the three methods.

In the light of these considerations the decision was made to take an average modelling approach, and then to further model the implications of any generated policy if and when time phasing became an issue. The basic principle used was to keep the modelling as simple as possible, whilst retaining credibility for the results, with the credibility being measured by the usefulness of the results in aiding the decision making process of the users of the system. Another important factor that was considered in developing the model was the type and availability of the data to be used, and the approach adopted was that the model would wherever possible only use data that was available within a typical MRP system. By using an average modelling approach, it was also possible to limit the model to considering only the base inventory, order and capacity load that a particular policy would generate, and ignore the effects of existing safety stocks or overage. This also allowed for a simple comparison to be performed between any proposed policy and the existing policy, as the effects of continuing with the existing policy could be easily modelled using the same assumptions as used for the proposed policy, that is, ignoring time phasing, current inventory levels and safety stock policies.

6.1.2 The Initial Approach - Spreadsheets.

The initial approach consisted of establishing the context in which the system would be used, analysing the outputs that would be required from the system in this context, and establishing the inputs which would be required to allow each of the four methodologies to translate the inputs into the required outputs. Having decided to model using an average modelling approach, a software development tool was then required. Initial trials were made using a spreadsheet approach, for the following reasons:

- The modelling had to be portable, so a personal computer (or Apple Mac) based system was needed.
- The researcher was already familiar with the use of spreadsheets.
- Spreadsheets are already in use in most businesses. So the technology should be familiar to most, if not all, participating companies.
- There are only two de facto standard spreadsheets, Lotus 123 and Microsoft Excel. All other spreadsheets can exchange data with one or both of these standards.

- Spreadsheets are quick to set up and relatively easy to modify, so an evolutionary approach to development would be possible.
- Programming skills are not needed to construct a working spreadsheet.
- Any calculations used are readily accessible to other participants in a standard format, rather than being hidden within a computer program in a language dependent format.
- Data exchanges with most host systems are generally unproblematic, most SQL's allow the import and export of either Lotus 123 or ASCII files, so avoiding re-entry of data.
- Both Microsoft Excel and Lotus 123 were available for use.

The basic requirements of the system were that three performance criteria would be used to measure the effectiveness of any policy generated by any of the four methods:

- The financial load in terms of average inventory value.
- The administrative load in terms of orders per annum.
- The capacity load in terms of set-up and run minutes per annum or per day.

The inputs that would be required to calculate these figures are as follows:

For each Model:	Inventory Holding Rate (i)
	Period Order Day Classes
	Working Days per Year
For each Item:	Item Code
	Cost Price
	Annual Usage Quantity
For each Item / Operation:	Item Code
	Operation Sequence
	Workcentre Code
	Run Time
For each Set-Up Group / Item:	Set-up Group code
	Item Code
	Set-up Group level
	Set-up Cost

For each Set-Up Group / Item / Operation: Set-up Group code
Item Code
Operation Sequence
Set-up Group level
Set-up Time

One of the design criteria for the software was that it would not require modification to automatically take account of differing relationships between the items and operations, and not require bespoke programming for each set of data. To obtain the base data and calculate the period order day class that a particular item should be allocated to did not prove too troublesome, however, the limitations of this approach soon became apparent, for the following reasons:

- The number of items to be modelled is not fixed.
- The number of operations per item is not fixed. Each item may have one or more operations.
- An item may or may not belong to a set-up group.
- A set-up group may have more than one level, and different parts of a set-up group can stop at different levels within the set-up hierarchy.
- The number of classes in the period order day class series is not fixed.
- The number of workcentres is not fixed.
- The data values or format are not validated by a spreadsheet.

Spreadsheets are excellent at dealing with data which has a reasonably fixed format, however, the research needed to be able to deal with data structures which were flexible, and to deal with these flexible data structures automatically and as a matter of course, rather than on a ‘one off’ basis. The reasons that this was important for the research are: firstly, that the software was an enabling technology for the research, not an end in itself, secondly, that if the software was modified for each set of data it would require re-testing and re-validation, and thirdly that the results from each modelling exercise may not be directly comparable due to differences in functionality. So, although the benefits of using a spreadsheet approach are great, as it was not possible to provide the required flexibility, alternative software development tools were investigated.

6.1.3 The Final Approach - Relational Database Management System.

Having established that the database facilities contained within a spreadsheet were incapable of automatically supporting the flexible data structures and relationships that the data exhibited, a different approach was required. Wishing to avoid the extended timescales associated with developing applications in low level programming languages, if at all possible, investigations were then made into the functionality of relational database management systems (RDBMS) available on a personal computer.

After a brief look at the numerous relational database systems on the market, three were investigated in detail, Access, Dbase and Dataease. The three to be investigated in detail were chosen because they were all well established, all appeared to overcome the limitations imposed by the spreadsheet approach, all had been used within industry to build working applications and were all available and supported to a greater or lesser extent within Aston University.

In order to assess the suitability of this approach, further details of the data and relationships between the data had to be established. This resulted in the simplification of the initial file definitions for the descriptive modelling options by assuming that three levels of set-up (major, intermediate and minor set-up costs and times) should be sufficient, and the addition of workcentre and cost centre details, arriving at a file structure containing four master files, as follows:

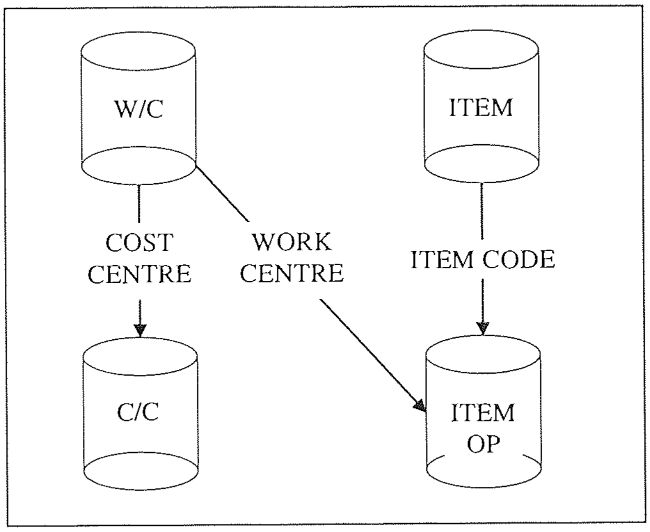

Figure 6.1 - Initial File Structure - Descriptive Modelling.

The Item file containing the item level data. The Item Operation file containing the details of the operations for each Item. This to be unique on Item Code and Operation Sequence, related to the Item file through the Item Code, and related to the Workcentre file through the Workcentre Code. The Workcentre file containing the Workcentre details and to be unique on the Workcentre Code, and related to the Cost Centre file through the Cost Centre Code as well as to the Item Operation file. The Cost Centre to contain the Cost Centre details and to be unique on the Cost Centre Code and related to the Workcentre file. The software was then tested to see how long it took to set up the files and access paths, and how easy it was to develop a procedure to program Method 1 - No Set-Up.

The result of this trial was that Dataease was chosen as the development tool. As well as offering a powerful Structured Query Language (SQL) for programming, the system seemed totally robust (unlike Access, which produced several general protection errors under Windows, and also 'froze' the computer on several occasions), was self contained, and was capable of running on a low specification portable computer.

Further refinement of the file structures took place, and the initial software development concentrated on developing descriptive modelling options for each of the four methods. The file structures were modified to save the details of the items totalled for Method 4 - Group Total Set-Up (Item Temporary), retain details of the modelling parameters (Static Data), and a further file was added which automatically calculated the Class Limits for the period order day classes. The file structure now looked like:

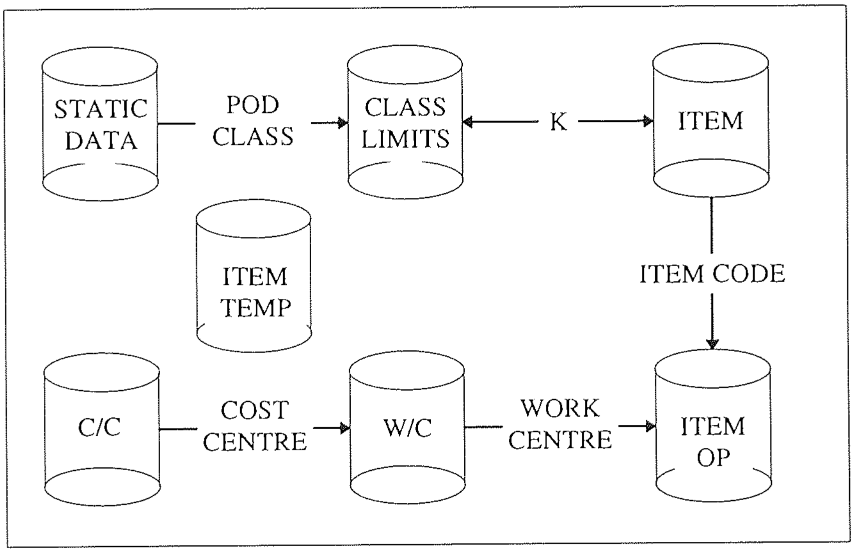

Figure 6.2 - Second File Structure - Descriptive Modelling.

Having developed the descriptive modelling options, it was recognised that the ability to save and retrieve the results of a modelling exercise would be a useful additional feature. The file structure now looked like:

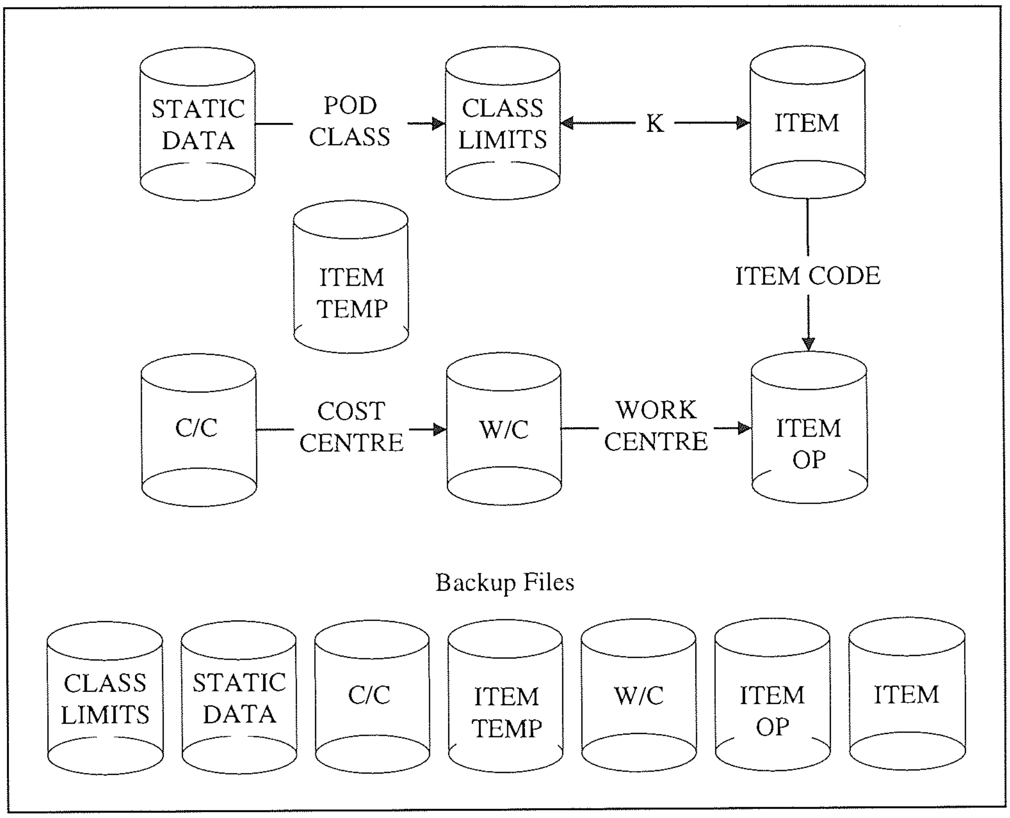

Figure 6.3 - Final File Structure - Descriptive Modelling.

The next item to be considered was the execution cycle capacity planning option. This required the addition of six new master files, one to hold the order details *(Schedule Maintenance)*, one to hold the details of the prime and alternate routes *(Item Op Master)*, one to hold the order operation details *(Schedule Operation)*, one to hold the workcentre capacity load *(Schedule Workcentre)*, one to hold details of the cost centre capacity load *(Schedule Cost Centre)* and a work file *(Schedule Temporary)*, as follows:

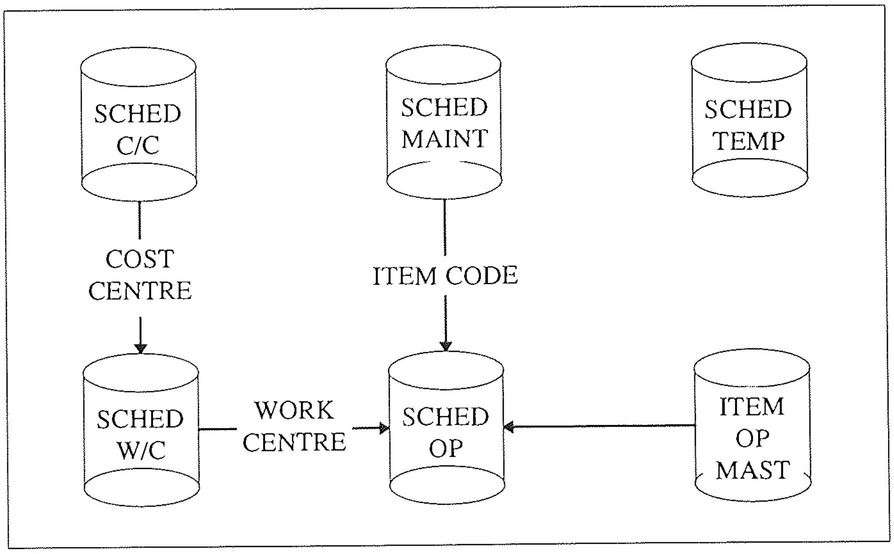

Figure 6.4 - File Structure - Schedule Planning.

Finally, the normative modelling options were considered. Three new files were added to the system, one to contain the results of the modelling for each item *(Model Item)*, one to contain the results at an item operation level *(Model Operation)*, and one to contain the modelling parameters and results at an overall level *(Model Static Data)*, as follows:

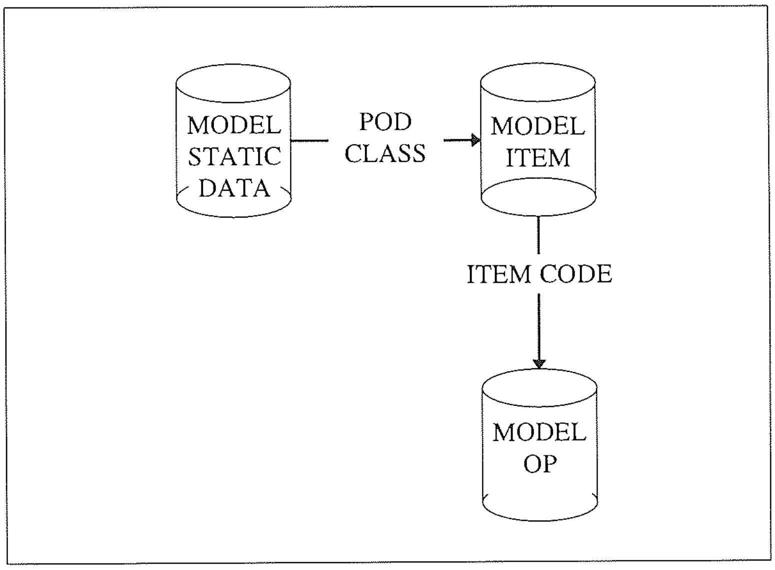

Figure 6.5 - File Structure - Normative Modelling.

The final system therefore consisted of a total 22 discrete files, as follows:

File Name	Appendix
Item File	1. 0
Item Operation	1. 1
Workcentre	1. 2
Cost Centre	1. 3
Static Data	1. 4
Class Limits	1. 5
Item Temporary	1. 6
Item Op Master	1. 7
Item Backup	1. 8
Item Op Backup	1. 9
Workcentre Backup	1.10
Cost Centre Backup	1.11
Static Data Backup	1.12
Item Temp Backup	1.13
Model Item	1.14
Model Operation	1.15
Model Static Data	1.16
Schedule Maintenance	1.17
Schedule Temporary	1.18
Schedule Operation	1.19
Schedule Workcentre	1.20
Schedule Cost Centre	1.21

Table 6.1 - Master File List.

A more detailed layout for each of the files is provided in *Appendix 1 - File Layouts*.

For each of the descriptive modelling options an exchange curve approach was adopted, in that the model initially calculated order and average inventory value loads for up to nine different values of K. This modelling process being repeated until the financial and administrative constraints were both within acceptable limits for one of the values of K, and then the capacity load was then checked to ensure that the capacity constraint was not overloaded. In this way the model was validated in the three constraints.

For each of the normative modelling options, a limit could be stated in one of the three constraints (average inventory value, administrative workload or capacity), and the model would then attempt to match, as near as possible, to the prescribed constraint limit.

For the schedule overall capacity planning option, a schedule is entered for a period and year, and the minimum capacity requirements are then calculated, taking full advantage of sequence based set-up reductions.

In total, over two hundred and fifty different programs had to be written to support the modelling options. Details of the software logic flow can be found in *Appendix 2 - Software Logic Flow by Program*. This appendix is arranged by menu option, and provides summary details of the function of each individual program which is run from each option.

The rest of this section describes the descriptive modelling options, the normative modelling options and the schedule overall capacity planning in more detail.

6.2 SOFTWARE OPTIONS.

6.2.1 Introduction.

Navigation around the system is supported by a hierarchical menu system, arranged functionally, with a depth of four levels, as follows:

- The *Main Menu* which controls the access to and navigation around the system.
  - The *MRP Parameters Menu* which controls access to the four descriptive modelling options, set-up modification and the saving and retrieval of previous models.
    - The *Import / Export Menu* which controls the importation of data into the system from a host system, and the export of parameter back to the host.
    - The *Enquiry Menu* which allows full access to the system master files, for modification and enquiry at an individual item level.
    - The K^+ *Simulation - No Set-Up Menu* which controls the running of the descriptive modelling options which take no account of any set-up cost when allocating items to a period order day class, but takes account of potential reductions in set-up times when calculating capacity usage.
      - The *Enquiry Menu* as before.
    - The K^+ *Simulation - Item Set-Up Menu* which controls the running of the descriptive modelling options which use the major set-up cost for each item when allocating items to a period order day class, and takes account of reductions in set-up times when calculating capacity usage.
      - The *Enquiry Menu* as before.
    - The K^+ *Simulation - Group Item Set-Up Menu* which controls the running of the descriptive modelling options which takes account of possible reductions in set-up costs for each item when allocating items to a period order day class, and also takes account of reductions in set-up times when calculating capacity usage.
      - The *Enquiry Menu* as before.

  - The K^+ *Simulation - Group Total Set-Up Menu* which controls the running of the descriptive modelling options which allocates items into period order day classes based on the total annual usage value and total set-up cost for a group of items using the same major set-up, and also takes account of reductions in set-up times when calculating capacity usage.
    - The *Enquiry Menu* as before.
  - The *Modify Set-Up Menu* which controls the running of the options which allow the bulk modification of set-up costs and times to allow for the benefits of implementing any potential improvements to be modelled.
  - The *Save Simulation Details Menu* which allows for the saving and retrieval of previous models.
- The *MRP Scenario Modelling Menu* which controls access to the normative modelling options.
- The *Schedule Overall Capacity Planning Menu* which controls access to the detailed capacity planning options.
  - The *Schedule Reports Menu* option which allows access to the detailed reporting options for a particular year and period.
  - The *Operation Master Menu* which is concerned with the maintenance of prime and alternate routes.

6.2.2 Outline Logic Flow for K^+ Simulation - No Set-Up.

The *Calculate K Values - No Set-Up* menu controls the running of the descriptive modelling options which take no account of any set-up cost when allocating items to a period order day class, but takes account of potential reductions in set-up times when calculating capacity usage. This modelling option is run in two phases, the first phase is the calculation of the order and inventory load, the second phase is the calculation of the run and set-up load.

This first phase takes the environmental parameters *(Inventory Holding Rate (i), the Improvement Factor (v), the Working Days per Annum, up to nine different values of K, and the Period Order Day Class series)* as entered and calculates the base inventory value and order load for each value of *K* by allocating each item to the relevant period order day class.

It assumes that all set-up costs are zero, and that only an order raising cost is to be used.

The outline logic flow for this option is as follows:

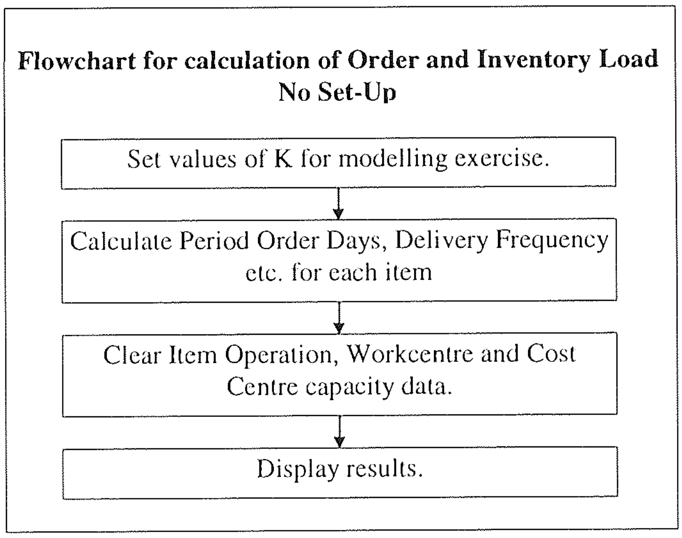

Figure 6.6 - No Set-Up - Order & Inventory Load Calculation Flowchart.

The second phase calculates the capacity used for one of the values of *K* for which a base inventory and order load has already been calculated. It assumes that set-up reductions can be achieved within a scheduling group, and as the items have been allocated to period order day classes according to the annual usage value of each item, that the item with the highest annual usage value within each scheduling group (or sub group) will be scheduled most often and incur the longest set-ups, and other items can be scheduled to take benefit of the shorter set-up times.

The basic logic flow for this option is as follows:

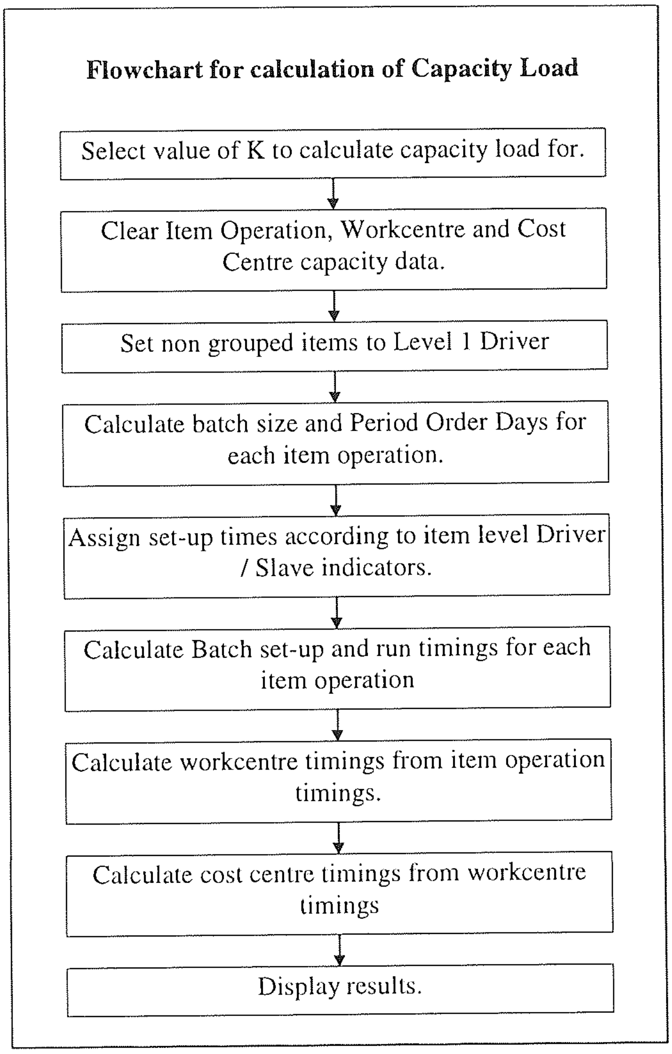

Figure 6.7 - No Set-Up - Capacity Load Flowchart.

6.2.3 Outline Logic Flow for K^+ Simulation - Item Set-Up.

The *Calculate K Values - Item Set-Up* menu controls the running of the descriptive modelling options which use the major set-up cost for each item when allocating items to a period order day class, and takes account of reductions in set-up times when calculating capacity usage. This modelling option is run in two phases, the first phase is the calculation of the order and inventory load, the second phase is the calculation of the run and set-up load.

The first phase takes the environmental parameters *(Inventory Holding Rate (i), the Improvement Factor (v), the Working Days per Annum, up to nine different values of K, and the Period Order Day Class series)* as entered and calculates the base inventory value and order load for each value of *K* by allocating each item to the relevant period order day class, taking into account only the major set-up cost for each item.

The outline logic flow for this option is as follows:

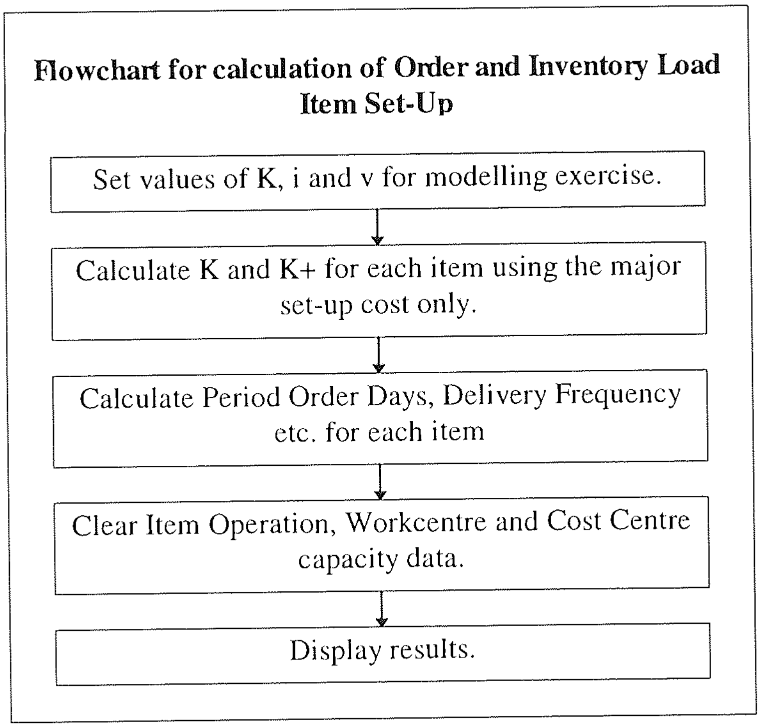

Figure 6.8 - Item Set-Up - Order & Inventory Load Calculation Flowchart.

The second phase calculates the capacity used for one of the values of *K* for which a base inventory and order load has already been calculated. This assumes that set-up reductions can be achieved within a scheduling group, and that as the item scheduled in the lowest period order day class within each scheduling group (or sub group) will be scheduled most often, it will incur the longest set-ups, and other items can be scheduled to take benefit of the shorter set-up times.

The basic logic flow for this option is as follows:

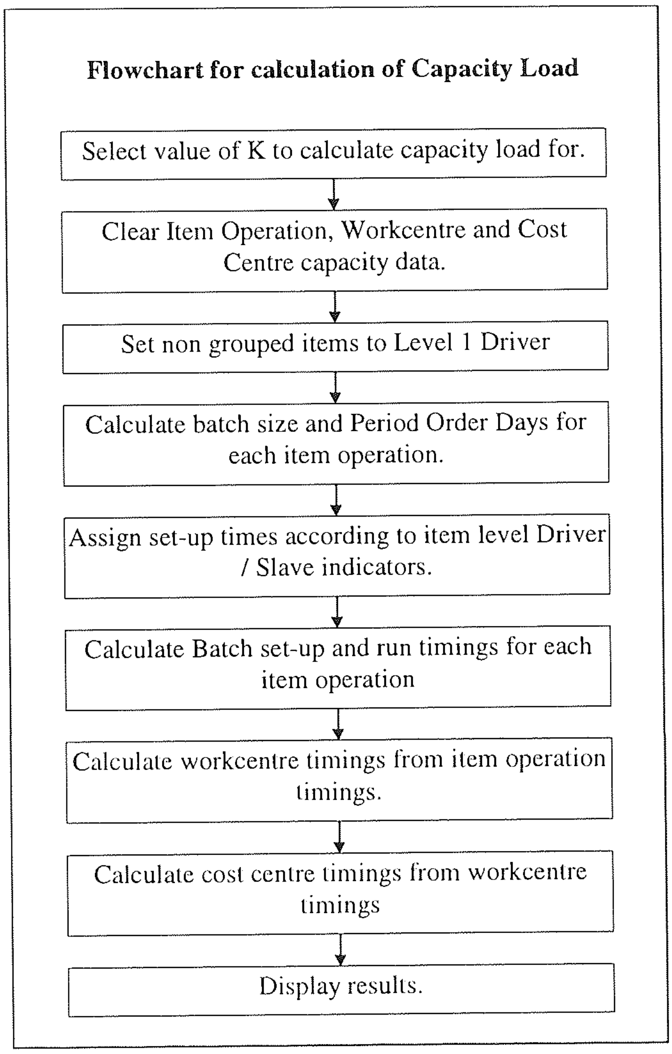

Figure 6.9 - Item Set-Up - Capacity Load Flowchart.

6.2.4 Outline Logic Flow for K^+ Simulation – Group Item Set-Up.

The *Calculate K Values - Group Item Set-Up* menu controls the running of the descriptive modelling options which takes account of possible reductions in set-up costs for each item when allocating items to a period order day class, and also takes account of reductions in set-up times when calculating capacity usage. This modelling option is run in two phases, the first phase is the calculation of the order and inventory load, the second phase is the calculation of the run and set-up load.

The first phase takes the environmental parameters *(Inventory Holding Rate (i), the Improvement Factor (v), the Working Days per Annum, up to nine different values of K, and the Period Order Day Class series)* as entered and calculates the base inventory value and order load for each value of *K* by allocating each item to the relevant period order day class. The individual item set-up cost used is established within each set-up group by allocating the major set-up cost to the highest annual usage value item within each group.

This process is then repeated for the items in sub set-up groups until all items are allocated a relevant set-up cost. The period order day classes are then calculated for each item and corrected to stop items within a group (or sub group) being scheduled more frequently than the item allocated the major set-up cost.

The outline logic flow for this option is as follows:

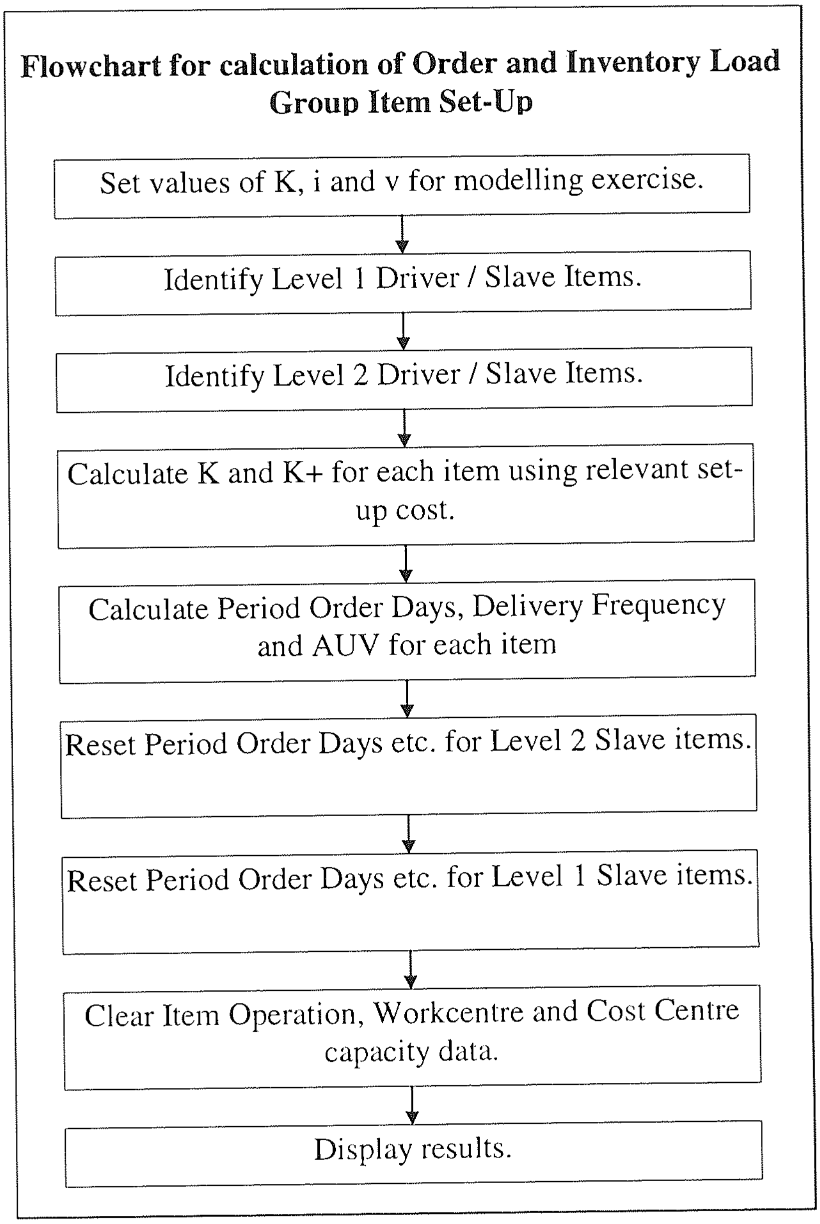

Figure 6.10 - Group Item Set-Up - Order & Inventory Load Calculation Flowchart.

The second phase calculates the capacity used for one of the values of *K* for which a base inventory and order load has already been calculated. This assumes that set-up reductions can be achieved within a scheduling group, and that as the item scheduled in the lowest period order day class within each scheduling group (or sub group) will be scheduled most often, it will incur the longest set-ups, and other items can be scheduled to take benefit of the shorter set-up times.

The basic logic flow for this option is as follows:

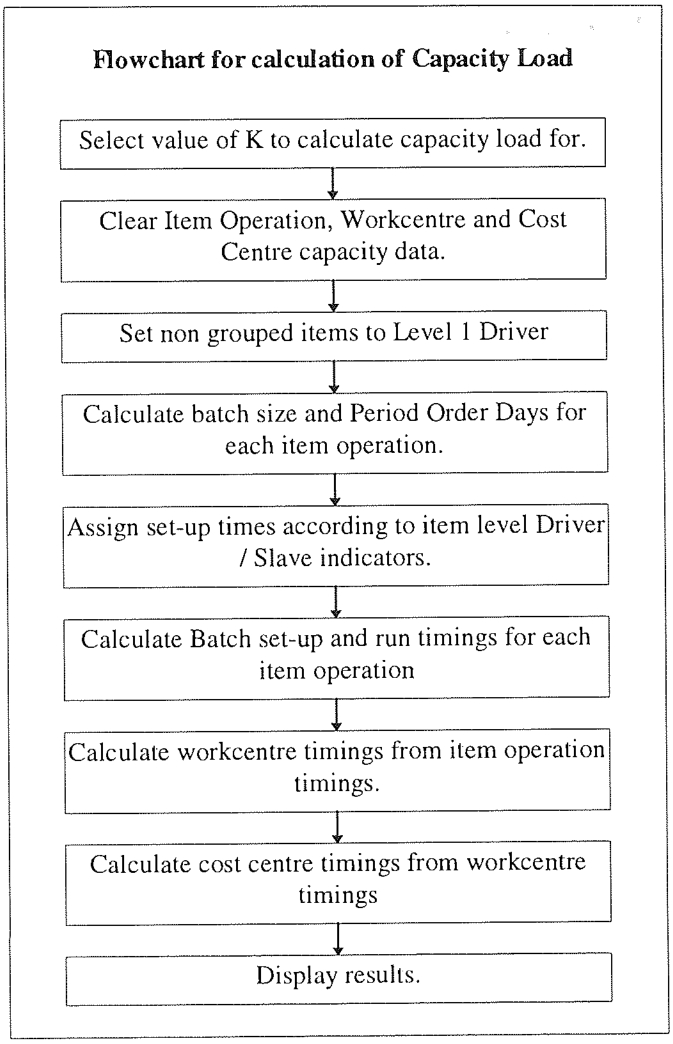

Figure 6.11 - Group Item Set-Up - Capacity Load Flowchart.

6.2.5 Outline Logic Flow for K^+ Simulation – Group Total Set-Up.

The *Calculate K Values - Group Total Set-Up* menu controls the running of the descriptive modelling option which allocates items into period order day classes based on the total annual usage value and total set-up cost for a group of items using the same major set-up, and also takes account of reductions in set-up times when calculating capacity usage. It allocates all items within a set-up group to the same period order day class, and is run in two phases, the first phase is the calculation of the order and inventory load, the second phase is the calculation of the run and set-up load.

The first phase takes the environmental parameters *(Inventory Holding Rate (i), the Improvement Factor (v), the Working Days per Annum, up to nine different values of K, and the Period Order Day Class series)* as entered and calculates the base inventory value and order load for each value of *K*. The individual item set-up cost used is established within each set-up group by allocating the major set-up cost to the highest annual usage value item within each group.

This process is then repeated for any items in sub set-up groups until all items are allocated a relevant set-up cost. The group total set-up cost is calculated as the sum of the costs of the constituent items. The period order day classes are then calculated for each item and each set-up group.

Items that are not within a set-up group are allocated the major set-up cost and time.

The outline logic flow for this option is as follows:

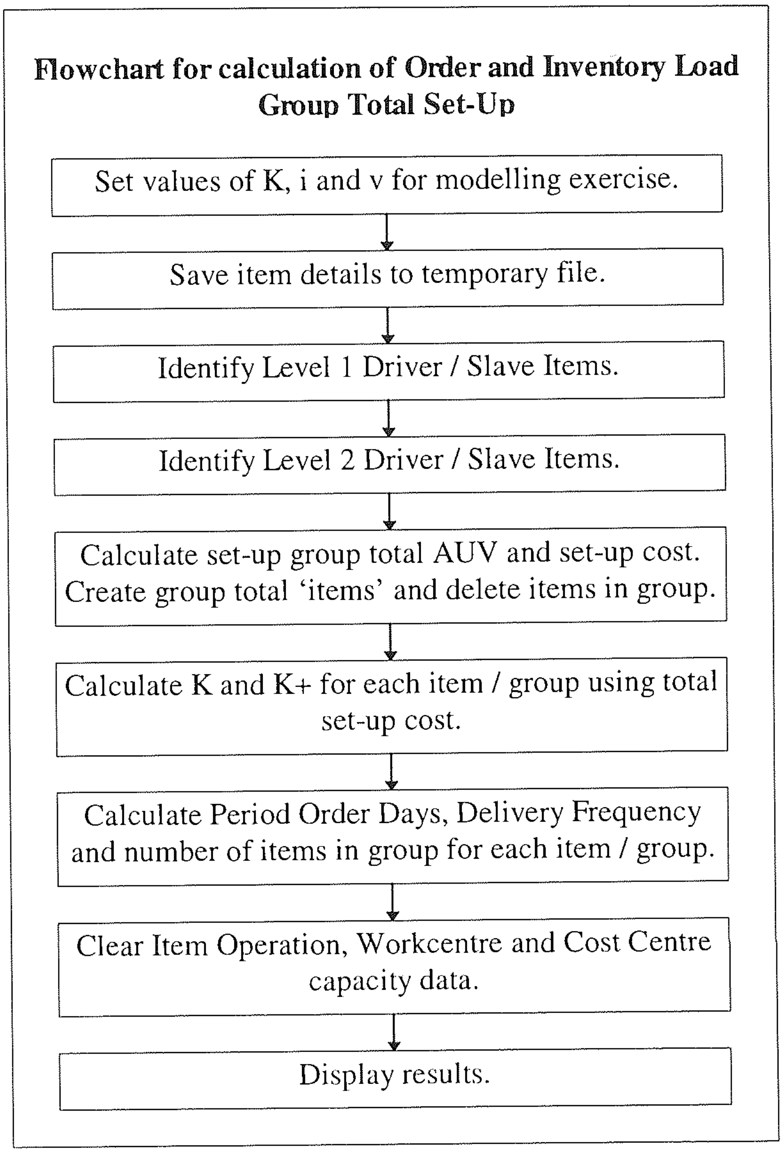

Figure 6.12 - Group Total Set-Up - Order & Inventory Load Calculation Flowchart.

The second phase calculates the capacity used for one of the values of *K* for which a base inventory and order load has already been calculated. This assumes that set-up reductions can be achieved within a scheduling group, and that as the item scheduled in the lowest period order day class within each scheduling group (or sub group) will be scheduled most often, it will incur the longest set-ups, and other items can be scheduled to take benefit of the shorter set-up times. The basic logic flow for this option is as follows:

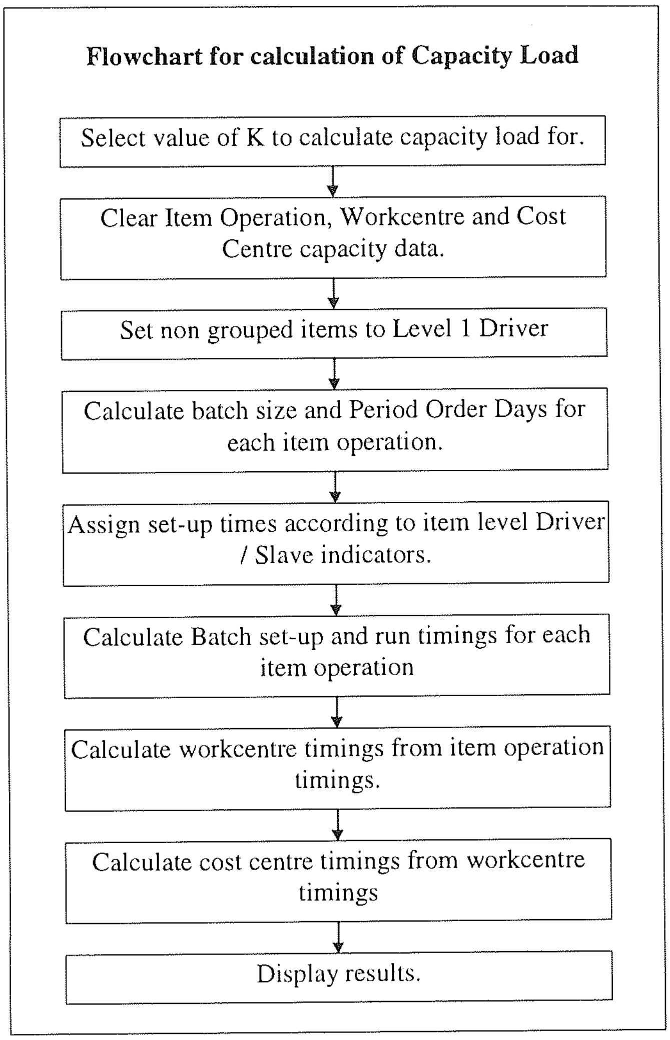

Figure 6.13 - Group Total Set-Up - Capacity Load Flowchart.

6.2.6 Outline Logic Flow for MRP Scenario Modelling Options.

6.2.6.1 Overview of MRP Scenario Modelling Logic Flow.

The *MRP Scenario Modelling Menu* controls the running of the three normative modelling options *(match on orders, inventory or capacity)* which take account of possible reductions in set-up costs for each item when allocating items to a period order day class, and also take account of reductions in set-up times when calculating capacity usage.

Each of the options is run in two phases, the first phase is concerned with ascertaining the range of feasible limits within which the modelling can take place, the second phase is the matching of the inventory parameters to the stated limit on the key performance indicator *(orders per year, average base inventory value or capacity load)* selected.

Each of the three modelling options takes as input the environmental parameters entered into, and limits calculated by the *Calculate Scenario Limits* option. Having calculated the limits and assigned set-up costs and times to each item a limit on one of the key performance indicators is entered, and the modelling process then allocates the items to the stated period order day classes to achieve a match with the stated limit.

All the modelling options use the *Group Item Set-Up* method. The items are allocated into set-up groups, and the set-up level, costs and times are assigned according to the annual usage value hierarchy within each set-up group. The individual item set-up cost or time used is established within each set-up group by allocating the major set-up cost to the highest annual usage value item within each group. This process is then repeated for any items in sub set-up groups until all items are allocated a relevant set-up cost and time.

Each individual match option *(match on orders, match on average inventory value or match on capacity)* then attempts to match on the specified limit by progressively reducing the improvement factor *(v)* from 1.0 to 0.1 for a range of values of K from 1 through 4095 until it either achieves an exact match, or the results of the current and previous simulations straddle the desired order limit with a difference of 1 in the value K from the current and previous simulations. As the improvement factor *(v)* modifies the set-up cost, the effect of progressively reducing the value from 1.0 to 0.1 is twofold. Firstly the reduction in the set-up cost will reduce the value of K^+ calculated for each item. As the value of K reduces, so the class limit boundaries in terms of annual usage value reduce, and so items with lower annual usage value will be scheduled more frequently. Secondly, as the set-up costs are all reduced by the same factor, the range of values for the set-up costs will be reduced. The effect of this for a value of K is to reduce the spread of the period order day classes that the items will be allocated to, as the range of values of K^+ will be smaller.

6.2.6.2 Outline Logic Flow for Calculate Scenario Limits.

The *Calculate Scenario Limits* option accepts the environmental parameters *(Inventory Holding Rate (i), Working Days per Annum, and the Period Order Day Class series)* to be used by the normative modelling options and calculates the low and high limits on average inventory value, order load and capacity load.

To achieve this, items are firstly allocated into set-up groups, and the set-up level, costs and times are assigned according to the annual usage value hierarchy within each set-up group. Then the individual item set-up cost or time used is established within each set-up group by allocating the major set-up cost to the highest annual usage value item within each group. This process is then repeated for the any items in sub set-up groups until all items are allocated a relevant set-up cost.

The low limits are calculated by assuming that every item it allocated into the lowest period order day class (e.g. 5 days). The high limit assumes that that every item is allocated into the highest period order day class (e.g. 160 days).

By calculating the limits in terms of average base inventory value, administrative workload (orders per annum) and total capacity, it is possible to specify the range of feasible values that each of the normative modelling options could theoretically work within, and discount any modelling outside the range without modifying one or all of the period order day classes, the item cost prices or the item operation set-up times to make the desired scenario possible.

The outline logic flow for the *Calculate Scenario Limits* option is as follows:

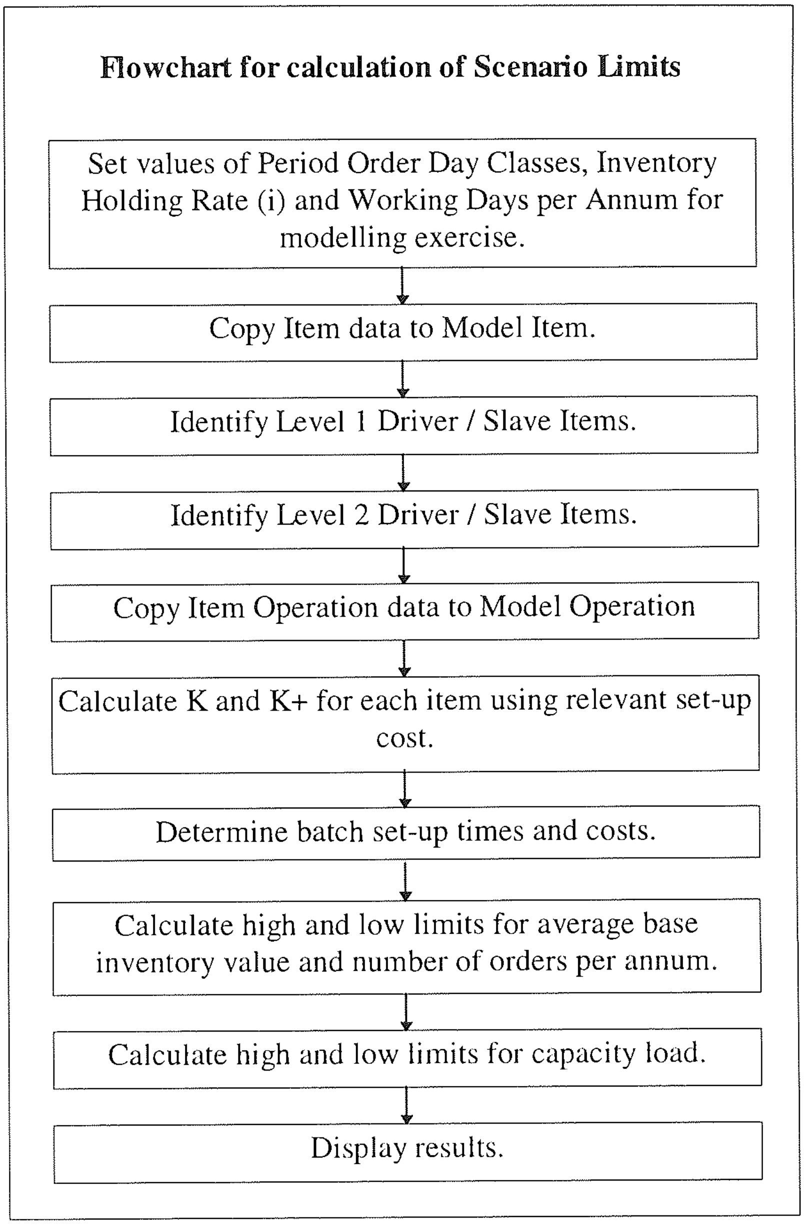

Figure 6.14 - Scenario Modelling - Calculation of Scenario Limits Flowchart.

6.2.6.3 Outline Logic Flow for Match on Orders.

The *Match on Orders* option allocates the items to the stated period order day classes so that a stated order load is satisfied. The inputs to this process are the outputs from the *Calculate Scenario Limits* process and the required order limit.

The match is achieved by progressively reducing the improvement factor *(v)* from 1.0 to 0.1 for a range of values of *K* from 1 through 4095 until it either achieves an exact match, or the results of the current and previous simulations straddle the desired order limit

It calculates the base inventory value and order load for each value of *K* being modelled by allocating each item to the relevant period order day class, taking into account the modified set-up cost. The period order day classes are then calculated for each item and corrected to stop items within a group (or sub group) being scheduled more frequently than the item allocated the major set-up cost.

The capacity load is then calculated, assuming that set-up reductions can be achieved within a scheduling group, and that as the item scheduled in the lowest period order day class within each scheduling group (or sub group) will be scheduled most often, it will incur the longest set-ups, and other items can be scheduled to take benefit of the shorter set-up times.

The basic logic flow for this option is as follows:

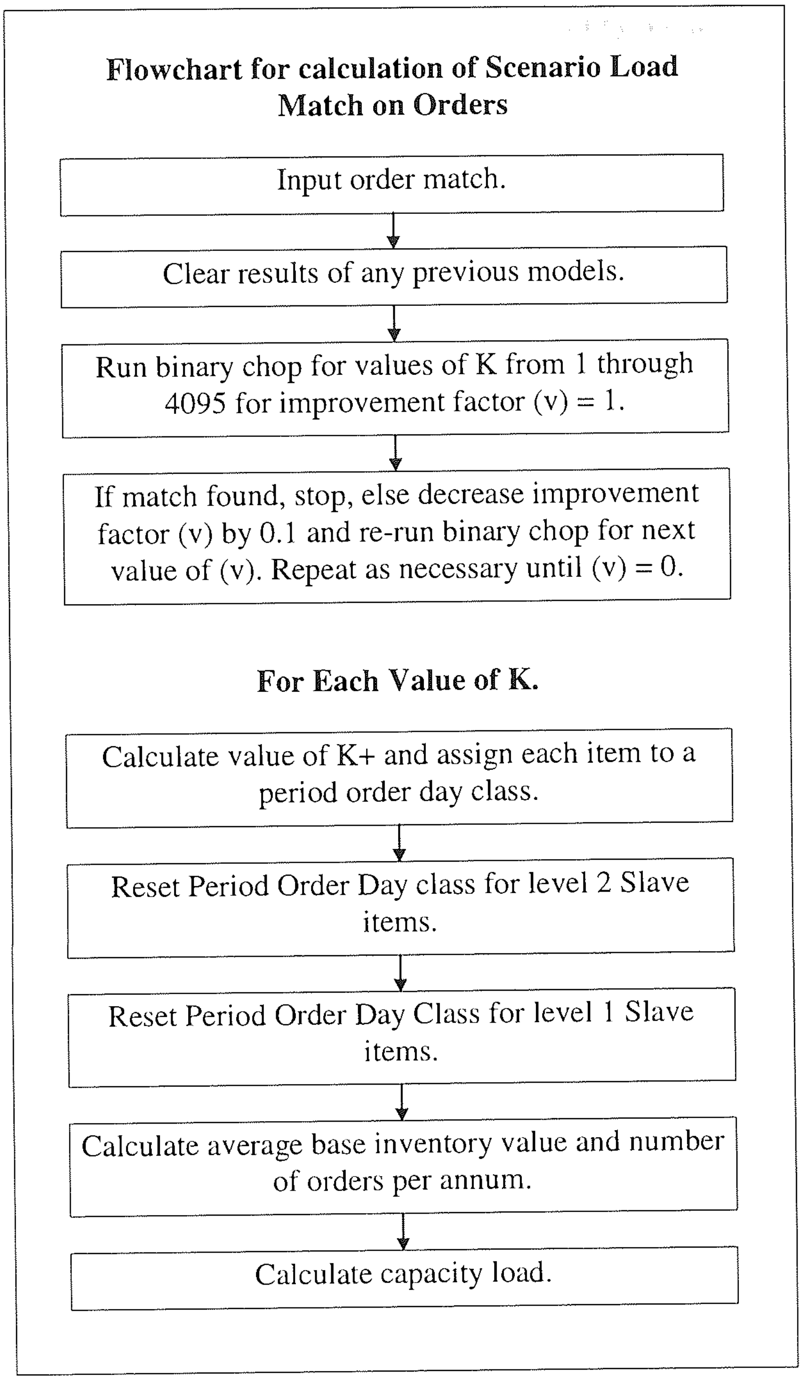

Figure 6.15 - Scenario Modelling - Match on Orders Flowchart.

6.2.6.4 Outline Logic Flow for Match on Average Inventory Value.

The *Match on Average Inventory Value* option allocates the items to the stated period order day classes so that a stated average inventory value load is satisfied. The inputs to this process are the outputs from the *Calculate Scenario Limits* process and the average base inventory value limit.

The match is achieved by progressively reducing the improvement factor *(v)* from 1.0 to 0.1 for a range of values of *K* from 1 through 4095 until it either achieves an exact match, or the results of the current and previous simulations straddle the desired average base inventory value limit.

It calculates the base inventory value and order load for each value of *K* being modelled by allocating each item to the relevant period order day class, taking into account the modified set-up cost. The period order day classes are then calculated for each item and corrected to stop items within a group (or sub group) being scheduled more frequently than the item allocated the major set-up cost.

The capacity load is then calculated, assuming that set-up reductions can be achieved within a scheduling group, and that as the item scheduled in the lowest period order day class within each scheduling group (or sub group) will be scheduled most often, it will incur the longest set-ups, and other items can be scheduled to take benefit of the shorter set-up times.

The basic logic flow for this option is as follows:

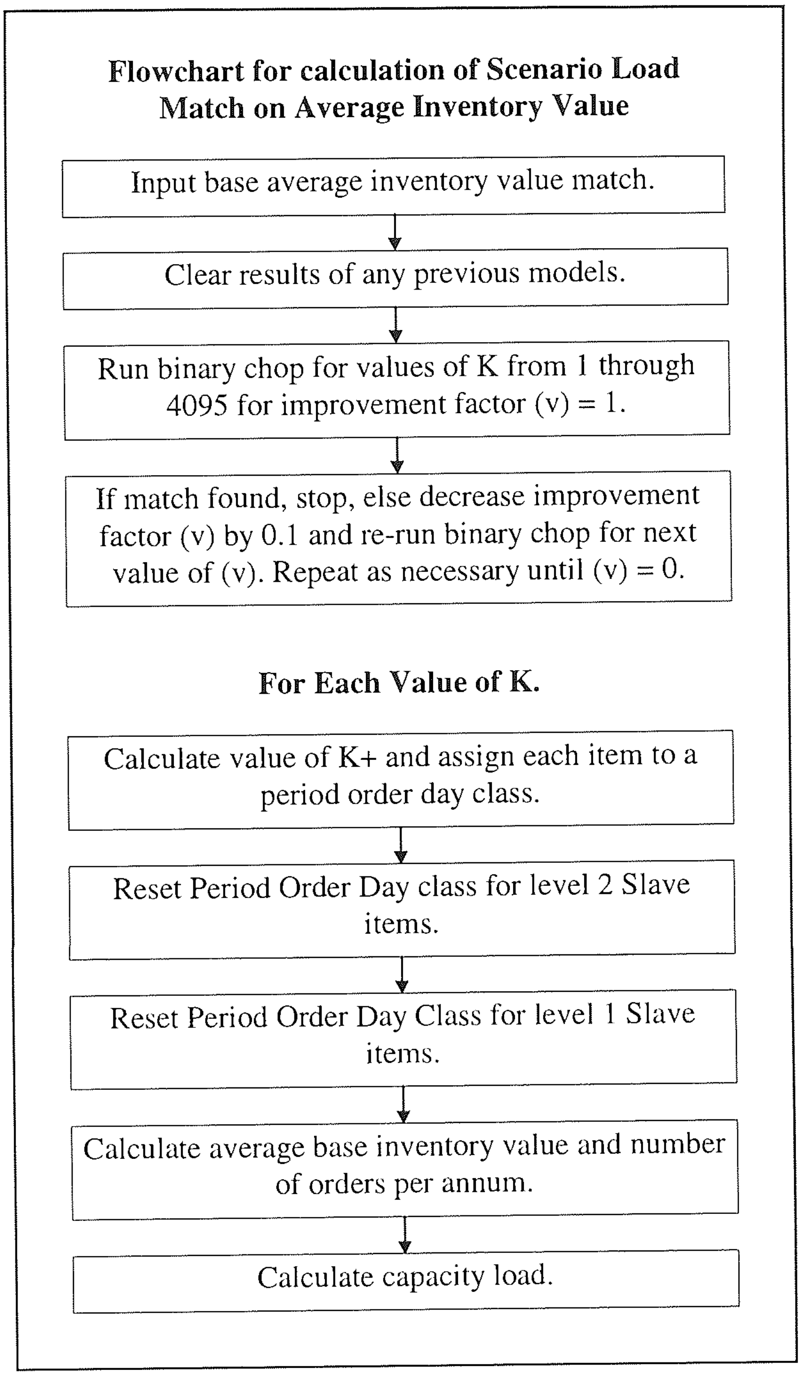

Figure 6.16 - Scenario Modelling - Match on Average Inventory Value Flowchart.

6.2.6.5 Outline Logic Flow for Match on Capacity.

The *Match on Capacity* option allocates the items to the stated period order day classes so that a stated overall capacity load is satisfied. The inputs to this process are the outputs from the *Calculate Scenario Limits* process and the overall capacity limit.

The match is achieved by progressively reducing the improvement factor *(v)* from 1.0 to 0.1 for a range of values of *K* from 1 through 4095 until it either achieves an exact match, or the results of the current and previous simulations straddle the desired overall capacity limit.

It calculates the base inventory value and order load for each value of *K* being modelled by allocating each item to the relevant period order day class, taking into account the modified set-up cost. The period order day classes are then calculated for each item and corrected to stop items within a group (or sub group) being scheduled more frequently than the item allocated the major set-up cost.

The capacity load is then calculated, assuming that set-up reductions can be achieved within a scheduling group, and that as the item scheduled in the lowest period order day class within each scheduling group (or sub group) will be scheduled most often, it will incur the longest set-ups, and other items can be scheduled to take benefit of the shorter set-up times.

The basic logic flow for this option is as follows:

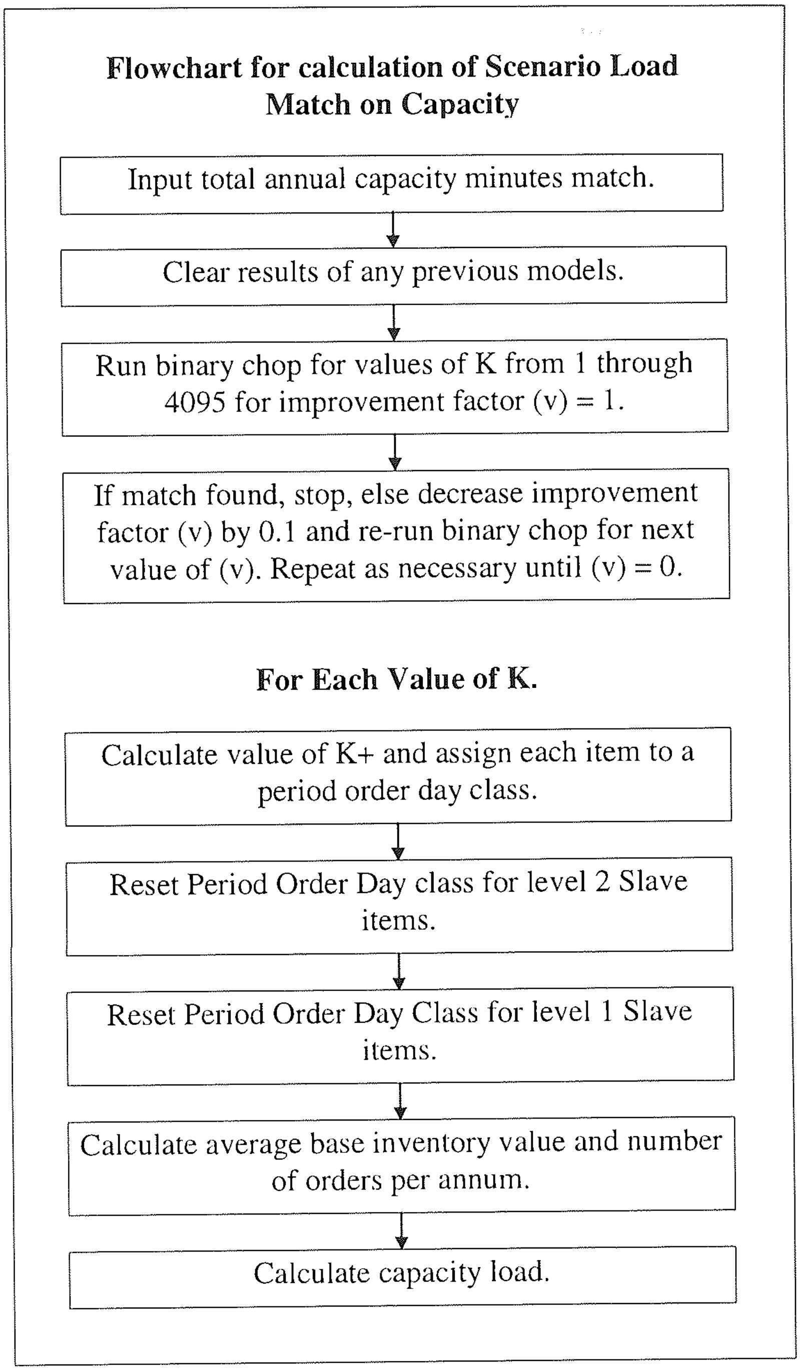

Figure 6.17 - Scenario Modelling - Match on Capacity Flowchart.

6.2.7 Outline Logic Flow for Schedule Capacity Planning.

6.2.7.1 Overview of Schedule Capacity Planning Logic Flow.

The *Schedule Overall Capacity Planning Menu* controls the running of the capacity planning options. These are concerned with analysing the orders scheduled for production in a period (which can be from 0.1 to 9.9 days in length) and calculating the theoretical minimum capacity required to manufacture the required articles.

It takes account of reductions in set-up times through re-forming partial set-up groups using only those items within each set-up group that are to be manufactured. Each item may be manufactured more than once and orders may be split across different routes and workcentres.

The principle that this option works by is that if it is assumed that all of the orders for items within a particular period and year are due at the end of the period, and the minimum possible time taken to schedule a set of orders for items within a particular set-up group is to schedule them together, sequenced to minimise the set-up times within the set-up group, then the sequence that the individual set-up groups are scheduled is immaterial to the capacity load.

So, if the set-up groups can be identified and internally sequenced, taking into account sequence dependent set-up reductions, then the minimum possible capacity load can be calculated. This can be used to confirm the feasibility of the order load, identify bottlenecks and be used as a benchmark for comparison with detailed sequencing.

Where orders need to be split or re-routed, the minimum possible capacity load can be re-calculated and used for comparison purposes with more detailed machine level sequencing. Where a workcentre comprises of a single machine, the output from this option can be used as a guide for machine level sequencing.

The *Operation Master Menu* contains the options concerned with the maintenance and use of prime and alternate routes. Prime routes are used by the descriptive and normative modelling options. Alternate and prime routes are used by the schedule planning options. Each item may have more than one route, and each route may contain more than one operation, with different set-up and run times.

6.2.7.2 Schedule Capacity Load Logic Flow.

The *Schedule Maintenance* option allows for the maintenance of orders for items for a particular year and period. Each order contains the order number, item code, year, period number, required quantity, due date and route code and is unique on year, period, route code, item code and order number. The route code is used to specify the which route from the item operation master file is used, so allowing the order to be loaded either totally or partially to a different workcentre from that on the prime route.

The *Schedule Capacity Load* option calculates the capacity load generated by all the orders for the specified year and period. It takes account of available set-up reductions through reforming partial set-up groups by workcentre using the items scheduled in the period and year.

The outline logic flow for this option is as follows:

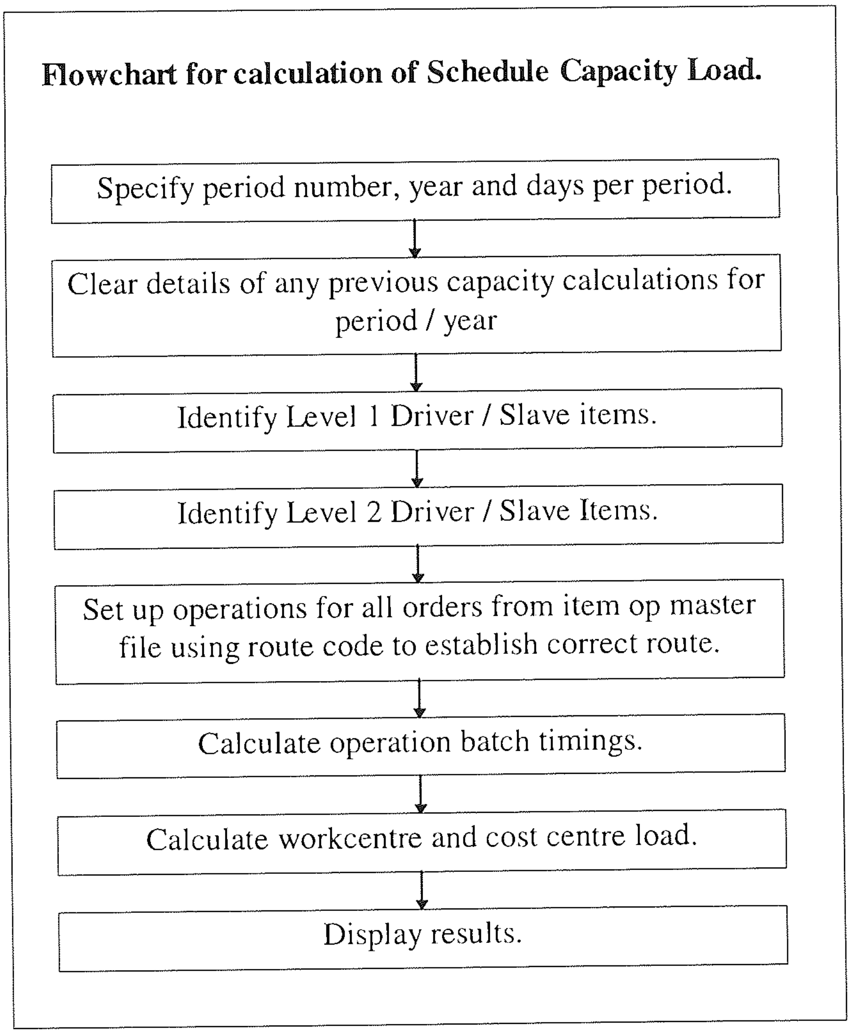

Figure 6.18 - Schedule Planning - Calculate Schedule Capacity Load Flowchart.

6.2.7.3 Delete Schedule for Year / Period Logic Flow.

The *Delete Schedule for Year / Period* option completely removes a schedule for the specified year and period.

The outline logic flow for this option is as follows:

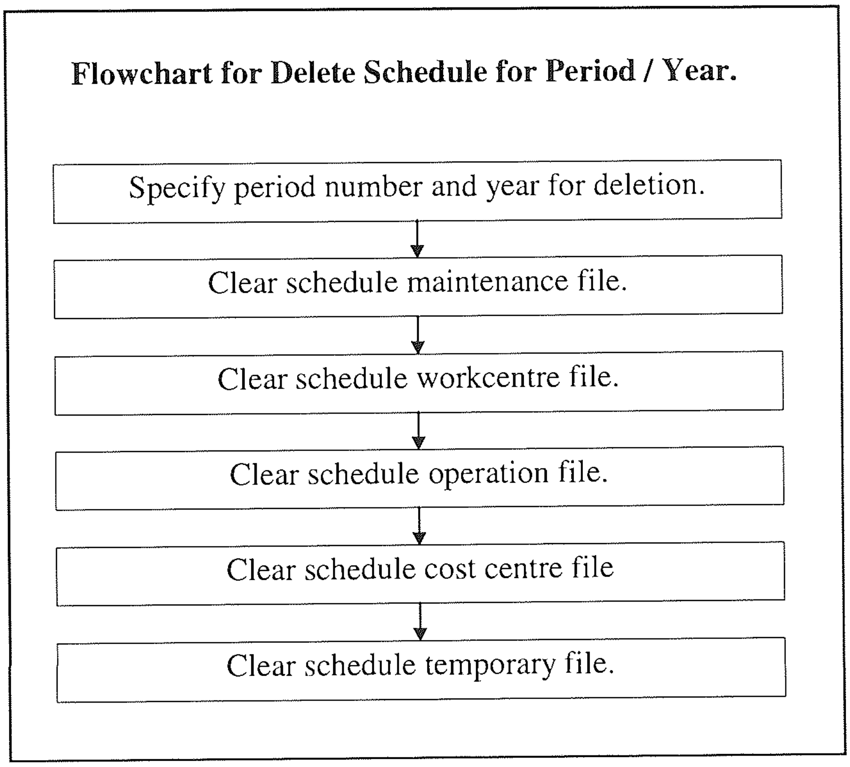

Figure 6.19 - Schedule Planning - Delete Schedule for Year / Period Flowchart.

6.3 SUMMARY OF THE SOFTWARE DEVELOPMENT.

In this chapter the development of the computer software required to support the case studies was investigated. This was designed to serve five purposes:

1. To accurately translate the theoretical background into a working model.
2. To obtain results from the modelling process which were consistent, repeatable, reliable, and in terms that were acceptable to the participating companies.
3. To examine the applicability of the overall approach as a consulting tool capable of provoking creative and perceptive thought about the organisation and organisational problems.
4. To assist in the problem solving process of choosing between alternative courses of action relevant to the problems faced.
5. For the problem solving activity to have substance, with critical appraisals being made of the generated outcomes.

The method chosen to satisfy the above criteria was average symbolic modelling, using PC based relational database technology, and developed using a fourth generation programming language. The system that was developed had to be open ended, dealing with relationships within the data which were not fixed, and able to communicate in both directions with a variety of host planning systems.

Three key performance criteria were chosen to assess the relative merits of different strategies:

1. The financial load in terms of average inventory value.
2. The administrative load in terms of orders per annum.
3. The capacity load in terms of set-up and run minutes per annum or per day.

The development methodology was evolutionary, with the core descriptive modelling options being developed first, followed by the capacity planning options, and finally the normative modelling options. This allowed any errors or omissions in the original design to be rectified and the modifications made. The scale of the software development was substantial, as each of the four methodologies had to be tested and trialled to assess their individual performance, and resulted in over 250 separate programmes being written, tested, and implemented.

The validation of the software took five forms:

1. The publication of the proposed methodology in the form of working papers *(Dupernex 1994) (Dupernex 1995 (1)) (Dupernex 1995 (2)) (Dupernex 1995 (3))* and in refereed journals *(Burcher, Dupernex, Relph 1995 (1)) (Burcher, Dupernex, Relph 1995 (2)) (Burcher, Dupernex, Relph 1996 (1)) (Burcher, Dupernex, Relph 1996 (2))* to promote the wider dissemination of the ideas behind the methodology, and to invite a critical response from the academic and business communities.
2. The presentation of the theoretical background internally within Aston University, at seminars at IBM and with the presentation of a paper at the 1996 IOM Conference.
3. By the use of standard testing methods to ensure that the software performed to specification.
4. By field trials with the participating companies to ensure that there was a real need to be addressed.
5. Once it was accepted by the interested parties that there was a need for the software, it was performing as specified, and that the specification was correct in its interpretation of the business problem, on the utility value of the methodology relative to alternative methods. Was it useful to the decision making process, how sensitive was the model to data or parameter changes, how useful was it as an aid to the decision making process, and what level of commitment was elicited from the users.

7 CASE STUDIES.

7.1 INTRODUCTION TO THE CASE STUDIES.

In this chapter we will look at the seven case studies carried out at five firms, using the modelling approach described earlier. The layout of the chapter is as follows:

- A description of the performance measures used to measure the effectiveness of the various scenarios.
- An analysis of the individual case studies.
- A resume of the overall results.

A case study approach was used which involved interviews with managers and operational staff within the participating companies, forming informal project teams, acting as a member of the project team, and obtaining data from the manufacturing planning and control system. After the modelling process, opinions were sought as to the utility value of the technique and to its use as a catalyst for change, opening up new ideas for the management of the operations.

After developing the theoretical model and initial software package, what was needed was the application of the research in a live environment, and to study of the effects of making any proposed changes. The objectives of the case studies was to:

- Identify whether the initial theoretical approach was addressing a real need, or not.
- Identify performance measures capable of being used to compare the outcome of different scenarios.
- Use the modelling process to provide a 'health check' on the current MRP parameter settings.
- Use the modelling process as a catalyst for change, to identify current and potential resource constraints, and validate the efficacy of planned remedial actions.
- Build on the experience gained with the collaborating companies in providing enhanced features into the model, and removing redundant features.

- To assess the validity of the modelling exercise according to the five criteria already identified in Chapter 5 – Model Validation, namely:
    1. The quality of insight gained into the perceived problem.
    2. The level of sensitivity of the model to data or parameter changes.
    3. The level of usefulness to the decision making process.
    4. The acceptability level of the suggestions.
    5. The level of commitment elicited from the users.

The case studies made use of the normative and descriptive modelling tools concerned with strategic MRP parameter setting. The operational capacity planning tools were not used in any of the case studies, as the complexity of the short term scheduling was not sufficient to warrant its use.

The modelling process looks at overall performance in terms of three criteria, the number of orders raised per annum, the average base inventory value, and the set-up and run minutes. The number of orders raised per annum is a measure of the administrative activity, the average base inventory load is a measure of the financial load, and the set-up and run minutes a measure of the capacity load. It uses an average modelling approach, ignores current stocks, and simply concentrates on the base activity level that a parameter set will generate on each of the three constraints. By concentrating on the overall effect of a parameter set, rather than at the performance of each individual item it is possible to compare the scale of the constraint use.

The fundamental difference between this approach and others, such as the EBQ, Exchange Curve, or K-Curve, is firstly, that it considers the capacity load at the strategic parameter planning stage, and secondly, that this load is considered in terms of the set-up reductions possible through normal, good, scheduling practices. The first point is generally ignored by the tools available to assist in the strategic parameter setting stage, and the second point is generally only considered at an operational level by finite capacity planning tools.

In order to test the validity of the approach, participating companies had to be found who:

- Were about to start an improvement programme. One of the difficult questions to answer when considering alternative improvement strategies is which of the identified improvements bring the greatest benefits. An evolutionary modelling approach could be of help in addressing this concern.

- Wanted to examine their existing MRP parameter settings. Once inventory parameters are set, they don't tend to be reviewed very often and can be based on historical work patterns, rather than relating to current demand.
- Were willing to co-operate with academic research, with the findings being published in the public domain.
- Could accept that there may be no tangible benefit for themselves from the participation. The proposed methodology may have produced results that were worse than those produced by existing methods.
- Could see a benefit to themselves in collaborating. For this relationship to work, there has to be a benefit to both parties. Companies are not generally willing to put time, effort and resources into providing commercially sensitive information to a third party just to have the warm glow of having helped an academic for the sake of pure research. To be able to promise hard benefits before investigating an area is impossible, for if the collaborating companies are perfect in everything they do, there will be no benefits. If they are not perfect, there is a reasonable chance that they will be able to benefit from co-operating with the research, and gain a better insight into their manufacturing operations.
- Manufactured items in batches, where groups of items could benefit from sequence dependent set-up reductions.

Five companies were involved in the seven case studies:

- Boots Contract Manufacturing provided two case studies, the D95 Tablet factory concerned with the packaging of vitamin tablets and D106 Sterile Products concerned with the bottling of Optrex lotion.
- Rhône Poulenc Rorer, a pharmaceutical manufacturer provided one case study concerned with the packaging of tablets.
- FMCG provided a case study concerned with moulding plastic components.
- Caradon Terrain, a manufacturer of plastic plumbing systems, provided two case studies, one in the extrusion of guttering and pipes, and the other in assessing the feasibility of setting up a cell for underground components.

- Zeneca Pharmaceuticals provided one case study concerned with the packaging of tablets.

In each of the seven case studies, each of the four modelling methods are compared with the current parameter settings and the EBQ. Many models were constructed using each of the modelling methods for each company, looking into the effects of implementing improvement programmes or changing the operational parameters. The details of the type of modelling undertaken for all the participating companies are provided in two case studies performed for Boots Contract Manufacturing. The details provided for the other case studies concentrate on the extent that the decision making process reached.

7.2 CALCULATION OF PERFORMANCE MEASURES.

In this chapter dealing with the case studies, certain performance measures, such as the Average Base Inventory Value, are calculated. The formulas used in calculating each of the performance measures are as follows:

Average Base Inventory Value.

This was calculated using the following formula:

$$BI = \frac{BQ.CP}{2}$$

where	BI	Base Inventory
	BQ	Batch Quantity (in units)
	CP	Cost Price per unit

This assumes that the stock decays in a linear fashion from the batch size to zero in the classic 'saw tooth' pattern, with the next batch replenishing the stock as it reaches zero.

Order Load.

This was calculated using the following formula:

$$OL = \frac{AD}{BQ}$$

where	OL	Order Load
	AD	Annual Demand (in units)
	BQ	Average Batch Quantity (in units)

This assumes that the all batches are of the standard batch quantity, and that the estimated annual demand is correct.

Run Load.

The Run load was calculated for each item using the following formula:

$$RL = \frac{AD * 60}{S}$$

where	RL	Run Load (in minutes)
	AD	Annual Demand (in units)
	S	Speed (in units per hour)

This assumes that the speed in units per hour is a correct average, and that the estimated annual demand is correct.

Set-up Load.

The Set-up load was calculated for each item using the following formula:

$$SL = OL * ST$$

where	SL	Set-up Load (in minutes)
	OL	Order Load (in batches per year)
	ST	Set-up Time (in minutes)

This assumes that the previously calculated Order Load is correct and that the Set-up times correctly reflect the time taken.

Annual Usage Value.

This is the total value at cost of the estimated annual demand for the items being considered.

Annual Capacity.

This is the stated weekly availability multiplied by the number of weeks per year.

Capacity Usage.

The Annual Capacity Load is the sum of the Run Load and the Set-up Load.

Stock Turns.

The stock turns is the Annual Usage Value divided by the Average Inventory Value.

N.B. This only includes base inventory, and excludes planned safety stocks and inventory overage.

7.3 BOOTS.

7.3.1 Background to Boots.

Boots is Britain's biggest dispenser of prescription drugs and largest seller of cosmetics, having one third of the £8 billion home market for beauty products, four times that of its nearest rival. It comprises of three retailing activities, Boots the Chemist, the Halfords motorist chain, and the Do It All DIY stores. Its core retail division, Boots the Chemist, accounted for 75% of its total turnover of £4.1 billion in 1996, and it has managed as a group to provide a return of 21% per annum over the last five years for its shareholders, three times that of Tesco and Sainsbury, and comparable to that of Marks and Spencers.

The Boots the Chemist Division has been subjected to competitive pressures on two fronts: from supermarkets who have branched out into own brand cosmetics and health care products, and from specialist retailers, such as Body Shop, and has had to create its own range of natural creams and lotions in response to this particular challenge. Its response to this erosion in the 1970's and 1980's was to return to its core business activities. In the past six years health care and beauty has risen from 63% of turnover in 1990 to 75% of retail turnover, with another 10% being derived from baby products. One of Boots strengths is its strong focus and brand identification, which is in no small part derived from its image of trustworthy medical authority from its dispensing activities, with 43% of sales in the retailing division being own label. This dispensing activity also serves to firmly anchor the own brand products. It has expanded organically to 1,260 shops in Britain, with 160 new shops being opened in the past 4 years, and has plans to open a further 80, but its plans to expand into continental Europe are being limited by rules forbidding multiple pharmacy ownership.

However, one of the main hopes for Boots in the future is in the Boots Contract Manufacturing (BCM) Division, which makes a variety of pharmaceuticals, cosmetics, pills, lotions and creams. These are sold as Boots own brand through the Boots the Chemist shops, as own label products for other retailers, and as non Boots label branded products such as the Nurofen pain relieving drug based on ibuprofen, Strepsils cough drops, E45 skin cream, and Optrex eye drops. One quarter of the BCM turnover is in supplying other retailers with similar products to those produced under the Boots brand for its own retailing division, with these products being made in direct competition to the

Boots products only where there is an alternative source of supply available to the competitor.

The branded products such as Nurofen, Strepsils and Optrex are marketed through Boots Healthcare International, whose aim is to build strong international brands to meet the increasing demand for medicines available without prescription.

7.3.2 Boots Contract Manufacturing - D95 Tablet Factory.

7.3.2.1 Introduction.

The initial area of study within Boots Contract Manufacturing was the D95 Tablet Factory. D95 is a 20 year old purpose built facility manufacturing and packaging over 170 different formulations of tablets in 700 different SKU's with a shelf life of between 2 and 3 years. This initial study took place over a period of four months, from June to September 1995.

This investigation involved the local factory manager, and the line supervisors and was conducted solely for Boots to establish the credibility of the approach, and to decide whether to proceed to a 'live' application. The facility was already well understood, with an established local management team, and had already undergone an internal review, so the results of the modelling and the following discussions were able to be critically and openly examined in the light of the existing knowledge base, and the suitability of the overall approach, the comparison criteria, key performance indicators and the recommendations were all assessed in the context of their applicability to Boots.

The purpose of the investigation within the D95 Tablet Factory was therefore to provide a trial of the methodology in a relatively simple area so that BCM could assess the viability of proceeding to a full trial in a live area.

7.3.2.2 The Approach.

The investigation method used was:

1. Establish the areas of concern within the facility.
2. Outline the principles behind the modelling process, and establish, in principle, that the approach was viable for Boots.
3. Establish the boundaries of the investigation.
4. Investigate the current working environment.
5. Establish the current operating parameters.
6. Confirm the credibility of the timings and batching rules by running the model with historical data.
7. Use the forecasted demand to predict the activity level using the current parameter set, to identify and quantify the existing constraints.

8. Use the model to optimise the parameter set according to various scenarios.
9. Re-identify the constraints and consider the viability of the various scenarios.
10. Consider improvements to overcome the constraints and change the parameter set to reflect the outcome of these changes.
11. Repeat steps 8 to 10.

The initial contact at Boots took place in June 1995 and was with the Materials Manager for the Tablets / Opthalmics factory at the Beeston site in Nottingham. This was made through the Pharmaceuticals Special Interest Group (PSIG) Benchmarking Club organised by the Institute of Operations Management (IOM). From the initial conversations, it was apparent that Boots were interested in re-assessing the current working practices, with a view to implementing improvements, where these could be justified. During the initial conversations, the idea of obtaining a greater understanding of how the parameter set affected the operational performance of the factory, and using this understanding to increase the flexibility of the manufacturing operations using data that was already available within the MRP system, seemed to appeal to the Boots management, who arranged for a trial of the approach, and an investigation into its applicability to take place within the D95 Tablet Factory.

The first contact with the D95 Tablet Factory Manager and Line Supervisors took place the following month, in July 1995. After Boots had agreed in principle to continue with the relationship, the approach taken by the researcher was to establish a common ground with the management team, ascertain the areas of interest and concern for Boots, outline the scope and applicability of the research, see where the research interests and the Boots interests coincided, and agree a way forward. This relationship was never formalised in the sense that goals, responsibilities, authorities and timescales were contractually agreed, rather the participants (the researcher, the Materials Manager, and the Factory Manager) formed an informal project team with the purpose of testing the validity of the approach (the credibility of the software, the methodology and the researcher) with a view to assessing its wider applicability within Boots.

It was clearly stated from the outset by the researcher that although the outcome of the investigation could be of benefit to Boots, it may well be may be of no benefit. However, by modelling inventory behaviour earlier, there was probably a greater possibility of being able to cope with the unexpected, and that Boots would be able to assess the sensitivity of the operational parameters, therefore increasing the likelihood of coping with changing circumstances without causing major disruption, and also being able to increase the flexibility of the plant through reducing batch sizes. It was also hoped by Boots that the modelling process would lead to there being a more strategic or tactical view being taken of the management of the tablet factory, pulling back from the existing day to day operational and technical focus.

The principles of the modelling process were outlined, emphasising that the data used would be from Boots, and already available within the existing MRP system. The data collection exercise involved liasing with members of the Information Services function so that the live data could be extracted into the PC based modelling software. This started in mid July 1995, with a brief investigation of the Boots MRP system, and an identification of the data that was required. The initial data contained several errors, such as duplicate routes, and misinterpretations, such as the number of decimal places in the cost prices. These errors were uncovered in the comparison of the model using the current operational parameters against the current operating conditions. By early August 1995 the modelling process was producing the first results, and meetings started to take place to ascertain the suitability of the approach, and its applicability to Boots, this being the main point of the pilot. There then followed a period of 3 to 4 weeks where further trials of the model took place, to investigate various scenarios that Boots wanted to examine, the flexibility of the approach, the interaction of the team members, and their confidence in the capabilities of the model and the modeller. Some modifications to the software took place in this period, so the response to the various scenarios varied from the same day, where no modification was required, to the next week, where changes to the software had to be programmed, tested and implemented.

This pilot left Boots confident that the modelling process was of use, increased the level of understanding of the way that manufacturing planning and control system parameter settings affected the timing and size of the batches within the factory, produced results that were reasonable, understandable and acceptable, and gained the acceptance and commitment of the users. It was on this basis that Boots decided to stop the trials in September 1995 and proceed on to a full trial in a live area.

7.3.2.3 Overview of the manufacturing process.

Two packing lines were investigated, Lines 3 and 4, producing a range of bottled vitamin tablets comprising of 30 SKU's.

The manufacturing process in total consisted of the following 5 steps: dispensing, granulation, tablet making, coating, and packaging. Each of these steps are undertaken as discrete batch operations, it taking an elapsed time of between 6 and 8 weeks to complete the manufacturing process, with between 2 to 3 weeks processing time. There are four computer controlled dispensing rooms, the raw materials are weighed and issued in bulk from the warehouse, the weighed raw materials are placed in a cage, the unused materials re-weighed and returned to the issuing warehouse. The granulation is in batches of approximately 200 kg per blend, being dependent upon the capacity of the blender. The tablet making is a straightforward compression operation. The coating operation either film coats or sugar coats depending on the tablet. The printing operation is an offset gravure transfer printing process. The packaging step comprises of two identical close coupled lines, each essentially consisting of bottling, labelling and packaging operations. The actual manufacturing constraints are in the granulation and tablet making (compression) operations, rather than the packaging line. For the purposes of the exercise these constraints were ignored, and the packaging line constraints considered in isolation.

The packaging step on both lines 3 and 4 consisted of a close coupled line with the tablets being fed from a hopper, the bottles are then filled with the required tablet quantity, a wool pad inserted, the bottles are then capped, labelled, a tamper evident seal added, and then finally cartoned. The line must be cleaned between each different tablet formulation to prevent contamination, this being the major set-up. Additionally, there were two groups of items which shared a common formulation, with three items in each group, the changeover between these items is a minor set-up. The tablets are not considered to be medicinal. There are five bottle sizes (30 / 75 / 100 / 120 / 170 ml) with two different caps being fitted. The stated capacity of each line is 840 minutes per day giving a total theoretical daily capacity of 1,680 minutes. The lines are supposed to be loaded to not more than 80% of the theoretical capacity, giving a true capacity for loading purposes of 1,344 minutes per day.

The investigation only considered the packaging step and assumed that any recommendations on batch sizing for packaging would be reflected in the batch sizes in the preceding processes, and any seasonality in the demand was to be ignored.

The following information was provided for each item being considered:

Item Code.

Unit Cost per item.

Estimated Annual Demand.

Current run Batch Quantity.

Run Time in units per hour.

Major Set-up Time per run batch.

Major Set-up Cost per run batch.

The following additional information was also provided for the six items in the two set-up groups:

Minor Set-up Time per run batch.

Minor Set-up Cost per run batch.

The current batching rules of packing lines 3 and 4 were analysed and the average base (exclusive of safety stocks etc.) inventory levels, the annual order load and the average capacity load which would result from the current batching parameters was derived. This was first run historically to establish how well the existing batching rules, capacities and routing data were at predicting the actual usages, number of actual batches and inventory levels. After some adjustment of errors in both data and interpretation, Boots were confident that the output from the model was accurate enough to continue with the test using forecasted, rather than historical, data.

This provided the following results:

D95 - Current Position	
Daily Capacity (mins)	1,680 mins
Daily Run Load (mins)	1,016 mins
% Run	60%
Daily Set-up Load (mins)	320 mins
% Set-up	19%
Available Capacity (mins)	344 mins
% Load	80%
Annual Usage Value	£4,752,790
Annual Order Load	155.5
Average Inventory Value	£458,867
Stock Turns	10.4

Table 7.1 - Boots D95 - Current Position.

The daily capacity was stated as 840 minutes per machine, and as lines 3 and 4 are interchangeable, a total daily capacity of 1680 (840 * 2) minutes was used. The daily run load is the calculated annual capacity load required to produce the estimated annual demand forecast divided by 240, the number of working days per annum. The daily set-up load is the annual total set-up load divided by 240. The available capacity is the daily capacity less the sum of the daily run load and the daily set-up load. The % run % set-up and % load are calculated as the % of the daily capacity spent on the relevant activity.

The annual usage value is the total value at cost of the estimated annual demand forecast. The annual order load refers to the number of orders generated using the stated order policy and estimated annual demand forecast. The average inventory £ refers to the inventory held downstream from the packing lines and assumes a standard 'saw tooth' decay of stock. This figure does not include policy stocks such as safety. The value of the stocks of the 'upstream' components (pharmaceuticals, packaging etc.) have not been calculated and no assumptions have been made concerning their delivery frequencies or order sizes. The stock turns is the annual usage value divided by the average inventory value.

What this benchmark standard does is to establish a set of performance criteria that the facility can already meet, the next stage is to compare the results of using the current operating parameters with the those that would have been obtained using the standard EBQ formula.

7.3.2.4 Comparison with standard EBQ.

The next step was to compare this with what would have been the result using the standard EBQ equation, assuming a 10% inventory holding rate per annum. This provided the following results:

D95 - EBQ vs. Current Position		
	EBQ	Current Position
Daily Capacity		1,680 mins
Daily Run Load		1,016 mins
% Run		60%
Daily Set-up Load	294 mins	320 mins
% Set-up	18%	19%
% of current	92%	
Available Capacity	370 mins	344 mins
% Load	78.0%	79.5%
Annual Usage Value		£4,752,790
Annual Order Load	160.8 orders	155.5 orders
Order % of current	103%	
Average Inventory £	£453,312	£458,867
Inventory % of current	99%	
Stock Turns	10.48	10.35

Table 7.2 - Boots D95 - EBQ vs. Current Position.

The EBQ provided a very close match to the existing position in terms of average inventory value and orders raised, with an increase of 5.3 orders annually leading to a decrease in base inventory of £5,555 (1.3%) and an increase in stock turns from 10.35 to 10.48. There was also a reduction in the daily set-up load of 26 minutes. However, this was the only result that the EBQ could have provided with the given assumptions on the costs and forecasted sales volumes, and an increase or decrease in the available capacity would not have affected the answer provided. Taking the current position as 100%, the results, when plotted, are as follows:

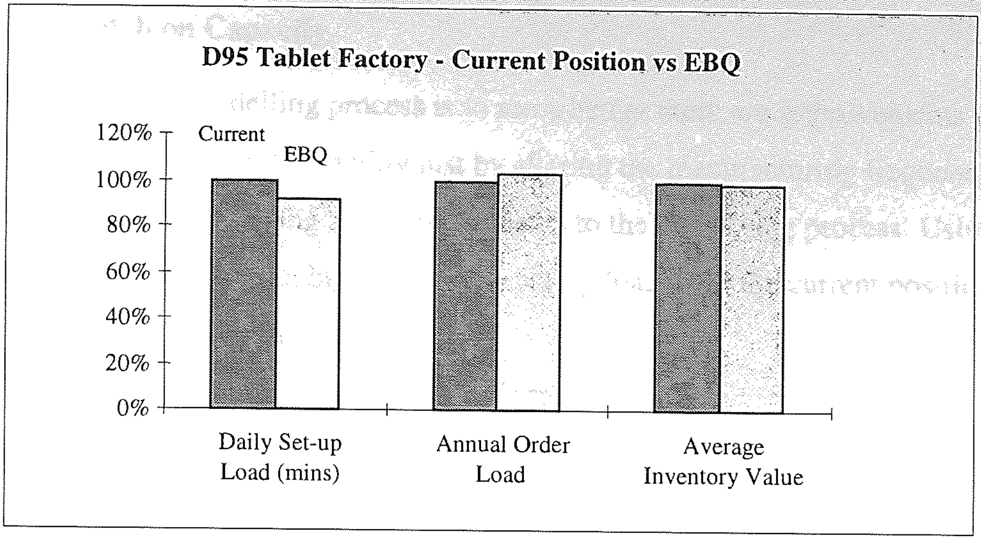

Figure 7.1 - Boots D95 - EBQ vs. Current Position.

Having calculated a reasonable approximation of the current position and that which would have been obtained using the EBQ, the first series of models were run using the parameters (run times, set-up times) as given to, firstly validate the model using the data provided, and secondly to see how optimal the current parameter set was. The geometric progression of 5, 10, 20, 40, 80, 160 day period order day classes was used for all runs. A 240 working day year was used for the calculation of the orders generated per annum and the average daily load in terms of set-up and run times. The inventory holding rate per annum was taken as 10%.

What is interesting to note is that if the EBQ result were constrained in the number of orders raised annually to the same level as that of the current position (155.5 per year), a decrease of 5.3 orders annually, there would be a compensating increase in the average inventory holding from £453,312 to £468,763. This figure exceeds that obtained by the existing batching rules by £9,896.

7.3.2.5 Match on Capacity.

The next stage of the modelling process is to see whether there are improvements that can be made to the operation of the facility just by altering the manufacturing frequency of the vitamin tablets, without making any improvements to the underlying process. Using the modelling software, and matching on the daily set-up load from the current position, the following results were obtained:

D95 - Capacity Match vs. Current		
	Capacity Match	Current Position
Daily Capacity		1,680 mins
Daily Run Load		1,016 mins
% Run		60%
Daily Set-up Load	329 mins	320 mins
% Set-up	20%	19%
% of current	103%	
Available Capacity	348 mins	344 mins
% Load	80%	79.5%
Annual Usage Value		£4,752,790
Annual Order Load	186.0 orders	155.5 orders
Order % of current	120%	
Average Inventory £	£368,637	£458,867
Inventory % of current	80%	
Stock Turns	12.9	10.35

Table 7.3 - Boots D95 - Capacity Match vs. Current Position.

The match on capacity showed that a reduction of the average base inventory value to about 80% of the present value may be possible by altering the batching rules as per the model recommendations, an inventory saving in the order of £90,000. This match provided an increase of 30.5 (20%) in the number of orders that would be required annually to support this policy, which led to a decrease in the base inventory of £90,230 (20%) and an increase in the stock turns from 10.35 to 12.9. Taking the current position as 100%, the results, when plotted, are as follows:

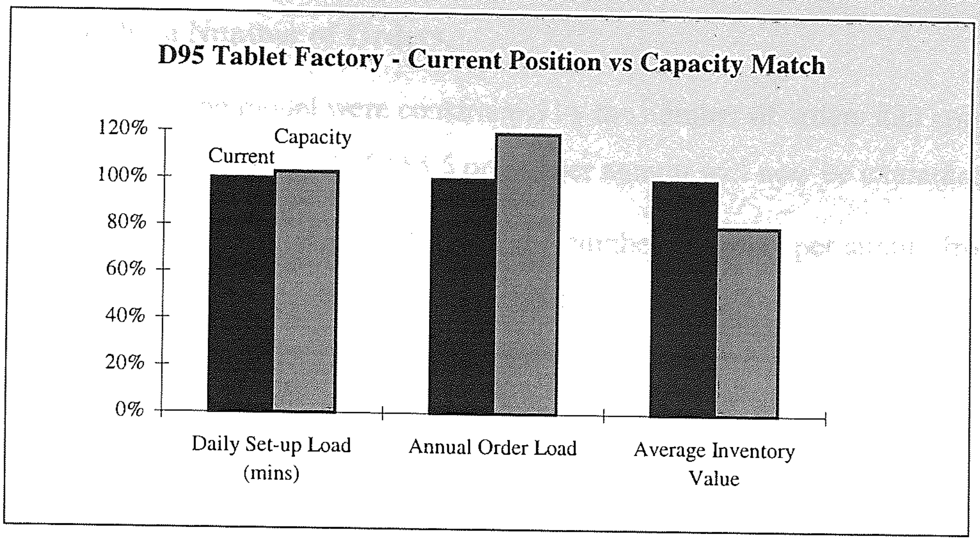

Figure 7.2 - Boots D95 - Capacity Match vs. Current Position.

What this illustrates is that it is theoretically possible to improve on the current batching rules so that an increase in the annual order load and decrease the average inventory holding can be made without increasing the capacity load.

7.3.2.6 Match on Number of Orders.

What would happen if the model were constrained by the number of orders that could be raised annually to the current level of 155.5 orders per annum will now be examined.

Using the modelling software, and matching on the number of orders per annum from the current position, the following results were obtained:

D95 - Order Match vs. Current		
	Order Match	Current Position
Daily Capacity		1,680 mins
Daily Run Load		1,016 mins
% Run		60%
Daily Set-up Load	262 mins	320 mins
% Set-up	16%	19%
% of current	82%	
Available Capacity	402 mins	344 mins
% Load	76.1%	79.5%
Annual Usage Value		£4,752,790
Annual Order Load	157.5 orders	155.5 orders
Order % of current	101%	
Average Inventory £	£451,957	£458,867
Inventory % of current	98%	
Stock Turns	10.5	10.35

Table 7.4 - Boots D95 - Order Match vs. Current Position.

This was also the closest match to the current average inventory value position that could be obtained from the modelling software.

The match on the current number of orders and average inventory value, provided a very close match to the existing position. The match provided an increase in the available capacity of 58 minutes daily through the optimisation of the scheduling cycles, representing a 18% reduction in the time spent on set-ups. There was an increase of 2 orders annually which led to a decrease in base inventory of £6,910 (2%) and an increase in stock turns from 10.35 to 10.5. Taking the current position as 100%, the results, when plotted, are as follows:

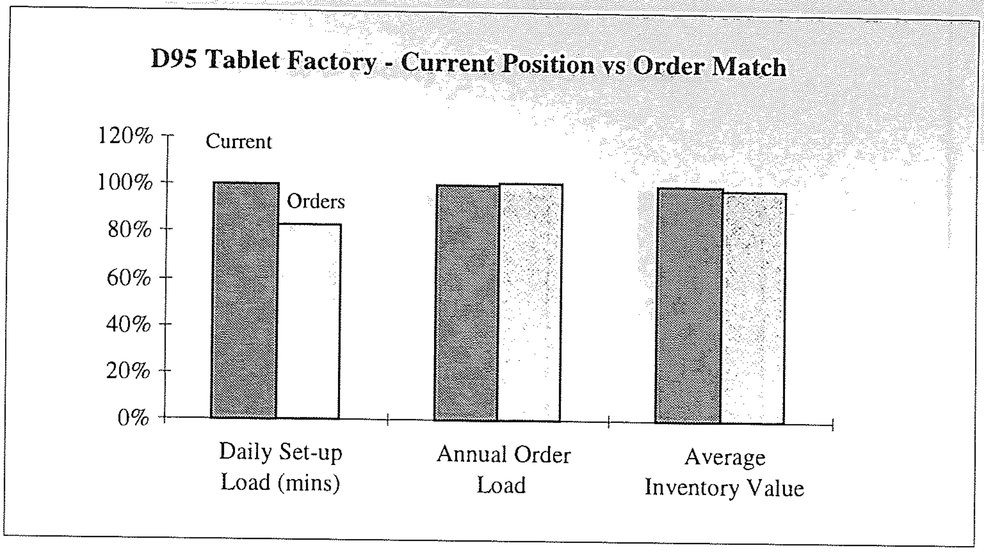

Figure 7.3 - Boots D95 - Order Match vs. Current Position.

What this illustrates is that it is theoretically possible to improve on the current batching rules so that a decrease in the capacity load can be obtained without increasing either the annual order load or the average inventory holding.

The results of this model and those obtained from the EBQ model can now be compared in each of the three dimensions, as follows:

D95 - Order Match vs. EBQ		
	Order Match	EBQ
Daily Set-up Load	262 mins	294 mins
% of EBQ	89%	
Annual Order Load	157.5 orders	160.8 orders
Order % of EBQ	98%	
Average Inventory £	£451,957	£453,312
Inventory % of EBQ	100%	
Stock Turns	10.5	10.48

Table 7.5 - Boots D95 - Order Match vs. EBQ.

The current match on orders model is theoretically not as optimal as the EBQ due to the partitioning of the items into the period order cycles, so it would have been expected that the result could only at best have equalled, but never exceeded in all of the measured dimensions, the result obtained by the un-partitioned EBQ. What happened in practice was that the EBQ was exceeded in all three dimensions. Taking the EBQ position as 100%, the results, when plotted, are as follows:

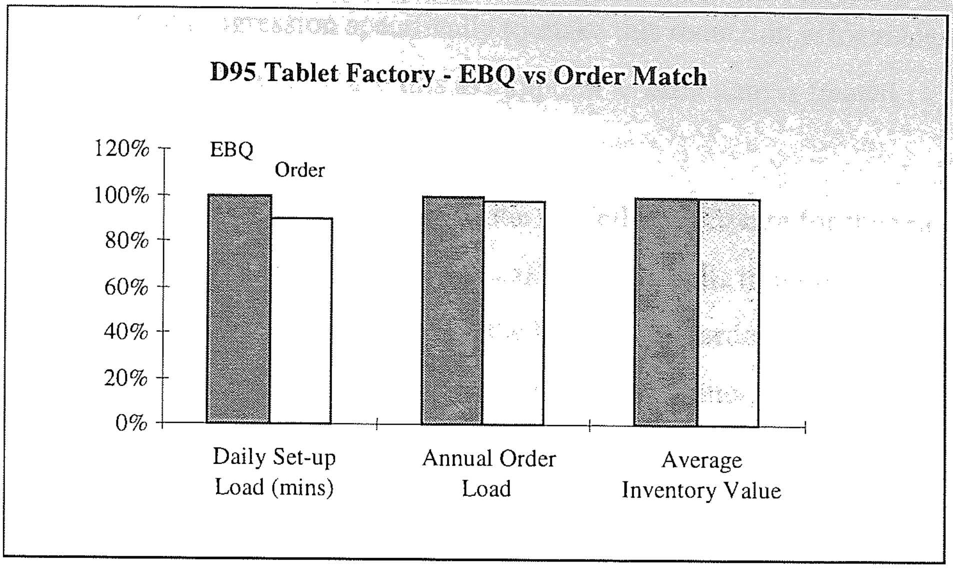

Figure 7.4 - Boots D95 - Order Match vs. EBQ.

What are the differences between the two approaches which could give rise to this:

1. The modelling software uses a compound 'order cost' containing two elements, the set-up cost and the order raising cost, whilst the EBQ only uses the set-up cost.
2. For the six items in the two scheduling groups, the modelling software uses the major set-up cost only for the item with the highest annual usage value within each group, and the minor set-up cost for the other items, which would tend to decrease the period order day classes that the items were allocated to. The EBQ uses the major set-up cost for all items.
3. The modelling software uses the major set-up time only for the item with the highest annual usage value within each group, and the minor set-up time for the other items. This could lead to a reduction in the overall set-up load for the model when compared with the EBQ approach.
4. The EBQ is calculated in a totally un-partitioned way, whereas the modelling software places items into period order day classes which can only be theoretically less optimal than the EBQ.

Taking these differences in turn:

#1 is due to the difference in approaches.

#2 is a valid assumption for the modelling software as it is designed to take this reduction into account and organises the items into period day classes with a geometric progression specifically to make this reduction achievable. It is not valid for the EBQ to make this assumption as each item is treated independently.

#3 is again a valid assumption for the modelling software for the reasons stated in #2 above. However, if the EBQ calculation results in more than one item within a scheduling group having the same period order days, it may be valid to assume that that the items could be scheduled together, and if they were scheduled together then it would be valid to make allowances for this in using the minor rather than major set-up times.

#4 is due to the differences in approaches, but would tend to favour the EBQ approach.

If the order days of the three items within the first group examined, using the table below, it would be possible to say that with a slight adjustment to the individual EBQ's the items could be scheduled together, with 2007975 being made every 15 days, 2007991 every 45 days and 2007983 every 60 days. If the set-up times used now adjusted and take this into account there is a potential saving of 13.6 minutes daily (26.7 minutes - 13.1 minutes).

Item Code	Major set-up mins	Minor set-up mins	EBQ	Batches / Year	Daily set-up mins	Order Days	Adjusted Set-up	Adjusted Daily mins
2007975	120	90	20,502	17.1	8.6	14.0	120	8.6
2007983	555	150	36,571	4.0	9.3	59.7	150	2.5
2007991	390	90	120,356	5.4	8.8	44.4	90	2.0
				Total	26.7			13.1

Table 7.6 - Boots D95 - Adjustment of EBQ for first set-up group.

If the order days of the three items within the second group are examined, using the table below, and each of the items scheduled every 45 days, when the set-up times used are adjusted to take this into account there is a potential saving of 15.4 minutes daily (26.5 minutes - 11.1 minutes).

Item Code	Major set-up mins	Minor set-up mins	EBQ	Batches / Year	Daily set-up mins	Order Days	Adjusted Set-up	Adjusted Daily mins
2008009	330	150	28,913	5.3	7.2	45.7	330	7.2
2008017	300	90	37,273	4.9	6.1	49.2	90	1.8
2008025	570	90	56,573	5.6	13.2	43.1	90	2.1
				Total	26.5			11.1

Table 7.7 - Boots D95 - Adjustment of EBQ for second set-up group.

The maximum total potential saving that is possible using the EBQ is therefore 29 minutes (13.6 minutes + 15.4 minutes) set-up daily. The original EBQ total daily set-up load was 294 minutes, when this saving of 29 minutes is subtracted, the adjusted set-up figure is 265 minutes daily. This is still greater than that achieved using the modelling software.

7.3.2.7 Load to Capacity of 95%.

So far, the capacity limitation has been set at 80% of the total available. The effect on the three dimensions (Capacity, Orders and Inventory £) of increasing the capacity available to a figure of 95% can now be investigated.

Matching to a load limit of 95%, inclusive of set-up, instead of the current 80% provided the following results:

D95 - 95% Capacity vs. Current		
	95% Capacity	Current Position
Daily Capacity		1,680 mins
Daily Run Load		1,016 mins
% Run		60%
Daily Set-up Load	581 mins	320 mins
% Set-up	35%	19%
% of current	182%	
Available Capacity	83 mins	344 mins
% Load	95.0%	79.5%
Annual Usage Value		£4,752,790
Annual Order Load	360.0 orders	155.5 orders
Order % of current	232%	
Average Inventory £	£207,199	£458,867
Inventory % of current	45%	
Stock Turns	22.9	10.35

Table 7.8 - Boots D95 - 95% Capacity Load vs. Current Position.

The raising of the available capacity to 95% led to a forecasted reduction in the average base inventory value in the order of £251,500. This scenario provided an increase of 204.5 (132%) in the number of orders that would be required annually to support this policy, which led to a decrease in the base inventory of £251,668 (55%) and an increase in the stock turns from 10.35 to 22.9. Taking the current position as 100%, the results, when plotted, are as follows:

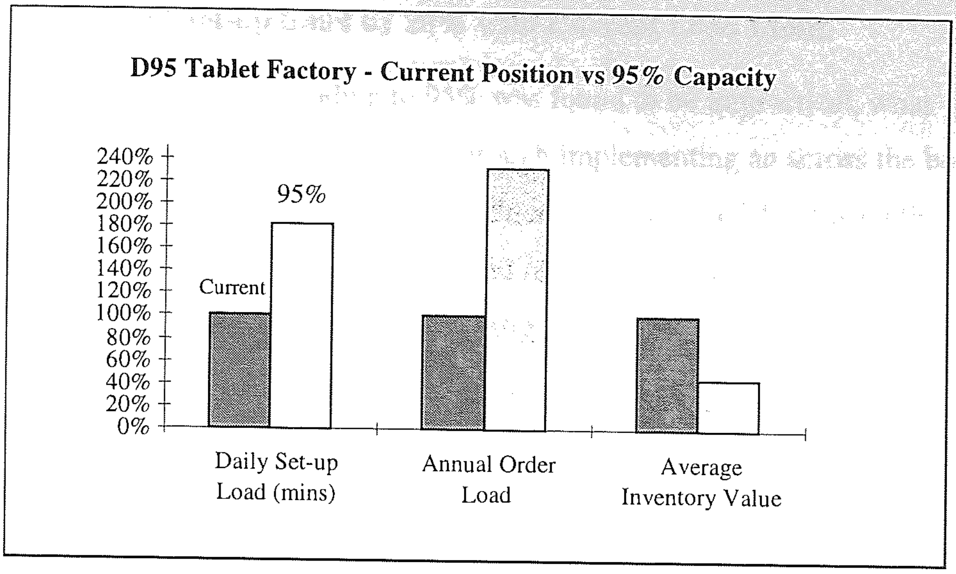

Figure 7.5 - Boots D95 - 95% Capacity Load vs. Current Position.

7.3.2.8 Reduce all Set-up times by 20% with Current Load Limit.

If the previous scenario, that of loading to 95% was found to be impractical, what performance improvements could be gained through implementing an across the board improvement in set-up times. The effect on the three dimensions of decreasing the set-up times by 20%, to 80% of their current values, and running a model to match on the existing capacity load of 80%, will now be investigated.

Reducing all the set-up times by 20% to 80% of the current value, with the lines loaded to the current loading of 80% of stated capacity provides the following results:

D95 - Set-up Reduction vs. Current		
	Set-up Reduction	Current Position
Daily Capacity		1,680 mins
Daily Run Load		1,016 mins
% Run		60%
Daily Set-up Load	322 mins	320 mins
% Set-up	19%	19%
% of current	101%	
Available Capacity	342 mins	344 mins
% Load	80.0%	79.5%
Annual Usage Value		£4,752,790
Annual Order Load	241.5 orders	155.5 orders
Order % of current	155%	
Average Inventory £	£302,236	£458,867
Inventory % of current	66%	
Stock Turns	15.7	10.35

Table 7.9 - Boots D95 - Set-up Reduction vs. Current Position.

The set-up reduction scenario provided a decrease of 2 minutes per day in the available capacity. The order load increased by 86 orders (55%) annually which led to a decrease in the average base inventory of £156,631 (34%) and an increase in stock turns from 10.35 to 15.7. Taking the current position as 100%, the results, when plotted, are as follows:

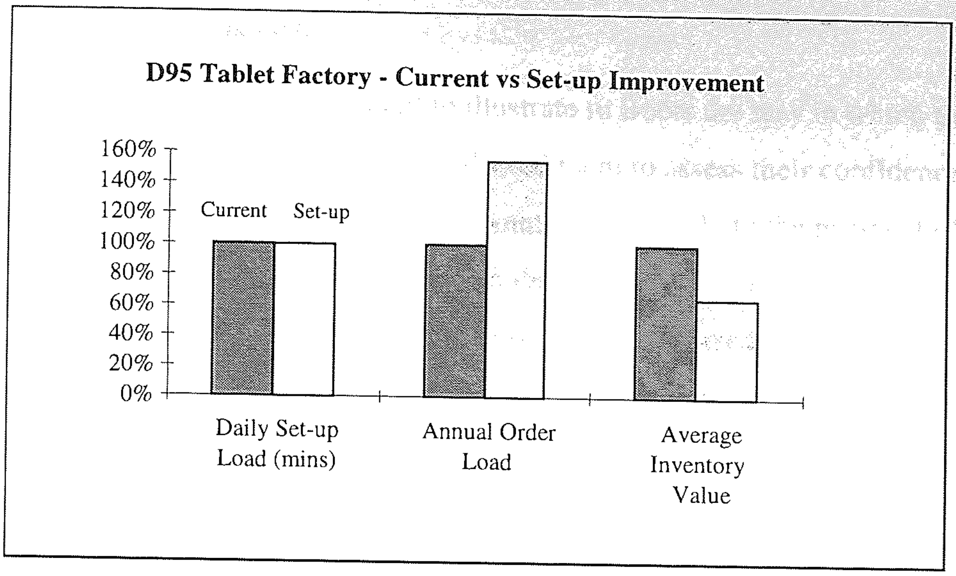

Table 7.6 - Boots D95 - Set-up Reduction vs. Current Position.

7.3.2.9 D95 - Conclusions.

The series of modelling exercises served to illustrate to Boots the way in which the modelling worked, and its applicability. It allowed them to assess their confidence in the process and the modeller without having to commit emotionally to the prospect of a live trial and implementation. The concentration on the three key performance indicators, Capacity, Administrative Workload, and Inventory Value, allowed them to quantitatively compare the results of the various scenarios and to assess the veracity of the approach. The modelling process increased their understanding of the way in which the batching rules impacted on the overall performance of the facility, brought to light certain data errors, and prompted a dialogue regarding the way in which the approach could be used to help justify an improvement programme.

Taking the model validation process previously described, Boots concluded that with the level of data validity, specifically the accuracy of cost prices, set-up times, set-up costs, and forecasted demand that the approach was operating at an appropriate level, and that the results obtained from the modelling process were sufficiently accurate to be of use in a live situation and as a comparison between different scenarios. They believed that the results were overall of use, and acceptable, but were not capable of being implemented without some degree of manual intervention.

What helped this acceptance was the methodology used, which proceeded through verifying that the model was producing results which were intended, validating that the modelling was addressing pertinent questions, that the results considered relevant factors, and were good enough to be of use, which helped Boots to be able to accredit the use of the model for use in a live situation. To summarise, the modelling process provided the following results:

	Average Inventory	Annual Order Load	Daily Set-up Load
Current Position	£458,867	155.5	320 mins
Standard EBQ approach	£453,312	160.8	294 mins
Match on Current Capacity Load (80%)	£368,637	186.0	329 mins
Match on Current # Orders / Inventory	£451,957	157.5	265 mins
Load to 95% of stated Capacity	£207,199	360.0	581 mins
Reduce all Set-up times by 20% with 80% Load	£302,236	241.5	322 mins

Table 7.10 - Boots D95 - Summary Results of Modelling.

The following graphs better illustrate the results:

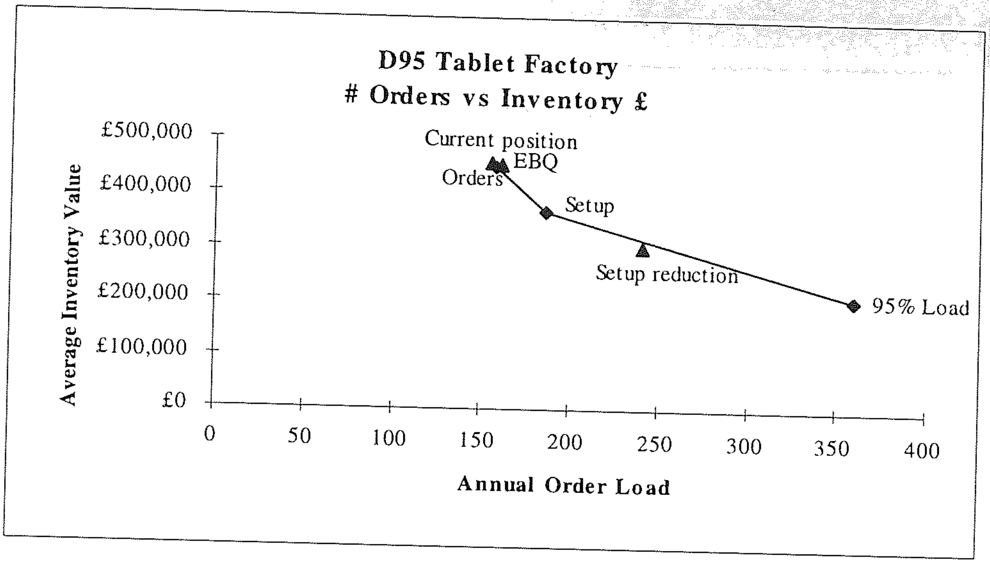

Figure 7.7 - Boots D95 - Orders vs. Inventory Value.

This shows the relationship between the average inventory value and the number of orders generated per year by the different policies. As the number of orders increase, the average batch size will reduce, as will the monetary value of each batch, so reducing the average inventory value overall. From this it is possible, using the three scenarios using unmodified base data, to obtain a feel for the level of order activity required (ignoring the 80% set-up reduction point) to achieve a required average inventory value.

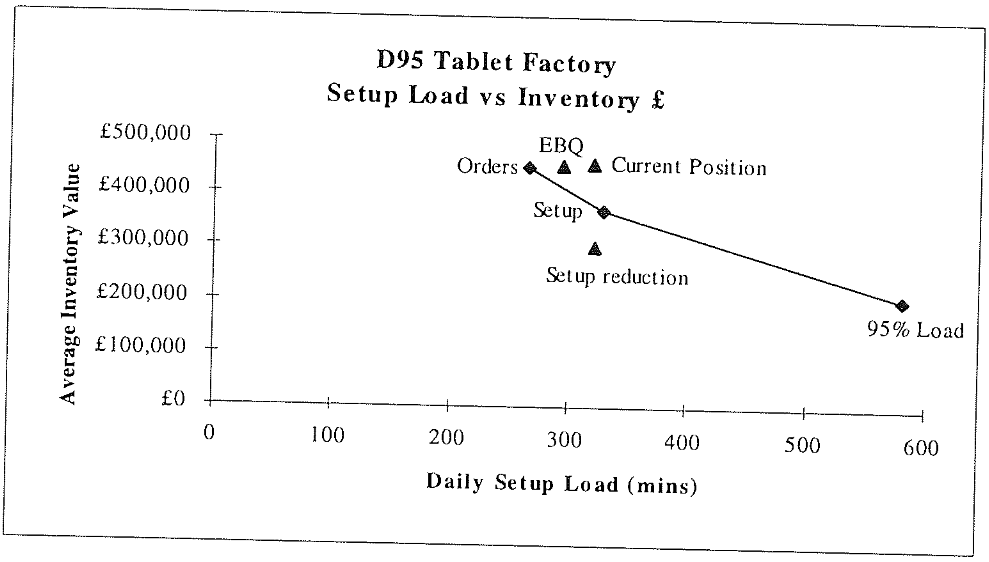

Figure 7.8 - Boots D95 - Set-up Load vs. Inventory Value.

This shows the relationship between the average inventory value and capacity load generated per day by the different policies. As the capacity load increases due to the increase in the number of batches (and therefore set-ups), the average inventory value decreases. What this does easily illustrate is the inventory savings possible from matching on capacity, and the further savings possible if the set-ups can be reduced to 80% of the current values.

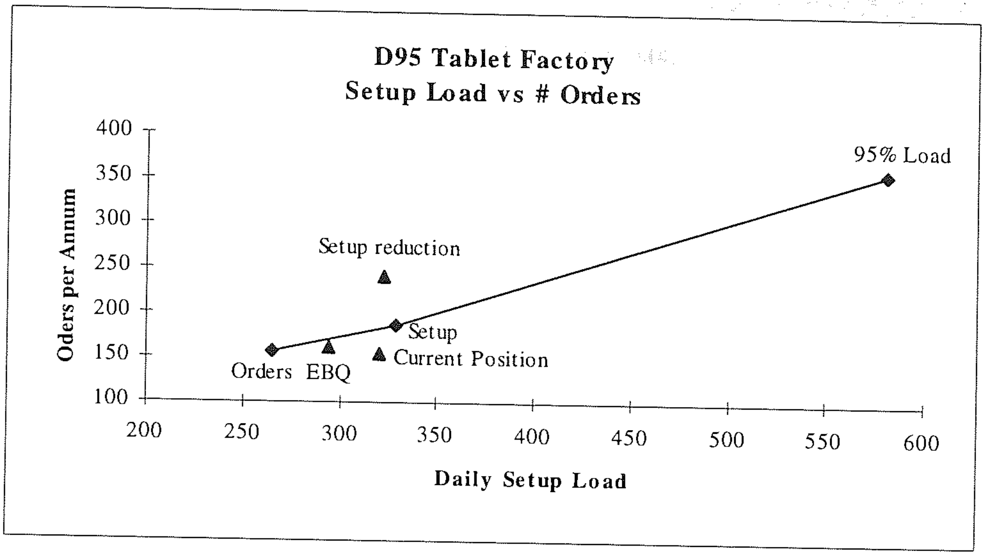

Figure 7.9 - Boots D95 - Set-up Load vs. Orders.

This shows the relationship between the set-up load generated per day and the number of orders generated per year by the different policies. As the number of orders increase, the number of batches will increase, so increasing the number of set-ups, so creating extra capacity load. What this illustrates is the capacity load savings possible from matching on # orders from the current policy.

Using the modelling software it was possible to point to the potential savings that could be achieved by reorganising the batching parameters on lines 3 and 4 subject to the desired constraints. An example of constraining the model in each of the constraints (Capacity, Administrative Workload, and Inventory Value) was used to illustrate the capability of the approach.

Two examples of 'what if' scenario modelling were provided, the first illustrated the probable inventory value and administrative (order) workload generated by loading capacity to 95% instead of the current 80% with no process improvements. The second illustrated the probable workload generated by a set-up reduction programme reducing the set-up times to 80% of the present figure.

It may be unrealistic to use the raw results of average modelling to predict the maximum workload which the policies generate because of uncertainty in the:

Reliability of the forecasted demand.

Time phasing of the demand.

Introduction of new products & removal of old products.

Reliability of the set-up and run times.

Accuracy of the cost prices and set-up costs.

These problems are not unique to Boots, they do appreciate that the demand forecast is a 'best guess', the time phasing of the demand is seasonal and is also affected by marketing campaigns, there is also substantial variation in the observed set-up times and an average (mean) time was used by the model, the cost prices were derived using absorption costing which depends, amongst other dubious assumptions, on a less than accurate forecasted demand, and the relationship of the major set-up times to the major set-up costs show a wide variation with a minimum cost of £0.33 per set-up minute and a maximum cost of £1.53 per set-up minute.

What the approach provided for Boots was a quick, inexpensive, average modelling tool which was capable of providing a good indication of what changes would be required to achieve desired performance levels by optimising the inventory parameters in the three constraints. The basic criteria used by Boots for assessing the exercise and deciding to continue on to a full trial in a live area were:

- Does the modelling produce meaningful results?
- Are the results useful?
- Do we trust the modelling process?
- Can we work with the modeller? and
- Do we want to invest further time and effort in pursuing the relationship?

7.3.3 Boots Contract Manufacturing - D106 Sterile Products.

7.3.3.1 Introduction.

The second area of investigation within Boots is the D106 Sterile Products factory in Nottingham, where Optrex is manufactured for the world market.

Optrex is a mature eyecare product, sold in bottles and as eye drops, and is basically composed of water, borax and witch hazel. There are no internationally competitive products. The two products, lotion sold in bottles, and eye drops, are both manufactured in D106, but use different personnel and machinery.

This case study is purely concerned with the lotion sold in bottles.

The approach used was similar to that used for the D95 Tablet Factory, namely:

1. Establish the areas of concern within the facility.
2. Outline the principles behind the modelling process, and establish, in principle, that the approach was viable for Sterile Products in particular.
3. Establish the boundaries of the investigation.
4. Investigate the current working environment.
5. Establish the current operating parameters.
6. Confirm the credibility of the timings and batching rules by running the model with historical data.
7. Use the forecasted demand to predict the activity level using the current parameter set, to identify and quantify the existing constraints.
8. Use the model to optimise the parameter set according to various scenarios.
9. Re-identify the constraints and consider the viability of the various scenarios.
10. Consider improvements to overcome the constraints and change the parameter set to reflect the outcome of these changes.
11. Repeat steps 8 to 10.

The purpose of the investigation was to identify and recommend changes to the current environment where these would lead to providing enhanced service levels for the customers and / or simplify the management of the planning and execution cycles within the facility.

The initial contact was made in September 1995, shortly after the arrival of a new Factory Manager, and was with the Materials Manager, the Factory Manager and the Factory Management team. The investigation and calculation phases were completed in December 1995, when it was recommended that implementation of the results of the investigation should take place from February to September 1996. However, the implementation of the modelling recommendations took place over a period of 15 months from February 1996 to May 1997.

7.3.3.2 Overview of the Manufacturing Process.

Optrex is produced under sterile conditions in two stages: Manufacturing of the lotion and Bottle Filling. As it has active ingredients which produce a recognised palliative effect it is classed as a medicine, and its production is regulated accordingly.

The manufacturing of the lotion occurs off-line of the filling and packing operations, with the manufacturing batch sizes being validated and fixed at 5,000 litres. The manufacturing of the lotion is not constrained by capacity or material supply.

Optrex is manufactured and sold in two different size of bottles, 300ml and 110ml, with annual unit sales of 880,000 units of the 300ml bottle and 2,750,000 of the 110ml bottle, over 3,500,000 bottles or 565,000 litres annually. As the manufacturing batch size of 5,000 litres is not split across filling batches, the bottle filling is to an approximate batch size of 40,000 bottles for 110ml and 15,000 bottles for 300ml. It is produced to 5 different formulations, with 16 different packaging variations giving a total of 21 SKU's. There is only one filling line and this is used for filling both the 110ml and 300ml bottles.

The filling line is 90m in length, continuous, and involves the following processes:

> Bottles enter the line and are washed then sterilised.
>
> After sterilisation the bottles are immediately filled and capped in a sterile environment.
>
> An inspection then takes place followed by the eye bath placement on the bottle top.
>
> The bottles are then labelled, leafleted and enclosed in a retail carton.
>
> Finally, the cartons are boxed.

It is a requirement of validation that the line is sterilised on a weekly frequency, this takes 360 elapsed minutes (18 man hours) and takes place on a Friday or over the weekend. There are three levels of set-up:

1. The major set-up is that of changing the bottle size. This takes 1,485 elapsed minutes (78 man hours), at a cost of £5,400.
2. The intermediate set-up is that of changing the formulation. This takes 360 elapsed minutes (18 man hours), at a cost of £1,200.
3. The minor set-up is that of changing the printed components only. This takes 30 elapsed minutes (6 man hours), at a cost of £400.

The demand for the product was initially believed to be seasonal, and at its highest in the spring and summer. However, the demand that Boots Contract Manufacturing (BCM) receives is from Boots Healthcare International (BHI), not the actual retail outlets or distributors in the various markets, but is interpreted by BHI before being passed over to BCM. BCM then re-interpret the BHI demand so that the due dates required by BHI are met as far as possible, after ensuring that the minimum batch size criteria etc. are met. BCM does not know what the retail markets have demanded from BHI, and BHI do not take account of production constraints when planning orders. Products delivered either late or early involve financial penalties for BCM. Optrex has a shelf life of 3 years from the date of manufacture.

After investigation within Boots it was found that the seasonality was largely self inflicted, due partially to end of year destocking within Boots to reduce the value of stocks reported in the annual accounts artificially depressing demand, partially due to annual price increases artificially increasing demand before they take effect, and partially due to marketing campaigns increasing demand from the distributors so that they can take advantage of the lower prices. When the true demand was analysed, it was shown that there was no seasonality at the retail level. This result is not surprising as Optrex is a mature product in a unique market, and tends to be purchased on a replacement basis.

The factory runs on roughly an 11 week cycle, with two campaigns of each bottle size in each cycle. Within each cycle approximately 7 to 8 weeks are spent running on 110ml bottles, and 3 to 4 weeks on 300ml bottles, with a bottle change being made for each campaign.

All the bottles required for a cycle are delivered at the start of the cycle. The packing materials are delivered 4 weeks in advance of use, and the raw materials delivered 8 weeks in advance of use. Scheduling is organised to satisfy BHI rather than for manufacturing efficiencies. Each batch of lotion must be filled within the week and not carried over. The work force are not multi skilled and work on a single shift pattern. The daily line capacity in minutes is stated as:

Monday	Tuesday	Wednesday	Thursday	Friday
495	495	495	495	270

Table 7.11 - Boots D106 - Daily Line Availability.

The available capacity for filling is given as 1,980 minutes per week (495 minutes a day * 4 days per week) as the Friday capacity is used to start the weekly line sterilisation, which takes 360 minutes. The factory works 46 weeks per year giving total capacity of 91,080 minutes (1,980 minutes per week * 46 weeks per year) annually.

The following information was provided for each item being considered:

Item Code.

Unit Cost per item.

Estimated Annual Demand.

Current run Batch Quantity.

Run Time in units per hour.

Major Set-up Time per batch.

Major Set-up Cost per batch.

Intermediate Set-up Time per batch.

Intermediate Set-up Cost per batch.

Minor Set-up Time per batch.

Minor Set-up Cost per batch.

The current batching rules of the filling line were analysed and the average base (exclusive of safety stocks etc.) inventory levels, the annual order load and the average capacity load which would result from the current batching parameters was derived. This was first run historically to establish how well the existing batching rules, capacities and routing data were at predicting the actual usage's, number of actual batches and inventory levels. After some adjustment of errors in both data and interpretation, Boots were confident that the output from the model was accurate enough to continue with the test using forecasted, rather than historical, data.

The current performance levels were validated by Boots as:

D106 - Current Position	
Annual Capacity (mins)	91,080 mins
Annual Run Load (mins)	76,882 mins
% Run	84%
Annual Set-up Load (mins)	29,202 mins
% Set-up	32%
Total Annual Load (mins)	106,083 mins
Available Capacity (mins)	(15,003) mins
% Load	116%
Annual Usage Value	£1,873,654
Annual Order Load	115.4
Average Inventory £	£235,831
Stock Turns	7.9

Table 7.12 - Boots D106 - Current Position.

When analysed by bottle size, the load split as follows:

	110ml	300ml	Total
Run Load	53,014	23,868	76,882
Set-up Load	14,227	14,975	29,202
Total	67,241	38,842	106,083

Table 7.13 - Boots D106 - Current Load by Bottle Size.

The annual run load is calculated from the estimated annual demand and the stated line speed. The annual set-up load calculated using the minimum set-up times possible assuming the maximum possible benefit from intelligent sequencing of batches. The available capacity is the stated annual capacity less the sum of the annual run load and the annual set-up load. The % run % set-up and % load are calculated as the % of the annual capacity spent on the relevant activity.

The annual usage value is the total value at cost of the estimated annual demand forecast. The annual order load refers to the number of set-ups generated using the stated order policy and estimated annual demand forecast. The average inventory £ refers to the inventory held downstream from the packing lines and assumes a standard 'saw tooth' decay of stock. This figure does not include policy stocks such as safety. The stock turns is the annual usage value divided by the average inventory value.

There are no material supply problems, the problems are those of cost, complexity, capacity and remoteness. Cost due to the endemic overtime and the 11 week cycle, complexity due to the 21 product varieties and scheduling constraints, capacity due to the volume of work that has to be accommodated through the line operating on a single shift pattern, and remoteness due to the double interpretation of the retail customer's demand by the distributors, BHI and BCM.

The key performance measures applied to the manufacturing process by BCM are schedule adherence, effectiveness (efficiency * utilisation) and output per payroll £. What this benchmark standard does is to establish a set of performance criteria that the facility can already meet, the next stage is to compare the results of using the current operating parameters with those that would have been obtained using the standard EBQ formula.

7.3.3.3 Comparison with standard EBQ.

The next step was to compare this with what would have been the result using the standard EBQ equation assuming a 10% inventory holding rate per annum. This provided the following results:

D106 - EBQ vs. Current Position		
	EBQ	Current position
Annual Capacity		91,080 mins
Annual Run Load		76,882 mins
% Run		84%
Annual Set-up Load	24,236 mins	29,202 mins
% Set-up	27%	32%
% of current	83%	
Available Capacity	(10,083)	(15,003) mins
% Load	111%	116%
Annual Usage Value		£1,873,654
Annual Order Load	16.3	115.4
Order % of current	14%	
Average Inventory £	£881,317	£235,831
Inventory % of current	374%	
Stock Turns	2.1	7.9

Table 7.14 - Boots D106 - EBQ vs. Current Position.

The EBQ was demonstrably worse than the existing position in terms of the average inventory value, with a £645,486 increase (374%) in average stock leading to a decrease in stock turns from 7.9 per annum to 2.1 per annum. It required almost 100 less orders to support the EBQ recommendations, and the capacity requirements decreased by 17%, giving a saving of approximately 4,950 minutes annually. Taking the current position as 100%, the results, when plotted, are as follows:

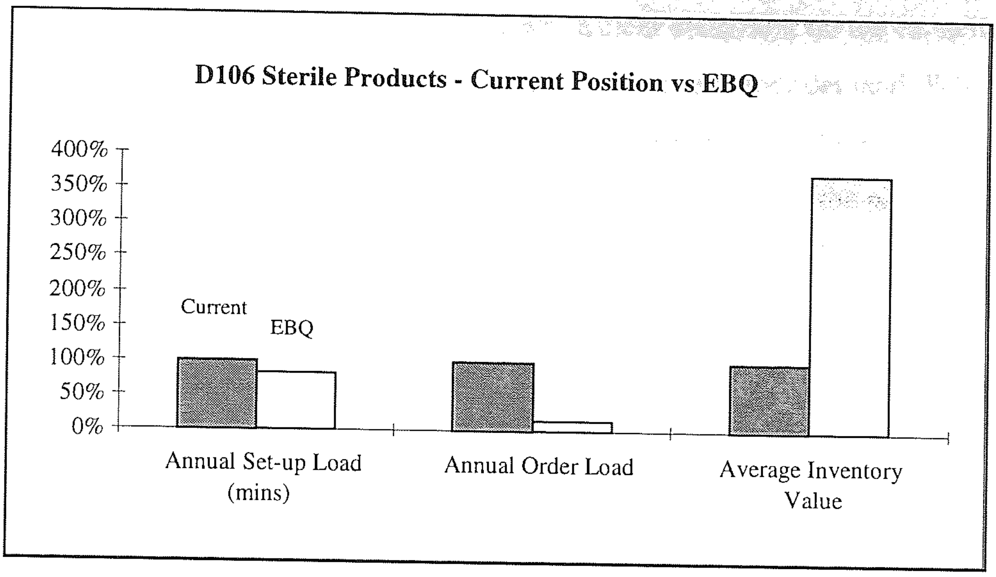

Table 7.10 - Boots D106 - EBQ vs. Current Position.

This poor performance was due mainly to there being no assumption of any savings in the set-up times or costs being taken into account. One other problem that the EBQ creates is that as the set-up costs are so large for each item (£5,400), the manufacturing frequency for small usage items can get close to, and even exceed, the 3 year shelf life of the product.

7.3.3.4 The Modelling Process.

Within the D106 Sterile Products facility there was a clear constraint on the capacity, together with a lack of predictability as to the timing of the customer demand. What Boots wanted to achieve, having established that there was a constant level of demand for the product at a retail level, was a way of reflecting the demand pattern in the production of the product.

The first set of models was constructed to explore the possibility of changing the cycle length without impacting adversely on the capacity by looking at the effect on the operating conditions of producing on true 5, 6, 7 and 8 week cycles. Having calculated a reasonable approximation of the current position and that which would have been obtained using the EBQ, the models were run using the parameters (run times, set-up times) as given, to firstly validate the model using the data provided, and secondly to see how optimal the current parameter set was.

The first model consisted of a linear progression of 25, 50, 75, 100, 125 and 150 day period order day classes. A 230 working day year was used for the calculation of the orders generated per annum and the average daily load in terms of set-up and run times. The inventory holding rate per annum was taken as 10%.

7.3.3.5 Five week cycle.

The first model explored the possibility of changing to cyclic scheduling based on a minimum cycle length of 5 weeks (25 days). Using the modelling software and matching on the annual set-up load from the current position, the following results were obtained:

D106 - 5 week cycle vs. Current Position		
	5 week cycle	Current position
Annual Capacity		91,080 mins
Annual Run Load		76,882 mins
% Run		84%
Annual Set-up Load	27,945 mins	29,202 mins
% Set-up	31%	32%
% of current	99%	
Available Capacity	(13,747) mins	(15,003) mins
% Load	115%	116%
Annual Usage Value		£1,873,654
Annual Order Load	110.4	115.4
Order % of current	95%	
Average Inventory £	£149,948	£235,831
Inventory % of current	64%	
Stock Turns	12.5	7.9

Table 7.15 - Boots D106 - 5 Week Cycle vs. Current Position.

The modelling of a change to a 5 week cycle showed that a reduction in the average base inventory to about 64% of the present value, together with a base inventory saving in the order of £86,000, and a reduction in the number of orders was theoretically possible.

However, as only three items were scheduled on the 25 day cycle, and all of these were of 110ml size, and all the remaining items were on a fifty day cycle the modelling process had resulted in an unworkable scenario. This is because it is not possible to spread the capacity load evenly across each cycle without allocating some production of the 300ml bottles to each 25 day cycle, adding a further 4.6 batches per year and 6,831 minutes (4.6 batches per year * 1,485 minutes set-up per batch) to the annual set-up load.

7.3.3.6 Six week cycle.

The second model explored the possibility of changing to cyclic scheduling based on a minimum cycle length of 6 weeks (30 days). This model consisted of a linear progression of 30, 60, 90, 120, 150 and 180 day period order day classes. Using the modelling software and matching on the annual set-up load from the current position, the following results were obtained:

D106 - 6 week cycle vs. Current Position		
	6 week cycle	Current position
Annual Capacity		91,080 mins
Annual Run Load		76,882 mins
% Run		84%
Annual Set-up Load	29,210 mins	29,202 mins
% Set-up	32%	32%
% of current	100%	
Available Capacity	(15,012) mins	(15,003) mins
% Load	116%	116%
Annual Usage Value		£1,873,654
Annual Order Load	103.5	115.4
Order % of current	90%	
Average Inventory £	£154,949	£235,831
Inventory % of current	66%	
Stock Turns	12.1	7.9

Table 7.16 - Boots D106 - 6 Week Cycle vs. Current Position.

The modelling of a change to a 6 week cycle provided a very close match on the existing capacity utilisation. The model showed that a reduction in the average base inventory to about 66% of the present value (a saving in the order of £81,000), together with a reduction in the annual order load of 12 orders annually was theoretically possible, giving an increase in the stock turns from 7.9 to 12.1. Taking the current position as 100%, the results, when plotted, are as follows:

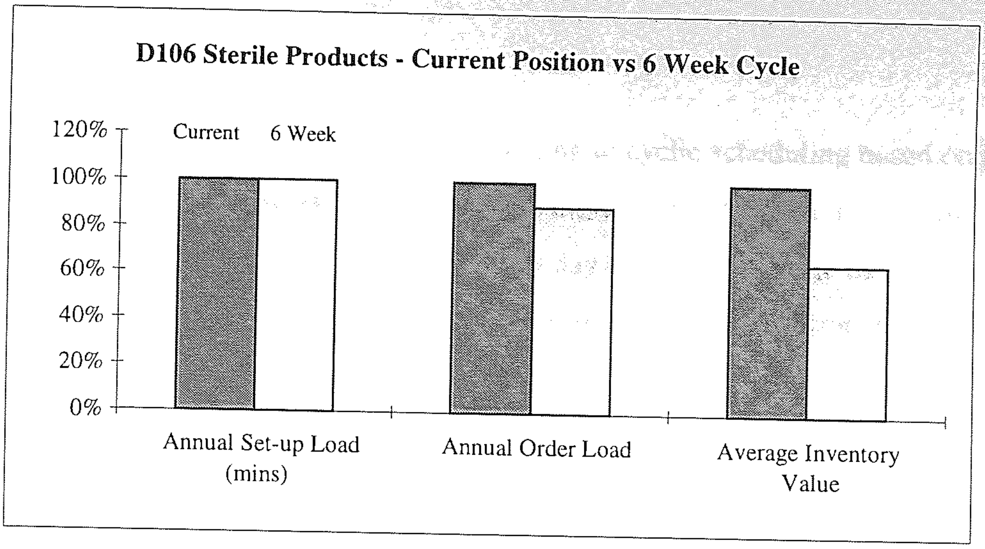

Figure 7.11 - Boots D106 - 6 Week Cycle vs. Current Position.

This scenario was feasible, as both 110ml and 300ml bottles were scheduled in the minimum cycle of 30 days. It is theoretically possible therefore to cycle the remaining items in every other cycle, and so to even the load.

7.3.3.7 Seven week cycle.

The third model explored the possibility of changing to cyclic scheduling based on a minimum cycle length of 7 weeks (35 days). This model consisted of a linear progression of 35, 70, 105, 140, 175 and 210 day period order day classes. Using the modelling software and matching on the annual set-up load from the current position, the following results were obtained:

D106 - 7 week cycle vs. Current Position		
	7 week cycle	Current position
Annual Capacity		91,080 mins
Annual Run Load		76,882 mins
% Run		84%
Annual Set-up Load	29,276 mins	29,202 mins
% Set-up	32%	32%
% of current	100%	
Available Capacity	(15,078) mins	(15,003) mins
% Load	116%	116%
Annual Usage Value		£1,873,654
Annual Order Load	121.6	115.4
Order % of current	105%	
Average Inventory £	£149,207	£235,831
Inventory % of current	63%	
Stock Turns	12.6	7.9

Table 7.17 - Boots D106 - 7 Week Cycle vs. Current Position.

The modelling of a change to a 7 week cycle provided a very close match on the existing capacity utilisation. The model showed that a reduction in the average base inventory to about 63% of the present value (a saving in the order of £85,000), which led to an increase in the annual order load of 6 orders annually was theoretically possible, giving an increase in the stock turns from 7.9 to 12.6. Taking the current position as 100%, the results, when plotted, are as follows:

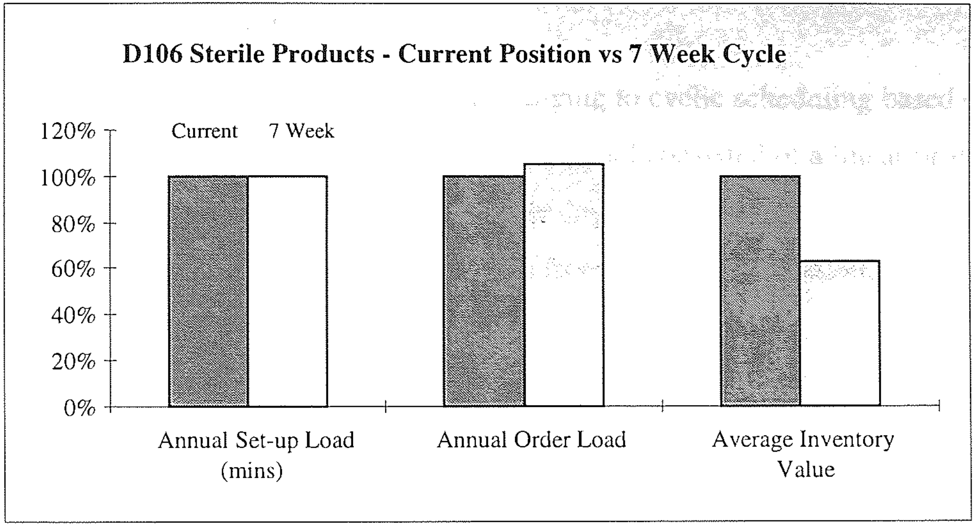

Figure 7.12 - Boots D106 - 7 Week Cycle vs. Current Position.

This scenario was feasible, as both 110ml and 300ml bottles were scheduled in the minimum cycle of 35 days. It is theoretically possible therefore to cycle the remaining 5 items in every other cycle, and so to even the load.

7.3.3.8 Eight week cycle.

The fourth model explored the possibility of changing to cyclic scheduling based on a minimum cycle length of 8 weeks (40 days). This model consisted of a linear progression of 40, 80, 120, 160, 200 and 240 day period order day classes. Using the modelling software and matching on the annual set-up load from the current position, the following results were obtained:

D106 - 8 week cycle vs. Current Position		
	8 week cycle	Current position
Annual Capacity		91,080 mins
Annual Run Load		76,882 mins
% Run		84%
Annual Set-up Load	26,048 mins	29,202 mins
% Set-up	29%	32%
% of current	89%	
Available Capacity	(11,850) mins	(15,003) mins
% Load	113%	116%
Annual Usage Value		£1,873,654
Annual Order Load	120.8	115.4
Order % of current	105%	
Average Inventory £	£162,926	£235,831
Inventory % of current	69%	
Stock Turns	11.5	7.9

Table 7.18 - Boots D106 - 8 Week Cycle vs. Current Position.

The modelling of a change to a 8 week cycle provided reduction of 3,150 minutes per year (13 minutes per day) on the existing capacity utilisation with every item being scheduled once per cycle. The model showed that a reduction in the average base inventory to about 69% of the present value (a saving in the order of £73,000), which led to an increase in the annual order load of 5 orders annually was theoretically possible, giving an increase in the stock turns from 7.9 to 11.5. Taking the current position as 100%, the results, when plotted, are as follows:

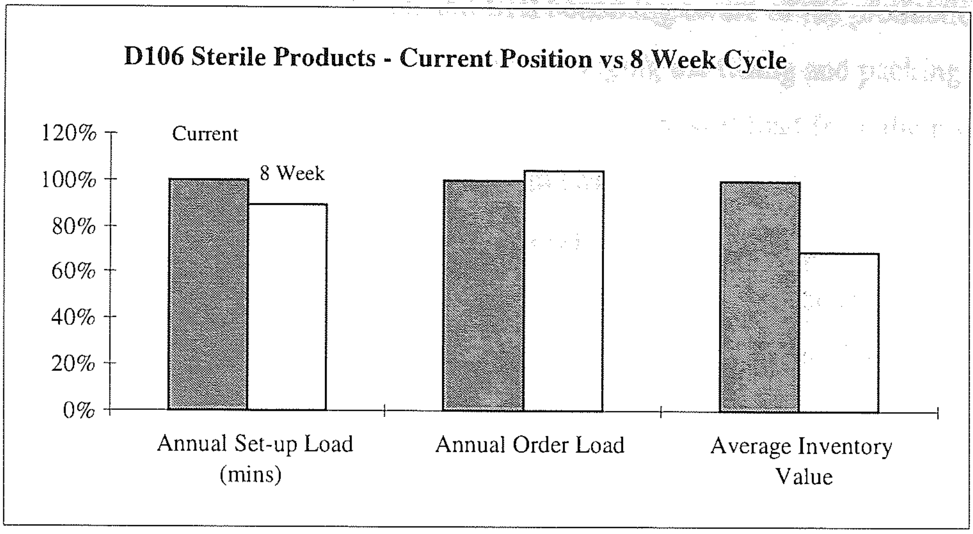

Figure 7.13 - Boots D106 - 8 Week Cycle vs. Current Position.

This scenario was feasible, as all product varieties were scheduled in the minimum cycle of 40 days. This 8 week cycle, with a split of 3 and 5 weeks between the bottle sizes was the one chosen for further investigation, as that allowed theoretically for each variation to be produced in each cycle, subject to the validated manufacturing batch size of 5,000 litres not being violated. It also allowed for a reduction of minimum filling batch sizes to 10,000 for the 110ml bottle (down from 40,000) and 7,500 for the 300ml bottle (down from 15,000). The cycle load for each bottle size was calculated as follows:

	110ml	300ml	Total
Annual Run Load	53,014	23,868	76,882
Annual Set-up Load	12,334	13,714	26,048
Total Annual Load	65,348	37,581	102,929
Av. Cycle Load	11,366	6,538	17,904
# weeks	5.74	3.30	9.04
Weeks per size	5	3	

Table 7.19 - Boots D106 - 8 Week Cycle Load by Bottle Size.

In parallel with this modelling exercise, the issue of seasonality was being investigated. Optrex is a mature product bought on a replacement basis, so was the seasonality of demand real, or not. Investigations were undertaken from which showed that the seasonality was caused by marketing promotions, end of financial year de-stocking, and price reviews, and not by retail sales, as retail demand for the product was found to be consistent throughout the year.

Using the results of the exercise it was then possible to look at offering an improved service to BHI by recognising and removing the causes of the external complexity, that of having skewed, unpredictable demand, and BHI becoming aware of the production constraints. This led on to looking at the idea of changing the filling and packing shift pattern from 5 to 4 days, removing the weekly sterilisation workload from the production workers overtime and onto the maintenance team (whose standard shift pattern was changed to include the weekly sterilisation process), and multi skilling the production workforce. The shifting of the weekly sterilisation work away from the standard production workload had the effect of adding 270 minutes per week to the available capacity, increasing the annual capacity by 12,420 minutes (270 minutes per week * 46 weeks per year). The effect of this was to make the available capacity greater than the planned load by 570 minutes annually (2 minutes per day).

The conceptual simplicity of offering the distributors and retailers (through BHI) each variant in each 8 week cycle, subject to a minimum manufacturing batch size for each formulation of 5,000 litres together with reduced filling and packing batch sizes, appealed to all the parties concerned. The next stage was to investigate the effect of reducing the number of formulation variants. This was considered as set-up reductions can be approached in two ways - the reduction in individual set-ups or the avoidance of the need to perform the set-up. A change of formulation requires that the line is unavailable for an elapsed 495 minutes. In each 8 week cycle 3 changes of formula are required, together with the 2 bottle changes (which incorporate formula changes). It is not possible to substantially reduce the formula change set-up as it is a requirement of validation that the line is heated to a certain temperature for a set time to completely sterilise the equipment. If the number of formula variations were reduced to 1 from 5, the time saved could be used in two ways:

To reduce the overall loading on the line.

To support further reductions in the filling batch sizes.

The next scenario investigates the effect of implementing this change.

7.3.3.9 Eight week cycle with formula variety reduction.

The fifth model explored the effects of using an 8 week cycle and reducing the number of formula variants from 5 to 1. Using the modelling software and matching on the annual set-up load from the current position, the following results were obtained:

D106 - 8 week cycle & Formula Reduction vs. Current Position		
	8 week cycle & formula reduction	Current position
Annual Capacity		91,080 mins
Annual Run Load		76,882 mins
% Run		84%
Annual Set-up Load	20,355 mins	29,202 mins
% Set-up	22%	32%
% of current	70%	
Available Capacity	(6,137) mins	(15,003) mins
% Load	107%	116%
Annual Usage Value		£1,873,654
Annual Order Load	120.8	115.4
Order % of current	105%	
Average Inventory £	£162,926	£235,831
Inventory % of current	69%	
Stock Turns	11.5	7.9

Table 7.20 - Boots D106 - 8 week cycle & Formula Reduction vs. Current Position.

The only difference between this model and the standard 8 week cycle model is that the annual set-up load has been reduced by approximately 5,700 minutes, from 26,048 minutes to 20,355 minutes. The number of orders raised, average inventory value and stock turns are unchanged when compared with the standard 8 week cycle results. Taking the current position as 100%, the results, when plotted, are as follows:

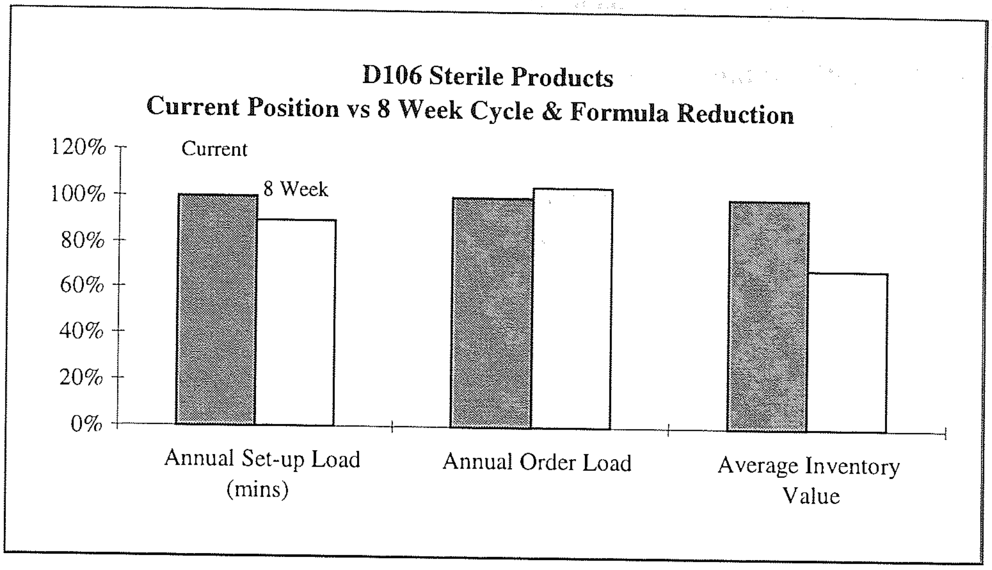

Figure 7.14 - Boots D106 - 8 week cycle & Formula Reduction vs. Current Position.

What this scenario achieved was the quantification of changing one of the operating parameters, that of removing the intermediate formula change set-up. The benefits in terms of operational flexibility were quite great in that if this were achieved then the service offered to the customers could be further enhanced in that the sequencing of batches within a bottle size would no longer be an issue.

Assuming that this change could be made, it raised the possibility of BHI directly planning the production for BCM, as the production planning rules could now be simply stated as:

> The production will be planned in an 8 week cycle.
>
> There will be 1 change of bottle size within the 8 week cycle.
>
> Each week on 110ml bottle filling has a maximum capacity of 15,000 litres (3 manufacturing batches). Each week on 300ml bottle filling has a maximum capacity of 25,000 litres (5 manufacturing batches).
>
> The minimum filling batch size is 10,000 bottles for the 110ml bottle and 7,500 bottles for the 300ml bottle per item code.
>
> Each Item Code can be planned once per cycle.

One final scenario was looked at, that of removing the need for a bottle size change by changing to a single size of 200ml.

This involved figures being calculated and certain assumptions being made regarding the operational characteristics of the filling line, for instance:

> How would the current annual sales volume in litres would be affected by a change to a single size? Both bottles are sold in only 5 markets. As a replacement product, would the demand in the remaining markets go up in the short term for the litreage supplied in 110ml bottles and down for that supplied in the 300ml bottle until a new equilibrium is established?
>
> Although the product demand is stable, how much of each bottle is actually used, and how much thrown away? How many bottles reach their use by date and are then disposed of before being completely used up? How would a bottle size change be affected by this?
>
> What speed would the line run at? It would be somewhere between that for 110ml bottles (3,200 units per hour) and 300ml bottles (2,000 units per hour). This translates to a filling rate of 352 litres per hour is for 110ml bottles and 600 litres per hour for 300ml bottles. At 2,250 units per hour, this would create an annual run load of 73,292 minutes.
>
> The presentation of the product is a marketing, not a manufacturing responsibility. The marketing rationale for the dual sizing would need to be investigated.

Assuming the demand at the litreage level remains constant, and a conservative estimate of the achievable line speed of 2,250 units per hour for the 200ml size, the run load would be 73,292 minutes. By changing to a single size, within each 8 week cycle each of the major bottle size change set-ups would replaced by changes of printed components. This would save 2,910 minutes (1,485 minutes * 2 less 30 minutes * 2) within each cycle. On top of this 5 changes of printed components would not be required within each cycle due to the 5 markets currently taking both bottle sizes. This would save 150 minutes (30 minutes * 5) within each cycle. The total saving on set-up being 3,060 minutes per cycle (2,910 minutes + 150 minutes) and this would decrease the annual set-up load by 17,595 minutes annually to 2,760 minutes.

If the potential savings in the run time are ignored, and the savings on set-up concentrated upon, the following results are obtained:

D106 - 8 week cycle & 200ml & Formula Reduction vs. Current Position		
	8 week & 200ml & formula reduction	Current Position
Annual Capacity		91,080 mins
Annual Run Load		76,882 mins
Annual Set-up Load	2,760 mins	29,202 mins
% Set-up	3%	32%
% of current	9%	
Available Capacity	11,438 mins	(15,003) mins
% Load	87%	116%

Table 7.21 - Boots D106 - 8 week cycle, 200ml Bottle & Formula Reduction vs. Current Position.

When the extra capacity of 270 minutes per week freed by the revised shift patterns is taken into consideration, the following results are obtained:

D016 - 8 week & 200ml & formula vs. Current Position including revised shifts		
	8 week & 200ml & formula	Current Position & revised shifts
Annual Capacity		103,500 mins
Annual Run Load		76,882 mins
Annual Set-up Load	2,760 mins	29,202 mins
% Set-up	3%	28%
% of current	9%	
Available Capacity	23,858 mins	(2,584) mins
% Load	77%	103%

Table 7.22 - Boots D106 - 8 week cycle & 200ml bottle & formula reduction vs. Current Position including revised shifts.

This appears to provide the greatest benefits, and further investigation within Boots is required to establish whether this is a viable option, by investigating the market requirements, agreeing on the bottle and packaging characteristics to establish a true line speed, establishing revised cost and selling prices for the 200ml variant, re-estimating the demand, and establishing how the overall profitability of the product is affected by the proposed changes.

7.3.3.10 Implementation Plan.

At the same time that the investigation into cyclic scheduling was taking place, the Boots marketing people had decided that Optrex required a new shape bottle. This was scheduled to be implemented in February 1996. Discussions also took place with the distributors and retailers (the customers of BHI) to investigate the benefits of them being able to order smaller, more frequent, batches. The initial barrier to this was that Optrex was supplied overseas in a delivery with no other products. What this meant was that the delivery costs would almost double if the order frequency was doubled, and so negate the cost benefits of the smaller batch sizes. In order to circumvent this problem it was suggested that if Optrex could be combined with other products and that these were all delivered more frequently and in smaller quantities, then it was possible for the total overall delivery costs to remain the same, and to reduce the overall stocks throughout the system. It was decided to adopt this suggestion.

It was agreed in December 1995 that the 8 week cycle would start in February 1996 with a new style of 110ml and 300ml bottles. The retailers, distributors, and BHI would all gain from having smaller stocks which had a longer shelf life, and BCM gained from the production process being easier to manage, with there being a greater understanding of the production planning process and constraints both within and external to BCM.

Boots had decided to implement the following changes on top of the change of bottle design:

1. The reduction in the minimum filling batch sizes to 10,000 bottles for 110ml and 7,500 bottles for 300ml.
2. Improved sequencing to reduce unnecessary set-ups.
3. A change to an 8 week cycle of production for all product variants.
4. A reduction in the formula variants from 5 to 1, subject to market validation.
5. That BHI would plan the production.

The changes to the filling sizes and the move to the 8 week cycle were planned to be implemented in the first cycle in February 1996, with the change in responsibility for production planning taking place after the reduction in formula variations had been agreed. It was anticipated that all the changes would be in place after the third or fourth complete cycle, by approximately the start of September 1996. The actual chain of events was as follows:

February 1996 - The changeover was unable to go ahead as there were filling problems with the new design of bottle, so the implementation delayed until July.

July 1996 - The challenge to Retail Price Maintenance for over the counter medicines by Asda etc. led to odd market conditions, so only the filling batch size changes implemented, together with improved sequencing rules. This led to a flattening of demand. The 8 week cyclic production implementation delayed.

November 1996 - Cyclic production started. Cycle 1 was planned by BCM. Cycle 2 saw the reduction of formulations to 1. Cycle 3 sees BHI directly planning production into the 8 week cycle, subject to there only being one change of bottle size.

May 1997 - BHI now gives BCM a fixed 12 week manufacturing schedule (i.e. half way through one cycle the next is fixed) in the form of a master production schedule. Cyclic production is fully implemented.

Raw materials are now ordered on blanket orders deliveries 20 days before being required instead of 8 weekly deliveries.

Bottles are now delivered 12 to 13 days before being required instead of 8 weeks at a time. An off-line irradiation of the bottle tops is now being done by the supplier, rather than a third party.

Packaging materials are now delivered 15 days before they are required instead of 8 weeks at a time.

BCM have either eliminated (through reducing the number of formulations) or reduced set-up times (by up to 50%), so freeing capacity on the manufacturing constraint, the filling line.

The working hours have changed from a 5 day working week to a 4 day working week, and habitual overtime for sterilisation is being eradicated. The workforce is multi skilling, and team working. There is a continuous improvement programme in place.

7.3.3.11 Results.

There has been considerable effort expended in simplifying the complexity associated with planning the manufacturing of Optrex. It would be untrue to claim that the modelling exercise caused all this to take place, but it is fair to say that without it, the changes would not have taken place so quickly, or be of such a radical nature.

The initial use of the model coincided with the arrival of a new manager who did not possess existing manufacturing expertise, but wanted to improve matters. It was used to see if a simplification of the existing complex customs and practice could be achieved and it provided a quick, quantitative analysis of various scenarios and acted as a catalyst for change.

The initial investigation demonstrated that although the current parameters generated a large number of discrete orders, with the intention of improving customer service levels, the size, timing and sequencing of the orders had the opposite effect. This was compounded by the arms length approach and re-interpretation of retail customer demand that took place at three levels, the distributors, BHI and BCM, which when combined with the skewing of demand caused by marketing promotions, price reviews and end of year de-stocking created an unstable manufacturing environment. By starting a meaningful dialogue between all the parties concerned, and establishing the true demand profile, BCM were able to use the modelling process to challenge the accepted planning paradigms and offer their customers an improved service whilst at the same time simplifying their own operational environment. A true win / win situation for all the participants.

The customers now understand the way in which the product is manufactured, and are delighted at the way the revised planning system operates. They can now order each product every 8 weeks for every market, and have also benefited from a lower cost price as the production savings have been passed on. The reduction in the number of formulations and improved sequencing rules has allowed the filling batch sizes to be reduced, so allowing greater flexibility. The ordering process has changed from chaos to order, and this has allowed a focus outwards to the customer, and attention to the development of the suppliers.

The move to a single 200ml bottle is being progressed.

7.3.3.12 Conclusions.

The involvement of Boots in the research spanned 23 months, from June 1995 through to May 1997. This was split into 3 phases:

- The trial and assessment of the methodology within the D95 Tablet Factory, which took place from June to September 1995.
- The live application of the methodology within D106 Sterile Products, which took place from September to December 1995.
- The implementation of the recommended changes to the working practices, which took place from February 1996 to May 1997.

During the first phase, Boots were able to assess the validity of the approach, and judge whether or not to proceed in a safe test environment. That they did proceed to a live trial clearly demonstrated their confidence in: the ability of the researcher to work creatively within a multi-disciplinary team; the applicability of the modelling process in that particular context; the use of the methodology to focus attention on the key operational issues; and the way in which the methodology aided creative thinking.

During the second phase, the approach was used to aid change in a live environment. The new manager wanted to change, the existing management saw the need to alter the existing working practices, but they did not know how to move forward. The modelling provided a tool to examine alternative strategies, the researcher provided practitioner skills in factory re-design and JIT manufacturing practices, and the ability to work within informal teams, questioning and inquiring approach, and an independent viewpoint. The modelling was used to provide a quantitative assessment of the likely outcome of the various scenarios. This proved to be a powerful aid to the decision making process. Boots were using their own current live data to evaluate the various options, and as this was familiar to the participants, it was possible to move easily from the overall principles of a scenario to the details of a specific item without losing focus of the overall strategy.

The composition of the team, and the manner in which the team was managed had a fundamental effect on the success of the research. The management team altered their focus from a *'how do we manage this better day to day'* basis to a *'what do our customers want and how can we most easily provide this'* basis, and actively involved their customers and suppliers in the planned changes.

The third phase proved in many ways the most problematic, with a change of bottle design causing severe production difficulties, so putting back the implementation by 9 months, from September 1996 to May 1997.

In conclusion, the methodology dramatically increased the understanding of the way in which the factory could operate, and how the approaches used in different industries (e.g. multi skilling the workforce) could be effectively transplanted into a pharmaceutical environment. This was achieved by using a combination of the modelling capabilities of the software, and by the open mindedness of researcher, the factory manager, and the factory management.

By modelling different scenarios, and changing the modelling parameters, the sensitivity of the output of the modelling software was assessed. Also, taking a particular parameter set, if there was a 10% increase in overall sales, only the run times and the average inventory value would be affected. The number of orders raised and the set-up times would not be changed by the increase in sales.

The three key performance criteria identified and used by the modelling software were critical to the success of the approach. It would not have been possible to obtain the commitment to the research without measuring all three criteria, the average inventory value, the order activity level, and the capacity usage, and comparing the results to the stated limits in each dimension.

Boots were fully committed to the approach, and used the model to communicate the benefits of the various scenarios internally. The research clearly improved communication between the participants, the customers, the suppliers, and the factory.

In June 1997, the Factory Manager stated that the approach acted as

> *'A catalyst for change'*
>
> *'Moved the factory from chaos in ordering to order'*
>
> *'Moved the focus outwards to customers and backwards to suppliers'*
>
> *'Provided confidence in the ability to change'*

7.4 RHÔNE POULENC RORER.

7.4.1 Introduction.

Rhône Poulenc Rorer (RPR)is a global pharmaceutical company dedicated to the discovery, development, and manufacture of human pharmaceuticals. It was formed in 1990 by the merger between American (USA) based Rorer Group Inc. and the human pharmaceutical business of Rhône-Poulenc SA, a French chemical company. In 1995 it acquired Fisons plc and Applied Immune Sciences Inc., and is involved in collaborative ventures with other pharmaceutical companies, such as the joint development of Centeon with Hoechst. It markets products in over 140 countries and has manufacturing operations in 30, employing 26,000 employees world-wide.

It is among the top 15 pharmaceutical companies in the world, and one of the top 3 in Europe. In 1996 it had total sales of $5.42 billion (with a gross margin of 66% of sales) and invested $882m in research and development, and sales per employee were $20,800.

Rhône Poulenc Rorer manufacture a variety of ethical pharmaceuticals at their Rainham Road manufacturing plant in Dagenham. These are available on prescription only, and are produced in the main for the European market.

Rhône Poulenc Rorer became involved when they attended a seminar where the theoretical background to the new methodology was being expounded with a view to attracting participating companies.

At the time RPR were starting an inventory reduction programme, called Quest, which had the stated aim of reducing all inventories to 60% of their current values. What RPR were looking for was a ‘scientific’ basis for planning those inventory reductions so that a cost benefit analysis could be performed to ascertain the financial viability of any proposed changes. Of the products being considered, Oruvail / Profenid is the fourth highest sales volume product for the company, with total sales of $200 million in 1995, and Flagyl is the tenth highest sales volume product with total sales of approximately $120 million in 1995. The products are not identified within the research by trade name, only by product code, to preserve the confidentiality of the costing and sales volumes by market.

7.4.2 The Approach.

The investigation method used was:

1. Establish the areas of concern within the facility.
2. Outline the principles behind the modelling process, and establish, in principle, that the approach was viable for Rhône Poulenc Rorer.
3. Establish the boundaries of the investigation.
4. Investigate the current working environment.
5. Establish the current operating parameters.
6. Confirm the credibility of the timings and batching rules by running the model with historical data.
7. Use the forecasted demand to predict the activity level using the current parameter set, to identify and quantify the existing constraints.
8. Use the model to optimise the parameter set according to various scenarios.
9. Re-identify the constraints and consider the viability of the various scenarios.
10. Consider improvements to overcome the constraints and change the parameter set to reflect the outcome of these changes.
11. Repeat steps 8 to 10.

The investigation method was derived to identify the constraints within the packaging line, and to establish a theoretical improvement program for the facility.

The initial contact with RPR was made through a K-Curve Seminar in April 1994 at IBM Warwick. IBM had offered consulting services to RPR in July 1992, but this had not resulted in any concrete work, and IBM were anxious to rekindle the relationship with a view to obtaining paid consultancy. One way of them doing this was to suggest that the research could be of use to RPR in the particular context of a stock reduction programme, that the involvement with Aston University would be free of charge to RPR, and that IBM would monitor progress.

A meeting took place between the researcher, a representative of IBM Consulting, the Materials Manager for Pharmaceutical Operations, and the Pharmaceutical Planning Manager in May 1994. The RPR personnel were keen to be involved with the research because they had a problem to address which would benefit from independent advice, that they were confident in principle with the philosophy behind the modelling approach, they had a sequence dependent set-up environment that they were finding difficult to model, that the data to be used was basically available within the existing MRP system, that IBM were recommending the involvement with Aston, and that the involvement would be free of charge. On this basis RPR decided to proceed, limiting the involvement to assessing the viability of achieving a 60% inventory reduction through changing the MRP parameter set and the use of enhanced scheduling practices.

A return visit was made to RPR at the end of May 1994 to meet the factory management and line supervisors, obtain an understanding of the manufacturing processes, and discuss the detailed data requirements with the information systems personnel.

The data was received in June 1994. There followed a series of visits where the meaning of the data was clarified, and errors and omissions corrected. For instance, although the manufacturing process was basically quite straightforward, quantifying the set-up times between the products proved to be a lengthy process, also the data held on the MRP system proved to be incomplete in terms of unit prices and routings. It was not until September 1994 that the data was finally error free and able to be validated against the current working practices.

The modelling process then took a further two sessions, finishing in October 1994, to produce the initial results from the various scenarios, to examine the feasibility of implementing the suggestions, and to finally identify distribution as the easiest place in which to achieve the goal of a 60% reduction in stocks.

7.4.3 Overview of the manufacturing process.

The manufacturing process consisted of 5 steps, dispensing, granulation, tablet making, coating and packaging, with each step undertaken as a discrete batch operation. The tablet manufacturing process is essentially the same as that already described in detail for the Boots D95 Tablet Factory. Each of the tablets has a validated manufacturing batch size which is (with 3 exceptions) the same as the current packaging batch size, with the manufacturing batch of tablets being packaged within 2 weeks of being manufactured.

The area of study, and the bottleneck, was the packaging operation which consisted of two identical close coupled lines. The tablets were fed from a hopper and guided into the blister pack, this was checked using a camera to ensure that each of the blisters contained a tablet, the foil seal is then applied to the blister, the blister(s) packed in a carton and then shrink wrapped. The lines packaged 36 SKU's comprising of 33 different formulations or strength of tablet. Each of the lines has a stated capacity of 480 minutes (8 hours) per day and is run for 240 days per year, giving a total available annual capacity of 230,400 minutes (480 minutes per day * 2 machines * 240 days per year).

This involved the following set-up operations:

- A change of formulation or strength of tablet required a complete strip down and clean of the line, taking 240 minutes at a cost of £60.59. This also includes a change of carton design and a change in the number of tablets per blister.
- A change of carton size required 60 minutes to complete, at a cost of £11.18.
- A change in the number of blister packs per carton required 20 minutes to complete, at a cost of £3.34.
- A change of carton design required 20 minutes to complete, at a cost of £3.34.

However, with the exception of the change in the number of tablets per blister and number of blister packs per carton, the set-up operations were not timed to be concurrent. So, for example, to change all the options would take an elapsed 320 minutes, 240 minutes to strip and clean the line and change the carton design, plus 60 minutes to change the carton size, plus 20 minutes to change the number of tablets per blister and / or the number of blister packs per carton. To change the carton design and the number of blisters per carton without changing the anything else would take an elapsed 40 minutes, 20 minutes to change the number of blisters per carton and 20 minutes to change the carton design. The full impact of this is illustrated by the set-up matrix, which details all the possible changeover combinations and the respective set-up timings.

7.4.4 Determination of set-up times.

The approach used within the research to calculate the theoretical changeover is to identify a hierarchy of set-ups, with one value per level, where the time spent on set-up could reasonably be minimised through good sequencing practice. Clearly, to minimise the set-ups in this instance, the first objective would be to minimise the number of 240 minute change of formulation or strength set-ups by identifying where the same formula and strength of tablet was packaged in more than one SKU with the same number of tablets per blister and blisters per pack. Within the 36 SKU's being considered, there were only 5 tablets in 2 groups which were of the same strength and formulation:

Item Code	Set-up Group
839433	A
818638	A
802053	B
839632	B
839684	B

Table 7.23 - R.P.R. - Determination of set-up groups at formulation level.

Within either of these groups, once one of the tablets was being packaged, it would only take a change of carton design taking 20 minutes to start packing another tablet in the same set-up group.

The next step was to identify those items where the tablet changes formula and / or strength, but the pack size and number of blister packs per carton stays the same. This identified a further 6 sub groups, as follows:

QP 1	QP 2	QP 3	QN 2	QR 3	QR 4
809010	826115	838015	839426	839406	839639
839701	826116	838010	844001	839594	839516
840240	826117	871240	802030	839527	826118
802500	847526				802550
882500	863845				843035
	871241				863055
	867000				
plus A	832004		plus B		

Table 7.24 - R.P.R. - Determination of set-up groups at pack level.

For the above items, it would take a change of tablet strength or formulation and carton design taking 240 minutes to start packing another tablet in the same set-up group.

Additionally, the items within set-up group A are part of sub group QP 1, and those in set-up group B are part of sub-group QN 2.

This still left 3 items unallocated within group. These were the two tablets within carton group QO, 839523 and 843030 which contained 6 and 8 blisters per pack respectively, and tablet 839674 within carton group QN, but with only 1 blister per pack. To change between 839523 and 843030 would take 260 minutes, and to change between any item in sub group QN 2 to 839674 would also take 260 minutes.

The situation regarding changeovers at Rhône Poulenc Rorer can be summarised as follows:

1. Change of formulation, carton design, carton size, and number of blister packs per carton taking 320 minutes, at a total cost of £75.11 (£60.59 + £11.18 + £3.34).
2. Change of formulation, carton design, and carton size taking 300 minutes, at a total cost of £71.77 (£60.59 + £11.18).
3. Change of formulation, carton design, and number of blister packs per carton taking 260 minutes, at a total cost of £63.93 (£60.59 + £3.34).
4. Change of formulation and carton design taking 240 minutes, at a total cost of £60.59.
5. Change of carton design taking 20 minutes, at a total cost of £3.34.

The changeovers at levels 1, 2, and 3 are more easily understood when arrayed in a table, as follows:

Rhône Poulenc Rorer - Set-up Matrix
By Carton Size and # Blisters per Carton

	QP 1	QP 2	QP 3	QN 1	QN 2	QR 3	QR 4	QO 6	QO 8
QP 1	0	260	260	300	320	320	320	320	320
QP 2		0	260	320	300	320	320	320	320
QP 3			0	320	320	300	320	320	320
QN 1				0	260	320	320	320	320
QN 2					0	320	320	320	320
QR 3						0	260	320	320
QR 4							0	320	320
QO 6								0	260
QO 8									0

Table 7.25 - R.P.R. - Set-up matrix.

These relationships can be simply portrayed in a tree structure, with 4 levels to the hierarchy, as follows:

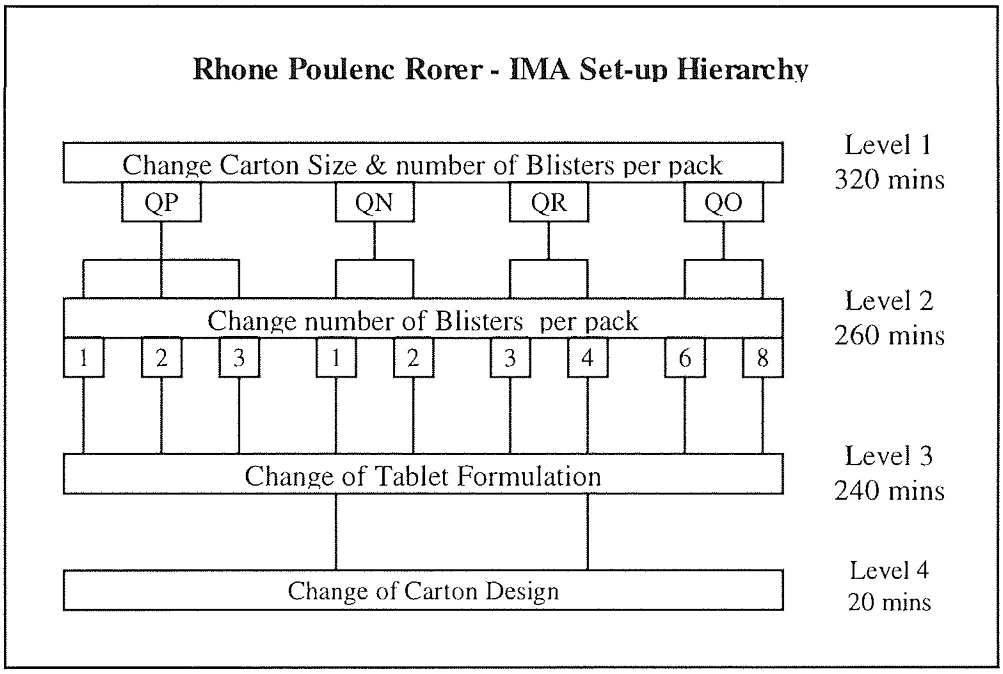

Figure 7.15 - R.P.R. - IMA set-up hierarchy.

However, this representation is not correct. The problem is at Level 1, where there are two different choices, with different timings and costs, as follows:

- Change of formulation, carton design, carton size, and number of blister packs per carton taking 320 minutes.

- Change of formulation, carton design, and carton size taking 300 minutes.

The problem is that a change of carton type does not take a standard time, it either takes 300 minutes or 320 minutes, depending on whether or not there is a change in the number of blisters per carton. This is not capable of resolution through a simple hierarchy and needs to be represented through a matrix. This had an effect on the research, in that the approach adopted is one where the current performance is initially automatically calculated in order to establish a benchmark for comparison, and requires a clear idea of the set-up that would have been used for changing over between products. Clearly, the set-up matrix challenges this view, in that changeovers cannot always be represented hierarchically, and so calculated automatically. Following discussions with the local management and reference to historical data, it was clear that although the batches due to be packaged in a particular week were sequenced onto the lines to minimise set-ups, that the vast majority of these were of 240 minute and 260 minute duration, with no 300 minute set-ups being observed in the sample. The practical implication of this was that a reasonable estimate of the time taken on set-up could be obtained if a four level hierarchy was used, timing all the level 1 changeovers at 320 minutes. Using this simplification, it was possible to allocate a set-up time to each of the items for the current batching rules and for the modelling exercise.

7.4.5 Calculation of current position.

The current batching rules of the IMA packing lines were analysed and the average base (exclusive of safety stocks etc.) inventory levels, the annual order load and the average capacity load which would result from the current batching parameters was derived. This was first run historically to establish how well the existing batching rules, capacities and routing data were at predicting the actual usages, number of actual batches and inventory levels. After some adjustment of errors in both data and interpretation, Rhône Poulenc Rorer were confident that the output from the model was accurate enough to continue with the test using forecasted, rather than historical, data.

This provided the following results:

IMA - Current Position	
Daily Capacity (mins)	960 mins
Daily Run Load (mins)	585 mins
% Run	61%
Daily Set-up Load (mins)	304 mins
% Set-up	32%
Available Capacity (mins)	71 mins
% Load	7%
Daily Usage Value	£7,979,336
Annual Order Load	253 orders
Average Inventory Value	£572,816
Stock Turns	13.9

Table 7.26 - R.P.R. - Current Position.

The daily capacity was stated as 480 minutes per machine, and as both lines are interchangeable, a total daily capacity of 960 (480 * 2) minutes was used. The daily run load is the calculated annual capacity load required to produce the estimated annual demand forecast divided by 240, the number of working days per annum. The daily set-up load is the annual total set-up load divided by 240. The available capacity is the daily capacity less the sum of the daily run load and the daily set-up load. The % run % set-up and % load are calculated as the % of the daily capacity spent on the relevant activity.

The annual usage value is the total value at cost of the estimated annual demand forecast. The annual order load refers to the number of orders generated using the stated order policy and estimated annual demand forecast. The average inventory £ refers to the inventory held downstream from the packing lines and assumes a standard 'saw tooth' decay of stock. This figure does not include policy stocks such as safety. The value of the stocks of the 'upstream' components (pharmaceuticals, packaging etc.) has not been calculated and no assumptions have been made concerning their delivery frequencies or order sizes. The stock turns is the annual usage value divided by the average inventory value.

What this benchmark standard does is to establish a set of performance criteria that the facility can already meet, the next stage is to compare the results of using the current operating parameters with the those that would have been obtained using the standard EBQ formula.

7.4.6 Comparison with standard EBQ.

The next step was to compare this with what would have been the result using the standard EBQ equation, assuming a 10% inventory holding rate per annum. This provided the following results:

IMA - EBQ vs. Current Position		
	EBQ	Current Position
Daily Capacity		960 mins
Daily Run Load		585 mins
% Run		61%
Daily Set-up Load	497 mins	304 mins
% Set-up	52%	32%
% of current	164%	
Available Capacity		71 mins
% Load	112%	93%
Annual Usage Value		£7,979,336
Annual Order Load	372.4 orders	253.0 orders
Order % of current	147%	
Average Inventory £	£279,714	£572,816
Inventory % of current	49%	
Stock Turns	28.5	13.9

Table 7.27 - R.P.R. - EBQ vs. Current Position.

The EBQ was a considerable improvement on the existing position in terms of the average inventory value, with a £293,102 decrease (51%) in average stock leading to an increase in stock turns from 13.9 per annum to 28.5 per annum. It required almost 120 more orders to support the EBQ recommendations, and the capacity requirements increased by 189 minutes per day. Taking the current position as 100%, the results, when plotted, are as follows:

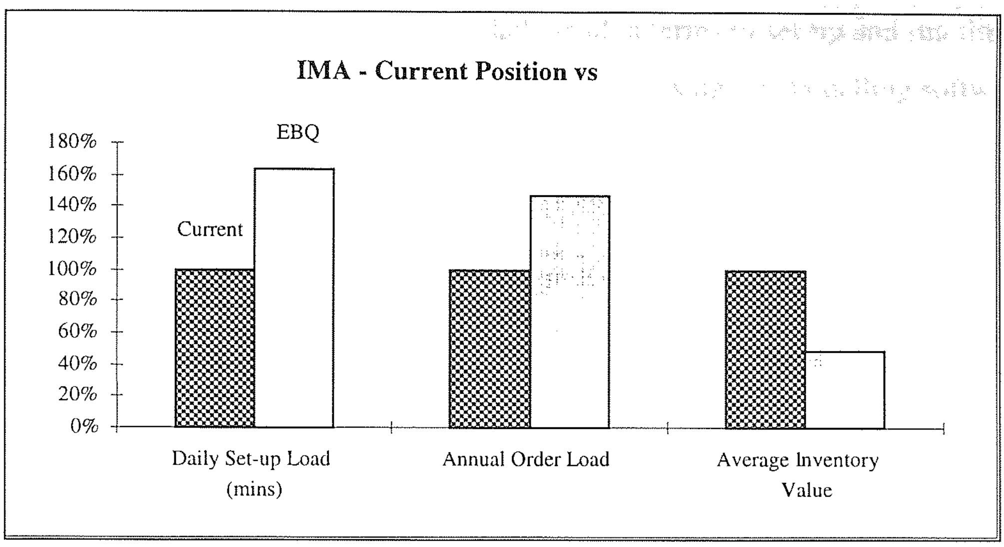

Figure 7.16 - R.P.R. - EBQ vs. Current Position.

The EBQ was a reasonably close match to the stated objective of reducing the average inventory to 60% of the current value, however it performed relatively poorly in terms of the capacity usage. This was due to there being no assumption of any savings in the set-up times or costs being taken into account. A standard 320 minutes per set-up costing £75.11 was used for each item.

7.4.7 The Modelling Process.

Having accepted the validity of the approach, the first objective was to establish a set-up time and cost for each of the items, assuming that a geometric progression would be used for the period order day classes. This entailed allocating a 320 minute set-up to the highest annual usage value item within each carton type, assuming that everything would be changed going between different carton types. The next set-up to be allocated was the 260 minute changeover allocated to the highest annual usage value item within each blister subgroup of each carton type. All the items left within each group with unique formulations were then allocated a 240 minute changeover. Of the remaining items with identical formulations, carton types and number of blisters, the highest annual usage item within each group was allocated the relevant major set-up (in this case either 320 minutes or240 minutes), and the remaining items allocated a 20 minute changeover.

Having assigned a set-up time and cost to each of the items, the next step was to allocate the items within a six period order day class series of 5, 10, 20, 40, 80, and 160 days, and to match on the desired average inventory level of £343, 690, 60% of the current average inventory level of £572,816. A 240 working day year was used for the calculation of the orders generated per annum and the average daily load in terms of set-up and run times. The inventory holding rate per annum was taken as 10%. Using the modelling software and matching on the 60% of the current inventory levels from the current position, the following results were obtained:

	60% Inventory	Current position
Daily Capacity		960 mins
Daily Run Load		585 mins
% Run		61%
Daily Set-up Load	326 mins	304 mins
% Set-up	34%	32%
% of current	107%	
Available Capacity	49 mins	71 mins
% Load	95%	93%
Annual Usage Value		£7,979,336
Annual Order Load	325.5 orders	253.0 orders
Order % of current	129%	
Average Inventory £	£336,211	£572,816
Inventory % of current	59%	
Stock Turns	23.7	13.9

Table 7.28 - R.P.R. - Inventory Reduction vs. Current Position.

To achieve the desired reduction in the average base inventory to 60% of its current value required an increase of 72.5 (129%) in the number of orders annually that would be necessary to support this policy, and a corresponding increase of 22 minutes per day (107%) in the set-up minutes. The stock turns increased from 13.9 to 23.7. Taking the current position as 100%, the results, when plotted, are as follows:

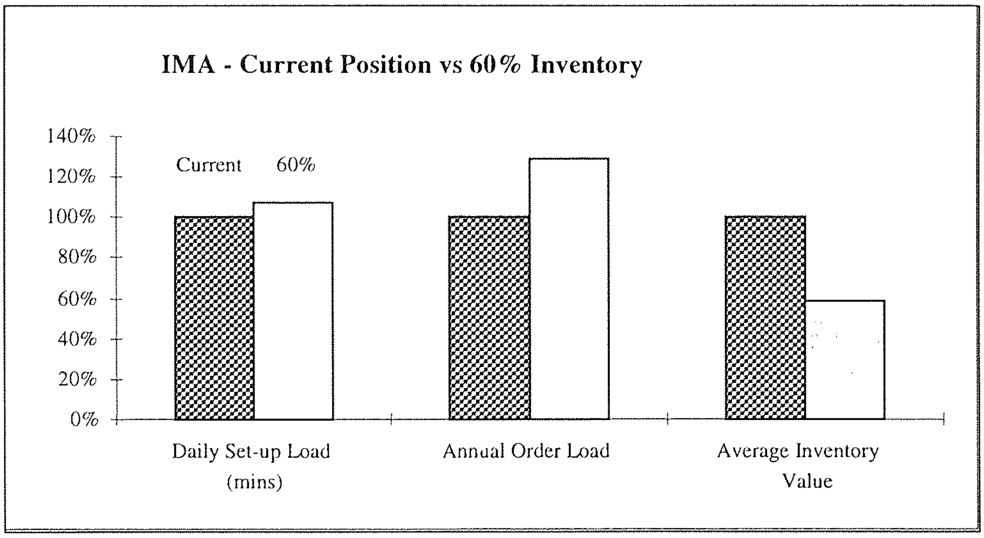

Figure 7.17 - R.P.R. - Inventory Reduction vs. Current Position.

This scenario provided a theoretically achievable result. The objective of reducing the inventory was satisfied, and it was possible to take the full benefit of any possible set-up reductions. If the number of items in the recommended period order day classes are compared with the current order policy codes, the results, when plotted, are as follows:

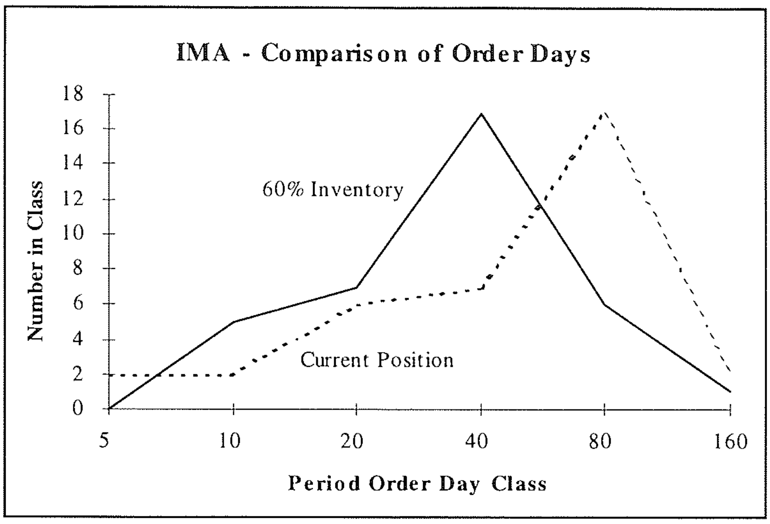

Figure 7.18 - R.P.R. - Comparison of Period Order Day Classes.

Although the results are theoretically achievable, the capacity utilisation is still very high, 95%. If the sizes of cartons QN and QP are examined, it can be seen that they differ by 2mm in one dimension, as follows:

Carton	Dimensions in mm		
QN	17	102	18
QP	17	102	20

Table 7.29 - R.P.R. - Dimensions of Carton Types QN and QP.

The tablets are not sold over the counter through retail outlets, but are available on prescription only, so what would be the effect of replacing the smaller carton, QN, with the larger carton, QP? Would the customer notice, or care, if this change were made, and how much time would be saved by removing the extra changeovers between these two carton sizes? This affected one item, the item taking the major set-up time and cost within group QN, item 840240, with the results for all the other items being the same as for the 60% inventory reduction, as follows:

Item Code	K+	Period Order Days	Batches / Year	Set-up mins	Annual Set-up Load (mins)
840240	2,339	20	12.0	260	3,120
	2,306	20	12.0	240	2,880

Table 7.30 - R.P.R. - Effect of combining Carton Types QN and QP on set-up load.

So, the annual set-up load would be decreased by 240 minutes, or one minute per day if this rationalisation were made.

7.4.8 Conclusions.

Up to this point the main drive within the company had been to ensure continuity of supply, rather than to reduce batch sizing or to look at more effective line sequencing, with current finished goods inventory levels of between 110 and 240 days supply, when taking account of policy stocks. The company has historically operated with high margins, with a gross margin of 66% of sales, and so reducing inventory has not been a priority, especially where this would conflict with continuity of supply.

It is theoretically possible to achieve the required reduction in base inventory levels with a very small change in the capacity utilisation. However, changing packaging batch sizes without changing manufacturing batch sizes would do little to decrease overall inventory levels as most of the value in the product is in the tablet. This would certainly serve to reduce the stock levels in distribution, but there would be a corresponding increase in the value of stocks held within manufacturing. Overall for the company this would achieve little, as the increased stocks within manufacturing would be more liable to contamination or deterioration, and also room would have to be found to store the unpacked part batches. The packaging would also be further complicated as the batch integrity would be compromised, as it would be highly likely that a packaging batch would incorporate more than one manufacturing batch.

If ways of reducing the overall load are looked at, then a rationalisation of the pack sizes would yield little benefit, with a potential saving of one minute per day to be balanced against the costs of re-proofing the packaging. Also this was not a manufacturing concern, but a marketing responsibility.

If changing the packaging batch sizes alone do not yield many benefits, what would be the result of changing the manufacturing batch sizes to more closely fit the 'optimum' results provided by the modelling process? This is a manufacturing responsibility, but the batch sizes are fixed due to the validation process required to manufacture ethical pharmaceuticals. To change the manufacturing batch sizes requires revalidation by relevant agencies, so this was to be avoided if at all possible.

One further avenue of investigation remained, that of the stocks within distribution. This had to be approached somewhat obliquely, as it was the manufacturing management that had requested assistance. By analysing the current batching rules, and validating historically that the rules as stated were those used, an average base inventory level was calculated. Of the items being investigated, the lowest inventory level within distribution was 110 days stock, and the highest 240 days stock. What would the number of days stock would be if a policy stock (i.e. safety stock) equal to the batch quantity to each of the items was considered, that is, an average stock level of one and a half times the current batch quantity. This would give an average inventory value of £1,718,449, equating to only 52 days stock or 4.6 stock turns per annum. The number of days stock being calculated as follows:

$$\begin{aligned} DS &= DPY * \frac{AIV}{AUV} \\ &= 240 * \frac{£1,718,449}{£7,979,336} \\ &= 52 \end{aligned}$$

where DPY Days per Year

AIV Average Inventory Value

AUV Annual Usage Value

With an average of 52 stock days, this scenario would outperform the policy used in distribution in terms of average inventory value, with an average inventory days stock under half that of the minimum value currently being attained.

With the regulations concerning the manufacturing of ethical pharmaceuticals, there is no quick, cheap and easy way to change the manufacturing batch sizes. For the products being considered, these were set with the intention of running on reasonably high volume packaging lines, with large set-ups between products. A set-up reduction programme would certainly reduce the line loading, as would a more considered use of packaging, it cannot make commercial sense to order outer packaging which differs by only 2mm, adding unnecessary cost to both the materials and to the packaging process. Changing the packaging batch sizes would do little to the overall value of stock within the company, merely transferring the value out of distribution and into manufacturing, and adding extra complexity to manufacturing by having to maintain control of the stocks of unpacked tablets. Unless the manufacturing batch sizes could be reduced in line with the packaging batch sizes, the inventory reduction would be a mirage, just transferred from one area of responsibility to another.

The inference drawn from this was that as most of stockholding of the items being considered was held as policy stocks within distribution, that a focused destocking within that area would be the simplest way of achieving the stated inventory reduction objectives.

In conclusion, RPR used the research as free consultancy in a political situation. RPR accepted the validity of the approach and its usefulness to the decision making process, and were interested in obtaining unbiased confirmation of what was already suspected, that a stock reduction programme should concentrate on distribution, rather than packaging. The packaging factory management gained considerable insight into the planning and control of the packaging lines, the set-up matrix being used by the line supervisors to reduce changeover times, and the quality of the MRP system has improved by the correction of data errors on the routes and costs. The RPR factory and planning management were extremely helpful, were (unsurprisingly) fully committed to using the research as a way of focussing the stock reduction programme away from packaging and onto distribution, and using the results of the modelling exercises with the site executive to justify their statements regarding the stockholdings within distribution and the amount of work that would be required to significantly alter the manufacturing and packaging batch sizes.

7.5 FMCG.

7.5.1 Introduction.

In order to obtain access to this particular company a confidentiality agreement was entered into. This prohibited either use of the company's name or the details of its products being made public knowledge.

The FMCG company is involved in producing premium branded personal use giftware items with a price range from £4 to £500. These are produced in three manufacturing centres, one in Great Britain, one in France and one in the United States. Originally an American company formed as a partnership in 1891 it was incorporated in 1892 and relied on technical innovation for its success, with four patents being granted in the first two years of operation and with annual sales of a million dollars by 1918. In 1928 the company became publicly owned, with 75% of the shares being floated on the Chicago stock exchange. In 1986, the company was the subject of a leveraged buy out by the UK management, who subsequently sold out to an American competitor. It still competes in its traditional marketplace.

The products are made from a combination of metal and plastic parts, with there being a certain amount of commonality of parts between the different models. The research was conducted into a set of moulding operations, producing components which are used directly in the finished articles. The FMCG does not sell directly to the public, but sells to retailers and wholesalers. The company operates as a sales organisation and a production organisation, with the sales organisation placing date, quantity and market specific orders on to production. The retail demand for the products is seasonal, with the highest demand in the Christmas period. The production demand is levelled to smooth the capacity load, and finished goods stocks built up in advance of the peak sales period.

The investigation method used was the same as that for Boots and Rhone Poulenc Rorer and took place over a period of 6 months between July and December 1994. The initial contact took place in July 1994 through IBM Consulting, and was with the Production Planning Manager. The FMCG were already mature users of the original K-Curve Methodology (KCM) and were using it to set the ordering parameters for purchased parts and raw materials. The Production Planning Manager was interested in extending the use of a KCM style of parameter management into the manufacturing process, and had realised the deficiencies of the original KCM in this area. The initial meeting was concerned with assessing the suitability of the modelling approach in general, and the credibility of the researcher. A major concern for the FMCG, who operate in a highly competitive giftware market, was that of confidentiality. Having decided to proceed in principle, and to concentrate on the moulding area, it took a further month before proper access could be obtained to the company's data, the delay being due to the lawyers representing the FMCG drafting, and Aston University agreeing, the confidentiality restrictions.

Two visits took place in August 1994. The purpose of the first visit was to investigate the production process, meet the production management and the Master Production Scheduler (who from then onwards acted as the prime contact within the FMCG), outline the way in which the modelling worked, and define the data requirements with the information technology department. The second visit, at the end of the month, was to collect the extracted data, and sort out the obvious errors and omissions, with the timings on the routes, the identification of set-up groups, set-up times and costs being particular problems.

The next visit took place at the beginning of September 1994. This looked at the results of modelling as per the current operating parameters, uncovered some less obvious errors with the routes, which were rectified, and the integrity of the model in correctly interpreting the existing parameter set was agreed. As this was the first live use of the system, the modelling process then took a further 4 weeks, where the results of the modelling were manually checked, minor software errors corrected, and two modifications made to the system, the first being the increase of the levels of the set-up hierarchy from 2 to 3, and the second being the inclusion of the improvement factor *(v)*. By the end of September 1994 the first results were available, and a further visit was made. The validity of the initial modelling was agreed, and further models were requested, to show the results of potential set-up improvements, and differing activity levels. The next visit was scheduled for the end of October 1994, with representatives from IBM, the FMCG and the researcher, to review the results of the modelling and to assess the practical application of the findings. This meeting was very positive, and further work was performed to look at extending the modelling into other areas and to look at the implications within the manufacturing and material supply areas of implementing the proposals. During the remaining period with the FMCG, the staff were always very co-operative, but seemed to lose their enthusiasm for proceeding too far with their implementation plans. The reason for this soon became clear, when it was announced in November 1994 that they were to merge certain of their manufacturing and distribution operations with those of a competitor who had just been taken over by the parent company of the FMCG.

The main involvement with the FMCG came to an end in December 1994.

7.5.2 Overview of the Manufacturing Process.

The manufacturing process consisted of a standard injection moulding operation, with 21 moulding machines being fed clear plastic granules and master batch colour pigment granules via a hopper system. The items produced were components which were used directly in the assembly operations.

There were basically two levels of set-up, a change of mould taking either 30, 120 or 180 minutes depending on the size of the mould, and a change of colour taking 30 minutes.

The investigation only considered the moulding operation. As the raw material into this operation was common between components, consisting of plastic granules and master batch, the time phasing of any raw material stock supply would not necessarily be affected by any changes made in the component manufacture.

7.5.3 Determination of set-up times.

The approach used within the research to calculate the theoretical changeover is to identify a hierarchy of set-ups, with one value per level, where the time spent on set-up could reasonably be minimised through good sequencing practice. Clearly, to minimise the set-ups in this instance, the first objective would be to minimise the number of mould changes of 120 or 180 minutes by identifying where the same mould was used by more than one item.

Within the 124 items being considered, there were 68 components in 18 set-up groups which were capable of benefiting from a sequence dependent set-up, as follows:

Set-Up Group	Major set-up time (mins)	Major set-up cost (£)	Minor set-up time (mins)	Minor set-up cost (£)
A	120	£42.00	30	£10.50
B	120	£42.00	30	£10.50
C	30	£10.50	30	£10.50
D	30	£10.50	30	£10.50
E	120	£42.00	30	£10.50
F	120	£42.00	30	£10.50
G	120	£42.00	30	£10.50
H	30	£10.50	30	£10.50
I	120	£42.00	30	£10.50
J	30	£10.50	30	£10.50
K	180	£63.00	30	£10.50
L	120	£42.00	30	£10.50
M	120	£42.00	30	£10.50
N	120	£42.00	30	£10.50
O	120	£42.00	30	£10.50
P	120	£42.00	30	£10.50
Q	120	£42.00	30	£10.50
R	120	£42.00	30	£10.50

Table 7.31 - FMCG - Determination of set-up times and costs.

7.5.4 Calculation of current position.

The current batching rules were analysed and the average base (exclusive of safety stocks etc.) inventory levels, the annual order load and the average capacity load which would result from the current batching parameters was derived. This was first run historically to establish how well the existing batching rules, capacities and routing data were at predicting the actual usages, number of actual batches and inventory levels. After some adjustment of errors in both data and interpretation, the FMCG were confident that the output from the model was accurate enough to continue with the test using forecasted, rather than historical, data.

This provided the following results:

FMCG - Current Position	
Daily Capacity (mins)	18,396 mins
Daily Run Load (mins)	15,054 mins
% Run	82 %
Daily Set-up Load (mins)	611 mins
% Set-up	3 %
Available Capacity (mins)	2,730 mins
% Load	85 %
Annual Usage Value	£1,859,523
Annual Order Load	1,877 orders
Average Inventory Value	£61,817
Stock Turns	30

Table 7.32 - FMCG - Current Position.

The daily capacity was stated as 876 minutes per machine, and as there were 21 moulding machines a total daily capacity of 18,396 (876 * 21) minutes was used. The daily run load is the calculated annual capacity load required to produce the estimated annual demand forecast divided by 247, the number of working days per annum. The daily set-up load is the annual total set-up load divided by 247. The available capacity is the daily capacity less the sum of the daily run load and the daily set-up load. The % run % set-up and % load are calculated as the % of the daily capacity spent on the relevant activity.

The annual usage value is the total value at cost of the estimated annual demand forecast. The annual order load refers to the number of orders generated using the stated order policy and estimated annual demand forecast. The average inventory £ refers to the inventory held downstream from the moulding operation and assumes a standard 'saw tooth' decay of stock. This figure does not include policy stocks such as safety. The value of the stocks of the raw materials has not been calculated and no assumptions have been made concerning their delivery frequencies or order sizes. The stock turns is the annual usage value divided by the average inventory value.

What this benchmark standard does is to establish a set of performance criteria that the facility can already meet, the next stage is to compare the results of using the current operating parameters with the those that would have been obtained using the standard EBQ formula.

7.5.5 Comparison with standard EBQ.

The next step was to compare this with what would have been the result using the standard EBQ equation, assuming a 20% inventory holding rate per annum. This provided the following results:

FMCG - EBQ vs. Current Position		
	EBQ	Current Position
Daily Capacity		18,396 mins
Daily Run Load		15,054 mins
% Run		82 %
Daily Set-up Load	276 mins	611 mins
% Set-up	1.5 %	3 %
% of current	45 %	
Available Capacity	3,066 mins	2,730 mins
% Load	83 %	85 %
Annual Usage Value		£1,859,523
Annual Order Load	691 orders	1,877 orders
Order % of current	37 %	
Average Inventory £	£119,335	£61,817
Inventory % of current	193 %	
Stock Turns	16	30

Table 7.33 - FMCG - EBQ vs. Current Position.

The EBQ was demonstrably worse than the current position in terms of inventory value, with a £57,518 (193%) increase in average stock leading to a decrease in stock turns from 30 per annum to 16 per annum. It required almost 1,200 less orders to support the EBQ requirements, and the set-up capacity requirements decreased by 55%, a saving of 335 minutes daily across the 21 machines. Taking the current position as 100%, the results, when plotted, are as follows:

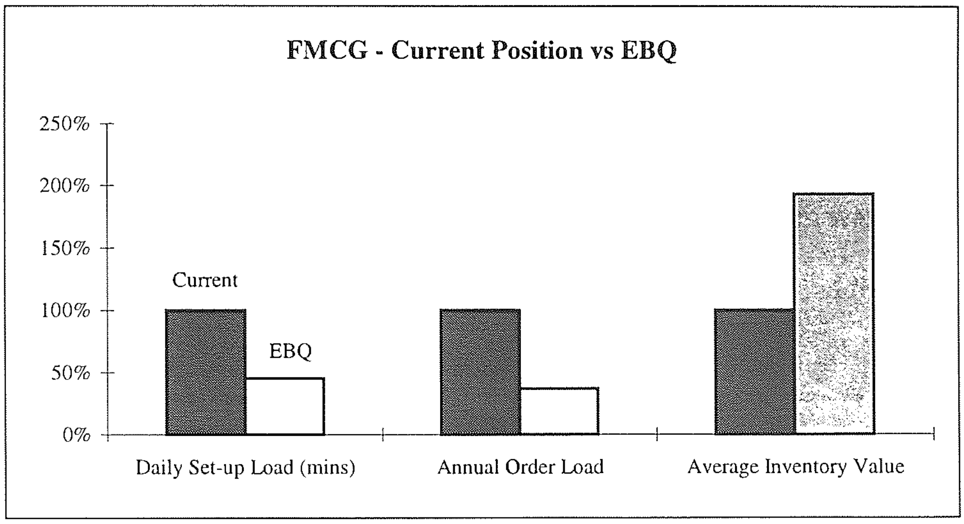

Figure 7.19 - FMCG - EBQ vs. Current Position.

Although the EBQ performed relatively poorly, if the exchange curve principles were used and the order load was doubled to 1,382 orders annually by making all the parts at half the recommended EBQ batch sizes, the set-up load would double to 552 minutes daily, and the inventory value would halve to £59,668, a result that is better than the current position in all three dimensions.

7.5.6 The Modelling Process.

Having accepted the validity of the approach, the first objective was to establish a set-up time and cost for each of the items, assuming that a geometric progression would be used for the period order day classes. The inventory holding rate per annum was taken as 20%.

Using the modelling software and matching on the current capacity load levels from the current position, the following results were obtained:

FMCG - Capacity Match vs. Current Position		
	Capacity Match	Current Position
Daily Capacity		18,396 mins
Daily Run Load		15,054 mins
% Run		82 %
Daily Set-up Load	606 mins	611 mins
% Set-up	3 %	3 %
% of current	99 %	
Available Capacity	3,066 mins	2,730 mins
% Load	85 %	85 %
Annual Usage Value		£1,859,523
Annual Order Load	1,840 orders	1,877 orders
Order % of current	98 %	
Average Inventory £	£45,221	£61,817
Inventory % of current	73 %	
Stock Turns	41	30

Table 7.34 - FMCG - Capacity Match vs. Current Position.

The match on capacity showed that a reduction of the average base inventory value to 73% of the current level may be possible through altering the batching rules as per the model recommendations, an inventory saving in the order of £16,500. The set-up load was also decreased by 5 minutes daily, and the number of orders required to support this policy fell by 37 when compared with the current position. Taking the current position as 100% the results, when plotted, are as follows:

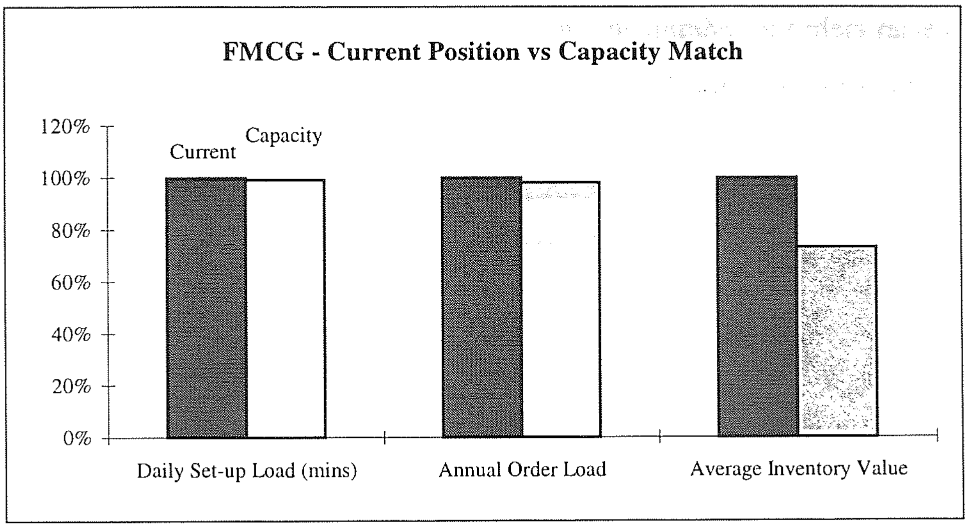

Figure 7.20 - FMCG - Capacity Match vs. Current Position.

What this illustrates is that is theoretically possible to improve on the current position in all three dimensions, with a lower average inventory value requiring fewer orders which generated a lower level of set-up load.

The next stage was to model the effect of implementing a set-up reduction programme which would reduce changeover costs and times by 50% across the board, and loading the capacity to the current levels. Using the modelling software and matching on the current capacity load levels from the current position, the following results were obtained:

FMCG - Set-up Reduction vs. Current Position		
	Set-up Reduction	Current Position
Daily Capacity		18,396 mins
Daily Run Load		15,054 mins
% Run		82 %
Daily Set-up Load	609 mins	611 mins
% Set-up	3 %	3 %
% of current	100 %	
Available Capacity	2,732 mins	2,730 mins
% Load	85 %	85 %
Annual Usage Value		£1,859,523
Annual Order Load	3,785 orders	1,877 orders
Order % of current	202 %	
Average Inventory £	£23,018	£61,817
Inventory % of current	37 %	
Stock Turns	81	30

Table 7.35 - FMCG - Set-up Reduction vs. Current Position.

If the set-up costs and times could be reduced by 50%, using the same capacity load as a present, it would be theoretically possible to reduce the base average inventory to

£23,000, 37 percent of its current value, by doubling the number of orders raised. The stock turns per annum would also increase from 30 to 81. Taking the current position as 100% the results, when plotted, are as follows:

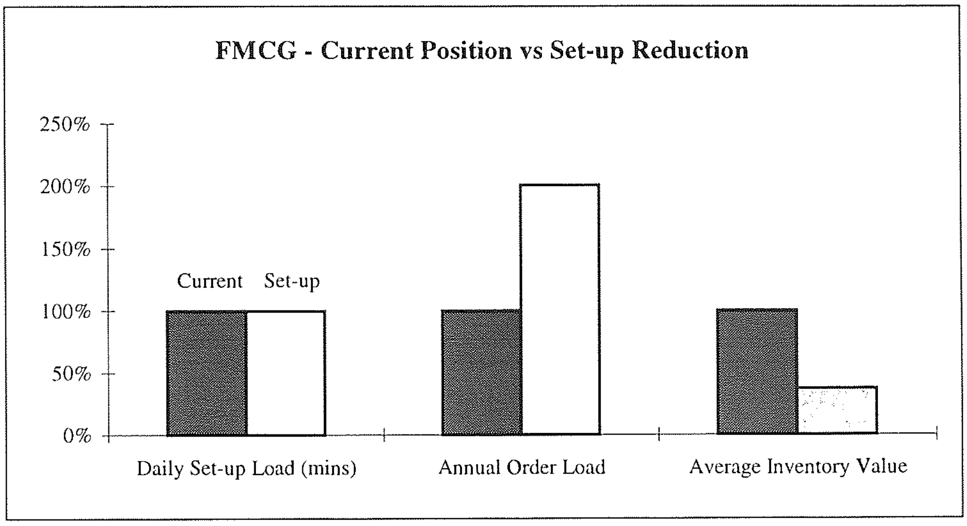

Figure 7.21 - FMCG - Set-up Reduction vs. Current Position.

7.5.7 Conclusions.

As the FMCG were already mature users of the original K-Curve, it was not expected that great improvements would be found, but it was possible to show improvements in all three dimensions when matching on current capacity utilisation. The exercise on set-up reduction illustrated to the FMCG the benefits to be gained from following a structured set-up reduction programme.

However, with the finished articles being produced in batches, it must be questioned whether the supply of the components could not be better satisfied by producing them in line with the production of the finished articles, rather than decoupling the supply of the components from the demand. Running an MRP system with three levels controlled by works orders would produce a very nervous system, which would not reflect the flexibility inherent in the moulding operation and the raw material supply.

Three important points were learnt at the FMCG:

- One was the level that the access was gained to the company was vital to the perception of the importance of the exercise. At the FMCG this was at the production planner level. The production planners could see the benefits of the approach, and wanted to use a reasonably self contained area as a testing ground. This was successful in itself, however, there was a resistance at the next level of management to discuss the results of the exercise at a director level.

- The second point was that the company itself had to have a clear idea of what it wanted to achieve, and how it would use any results if it helped them in their goal. The FMCG lacked this insight. It was looking for ways to reduce inventory, but somehow lacked the confidence to follow through the modelling. The reason for this became clear:
- The third point was that the American owner bought out a competitor, and was looking for ways of achieving economies of scale in both production and sales by combining certain aspects of the two companies. Until this was resolved, it would be pointless to re-organise the production, as the manufacturing location and the production quantities could not be properly established.

In conclusion, the FMCG proved to be a useful case study, as it helped to demonstrate that although the methodology successfully addressed the five validation criteria (insight gained, sensitivity, usefulness, acceptability and commitment), it failed to result in an implementation. This was not due to particular shortcomings in the approach as such, but rather due to the changes in the organisation made necessary by the acquisition of a competitor, and the lack of profile that the research had at a board level. It is worthwhile noting that the FMCG personnel seemed happy to continue with the modelling almost indefinitely, without there being any perceived focus from themselves for their involvement.

7.6 CARADON TERRAIN.

7.6.1 Introduction.

Caradon Terrain is a member of the MB-Terrain group of manufacturing companies involved with building products, comprising of Caradon Terrain who produce plumbing systems, Caradon Mira who specialise in shower fittings and thermostatic valves, Caradon Everest who manufacture double glazed doors and windows, Caradon Bathrooms who manufacture bathroom and sanitary wares, Caradon Heating who manufacture the Stelrad range of central heating products and Caradon Celuform who manufacture plastic timber replacement systems.

Caradon Terrain serves two, quite distinct marketplaces. It services builders merchants directly from stock, if they do not have the stock on hand, the sale will go elsewhere. For major building projects, they make to order. The products are sold in three areas:

- Rainwater systems. Plastic guttering, pipes and accessories in a variety of profiles and capacities designed to remove surface water from domestic and commercial buildings.
- Soil, Waste, Overflow and Traps. Plastic pipes, fittings and assemblies designed for the removal of kitchen and bathroom waste for use in domestic and commercial environments.
- Buried Drain. Plastic drain pipes, fittings and assemblies for underground use in domestic and commercial environments.

The case study looked at two areas within Caradon Terrain, the first being the extrusion of plastic pipes and guttering, the second being the manufacture of underground assemblies, and in both cases considered the parameter setting of items produced for sale from stock.

The investigation method used was the same as that for Boots and Rhone Poulenc Rorer and involved investigations into two areas, extrusion and underground components. The investigation into extrusion took place over a period of 5 months between November 1994 and March 1995, and that into underground components took place over a period of 3 months between November 1995 and January 1996. The initial contact took place in October 1994 through IBM Consulting, and was with the Master Production Scheduling (MPS) Manager. Although IBM arranged the initial meeting, they had no further direct involvement in the work performed during the case study. Caradon Terrain were already mature users of the original K-Curve Methodology (KCM) and were using it to set the ordering parameters for purchased parts, assemblies and raw materials. The MPS Manager was interested in extending the use of a KCM style of parameter management into the manufacturing process, and had understood the deficiencies of the original KCM in this area.

The approach of Caradon Terrain in general, and the MPS manager in particular, was akin to that of Boots, in that the MPS Manager, who was an active member of BPICS, was generally interested in finding out about advancements in production and material control theory and practice, simplifying the management and control of the production processes, improving the customer service levels, looking to continually improve the performance and competitiveness of the firm.

With regard to the extrusion case study, the initial meeting took place in November 1994 with the MPS Manager, the Production Director, the Extrusion process managers, and the production control staff, and was concerned with assessing the suitability of the modelling approach in general, investigating the production process, meeting the production management, outlining the way in which the modelling worked, and for Caradon Terrain to assess the credibility of the researcher. Having decided to proceed in principle, and to concentrate on the extrusion area, the next step was to examine the MRP system, the current parameter settings, the demand patterns, the working patterns, and to define the data requirements with the computer department. The second visit, at the beginning of December 1994, was to collect the extracted data, and sort out the obvious errors, omissions, and misunderstandings, with the timings on the routes, the identification of prime and alternate routes, and the interpretation of the order policy codes being the main problems. The next step was to model the theoretical performance of extrusion against the current operating performance. This uncovered some less obvious errors with the routes, which were rectified, and confirmed that the MRP calculations were being used to generate production orders, without manual intervention, and that the modelling software was correctly interpreting the existing parameter set. This process involved a further visit in mid December 1994, and took until January 1995 to complete, at which point the scenario modelling started. The modelling process then took a further two visits, finishing in February 1995, to produce the results from the various scenarios, to examine the feasibility of implementing the suggestions, and to plan how to introduce cyclic scheduling into the extrusion area without degrading the customer service levels during the changeover period. These plans were, however, overtaken by events as Caradon Terrain took over a competitor based in Leeds, called Rymway. This totally changed the management focus from one of improving the existing processes, to one of merging the two businesses together, and the initial formal contact ceased in March 1995. Informal contacts were, however, maintained in the interval.

The Underground Assemblies case study came about as a result of the transfer of the Rymway manufacturing plant to Caradon Terrain, and the consolidation of the two businesses on the Maidstone site. This further involvement came about as a result of the continuing informal contacts with the MPS Manager, with the researcher being asked by Caradon Terrain to validate the initial design for the underground cell. Due to their previous involvement, Caradon Terrain already thought the approach adopted by the research to be of merit, and this exercise started in November 1995. The initial visit in November 1995 was concerned with gaining an understanding of the purpose of the cell, where it was to be physically located within the factory, what the demand patterns were, what were the shared resources, how was the cell to interact with the feeder operations, and arranging for the data to be supplied by the computer department. A further visit was made in December 1995 to sort out errors and omissions in the data and of interpretation, and to model the theoretical performance of the underground cell against the current operating performance of the individual items. This confirmed that the modelling software was correctly interpreting the existing parameter set. Various configurations of the cell were then modelled, and the results discussed at the final visit in January 1996.

In this case study, the results for the extrusion area will be presented first, followed by those for the underground assemblies.

7.6.2 Overview of the Manufacturing Process - Extrusion.

The manufacturing process consisted of a standard plastic extrusion operation, with 8 extrusion machines working on a 5 day, 3 shift system. The first two hours of the week for each line are taken up with heating the extrusion machine up to its working temperature. Once at temperature, the line is run continuously until the work scheduled for the line that week is completed. Each line comprises of an extrusion machine and a cutting machine, the extruded moulding being continually produced, cut to length, and palletised.

The 113 items considered consisted of 11 product ranges comprising of circular section soil pipes from 32mm through to 110mm diameter, a 19mm circular section overflow pipe, circular section underground drain pipes from 82mm through 200mm, 105mm and 131mm half round gutters, 120mm and 137mm rectilinear gutters, a 69mm circular section rainwater down pipe, and 62mm and 75mm square section rainwater down pipes. The items were produced in up to four colours, white, rust, grey and black, and from 2.5 metres to 6.0 metres in length.

There were basically three levels of set-up, a change of mould taking either two, four or six hours, depending on the size of mould, a change of colour taking one hour, and a change of length taking zero minutes.

The investigation only considered the extrusion operation. As the raw material into this operation was common between items, consisting of plastic granules and master batch, the time phasing of any raw material stock supply would not be affected by any changes made in the component manufacture.

7.6.3 Determination of set-up times - Extrusion.

The approach used within the research to calculate the theoretical changeover is to identify a hierarchy of set-ups, with one value per level, where the time spent on set-up could reasonably be minimised through good sequencing practice. Clearly, to minimise the set-ups in this instance, the first objective would be to minimise the number of mould changes of 120, 240 or 360 minutes by identifying where the same mould was used by more than one item. The second objective would be to minimise the number of colour changes of 60 minute duration. The set-up cost is calculated by multiplying the set-up time by an hourly rate of twenty pounds. Within the 113 items being considered, all were capable of benefiting from a sequence dependent set-up.

The situation at Caradon Terrain can be summarised as follows:

- A change of mould taking either two, four or six hours, at a cost of £40, £80 or £120.
- A change of colour taking one hour, at a cost of £20.
- A change of length taking zero minutes, at a cost of £0.

This gave three different kinds of set-up hierarchy:

- A set-up group with Mould, Colour and Length changes.
- A set-up group with Mould and Colour changes.
- A set-up group with Mould and Length changes.

Within each of the set-up groups, the item with the highest annual usage value was allocated the relevant mould change set-up time and cost. Where different colour extrusions were made, the item with the highest annual usage value in each colour sub set-up group was allocated a colour change set-up time and cost. Where different lengths were made, each item not already allocated a set-up cost and time was allocated the length change set-up cost and time.

7.6.4 Calculation of current position - Extrusion.

As Caradon Terrain were already mature users of K-Curve, the items had already been arranged into period order day classes based on the annual usage value of each item. As a geometric progression was used, it was possible to make full allowance for set-up reductions.

The current batching rules were analysed and the average base (exclusive of safety stocks etc.) inventory levels, the annual order load and the average capacity load which would result from the current batching parameters was derived. This was first run historically to establish how well the existing batching rules, capacities and routing data were at predicting the actual usages, number of actual batches and inventory levels. After some adjustment of errors in both data and interpretation, Caradon Terrain were confident that the output from the model was accurate enough to continue with the test using forecasted, rather than historical, data. This provided the following results:

Extrusion - Current Position	
Daily Capacity (mins)	10,752 mins
Daily Run Load (mins)	3,912 mins
% Run	60%
Daily Set-up Load (mins)	481 mins
% Set-up	4%
Available Capacity (mins)	6,359 mins
% Load	41%
Annual Usage Value	£3,578,522
Annual Order Load	1,317 orders
Average Inventory Value	£93,713
Stock Turns	38

Table 7.36 - Caradon Extrusion - Current Position.

The weekly capacity was stated as 114 hours per machine, less 2 hours per week to bring each machine up to temperature. As there were 8 extrusion machines the total theoretical weekly capacity was 896 hours (112 * 8), giving a total daily capacity of 10,752 minutes (896 * 60 / 5). The daily run load is the calculated annual capacity load required to produce the estimated annual demand forecast divided by 245, the number of working days per annum. The daily set-up load is the annual total set-up load divided by 245. The available capacity is the daily capacity less the sum of the daily run load and the daily set-up load. The % run % set-up and % load are calculated as the % of the daily capacity spent on the relevant activity.

The annual usage value is the total value at cost of the estimated annual demand forecast. The annual order load refers to the number of orders generated using the stated order policy and estimated annual demand forecast. The average inventory £ refers to the inventory held downstream from the moulding operation and assumes a standard 'saw tooth' decay of stock. This figure does not include policy stocks such as safety. The stock turns is the annual usage value divided by the average inventory value.

What this benchmark standard does is to establish a set of performance criteria that the extrusion facility can already meet, the next stage is to compare the results of using the current operating parameters with the those that would have been obtained using the standard EBQ formula.

7.6.5 Comparison with standard EBQ - Extrusion.

The next step was to compare this with what would have been the result using the standard EBQ equation, assuming a 20% inventory holding rate per annum. This provided the following results:

Extrusion - EBQ vs. Current Position		
	EBQ	Current Position
Daily Capacity		10,752 mins
Daily Run Load		3,912 mins
% Run		60%
Daily Set-up Load	507 mins	481 mins
% Set-up	5%	4%
% of current	105%	
Available Capacity	6,333 mins	6,359 mins
% Load	41%	41%
Annual Usage Value		£3,578,522
Annual Order Load	679 orders	1,317 orders
Order % of current	52%	
Average Inventory £	£170,851	£93,713
Inventory % of current	182%	
Stock Turns	21	38

Table 7.37 - Caradon Extrusion - EBQ vs. Current Position.

The EBQ was a very close match to the existing position in terms of the capacity used, with a 5% (26 minutes per day) increase in the time spent on set-up. The number of orders reduced by 48%, from 1,317 per annum to 679 per annum, but there was an increase in inventory of £77,137 to 182% of the current level. Taking the current position as 100%, the results, when plotted, are as follows:

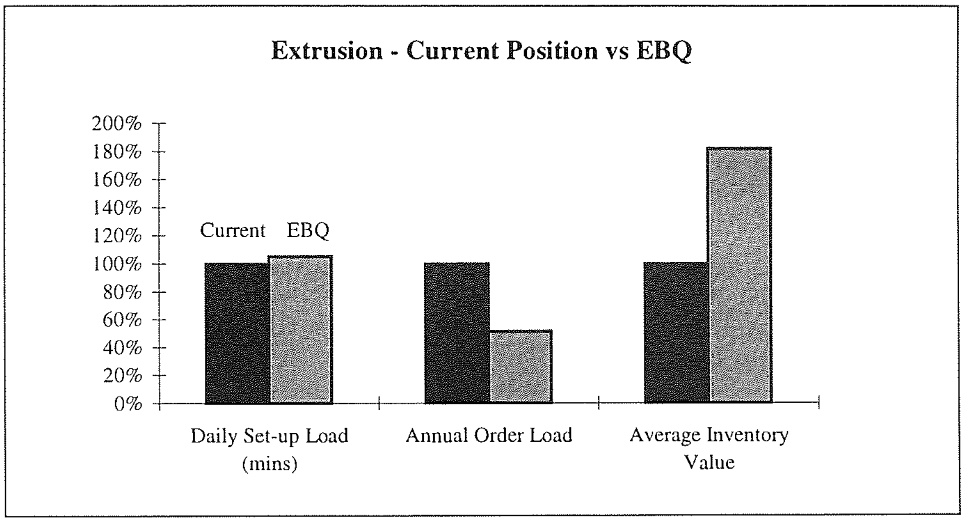

Figure 7.22 - Caradon Extrusion - EBQ vs. Current Position.

The EBQ performance was relatively poor when compared with the current situation mainly because it was not possible to take account of potential savings in set-up times when calculating the capacity load, with a mould change set-up being assumed for each item.

7.6.6 The Modelling Process - Extrusion.

Having accepted the validity of the approach, the first objective was to establish a set-up time and cost for each of the items, assuming that a geometric progression would be used for the period order day classes. The inventory holding rate per annum was taken as 20%.

Using the modelling software and matching on the current capacity load levels from the current position, the following results were obtained:

Extrusion - Capacity Match vs. Current Position		
	Capacity Match	Current Position
Daily Capacity		10,752 mins
Daily Run Load		3,912 mins
% Run		60%
Daily Set-up Load	483 mins	481 mins
% Set-up	4%	4%
% of current	100%	
Available Capacity	6,357 mins	6,359 mins
% Load	41%	41%
Annual Usage Value		£3,578,522
Annual Order Load	1,926 orders	1,317 orders
Order % of current	146%	
Average Inventory £	£66,671	£93,713
Inventory % of current	71%	
Stock Turns	54	38

Table 7.38 - Caradon Extrusion - Capacity Match vs. Current Position.

The match on capacity showed that a reduction of the average base inventory value to 71% of the current level may be possible through altering the batching rules as per the model recommendations, an inventory saving in the order of £27,000. The set-up load increased by 2 minutes daily, and the number of orders required to support this policy increased by 609 when compared with the current position. Taking the current position as 100% the results, when plotted, are as follows:

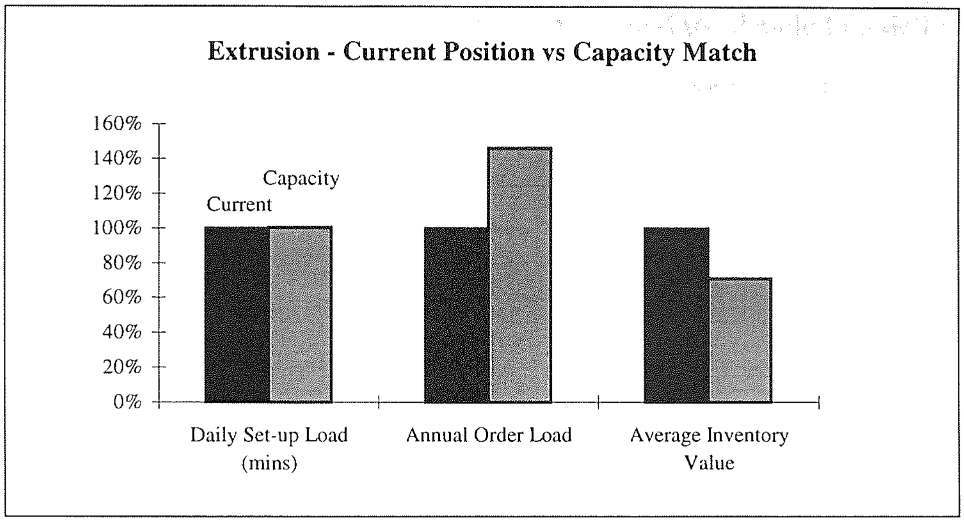

Figure 7.23 - Caradon Extrusion - Capacity Match vs. Current Position.

What this illustrates is that is theoretically possible to improve on the current position in terms of average base inventory value, although at a cost of the extra order workload, whilst not increasing the capacity load.

7.6.7 Conclusions - Extrusion.

As Caradon Terrain were already mature users of the original K-Curve, and had set their current extrusion period order day classes according to the KCM recommendations, it was not expected that great improvements would be found, but it was possible to show substantial improvements were possible in average base inventory value when matching on the current capacity utilisation.

In the light of these figures, Caradon Terrain were set to implement the recommendations when they acquired a competitor, Rymway. Rymway was based in Leeds, and it was originally intended to retain the two manufacturing and distribution centres, with certain production equipment moving between each centre. So, the implementation was put on hold while the consolidation of the two companies took place. However, over the course of the next two years, the entire Rymway manufacturing operation in Leeds was closed down and moved to the Caradon Terrain site at Maidstone. With the extended timescales associated with this consolidation and re-organisation, the implementation never took place. But, a further exercise was undertaken for Caradon Terrain, in the investigation into the setting up of a cellular manufacturing facility for underground assemblies.

The modelling of extrusion allowed Caradon Terrain to assess their confidence in the modelling process and the modeller. They were already familiar with the KCM, and were probably the only set of users who actually fully understood the detailed modelling process. The concentration on the three key performance indicators, Capacity, Administrative Workload, and Inventory Value, allowed them to quantitatively compare the results of the various scenarios and to assess its overall applicability. The modelling process increased their understanding of the way in which the batching rules impacted on the overall performance of extrusion, brought to light certain data errors, and prompted a dialogue regarding the way in which the approach could be used improve their operational effectiveness without impacting upon their customer service levels.

Taking the model validation process previously described, Caradon Terrain concluded, like Boots, that with the level of data validity that the approach was operating at an appropriate level, and that the results obtained from the modelling process were sufficiently accurate to be of use in a live situation and as a comparison between different scenarios. They believed that the results were overall of use, and acceptable, and in the case of extrusion were capable of being implemented without manual intervention.

The methodology used helped this acceptance by, firstly, verifying that the model was producing results which were intended, secondly, validating that the modelling was addressing pertinent questions, thirdly, ensuring that the results considered factors that were relevant, and finally that the results were good enough to be of use in the particular context of extrusion. The basic criteria used by Caradon Terrain for assessing the exercise and deciding to continue on to a full trial in a live area were:

- Do we understand the details of the modelling process?
- Does the modelling produce meaningful results?
- Are the results useful?
- Do we trust the modelling process?
- Can we work with the modeller? and
- Do we trust the results sufficiently to adopt them?

7.6.8 Overview of the Manufacturing Process - Underground Components.

The items considered were all assemblies produced for the buried drain range of products and consisted of one or more plastic mouldings assembled together to form a finished goods item. The range of products was a combination of those produced previously by Caradon Terrain and those produced by Rymway. The manufacturing process consisted of two operation steps, a series of plastic moulding operations and a hand assembly operation producing a total of 73 distinct finished goods items.

The set-up for the assembly operation was zero, and for the moulding operation was either three, four, eight or twelve hours depending upon the mould size. There were no sequence dependent set-ups. The set-up cost is calculated by multiplying the set-up time by an hourly rate of twenty pounds.

To create the cell, the assembly operation was fully dedicated with five personnel working a single shift. The moulding operation was more complex, with six moulding machines fully dedicated to producing thirty seven of the items, with the remaining thirty six mouldings being manufactured on moulding machines producing for a mixture of product ranges.

As the assembly operation had a zero set-up, the capacity utilisation would theoretically remain constant whatever the batch size, so the only check required on assembly was whether there was sufficient overall capacity to produce the stated quantities of each product. This check showed that taking all seventy three items with the stated annual quantities, and a manning level of five, that the available daily capacity would be 2,400 minutes (8 * 5 * 60), and the load 2,223 minutes, a load factor of 93%.

If the moulding operation is now considered, then it was possible to model the performance of the thirty seven items produced on the six dedicated moulding machines, but not possible to model the remaining thirty six items without considering all the other, non underground, moulded items produced on the other moulding machines. Accordingly, the investigation was limited, apart from the assembly capacity check, to the thirty seven items produced on the six dedicated moulding machines.

7.6.9 Calculation of current position - Underground Components.

As Caradon Terrain were already mature users of K-Curve, the items had already been arranged into period order day classes based on the annual usage value of each item. As a geometric progression was used, it was possible to make full allowance for set-up reductions.

The current batching rules were analysed and the average base (exclusive of safety stocks etc.) inventory levels, the annual order load and the average capacity load which would result from the current batching parameters was derived. This was first run historically to establish how well the existing batching rules, capacities and routing data were at predicting the actual usages, number of actual batches and inventory levels. After some adjustment of errors in both data and interpretation, Caradon Terrain were confident that the output from the model was accurate enough to continue with the test using forecasted, rather than historical, data. This provided the following results for the moulding operation:

Underground Cell - Current Position	
Daily Capacity (mins)	2,880 mins
Daily Run Load (mins)	1,618 mins
% Run	56%
Daily Set-up Load (mins)	390 mins
% Set-up	14%
Available Capacity (mins)	872 mins
% Load	70%
Annual Usage Value	£600,050
Annual Order Load	295
Average Inventory Value	£28,103
Stock Turns	21

Table 7.39 - Caradon Underground Cell - Current Position.

The weekly capacity was stated as 40 hours per machine and as there were 6 moulding machines the total theoretical weekly capacity was 240 hours (40 * 6), giving a total daily capacity of 2,880 minutes (240 * 60 / 5). The daily run load is the calculated annual capacity load required to produce the estimated annual demand forecast divided by 245, the number of working days per annum. The daily set-up load is the annual total set-up load divided by 245. The available capacity is the daily capacity less the sum of the daily run load and the daily set-up load. The % run % set-up and % load are calculated as the % of the daily capacity spent on the relevant activity.

The annual usage value is the total value at cost of the estimated annual demand forecast. The annual order load refers to the number of orders generated using the stated order policy and estimated annual demand forecast. The average inventory £ refers to the inventory held downstream from the moulding operation and assumes a standard 'saw tooth' decay of stock. This figure does not include policy stocks such as safety. The stock turns is the annual usage value divided by the average inventory value.

What this benchmark standard does is to establish a set of performance criteria that the extrusion facility can already meet, the next stage is to compare the results of using the current operating parameters with the those that would have been obtained using the standard EBQ formula.

7.6.10 Comparison with standard EBQ - Underground Components.

The next step was to compare this with what would have been the result using the standard EBQ equation, assuming a 20% inventory holding rate per annum. This provided the following results:

Underground Cell - EBQ vs. Current Position		
	EBQ	Current Position
Daily Capacity		2,880 mins
Daily Run Load		1,618 mins
% Run		56%
Daily Set-up Load	135 mins	390 mins
% Set-up	5%	14%
% of current	35%	
Available Capacity	1,127 mins	872 mins
% Load	61%	70%
Annual Usage Value		£600,050
Annual Order Load	111	295
Order % of current	38%	
Average Inventory £	£54,956	£28,103
Inventory % of current	196%	
Stock Turns	11	21

Table 7.40 - Caradon Underground Cell - EBQ vs. Current Position.

Due to the large set-up costs, the EBQ created large batch sizes which used substantially less capacity than the current batching rules. There was a 65% (255 minutes per day) decrease in the time spent on set-up. The number of orders reduced by 62%, from 295 per annum to 111 per annum, and there was an increase in inventory of roughly £27,000 to 196% of the current level. Taking the current position as 100%, the results, when plotted, are as follows:

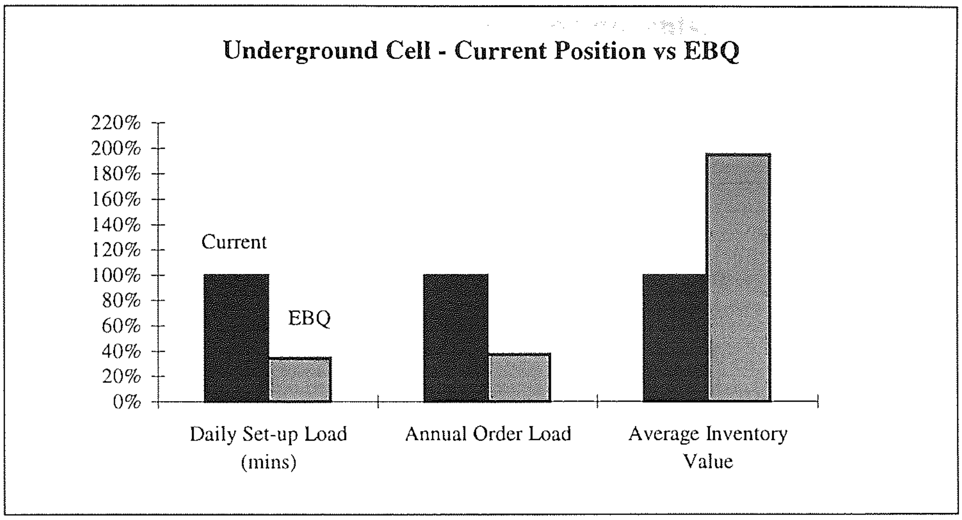

Figure 7.24 - Caradon Underground Cell - EBQ vs. Current Position.

What this does graphically illustrate is that the raw EBQ results can be somewhat wide of the mark as regards to effectiveness in this type of situation.

7.6.11 The Modelling Process - Underground Components.

Using the modelling software and matching on the current capacity load levels from the current position, the following results were obtained:

Underground Cell - Capacity Match vs. Current Position		
	Capacity Match	Current Position
Daily Capacity		2,880 mins
Daily Run Load		1,618 mins
% Run		56%
Daily Set-up Load	410 mins	390 mins
% Set-up	14%	14%
% of current	105%	
Available Capacity	852 mins	872 mins
% Load	70%	70%
Annual Usage Value		£600,050
Annual Order Load	307	295
Order % of current	104%	
Average Inventory £	£20,378	£28,103
Inventory % of current	73%	
Stock Turns	29	21

Table 7.41 - Caradon Underground Cell - Capacity Match vs. Current Position.

The match on capacity showed that a reduction of the average base inventory value to 73% of the current level may be possible through altering the batching rules as per the model recommendations, an inventory saving in the order of £7,700. The set-up load increased by 20 minutes daily, and the number of orders required to support this policy increased by 12 when compared with the current position. Taking the current position as 100% the results, when plotted, are as follows:

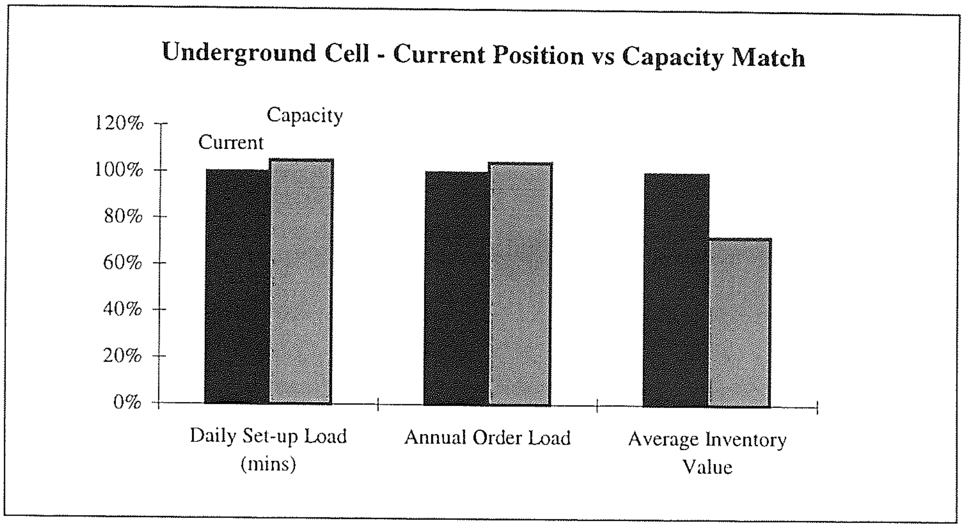

Figure 7.25 - Caradon Underground Cell - Capacity Match vs. Current Position.

What this illustrates is that is theoretically possible to reduce the current position in terms of average base inventory value by 27%, with only a 4% increase in order workload, and a 5% increase in the capacity load.

7.6.12 Conclusions - Underground Components.

As Caradon Terrain were already mature users of the original K-Curve, and had set their current moulding period order day classes according to the KCM recommendations, it was not expected that great improvements would be found, but it was possible to show substantial improvements were possible in average base inventory value when matching on the current capacity utilisation.

In this exercise, a different value of K was used for each machine, to allow the capacity load to be matched on a machine by machine basis.

So, why did Caradon Terrain look to use the approach again? One reason must be that they had confidence in the way the modelling worked, and the results it produced, and were looking for ways to increase the effectiveness and responsiveness of their manufacturing operations. Another reason was undoubtedly political, in that they were completing the consolidation of two businesses onto one site, and there were substantial job losses taking place. In these circumstances it does no harm to be seen to be seen to be actively investigating other ways of organising the business, and to use an outsider in this role is a classic way of achieving this, especially if the modelling is done for free.

No decision was made with regard to the setting up of a cell to manufacture Underground Components. Certainly the modelling exposed the main weakness in the outline cell design, that of implementing a partial Group Technology, partly Process Orientation solution. It therefore proved impossible to successfully model the totality of the moulding operations, and so could lead to unbalanced production in the assembly area if the flow was not tightly controlled between the Group Technology and Process Orientation areas.

7.7 ZENECA PHARMACEUTICALS.

7.7.1 Introduction.

Zeneca is a leading international bioscience group which researches, develops, manufactures, and markets products in three business areas:

- Pharmaceuticals
- Agrochemicals, and
- Specialities

It has manufacturing operations in 25 countries, markets products in over 100 and employs 30,000 personnel world-wide. In 1996 it had total sales of £5.4 billion, made an operating profit of £1.04 billion and invested £602m in research and development, of which the Pharmaceutical division had sales of £2.4 billion and generated £757m operating profit. In the UK, Zeneca Pharmaceuticals has 3 manufacturing plants, at Macclesfield, Wilmslow and Abingdon.

This case study is concerned with tablet production at the Macclesfield manufacturing plant, providing a 'health check' on the current planning parameters, and using the methodology to model the effects of process and / or set-up improvements.

All of the pharmaceuticals involved in this study are available on prescription only for the treatment of cardiovascular disorders, such as the beta blockers Inderal and Tenormin. As these types of medicines are prescribed for chronic conditions, the patients continue to take them until they die, and so there is a relatively stable demand pattern.

The investigation method used was the same as that for Boots and Rhône Poulenc Rorer, and covered a period of 6 months from April to November 1995.

The initial contact at Zeneca took place by telephone in April 1995 and was with the Master Production Scheduling (MPS) Manager for the Tablets factory at the Macclesfield site in Cheshire, and was made through the Pharmaceuticals Special Interest Group (PSIG) Benchmarking Club organised by the Institute of Operations Management (IOM). This led to a meeting on site at Macclesfield in May 1995, with MPS Manager, the Production Controllers for Tablet Processing and for Tablet Packaging, and the Master Production Scheduler responsible for Business System Re-engineering. At this meeting the current Zeneca working practices, the areas of concern, and the scope and applicability of the research were discussed, and two key concerns were raised which coincided with the research area, the first of these was inventory reduction, and the second was a simplification of the existing scheduling practices. Zeneca agreed in principle to proceed with the relationship at this meeting.

The next meeting took place in June 1995, to look at the manufacturing processes, the MRP system, meet the production staff, and discuss the data requirements. From this meeting onwards the prime contact with Zeneca was the Master Production Scheduler responsible for Business System Re-engineering. The only major concern for Zeneca in participating with public domain research was that of having their costs and manufacturing volumes exposed to public scrutiny, especially when other pharmaceutical companies were being approached with a view to participating in the research. This was overcome by translating the product details prior to passing them over to the researcher. At this point the collaboration had two specific purposes for Zeneca, inventory reduction and the simplification of the process management, and each local factory was at that point in time responsible for co-ordinating its own improvement programme. The relationship was informal in the sense that goals, responsibilities, authorities and timescales were never contractually agreed, rather the participants formed an informal project team with the purpose of testing the validity of the approach in the context of addressing the identified areas of concern.

A further meeting was arranged later in June 1995 with a representative of the information systems department to arrange for the data required for the modelling process to be extracted. This was initially available in mid July 1995, but required further explanation regarding the meaning of order policy codes, the identification of set-up groups, set-up costs, set-up times and the correction of errors in the run times, and was eventually free of errors by the mid August 1995. There then followed a period of 5 to 6 weeks where further trials of the model took place, to investigate various scenarios that Zeneca wanted to examine, the flexibility of the approach, the interaction of the team members, and their confidence in the capabilities of the model and the modeller. Some modifications to the software took place in this period, so the response to the various scenarios varied from the same day, where no modification was required, to the next week, where changes to the software had to be programmed, tested and implemented.

At the end of this process Zeneca were confident that the modelling process was of use, increased the level of understanding of the MRP system, produced results that were reasonable, understandable and acceptable, gained the acceptance and commitment of the users, and could be used as a quantitative method for comparing various inventory reduction strategies. It was on this basis that Zeneca decided to stop the modelling process in November 1995 and proceed on to a live implementation, initially scheduled to take place in February 1996.

However, events were overtaken by the Laser project, which took control of the Business Process Re-Engineering (BPR) improvement programme away from the local management, and into the hands of external consultants controlled centrally. The details of the modelling exercise, the methodology used, and the results obtained were passed on to the consultants who also requested a copy of the software.

7.7.2 Overview of the manufacturing process.

The manufacturing process consisted of 5 steps, dispensing, granulation, tablet making, coating and packaging, with each step undertaken as a discrete batch operation. The tablet manufacturing process is essentially the same as that already described in detail for the Boots D95 Tablet Factory.

This study considers the packaging step, comprising of six lines, and is basically concerned with the downstream stock from the packaging operation. Although each of the tablets has a validated manufacturing batch size, the current packaging batch size was set according to either a period order day classification (166 items), a fixed batch quantity (24 items) or discrete (6 items) parameter setting, and there were existing inter process stocks between tablet manufacturing and packaging which were not necessarily consumed in a packaging run.

There were two levels of set-up, as follows:

- A change of formulation or strength of tablet requiring a complete strip down and clean of the line, taking either 516, 372, 284,156, 148, 126, or 116 minutes.
- A change of leaflet taking 30 minutes.

There were 26 groups of tablets sharing identical formulations and strengths within each group, comprising 173 of the 196 SKU's. The remaining 23 tablets had unique formulations and strengths.

Five of the six lines has a stated capacity of 347 minutes per day, the other line being available for 283 minutes per day, giving a total daily capacity of 2,018 minutes ((347 * 5) + 283).

7.7.3 Determination of set-up times.

The approach used within the research to calculate the theoretical changeover is to identify a hierarchy of set-ups, with one value per level, where the time spent on set-up could reasonably be minimised through good sequencing practice. Clearly, to minimise the set-ups in this instance, the first objective would be to minimise the number of formulation changes by identifying where the same formulation was used by more than one SKU.

Within the 196 SKU's being considered, there were 173 tablets in 26 set-up groups which were capable of benefiting from a sequence dependent set-up, as follows:

Set-Up Group	Major set-up time (mins)	Major set-up cost (£)	Minor set-up time (mins)	Minor set-up cost (£)
A	516	£430.00	30	£25.00
B	116	£96.67	30	£25.00
C	116	£96.67	30	£25.00
D	116	£96.67	30	£25.00
E	116	£96.67	30	£25.00
F	116	£96.67	30	£25.00
G	116	£96.67	30	£25.00
H	126	£105.00	30	£25.00
I	148	£123.33	30	£25.00
J	116	£96.67	30	£25.00
K	116	£96.67	30	£25.00
L	116	£96.67	30	£25.00
M	116	£96.67	30	£25.00
N	116	£96.67	30	£25.00
O	156	£130.00	30	£25.00
P	156	£130.00	30	£25.00
Q	156	£130.00	30	£25.00
R	156	£130.00	30	£25.00
S	156	£130.00	30	£25.00
T	156	£130.00	30	£25.00
U	156	£130.00	30	£25.00
V	372	£310.00	30	£25.00
W	116	£96.67	30	£25.00
X	116	£96.67	30	£25.00
Y	372	£310.00	30	£25.00
Z	116	£96.67	30	£25.00

Table 7.42 - Zeneca - Determination of set-up times and costs.

7.7.4 Calculation of current position.

The current batching rules of the six packing lines were analysed and the average base (exclusive of safety stocks etc.) inventory levels, the annual order load and the average capacity load which would result from the current batching parameters was derived. This was first run historically to establish how well the existing batching rules, capacities and routing data were at predicting the actual usages, number of actual batches and inventory levels. After some adjustment of errors in both data and interpretation, Zeneca were confident that the output from the model was accurate enough to continue with the test using forecasted, rather than historical, data.

This provided the following results:

Zeneca - Current Position	
Daily Capacity (mins)	2,018 mins
Daily Run Load (mins)	1,112 mins
% Run	55%
Daily Set-up Load (mins)	601 mins
% Set-up	30%
Available Capacity (mins)	305 mins
% Load	85%
Annual Usage Value	£140,762,000
Annual Order Load	2,160 orders
Average Inventory Value	£7,460,057
Stock Turns	19

Table 7.43 - Zeneca - Current Position.

The total daily capacity of the six lines being considered was stated as 2,018 minutes. The daily run load is the calculated annual capacity load required to produce the estimated annual demand forecast divided by 240, the number of working days per annum. The daily set-up load is the annual total set-up load divided by 240, and takes full advantage of sequence dependent set-up reductions. The available capacity is the daily capacity less the sum of the daily run load and the daily set-up load. The % run % set-up and % load are calculated as the % of the daily capacity spent on the relevant activity.

The annual usage value is the total value at cost of the estimated annual demand forecast. The annual order load refers to the number of orders generated using the stated order policy and estimated annual demand forecast. The average inventory £ refers to the inventory held downstream from the packing lines and assumes a standard 'saw tooth' decay of stock. This figure does not include policy stocks such as safety. The value of the stocks of the 'upstream' components (pharmaceuticals, packaging etc.) has not been calculated and no assumptions have been made concerning their delivery frequencies or order sizes. The stock turns is the annual usage value divided by the average inventory value.

What this benchmark standard does is to establish a set of performance criteria that the facility can already meet, the next stage is to compare the results of using the current operating parameters with the those that would have been obtained using the standard EBQ formula.

7.7.5 Comparison with standard EBQ.

The next step was to compare this with what would have been the result using the standard EBQ equation, assuming a 15% inventory holding rate per annum. This provided the following results:

Zeneca - EBQ vs. Current Position		
	EBQ	Current Position
Daily Capacity		2,018 mins
Daily Run Load		1,112 mins
% Run		55%
Daily Set-up Load	1,826 mins	601 mins
% Set-up	90%	30%
% of current	304%	
Available Capacity	(919 mins)	305 mins
% Load	146%	85%
Annual Usage Value		£140,762,000
Annual Order Load	3,007 orders	2,160 orders
Order % of current	139%	
Average Inventory £	£2,398,693	£7,460,057
Inventory % of current	32%	
Stock Turns	59	19

Table 7.44 - Zeneca - EBQ vs. Current Position.

The EBQ was a considerable improvement on the existing position in terms of the average inventory value, with a £5m decrease (68%) in average stock leading to an increase in stock turns from 19 per annum to 59 per annum. It required almost 900 more orders per annum to support the EBQ recommendations, and the capacity requirements increased approximately by 1,200 minutes per day, completely overloading the packaging lines. Taking the current position as 100%, the results, when plotted, are as follows:

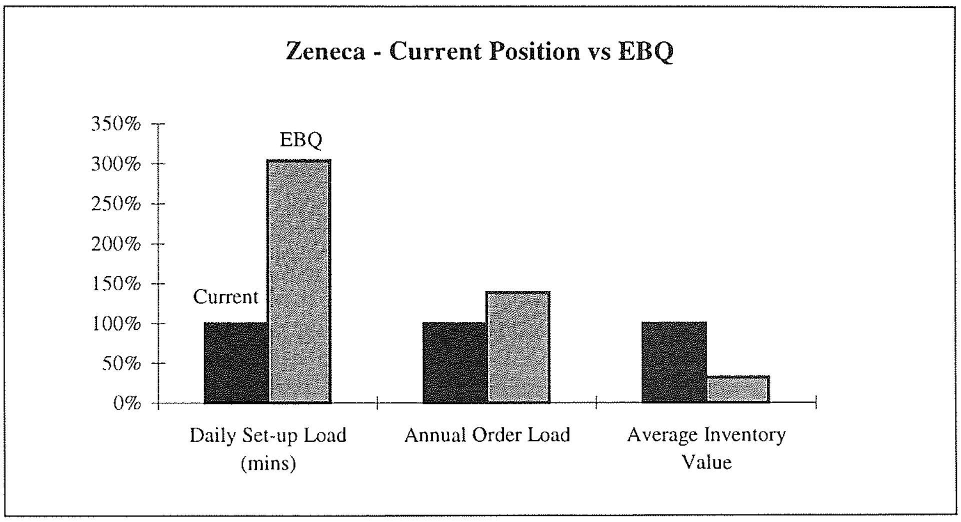

Figure 7.26 - Zeneca - EBQ vs. Current Position.

The EBQ was effective at reducing the average inventory value, however it performed extremely poorly in terms of the capacity usage. This was partly due to there being no assumption of any savings in the set-up times or costs being taken into account, with the major set-up time being used for each item.

7.7.6 The Modelling Process.

Having accepted the validity of the approach, the first objective was to establish a set-up time and cost for each of the items, assuming that a geometric progression would be used for the period order day classes. This entailed allocating a major set-up to the highest annual usage value item within each tablet group, and the remaining items allocated a 30 minute changeover.

Using the modelling software and matching on the current capacity load levels from the current position, the following results were obtained:

Zeneca - Capacity Match vs. Current Position		
	Capacity Match	Current Position
Daily Capacity		2,018 mins
Daily Run Load		1,112 mins
% Run		55%
Daily Set-up Load	602 mins	601 mins
% Set-up	30%	30%
% of current	100%	
Available Capacity	304 mins	305 mins
% Load	85%	85%
Annual Usage Value		£140,762,000
Annual Order Load	1,694 orders	2,160 orders
Order % of current	78%	
Average Inventory £	£4,375,941	£7,460,057
Inventory % of current	59%	
Stock Turns	32	19

Table 7.45 - Zeneca - Capacity Match vs. Current Position.

The match on capacity showed that a reduction of the average base inventory value to 78% of the current level may be possible through altering the batching rules as per the model recommendations, together with an average base inventory saving of over of £3m. The set-up load increased by 1 minutes daily, and the number of orders required to support this policy decreased by nearly 500 when compared with the current position. Taking the current position as 100% the results, when plotted, are as follows:

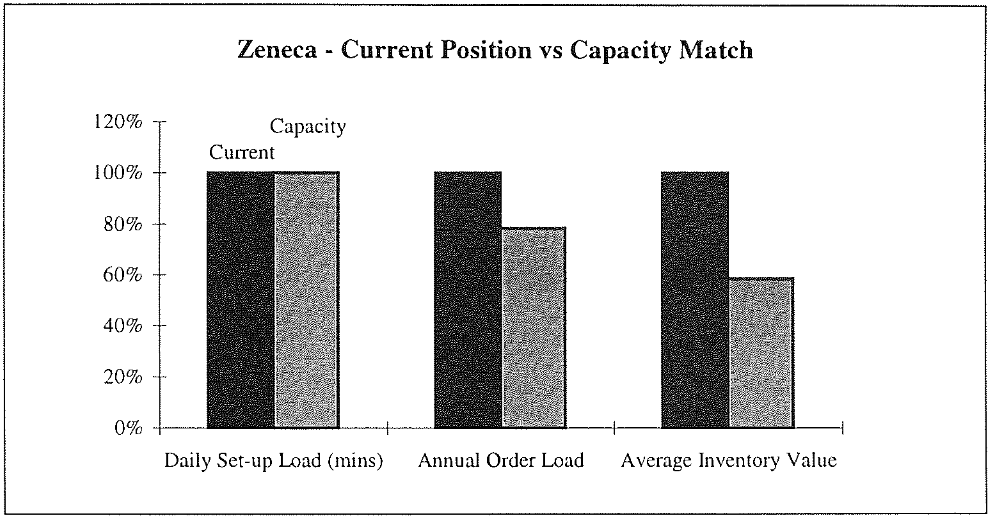

Figure 7.27 - Zeneca - Capacity Match vs. Current Position.

What this illustrates is that is theoretically possible to either improve on or match the current position in all three dimensions: in terms of average base inventory value, in terms of annual order load and in terms of capacity utilisation. Obviously, the saving was not £3m, as there was no account taken of the certified manufacturing batch sizes, which were not to be changed, however there were gains in flexibility to be had, as the unpackaged tablets were capable of being packed in any of the country variations.

7.7.7 Conclusions.

Up to this point the main drive within the company had been to ensure continuity of supply, rather than to reduce batch sizing or to look at more effective line sequencing. With the results of the modelling, there was a recognition that substantial savings in base inventory were there to be made. In order to implement any changes, the manufacturing and sales organisations within Zeneca needed to formulate a plan to ensure that supply continuity was maintained to the customer, that the planning parameters for sales reflected the revised packing frequencies, that the move to the revised packing frequencies was accomplished whilst keeping the packing and manufacturing busy, and that the packaging suppliers delivered in line with the revised packaging schedule.

Whilst this consultation process was being undertaken, the implementation was overtaken by events affecting the company as a whole, in that a major BPR (Business Process Re-engineering) exercise was started, called Laser, using an outside consultancy firm. The effect this had was that all changes to working practices were suspended, and the findings of the research, and details of the methodology used were passed on to the Laser project team.

Without this BPR exercise intervening, Zeneca seemed well on the way to implementing the recommendations, and then going on to look at a structured set-up reduction programme to further increase their flexibility. The modelling work that was done was accepted, championed, and would have been acted upon by the Zeneca local management team without the intervention of the company wide BPR exercise. From discussions with the local Tablet factory management it would appear that the results obtained from this exercise have been incorporated and repackaged within the Laser project.

In conclusion, the local Tablet factory management were pleased with their involvement with the research and found it *'a thought provoking exercise'* which helped them to address areas for improvement *'avoiding some of the factory politics'* due to the perceived independence of the researcher. The modelling process was deemed by them to be useful in aiding the decision making process, in that they had decided to proceed with an implementation based on the results of that process, and had performed a large amount of preparatory work for this prior to its cancellation. Not all the scenarios modelled were feasible, but the modelling process did assist in defining the theoretical limits within which it was possible to operate, and was *'invaluable in modelling the effect of change'*.

That the users were committed to the process is shown by their willingness to adopt and champion the results with the site executive, and obtain permission to proceed with the implementation.

7.8 COMPARISON OF RESULTS FROM THE DIFFERENT MODELLING METHODS.

7.8.1 Introduction.

All of the results presented for each of the five companies and the seven case studies were comparisons between the current position, the EBQ and the Group Item method of allocating set-up costs to items. The method chosen for presentation in the case studies was that which required the lowest base inventory value, whilst matching on the desired capacity constraint. Capacity was the overriding constraint for the companies, and inventory reduction the next priority. The number of orders, a measure of the administrative and order kitting workloads, was not a perceived problem for the participating companies.

In order to establish which of the modelling methods produced the 'best' results, according to the above criteria, modelling was performed for each of the case studies using each of the four methods. In each case, the Group Item set-up allocation method produced the lowest average base inventory value when matching on a capacity limitation, and so was the method of choice for comparison. The EBQ produced very erratic results, when considering capacity as the prime constraint, and was not able to benefit from planned set-up reductions as the batch size for each item was calculated to minimise the inventory and orders at an individual item level, rather than considering the wider picture.

The results produced by the other modelling methods when matching on the existing capacity load can now be considered, for each of the seven case studies.

7.8.2 Boots D95 Tablet Factory.

In this model, of the 30 SKU's being considered there were only two set-up groups containing 6 SKU's. The results obtained for each method when matching on the existing capacity load were as follows:

Method	Orders per Year	Av. Inv. £	Daily set-up mins	Order % of current	Inv. £ % of current
Current	155.5	£458,867	320		
Group Item	186.0	£368,637	329	120%	80%
No set-up	169.5	£385,859	316	109%	84%
Item set-up	174.0	£388,841	310	112%	85%
Group Total	186.0	£371,889	316	120%	81%

Table 7.46 - Boots D95 - Comparison Results vs. Current Parameters.

From the above table of results, the Group Item method produced the lowest average base inventory value, but at the expense of the number of orders raised. All of the methods were able to reduce the base inventory value substantially whilst matching on the current set-up load. When compared to the Group Item method, the other three methods produce the following results:

Method	Orders per Year	Av. Inv. £	Order % of G. Item	Inv. £ % of G. Item
Group Item	186.0	£368,637		
No set-up	169.5	£385,859	91%	105%
Item set-up	174.0	£388,841	94%	105%
Group Total	186.0	£371,889	100%	101%

Table 7.47 - Boots D95 - Comparison Results vs. Group Item Method.

In this comparison, the Group Total set-up method produced an almost identical result, and the Item set-up and No set-up methods exchanged inventory for orders.

7.8.3 Boots D106 Sterile Products.

In this model it was possible to schedule every item into a single period order day class of 8 weeks, and achieve the following results for each method:

Method	Orders per Year	Av. Inv. £	Annual set-up mins	Order % of current	Inv. £ % of current
Current	115.4	£235,831	29,202	100%	100%
All Methods	120.8	£162,926	26,048	105%	69%

Table 7.48 - Boots D106 - Comparison Results vs. Current Parameters.

In this case, once each of the items were allocated to the 8 week class, the number of orders generated, the average base inventory value, and the annual set-up load generated by each of the methods could only produce identical results.

7.8.4 Caradon Terrain - Underground Components.

In this model none of the 73 items were in a set-up group. The results obtained for each method when matching on the existing capacity load were as follows:

Method	Orders per Year	Av. Inv. £	Daily set-up mins	Order % of current	Inv. £ % of current
Current	295	£28,103	390		
All Methods	307	£20,378	410	104%	73%

Table 7.49 - Caradon Underground - Comparison Results vs. Current Parameters.

In this case, as there were no set-up groups, each of the lines was being loaded to the existing capacity utilisation, and the set-up cost within a line was constant, the number of orders generated, the average base inventory value, and the annual set-up load generated by each of the methods could only produce identical results.

7.8.5 Caradon Terrain - Extrusion.

In this model it was possible to schedule all of the 113 items into one of 19 set-up groups. The results obtained for each method when matching on the existing capacity load were as follows:

Method	Orders per Year	Av. Inv. £	Daily set-up mins	Order % of current	Inv. £ % of current
Current	1,317.0	£93,713	481		
Group Item	1,926.0	£66,671	483	146%	71%
No set-up	1,492.0	£80,982	483	113%	86%
Item set-up	1,561.0	£76,317	483	119%	81%
Group Total	2,646.0	£74,252	479	201%	79%

Table 7.50 - Caradon Extrusion - Comparison Results vs. Current Parameters.

From the above table of results, the Group Item set-up method produced the lowest average base inventory value, but at the expense of the number of orders raised. When compared to the Group Item method, the other three methods produce the following results:

Method	Orders per Year	Av. Inv. £	Order % of G. Item	Inv. £ % of G. Item
Group Item	1,926.0	£66,671		
No set-up	1,492.0	£80,982	77%	121%
Item set-up	1,561.0	£76,317	81%	114%
Group Total	2,646.0	£74,252	137%	111%

Table 7.51 - Caradon Extrusion - Comparison Results vs. Group Item Method.

In this comparison, the Group Total set-up method performed poorly, and the other two methods exchanged inventory for orders.

7.8.6 Rhône Poulenc Rorer.

In this model, all 36 items considered were in one of the four major set-up groups. The results obtained for each method when matching on the existing capacity load were as follows:

Method	Orders per Year	Av. Inv. £	Daily set-up mins	Order % of current	Inv. £ % of current
Current	253.0	£572,816	304		
Group Item	304.5	£363,345	301	120%	63%
No set-up	292.5	£373,454	306	116%	65%
Item set-up	304.5	£363,345	301	120%	63%
Group Total	325.5	£462,588	313	129%	81%

Table 7.52 - Rhône Poulenc Rorer - Comparison Results vs. Current Parameters.

From the above table of results, the Group Item and Item set-up methods jointly produced the lowest average base inventory value, but at the expense of the number of orders raised. When compared to the Group Item method, the other three methods produce the following results:

Method	Orders per Year	Av. Inv. £	Order % of G. Item	Inv. £ % of G. Item
Group Item	304.5	£363,345		
No set-up	292.5	£373,454	96%	103%
Item set-up	304.5	£363,345	100%	100%
Group Total	325.5	£462,588	107%	127%

Table 7.53 - Rhône Poulenc Rorer - Comparison Results vs. Group Item Method.

In this comparison, the Item set-up method produced an identical result, the Group Total set-up method performed poorly, the No set-up method exchanged inventory for orders.

7.8.7 FMCG.

In this model it was possible to schedule 68 of the 124 items into one of 18 set-up groups. The results obtained for each method when matching on the existing capacity load were as follows:

Method	Orders per Year	Av. Inv. £	Daily set-up mins	Order % of current	Inv. £ % of current
Current	1,877.0	£61,817	611		
Group item	1,840.0	£45,221	606	98%	73%
No set-up	1,681.0	£47,551	606	90%	77%
Item set-up	1,761.0	£46,944	610	94%	76%
Group Total	1,961.0	£50,322	603	104%	81%

Table 7.54 - FMCG - Comparison Results vs. Current Parameters.

All of the methods were able to improve on the current position in terms of average base inventory value and all but the Group Total set-up method showed an improvement in the number of orders raised. When compared to the Group Item method, the other three methods produce the following results:

Method	Orders per Year	Av. Inv. £	Order % of G. Item	Inv. £ % of G. Item
Group item	1,840.0	£45,221		
No set-up	1,681.0	£47,551	91%	105%
Item set-up	1,761.0	£46,944	96%	104%
Group Total	1,961.0	£50,322	107%	111%

Table 7.55 - FMCG - Comparison Results vs. Group Item Method.

In this comparison, the Group Total set-up method performed poorly, and the other two methods exchanged inventory for orders.

7.8.8 Zeneca Pharmaceuticals.

In this model it was possible to schedule 173 of the 196 items into one of 26 set-up groups. The results obtained for each method when matching on the existing capacity load were as follows:

Method	Orders per Year	Av. Inv. £	Daily set-up mins	Order % of current	Inv. £ % of current
Current	2,160	£7,460,057	601		
Group item	1,694	£4,375,941	602	78%	59%
No set-up	1,581	£4,663,610	594	73%	63%
Item set-up	1,629	£4,545,017	598	75%	61%
Group Total	2,732	£4,839,485	604	126%	65%

Table 7.56 - Zeneca - Comparison Results vs. Current Parameters.

All of the methods were able to improve on the current position in terms of average base inventory value and all but the Group Total set-up method showed an improvement in the number of orders raised. When compared to the Group Item method, the other three methods produce the following results:

Method	Orders per Year	Av. Inv. £	Order % of G. Item	Inv. £ % of G. Item
Group item	1,694	£4,375,941		
No set-up	1,581	£4,663,610	93%	107%
Item set-up	1,629	£4,545,017	96%	104%
Group Total	2,732	£4,839,485	161%	111%

Table 7.57 - Zeneca - Comparison Results vs. Group Item Method.

In this comparison, the Group Total set-up method performed poorly, and the other two methods exchanged inventory for orders.

7.8.9 Conclusions on comparisons of the different methods.

Within the seven case studies, there was one modelling method which consistently produced the 'best' results when matching on the current capacity usage with the objective of delivering the lowest average base inventory value, the modelling method was the Group Item set-up method.

The method which generally produced the 'worst' results when compared to those produced by the Group Item set-up method was the Group Total set-up method. Taking the Group Item set-up method as 100% in either axis, the Group Total set-up method produced the following results for the seven case studies:

Figure 7.28 - Relative performance of Group Total set-up to Group Item set-up.

As can be seen with the addition of the lines at 100% on either axis, the Group Total set-up method can only equal or be worse than the Group Item set-up method in terms of average base inventory value and number of orders.

If the Item set-up method is now considered, and its performance compared to that of the Group Item set-up method, the following results are obtained:

Figure 7.29 - Relative performance of Item set-up to Group Item set-up.

In this case, the number of orders is either less than or equal to, and the average base inventory value greater than, the Group Item set-up method. Without the plot produced by the Rhône Poulenc Rorer model (100% on Orders, 109% on Inventory), this method would have consistently 'exchanged' inventory for orders.

The No set-up method can now be finally considered, in which a constant value of K is used for all the items, the set-up cost being ignored. This, when compared with the Group Item set-up method, produces the following results:

Figure 7.30 - Relative performance of No set-up to Group Item set-up.

Within the constraints of the seven case studies, this method consistently 'exchanged' inventory for orders, and may be of use where capacity and administrative workload are the constraints, rather than capacity and finance.

Within a series of case studies covering five firms and seven production scenarios it would be rash to make claims as to the universal efficacy of any of the methods being tested. The sample size is too small to provide more than an indication of value in a general sense. However, in each particular exercise the modelling produced meaningful and comparable results, and clearly demonstrated the value of planning for set-up reductions made possible by using period order day classes in a geometric progression.

To say that the Group Item set-up method is universally going to produce the 'optimum' solution in all cases would be foolhardy, however it may be possible to say that it should be the first method to use where capacity and finance are the prime constraints.

Where capacity and administration are the prime constraints, the No set-up method seems to produce better results. This, when compared with the Item set-up method, produces the following results:

Figure 7.31 - Relative performance of No set-up to Item set-up.

The No set-up method was able to produce one superior result, two exact matches, and four results where orders were exchanged for inventory, and perhaps should be used first where the prime constraint is capacity, and the secondary constraint is administrative workload.

One thing that does appear to be consistent, in the admittedly small sample, is the poor performance of the Group Total set-up method, and the superior performance of the Group Item set-up method.

7.9 SUMMARY OF RESULTS OF THE CASE STUDIES.

In this chapter the seven case studies carried out at five firms were examined. The case studies resulted in one implementation, Boots Sterile Products, using the methodology to identify constraints and model the effect of implementing changes. Rhône Poulenc Rorer used the methodology to provide unbiased advice on the feasibility of implementing an across the board inventory reduction programme, and were able to clearly demonstrate using the model that the control of the inventory levels lay outside the local management's areas of responsibility, in that the manufacturing batch sizes needed to reduce to gain the benefit from smaller packaging batch sizes, and that the overall stock levels were mainly the result of the stocking policies in the distribution area.

None of the other companies acted directly upon the recommendations of the model. This was for a variety of reasons, none directly concerned with the validity of the approach or results obtained. The FMCG became involved in the take-over of a competitor, and the assimilation of the two businesses, which meant that the production volumes and capacities were uncertain. Caradon Terrain also took over a competitor, taking two years to combine the two businesses, with the way in which the businesses were to be eventually merged not being clear from the outset. Zeneca were all set to implement when a company wide BPR programme was started which stopped all local improvements.

Part of the problem with the case studies was that none of them were the CASE award collaborating company (this was IBM Consulting), and so were not emotionally involved from the outset of the research. The timing of the studies had to coincide with two windows of opportunity, the first being the duration of the research, and the second being the company concerned wanting to change existing working practices, being a repetitive batch manufacturer, and willing to participate in a research, rather than consulting, activity.

If we judge the acceptability of the modelling process with respect to the validation criteria already established, we can conclude the following:

- The quality of insight gained into the perceived problem. The modelling process can be said to have increased the level of insight into the problem area by both the model builders and model users.
- The level of sensitivity of the model to data or parameter changes. As the model uses an average method, if there are overall changes in the data, these

can be applied at the overall level. Where small changes in the costs or volumes of individual items are made, the period order day class will only be changed when the item is near to a class boundary, and so the model is reasonably insensitive.

- The level of usefulness to the decision making process. The participating companies were involved in establishing the performance criteria that would be used for comparison purposes to ensure that the model addressed the salient points.
- The acceptability level of the suggestions. Not all the suggestions made were either acceptable to, or feasible for, the participating companies. However, the lack of acceptability or feasibility was part of the investigation process of the continuous improvement cycle, where ideas and scenarios are investigated to assess feasibility. It is natural that some of the scenarios investigated will be rejected and some accepted.
- The level of commitment elicited from the users. In all the case studies the level of understanding regarding, and the insight into, the current system was increased. This was partly due to the local management being responsible for the management of the modelling process, and partly due to the modelling not being performed by an outside consultancy firm or internal expert with something to sell. This allowed the local management to be less guarded than would be normal, and to explore alternatives more openly, as they were able to take ownership of the problem area, and champion the results, rather than being told what to do.

In conclusion, the case studies resulted in the successful validation of the theoretical background and modelling approach, an indication of the overall superiority of the Group Item set-up modelling method, a greater understanding of the way in which this type of approach can assist repetitive batch manufacturers, and one successful implementation.

8 CONCLUSIONS AND RESULTS.

This research described the use in a repetitive batch manufacturing environment of a Pareto based capacitated batch sizing tool. It used a modified Economic Batch Quantity (EBQ) equation to determine the period order days class of each item being considered, with the results of four different methods of allocating set-up costs within the modified EBQ equation being analysed. By using a geometric progression (e.g. 5, 10, 20, 40, 80, 160 days supply) for the period order days series, it was possible to make allowances for set-up reductions when items incurring identical workcentre set-up characteristics were scheduled together. The common set-up groups are identified within a multi level set-up group hierarchy and a 'best case' constructed. This assumed that wherever it was possible to schedule items within a set-up group together, they would be.

The theoretical load in terms of Finance (Average Inventory Value), Administration (Orders per Year) and Capacity (Workcentre Load) was then calculated and compared against the stated limits in each area to identify potential constraints. Comparisons with the theoretical load that the current policy would generate were also made.

Having derived an inventory policy that broadly satisfied the limits within which the enterprise wished to operate, other operational considerations particular to individual items could be considered, and the parameters generated modified accordingly. The output from this phase was the setting of the order policy codes, validated in three dimensions (Finance, Administration and Capacity), for the planning system (typically MRP). The fundamental difference between this approach and others, such as the EBQ, Exchange Curve, or K-Curve, is firstly, that it considered the capacity load at the strategic parameter planning stage, and secondly, that this load is considered in terms of the set-up reductions possible through normal, good, scheduling practices.

Seven case studies were undertaken involving five participating companies, using the PC based modelling software developed to trial the methodology, during which each of the four modelling methods were compared with the current parameter settings and the results of using a standard EBQ approach. The case studies resulted in the successful validation of the theoretical background and modelling approach, an indication of the overall superiority of the Group Item set-up modelling method, a greater understanding of the way in which this type of approach can assist repetitive batch manufacturers, and one successful implementation.

The main emphasis of the research is to provide a means to assist traditional repetitive batch manufacturers in a route to continual improvement, by providing modelling tools, and by simplifying the effort required to control the business.

The research had the following four stated aims, each of which was successfully achieved, as follows:

1. To produce a new theoretical modelling tool, the K^+ Methodology, containing 4 different modelling methods.
2. To compare the results of using each of the new 4 modelling methods with the Economic Batch Quantity formula and existing practices.
3. To create novel modelling software, using average symbolic descriptive and normative modelling methods.
4. For the success of the approach to be validated using the following five criteria: the insight gained, the sensitivity of the model, its usefulness to the decision making process, the acceptability of the suggestions, and level of commitment elicited from the users.

In conclusion, the K^+ Methodology in all cases was able to provide better theoretical business results than either the existing parameters or the EBQ in the three measured dimensions. However, being able to translate the theoretical benefits into a live implementation was influenced by the stability of the external influences on the company, the level of access gained, the level of authority and responsibility of the users, and the way in which the researcher responded to the prevailing culture.

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.0 - Item File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Key	Key field	Text	4
AUV	Annual usage value	Number	11
Su	Set-up cost level 1	Number	6
Su Save	Work field	Number	6
Si	Set-up cost level 2	Number	6
Si Save	Work field	Number	6
Sm	Set-up cost level 3	Number	6
Setup Group	Set-up group id level 1	Text	8
Setup Group #2	Set-up group id level 2	Text	8
Std Cost	Cost price	Number	4.3
Std Cost per	Cost price per	Number	4
Driver/Slave	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 2	Text	1
Items in Group	# items in set-up group	Number	3
Schedule Period #1	not used	Number	3
Setup Group Key	Key field	Text	16
Days	Work field	Number	5
Batch Size	Work field	Number	8.2
Minimum Order Value	not used	Number	9
Current Order Days	not used	Number	3.1
K 1	Base value of K #1	Number	4.1
K+1	Value of K+ #1	Number	4.1
Freq 1	Orders per year #1	Number	3.1
Days 12	POD #1	Number	3.1
Inv 1	Av. Inventory value #1	Number	6
K 2	Base value of K #2	Number	4.1
K+2	Value of K+ #2	Number	4.1
Freq 2	Orders per year #2	Number	3.1
Days 22	POD #2	Number	3.1
Inv 2	Av. Inventory value #2	Number	6
K 3	Base value of K #3	Number	4.1
K+3	Value of K+ #3	Number	4.1
Freq 3	Orders per year #3	Number	3.1
Days 32	POD #1	Number	3.1
Inv 3	Av. Inventory value #1	Number	6
K 4	Base value of K #1	Number	4.1
K+4	Value of K+ #4	Number	4.1
Freq 4	Orders per year #4	Number	3.1
Days 42	POD #4	Number	3.1
Inv 4	Av. Inventory value #5	Number	6

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.0 - Item File Layout continued.

Name	Description	Format	Length
K 5	Base value of K #5	Number	4.1
K+5	Value of K+ #5	Number	4.1
Freq 5	Orders per year #5	Number	3.1
Days 52	POD #5	Number	3.1
Inv 5	Av. Inventory value #5	Number	6
K 6	Base value of K #6	Number	4.1
K+6	Value of K+ #6	Number	4.1
Freq 6	Orders per year #6	Number	3.1
Days 62	POD #6	Number	3.1
Inv 6	Av. Inventory value #6	Number	6
K 7	Base value of K #7	Number	4.1
K+7	Value of K+ #7	Number	4.1
Freq 71	Orders per year #7	Number	3.1
Days 72	POD #7	Number	3.1
Inv 7	Av. Inventory value #7	Number	6
K 8	Base value of K #8	Number	4.1
K+8	Value of K+ #8	Number	4.1
Freq 8	Orders per year #8	Number	3.1
Days 82	POD #8	Number	3.1
Inv 8	Av. Inventory value #8	Number	6
K 9	Base value of K #9	Number	4.1
K+9	Value of K+ #9	Number	4.1
Freq 9	Orders per year #9	Number	3.1
Days 92	POD #9	Number	3.1
Inv 9	Av. Inventory value #9	Number	6

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.1 - Item Operation File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Sequence #	Operation sequence #	Number	4
Key	Key field	Text	19
Operation Code	Operation description	Text	30
Work Centre	Workcentre code	Text	8
Description	Workcentre description	Text	20
Su	Set-up time level #1	Number	4
Si	Set-up time level #2	Number	4
Sm	Set-up time level #3	Number	4
Run Time	Run time	Number	4.2
Run Time per	Run time per	Number	8
Batch Size	Work field	Number	8.2
Setup Time	Work field	Number	6.2
Days	Work field	Number	4
Batch Run Time	Work field	Number	6.2
Total Batch Time	Work field	Number	6.2

Appendix 1.2 - Workcentre File Layout.

Name	Description	Format	Length
Work Centre	Workcentre code	Text	8
Description	Workcentre description	Text	20
Cost Centre	Cost centre code	Text	8
Capacity	Capacity / day / machine	Number	6
Machines	# machines in workcentre	Number	4.1
Workcentre Capacity	Total capacity per day	Number	7
Target Loading %	Target loading %	Number	3
Actual Loading %	Actual loading %	Number	3
Difference %	Target % less actual %	Number	3
Available minutes	Total capacity per day	Number	8.2
Actual minutes	Total load per day	Number	8.2
Difference minutes	Available less actual	Number	8.2
Setup minutes	Set-up minutes / day	Number	8.2
Actual Setup %	Set-up % of actual	Number	8.2
Run Minutes	Run minutes per day	Number	8.2
Actual Run %	Run % of actual	Number	8.2

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.3 - Cost Centre File Layout.

Name	**Description**	**Format**	**Length**
Cost Centre	Cost centre code	Text	8
Description	Cost centre description	Text	20
Capacity	Capacity per day	Number	6
Load	Load per day	Number	6
Difference	Capacity less load	Number	6

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.4 - Static Data File Layout.

Name	Description	Format	Length
Holding Rate	Inventory holding rate (i)	Number	3.2
i	Work field	Number	3.2
Improvement Factor		Number	5
Key	Key field	Text	4
K 1	Base value of K #1	Number	4.1
K 2	Base value of K #2	Number	4.1
K 3	Base value of K #3	Number	4.1
K 4	Base value of K #4	Number	4.1
K 5	Base value of K #5	Number	4.1
K 6	Base value of K #6	Number	4.1
K 7	Base value of K #7	Number	4.1
K 8	Base value of K #8	Number	4.1
K 9	Base value of K #9	Number	4.1
Co 1	Order Cost for K #1	Number	4.3
Co 2	Order Cost for K #2	Number	4.3
Co 3	Order Cost for K #3	Number	4.3
Co 4	Order Cost for K #4	Number	4.3
Co 5	Order Cost for K #5	Number	4.3
Co 6	Order Cost for K #6	Number	4.3
Co 7	Order Cost for K #7	Number	4.3
Co 8	Order Cost for K #8	Number	4.3
Co 9	Order Cost for K #9	Number	4.3
Days per Annum	Working days per year	Number	3
Cycles per Annum		Number	3
Days 1	POD class #1	Number	3.1
Days 2	POD class #2	Number	3.1
Days 3	POD class #3	Number	3.1
Days 4	POD class #4	Number	3.1
Days 5	POD class #5	Number	3.1
Days 6	POD class #6	Number	3.1
Days 7	POD class #1	Number	3.1
Days 8	POD class #1	Number	3.1
Days 9	POD class #9	Number	3.1
Freq1	Ordering frequency #1	Number	3.1
Freq2	Ordering frequency #2	Number	3.1
Freq1	Ordering frequency #3	Number	3.1
Freq4	Ordering frequency #4	Number	3.1
Freq5	Ordering frequency #5	Number	3.1
Freq6	Ordering frequency #6	Number	3.1
Freq7	Ordering frequency #7	Number	3.1
Freq8	Ordering frequency #8	Number	3.1
Freq9	Ordering frequency #9	Number	3.1

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.5 - Class Limits File Layout.

Name	Description	Format	Length
K	Value of K	Number	4.1
Key	Key	Text	4
Freq 1	POD frequency #1	Number	3.1
Freq 2	POD frequency #2	Number	3.1
Freq 3	POD frequency #3	Number	3.1
Freq 4	POD frequency #4	Number	3.1
Freq 5	POD frequency #5	Number	3.1
Freq 6	POD frequency #6	Number	3.1
Freq 7	POD frequency #7	Number	3.1
Freq 8	POD frequency #8	Number	3.1
Days 1	POD Class #1	Number	3.1
Days 2	POD Class #2	Number	3.1
Days 3	POD Class #3	Number	3.1
Days 4	POD Class #4	Number	3.1
Days 5	POD Class #5	Number	3.1
Days 6	POD Class #6	Number	3.1
Days 7	POD Class #7	Number	3.1
Days 8	POD Class #8	Number	3.1
CL1	Class boundary 1-2	Number	9
CL2	Class boundary 2-3	Number	9
CL3	Class boundary 3-4	Number	9
CL4	Class boundary 4-5	Number	9
CL5	Class boundary 5-6	Number	9
CL6	Class boundary 6-7	Number	9
CL7	Class boundary 7-8	Number	9
A 1	POD #1 value	Floating Point	14
A 2	POD #2 value	Floating Point	14
A 3	POD #3 value	Floating Point	14
A 4	POD #4 value	Floating Point	14
A 5	POD #5 value	Floating Point	14
A 6	POD #6 value	Floating Point	14
A 7	POD #7 value	Floating Point	14
A 8	POD #8 value	Floating Point	14

Appendix 1.6 - Item Temporary File Layout.

Name	**Description**	**Format**	**Length**
Item Code	Item code	Text	15
AUV	Annual usage value	Number	11
Su	Set-up cost level 1	Number	6
Si	Set-up cost level 2	Number	6
Sm	Set-up cost level 3	Number	6
Setup Group	Set-up group id level 1	Text	8
Setup Group #2	Set-up group id level 2	Text	8
Std Cost	Cost price	Number	4.3
Std Cost per	Cost price per	Number	4
Driver/Slave	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 2	Text	1
Schedule Period #1	not used	Number	3
Setup Group Key	Key field	Text	16
Days	Work field	Number	5
Batch Size	Work field	Number	8.2
Minimum Order Days	not used	Number	9
Key	Key field	Text	16

Appendix 1.7 - Item Op Master File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Route Code	Prime / alternate route id	Text	2
Sequence #	Operation sequence #	Number	4
Key	Key field	Text	21
Operation Code	Operation description	Text	30
Work Centre	Workcentre code	Text	8
Description	Workcentre description	Text	20
Su	Set-up time level #1	Number	4
Si	Set-up time level #2	Number	4
Sm	Set-up time level #3	Number	4
Run Time	Run time	Number	4.2
Run Time per	Run time per	Number	8

Appendix 1.8 - Item Backup File Layout.

Name	Description	Format	Length
Backup Identifier	Backup identifier	Text	4
Item Code	Item code	Text	15
AUV	Annual usage value	Number	11
Su	Set-up cost level 1	Number	6
Su Save	Work field	Number	6
Si	Set-up cost level 2	Number	6
Si Save	Work field	Number	6
Sm	Set-up cost level 3	Number	6
Setup Group	Set-up group id level 1	Text	8
Setup Group #2	Set-up group id level 2	Text	8
Std Cost	Cost price	Number	4.3
Std Cost per	Cost price per	Number	4
Driver/Slave	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 2	Text	1
Items in Group	# items in set-up group	Number	3
Schedule Period #1	not used	Number	3
Setup Group Key	Key field	Text	16
Days	Work field	Number	5
Batch Size	Work field	Number	8.2
Minimum Order Value	not used	Number	9
Current Order Days	not used	Number	3.1
K 1	Base value of K #1	Number	4.1
K+1	Value of K+ #1	Number	4.1
Freq 1	Orders per year #1	Number	3.1
Days 12	POD #1	Number	3.1
Inv 1	Av. Inventory value #1	Number	6
K 2	Base value of K #2	Number	4.1
K+2	Value of K+ #2	Number	4.1
Freq 2	Orders per year #2	Number	3.1
Days 22	POD #2	Number	3.1
Inv 2	Av. Inventory value #2	Number	6
K 3	Base value of K #3	Number	4.1
K+3	Value of K+ #3	Number	4.1
Freq 3	Orders per year #3	Number	3.1
Days 32	POD #1	Number	3.1
Inv 3	Av. Inventory value #1	Number	6
K 4	Base value of K #1	Number	4.1
K+4	Value of K+ #4	Number	4.1
Freq 4	Orders per year #4	Number	3.1
Days 42	POD #4	Number	3.1
Inv 4	Av. Inventory value #5	Number	6

Appendix 1.8 - Item Backup File Layout continued.

Name	Description	Format	Length
K 5	Base value of K #5	Number	4.1
K+5	Value of K+ #5	Number	4.1
Freq 5	Orders per year #5	Number	3.1
Days 52	POD #5	Number	3.1
Inv 5	Av. Inventory value #5	Number	6
K 6	Base value of K #6	Number	4.1
K+6	Value of K+ #6	Number	4.1
Freq 6	Orders per year #6	Number	3.1
Days 62	POD #6	Number	3.1
Inv 6	Av. Inventory value #6	Number	6
K 7	Base value of K #7	Number	4.1
K+7	Value of K+ #7	Number	4.1
Freq 71	Orders per year #7	Number	3.1
Days 72	POD #7	Number	3.1
Inv 7	Av. Inventory value #7	Number	6
K 8	Base value of K #8	Number	4.1
K+8	Value of K+ #8	Number	4.1
Freq 8	Orders per year #8	Number	3.1
Days 82	POD #8	Number	3.1
Inv 8	Av. Inventory value #8	Number	6
K 9	Base value of K #9	Number	4.1
K+9	Value of K+ #9	Number	4.1
Freq 9	Orders per year #9	Number	3.1
Days 92	POD #9	Number	3.1
Inv 9	Av. Inventory value #9	Number	6

Appendix 1.9 - Item Op Backup File Layout.

Name	Description	Format	Length
Backup Identifier	Backup identifier	Text	4
Item Code	Item code	Text	15
Sequence #	Operation sequence #	Number	4
Key	Key field	Text	19
Operation Code	Operation description	Text	30
Work Centre	Workcentre code	Text	8
Su	Set-up time level #1	Number	4
Si	Set-up time level #2	Number	4
Sm	Set-up time level #3	Number	4
Run Time	Run time	Number	4.2
Run Time per	Run time per	Number	8
Batch Size	Work field	Number	8.2
Setup Time	Work field	Number	6.2
Days	Work field	Number	4
Batch Run Time	Work field	Number	6.2
Total Batch Time	Work field	Number	6.2

Appendix 1.10 - Workcentre Backup File Layout.

Name	Description	Format	Length
Backup Identifier	Backup identifier	Text	4
Work Centre	Workcentre code	Text	8
Description	Workcentre description	Text	20
Cost Centre	Cost centre code	Text	8
Capacity	Capacity / day / machine	Number	6
Machines	# machines in workcentre	Number	4.1
Workcentre Capacity	Total capacity per day	Number	7
Target Loading %	Target loading %	Number	3
Actual Loading %	Actual loading %	Number	3
Difference %	Target % less actual %	Number	3
Available minutes	Total capacity per day	Number	8.2
Actual minutes	Total load per day	Number	8.2
Difference minutes	Available less actual	Number	8.2
Setup minutes	Set-up minutes / day	Number	8.2
Actual Setup %	Set-up % of actual	Number	8.2
Run Minutes	Run minutes per day	Number	8.2
Actual Run %	Run % of actual	Number	8.2

Appendix 1.11 - Cost Centre Backup File Layout.

Name	Description	Format	Length
Backup Identifier	Backup identifier	Text	4
Cost Centre	Cost centre code	Text	8
Description	Cost centre description	Text	20
Capacity	Capacity per day	Number	6
Load	Load per day	Number	6
Difference	Capacity less load	Number	6

Appendix 1.12 - Static Data Backup File Layout.

Name	Description	Format	Length
Backup Identifier	Backup identifier	Text	4
Holding Rate	Inventory holding rate (i)	Number	3.2
I	Work field	Number	3.2
Improvement Factor		Number	5
Key	Key field	Text	4
K 1	Base value of K #1	Number	4.1
K 2	Base value of K #2	Number	4.1
K 3	Base value of K #3	Number	4.1
K 4	Base value of K #4	Number	4.1
K 5	Base value of K #5	Number	4.1
K 6	Base value of K #6	Number	4.1
K 7	Base value of K #7	Number	4.1
K 8	Base value of K #8	Number	4.1
K 9	Base value of K #9	Number	4.1
Co 1	Order Cost for K #1	Number	4.3
Co 2	Order Cost for K #2	Number	4.3
Co 3	Order Cost for K #3	Number	4.3
Co 4	Order Cost for K #4	Number	4.3
Co 5	Order Cost for K #5	Number	4.3
Co 6	Order Cost for K #6	Number	4.3
Co 7	Order Cost for K #7	Number	4.3
Co 8	Order Cost for K #8	Number	4.3
Co 9	Order Cost for K #9	Number	4.3
Days per Annum	Working days per year	Number	3
Cycles per Annum		Number	3
Days 1	POD class #1	Number	3.1
Days 2	POD class #2	Number	3.1
Days 3	POD class #3	Number	3.1
Days 4	POD class #4	Number	3.1
Days 5	POD class #5	Number	3.1
Days 6	POD class #6	Number	3.1
Days 7	POD class #1	Number	3.1
Days 8	POD class #1	Number	3.1
Days 9	POD class #9	Number	3.1
Freq1	Ordering frequency #1	Number	3.1
Freq2	Ordering frequency #2	Number	3.1
Freq1	Ordering frequency #3	Number	3.1
Freq4	Ordering frequency #4	Number	3.1
Freq5	Ordering frequency #5	Number	3.1
Freq6	Ordering frequency #6	Number	3.1
Freq7	Ordering frequency #7	Number	3.1
Freq8	Ordering frequency #8	Number	3.1
Freq9	Ordering frequency #9	Number	3.1

Appendix 1.13 - Item Temp Backup File Layout.

Name	Description	Format	Length
Backup Identifier	Backup identifier	Text	4
Item Code	Item code	Text	15
AUV	Annual usage value	Number	11
Su	Set-up cost level 1	Number	6
Si	Set-up cost level 2	Number	6
Sm	Set-up cost level 3	Number	6
Setup Group	Set-up group id level 1	Text	8
Setup Group #2	Set-up group id level 2	Text	8
Std Cost	Cost price	Number	4.3
Std Cost per	Cost price per	Number	4
Driver/Slave	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 2	Text	1
Schedule Period #1	not used	Number	3
Setup Group Key	Key field	Text	16
Days	Work field	Number	5
Batch Size	Work field	Number	8.2
Minimum Order Days	not used	Number	9

Appendix 1.14 - Model Item File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Key	Key field	Text	4
AUV	Annual usage value	Number	11
Driver/Slave	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 2	Text	1
Su	Set-up cost level 1	Number	6
Si	Set-up cost level 2	Number	6
Si Save	Work field	Number	6
Sm	Set-up cost level 3	Number	6
Setup Group	Set-up group id level 1	Text	8
Setup Group #2	Set-up group id level 2	Text	8
Setup Group Key	Key field	Text	16
Items in Group	# items in set-up group	Number	3
Std Cost	Cost price	Number	4.3
Std Cost per	Cost price per	Number	4
K	Current base value of K	Number	4.1
K+	Current value of K+	Number	6.1
Freq	Current orders per year	Number	3.1
Days	Current POD	Number	3.1
Inv	Previous av. inventory £	Number	6
K #1	Previous base value of K	Number	4.1
K+ #1	Previous value of K+	Number	6.1
Freq #1	Previous orders per year	Number	3.1
Days #1	Previous POD	Number	3.1
Inv #1	Previous av. inventory £	Number	6
Freq Low	Low limit orders per year	Number	3.1
Days Low	Low limit POD	Number	3.1
Inv Low	Low limit av. inventory £	Number	6
Freq High	High limit orders per year	Number	3.1
Days High	High limit POD	Number	3.1
Inv High	High limit av. inventory £	Number	6
Current Order Days	Not used	Number	6
Inv Current	Not used	Number	3.1

Appendix 1.15 - Model Operation File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Sequence #	Operation sequence #	Number	4
Key	Key field	Text	19
Operation Code	Operation description	Text	30
Work Centre	Workcentre code	Text	8
Su	Set-up time level #1	Number	4
Si	Set-up time level #2	Number	4
Sm	Set-up time level #3	Number	4
Run Time	Run time	Number	4.2
Run Time per	Run time per	Number	8
Days	Current POD	Number	4
Batch Size	Current batch size	Number	8.2
Setup Time	Batch set-up time	Number	6.2
Batch Run Time	Current batch run time	Number	6.2
Total Batch Time	Current batch time	Number	6.2
Batch Size #1	Previous batch size	Number	8.2
Setup Time #1	Batch set-up time	Number	6.2
Batch Run Time #1	Previous batch run time	Number	6.2
Total Batch Time #1	Previous batch time	Number	6.2
Batch Size Low	Low limit batch size	Number	8.2
Setup Time Low	Batch set-up time	Number	6.2
Batch Run Time Low	Low limit batch run time	Number	6.2
Total Batch Time Low	Low limit batch time	Number	6.2
Batch Size High	High limit batch size	Number	8.2
Setup Time High	Batch set-up time	Number	6.2
Batch Run Time High	High limit batch run time	Number	6.2
Total Batch Time High	High limit batch time	Number	6.2

Appendix 1.16 - Model Static Data File Layout.

Name	Description	Format	Length
Holding Rate	Inventory holding rate (i)	Number	3.2
Key	Key field	Text	4
Days per Annum	Working days per year	Number	3
Days 1	POD class #1	Number	3.1
Days 2	POD class #2	Number	3.1
Days 3	POD class #3	Number	3.1
Days 4	POD class #4	Number	3.1
Days 5	POD class #5	Number	3.1
Days 6	POD class #6	Number	3.1
Days 7	POD class #1	Number	3.1
Days 8	POD class #1	Number	3.1
Days 9	POD class #9	Number	3.1
Freq1	Ordering frequency #1	Number	3.1
Freq2	Ordering frequency #2	Number	3.1
Freq1	Ordering frequency #3	Number	3.1
Freq4	Ordering frequency #4	Number	3.1
Freq5	Ordering frequency #5	Number	3.1
Freq6	Ordering frequency #6	Number	3.1
Freq7	Ordering frequency #7	Number	3.1
Freq8	Ordering frequency #8	Number	3.1
Freq9	Ordering frequency #9	Number	3.1
AUV Match	AUV match value	Number	8
Order Match	Order match value	Number	6.1
Minutes Match	Capacity match value	Number	7
v	Improvement factor (v)	Number	1.1
K 1	Current base value of K	Number	4.1
Co 1	Order cost for current K	Number	6.3
Av Inv	Current base av inv £	Number	8
Orders	Current total # orders	Number	6.2
Setup Minutes	Current total set-up mins	Number	7
Run Minutes	Current total run mins	Number	7
Total Minutes	Current total minutes	Number	7
K 2	Current base value of K	Number	4.1
Co 2	Order cost for current K	Number	6.3
Av Inv -1	Previous base av inv £	Number	8
Orders -1	Previous total # orders	Number	6.2
Setup Minutes -1	Previous total set-up mins	Number	7
Total Minutes -1	Previous total minutes	Number	7

Appendix 1.16 - Model Static Data File Layout continued.

Name	Description	Format	Length
Av Inv Low	Previous base av inv £	Number	8
Orders Low	Previous total # orders	Number	6.2
Setup Minutes Low	Previous total set-up mins	Number	7
Total Minutes Low	Previous total minutes	Number	7
Av Inv High	Previous base av inv £	Number	8
Orders High	Previous total # orders	Number	6.2
Setup Minutes High	Previous total set-up mins	Number	7
Total Minutes High	Previous total minutes	Number	7
K Difference	Latest K difference	Number	4

Appendix 1.17 - Schedule Maintenance File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Year	Schedule year	Number	4
Week Number	Period number	Number	2
Order Number	Order number	Text	8
Due Date	Order due date	Date	8
Route Code	Schedule route code	Text	2
Key	Key field	Text	23
Quantity	Order quantity	Number	6.2
Unique Key	Key field	Text	31
Setup Group	Set-up group id level 1	Text	8
Setup Group #2	Set-up group id level 2	Text	8
Driver/Slave #1	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 1	Text	1
Setup Key #1	Key field	Text	10
Setup Key #2	Key field	Text	18

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.18 - Schedule Temporary File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Year	Schedule year	Number	4
Week Number	Period number	Number	2
Order Number	Order number	Text	8
Due Date	Order due date	Date	8
Route Code	Schedule route code	Text	2
Quantity	Order quantity	Number	6.2
Setup Group	Set-up group id level 1	Text	8
Setup Group #2	Set-up group id level 2	Text	8
Driver/Slave #1	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 1	Text	1

Appendix 1.19 - Schedule Operation File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Route Code	Schedule route code	Text	2
Sequence #	Operation sequence #	Number	4
Work Centre	Workcentre code	Text	8
Year	Schedule year	Number	4
Week Number	Period number	Number	2
Driver/Slave #1	Driver / slave level 1	Text	1
Driver/Slave #2	Driver / slave level 1	Text	1
Order Number	Order number	Text	8
Key2	Key field	Text	35
Key	Key field	Text	21
Su	Set-up time level #1	Number	
Si	Set-up time level #2	Number	
Sm	Set-up time level #3	Number	
Quantity	Order quantity	Number	8.2
Setup Time	Work field	Number	6.2
Batch Run Time	Work field	Number	6.2
Total Batch Time	Work field	Number	6.2

Appendix 1.20 - Schedule Operation File Layout.

Name	Description	Format	Length
Item Code	Item code	Text	15
Route Code	Schedule route code	Text	2
Sequence #	Operation sequence #	Number	4
Order Number	Order number	Text	8
Year	Schedule year	Number	4
Week Number	Period number	Number	2

APPENDIX 1 - FILE LAYOUTS.

Appendix 1.21 - Schedule Workcentre File Layout.

Name	Description	Format	Length
Work Centre	Workcentre code	Text	8
Year	Schedule year	Number	4
Week Number	Period number	Number	2
Description	Workcentre description	Text	20
Key	Key field	Text	14
Cost Centre	Cost centre code	Text	8
Capacity	Capacity / day / machine	Number	6
Machines	# machines in workcentre	Number	4.1
Days per Week	Days per period	Number	1.1
Workcentre Capacity	Total capacity per period	Number	7
Target Loading %	Target loading %	Number	3
Actual Loading %	Actual loading %	Number	3
Difference %	Target % less actual %	Number	3
Available minutes	Total capacity per period	Number	8.2
Actual minutes	Total load per period	Number	8.2
Difference minutes	Available less actual	Number	8.2
Setup minutes	Set-up minutes / day	Number	8.2
Actual Setup %	Set-up % of actual	Number	3
Run Minutes	Run minutes per day	Number	8.2
Actual Run %	Run % of actual	Number	3

Appendix 1.22 - Schedule Cost Centre File Layout.

Name	Description	Format	Length
Cost Centre	Cost centre code	Text	8
Year	Schedule year	Number	4
Week Number	Period number	Number	2
Key	Key field	Text	14
Description	Cost centre description	Text	20
Capacity	Capacity per day	Number	6
Days per Week	Days per period	Number	1.1
Weekly Capacity	Capacity per period		8
Load	Load per day	Number	6
Load %	% load for period	Number	3
Difference	Capacity less load	Number	6
Setup minutes	Set-up minutes / day	Number	8.2
Actual Setup %	Set-up % of actual	Number	3
Run Minutes	Run minutes per day	Number	8.2
Actual Run %	Run % of actual	Number	3

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.0 - K+ Simulation - No Set-Up Menu.

Menu Option Program Name	Function
Set Environment.	
Static Data	Set values of K, i, v, working days per year and period order day class series.
Calculate K Values - No Set-Up.	
Update Days NSU 0	Controls logic flow.
Update Days SU1 1a	Identify Driver / Slaves at level 1.
Update Days SU1 1b	Identify Driver / Slaves at level 2.
Update Days NSU 1	Retrieve K values and period order day classes.
Update Days NSU 2a	Retrieve class limits for K #1.
Update Days NSU 2b	Retrieve class limits for K #2.
Update Days NSU 2c	Retrieve class limits for K #3.
Update Days NSU 2d	Retrieve class limits for K #4.
Update Days NSU 2e	Retrieve class limits for K #5.
Update Days NSU 2f	Retrieve class limits for K #6.
Update Days NSU 2g	Retrieve class limits for K #7.
Update Days NSU 2h	Retrieve class limits for K #8.
Update Days NSU 2i	Retrieve class limits for K #9.
Update Days NSU 3	Assign items to period order day classes.
Update Days NSU 4	Reset results for unused values of K.
Setup days SD2 0a	Clear workcentre capacity calculations.
Setup days SD2 0b	Clear item operation capacity calculations.
Setup days SD2 0c	Clear cost centre capacity calculations.
Display Simulation Results.	
Summary Results 0	Controls logic flow.
Summary Results 1	Outputs order / inventory £ results to screen.
Summary Results 2	Outputs order / inventory £ results to report.
Display Simulation Graph.	
Summary Export 0	Controls logic flow.
Summary Export 0	Output order / inventory results to file.
Lotus 123	Display graph of results.
Capacity Planning - No Set-Up.	
Setup Days NSD 0	Controls logic flow.
Setup Days SD2 0a	Clear workcentre capacity calculations.
Setup Days SD2 0b	Clear item operation capacity calculations.
Setup Days SD2 0c	Clear cost centre capacity calculations.
Setup Days NSD 1	Calculate item batch size.
Setup Days NSD 2	Calculate item operation timings.
Setup Days NSD 3	Calculate workcentre timings.
Setup Days NSD 4	Calculate cost centre timings.

Appendix 2.0 - K+ Simulation - No Set-Up Menu continued.

Menu Option Program Name	Function
Display Capacity Results.	
WC Capacity Results 0	Controls logic flow.
WC Capacity Results 1	Outputs summary capacity results to screen.
WC Capacity Results 2	Outputs summary capacity results to report.
Display Capacity Detail - by Total Load.	
WC Load Detail 0	Controls logic flow.
WC Load Detail 1	Output workcentre detail capacity results by load to screen.
WC Load Detail 2	Output workcentre detail capacity results by load to report.
Display Capacity Detail - by Set-Up.	
WC Setup Detail 0	Controls logic flow.
WC Setup Detail 1	Output workcentre detail capacity results by set-up to screen.
WC Setup Detail 2	Output workcentre detail capacity results by set-up to report.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.1 - K+ Simulation - Item Set-Up Menu.

Menu Option	Program Name	Function
Set Environment.		
	Static Data	Set values of K, i, v, working days per year and period order day class series.
Calculate K Values - Item Set-Up.		
	Update Days SU1 0	Controls logic flow.
	Update Days SU1 1a	Identify Driver / Slaves at level 1.
	Update Days SU1 1b	Identify Driver / Slaves at level 2.
	Update Days SU1 1	Calculate K+ for each item.
	Update Days SU1 2	Calculate period order days for each item.
	Reorganise	Item file.
	Setup days SD2 0a	Clear workcentre capacity calculations.
	Setup days SD2 0b	Clear item operation capacity calculations.
	Setup days SD2 0c	Clear cost centre capacity calculations.
Display Simulation Results.		
	Summary Results 0	Controls logic flow.
	Summary Results 1	Outputs order / inventory £ results to screen.
	Summary Results 2	Outputs order / inventory £ results to report.
Display Simulation Graph.		
	Summary Export 0	Controls logic flow.
	Summary Export 0	Output order / inventory results to file.
	Lotus 123	Display graph of results.
Capacity Planning - Item Set-Up.		
	Setup Days SD1 0	Controls logic flow.
	Setup Days SD2 0a	Clear workcentre capacity calculations.
	Setup Days SD2 0b	Clear item operation capacity calculations.
	Setup Days SD2 0c	Clear cost centre capacity calculations.
	Setup Days SD1 1	Calculate item batch size.
	Setup Days SD1 2	Calculate item operation timings.
	Setup Days SD1 3	Calculate workcentre timings.
	Setup Days SD1 4	Calculate cost centre timings.
Display Capacity Results.		
	WC Capacity Results 0	Controls logic flow.
	WC Capacity Results 1	Outputs summary capacity results to screen.
	WC Capacity Results 2	Outputs summary capacity results to report.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.1 - K+ Simulation - Item Set-Up Menu continued.

Menu Option **Program Name**	**Function**
Display Capacity Detail - by Total Load.	
WC Load Detail 0	Controls logic flow.
WC Load Detail 1	Output workcentre detail capacity results by load to screen.
WC Load Detail 2	Output workcentre detail capacity results by load to report.
Display Capacity Detail - by Set-Up.	
WC Setup Detail 0	Controls logic flow.
WC Setup Detail 1	Output workcentre detail capacity results by set-up to screen.
WC Setup Detail 2	Output workcentre detail capacity results by set-up to report.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.2 - K+ Simulation - Group Item Set-Up Menu.

Menu Option	Program Name	Function
Set Environment.		
	Static Data	Set values of K, i, v, working days per year and period order day class series.
Calculate K Values - Group Item Set-Up.		
	Update Days SU2 0	Controls logic flow.
	Update Days SU2 1	Identify Driver / Slaves at level 1.
	Update Days SU2 1a	Identify Driver / Slaves at level 2.
	Update Days SU2 1b	Calculate K+ for each item.
	Update Days SU2 2	Calculate period order days for each item.
	Update Days SU2 3	Reset period order days at level 2.
	Update Days SU2 4	Reset period order days at level 1.
	Reorganise	Item file.
	Setup days SD2 0a	Clear workcentre capacity calculations.
	Setup days SD2 0b	Clear item operation capacity calculations.
	Setup days SD2 0c	Clear cost centre capacity calculations.
Display Simulation Results.		
	Summary Results 0	Controls logic flow.
	Summary Results 1	Outputs order / inventory £ results to screen.
	Summary Results 2	Outputs order / inventory £ results to report.
Display Simulation Graph.		
	Summary Export 0	Controls logic flow.
	Summary Export 0	Output order / inventory results to file.
	Lotus 123	Display graph of results.
Capacity Planning - Group Item Set-Up.		
	Setup Days SD2 0	Controls logic flow.
	Setup Days SD2 0a	Clear workcentre capacity calculations.
	Setup Days SD2 0b	Clear item operation capacity calculations.
	Setup Days SD2 0c	Clear cost centre capacity calculations.
	Setup Days SD2 0d	Set non group items to Driver.
	Setup Days SD2 1	Calculate batch size.
	Setup Days SD2 1	Assign set-up times according to Driver / Slave flags.
	Setup Days SD2 2	Calculate item operation timings.
	Setup Days SD2 3	Calculate workcentre timings.
	Setup Days SD2 4	Calculate cost centre timings.
Display Capacity Results.		
	WC Capacity Results 0	Controls logic flow.
	WC Capacity Results 1	Outputs summary capacity results to screen.
	WC Capacity Results 2	Outputs summary capacity results to report.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.2 - K+ Simulation - Group Item Set-Up Menu continued.

Menu Option **Program Name**	**Function**
Display Capacity Detail - by Total Load.	
WC Load Detail 0	Controls logic flow.
WC Load Detail 1	Output workcentre detail capacity results by load to screen.
WC Load Detail 2	Output workcentre detail capacity results by load to report.
Display Capacity Detail - by Set-Up.	
WC Setup Detail 0	Controls logic flow.
WC Setup Detail 1	Output workcentre detail capacity results by set-up to screen.
WC Setup Detail 2	Output workcentre detail capacity results by set-up to report.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.3 - K+ Simulation - Group Total Set-Up Menu.

Menu Option **Program Name**	**Function**
Set Environment.	
Static Data	Set values of K, i, v, working days per year and period order day class series.
Calculate K Values - Group Item Set-Up.	
Update Days SU3 0	Controls logic flow.
Update Days SU3 1	Save items to item temporary file.
Update Days SU3 2a	Identify Driver / Slaves at level 1 for set-up cost.
Update Days SU3 2b	Identify Driver / Slaves at level 2 for set-up cost.
Update Days SU3 2c	Calculate group total AUV & set-up cost.
Update Days SU3 3	Flag non total group items for removal.
Update Days SU3 4	Delete non total group items.
Update Days SU3 5	set item code of group total to set-up code.
Update Days SU3 6	Calculate K+ for each item.
Update Days SU3 7	Calculate period order days for each item.
Update Days SU3 8a	Calculate number of items per set-up group.
Update Days SU3 8b	Calculate order frequency.
Reorganise	Item file.
Setup days SD2 0a	Clear workcentre capacity calculations.
Setup days SD2 0b	Clear item operation capacity calculations.
Setup days SD2 0c	Clear cost centre capacity calculations.
Display Simulation Results.	
Summary Results 0	Controls logic flow.
Summary Results 1	Outputs order / inventory £ results to screen.
Summary Results 2	Outputs order / inventory £ results to report.
Display Simulation Graph.	
Summary Export 0	Controls logic flow.
Summary Export 0	Output order / inventory results to file.
Lotus 123	Display graph of results.
Capacity Planning - Group Item Set-Up.	
Setup Days SD3 0	Controls logic flow.
Setup Days SD2 0a	Clear workcentre capacity calculations.
Setup Days SD2 0b	Clear item operation capacity calculations.
Setup Days SD2 0c	Clear cost centre capacity calculations.
Setup Days SD3 1	Set item days as per value of K.
Setup Days SD3 2	Identify Driver / Slaves at level 1 for capacity use.
Setup Days SD3 3	Identify Driver / Slaves at level 2 for capacity use.
Setup Days SD3 4	Calculate item operation timings.
Setup Days SD3 5	Calculate workcentre timings.
Setup Days SD3 6	Calculate cost centre timings.

Appendix 2.3 - K+ Simulation - Group Total Set-Up Menu continued.

Menu Option	Program Name	Function
Display Capacity Results.		
	WC Capacity Results 0	Controls logic flow.
	WC Capacity Results 1	Outputs summary capacity results to screen.
	WC Capacity Results 2	Outputs summary capacity results to report.
Display Capacity Detail - by Total Load.		
	WC Load Detail 0	Controls logic flow.
	WC Load Detail 1	Output workcentre detail capacity results by load to screen.
	WC Load Detail 2	Output workcentre detail capacity results by load to report.
Display Capacity Detail - by Set-Up.		
	WC Setup Detail 0	Controls logic flow.
	WC Setup Detail 1	Output workcentre detail capacity results by set-up to screen.
	WC Setup Detail 2	Output workcentre detail capacity results by set-up to report.
Restore Details - Group Total Setup.		
	Restore SU3 0	Controls logic flow.
	Delete Items	Clear item details.
	Restore SU3 1	Restores items from item temporary file.
	Restore SU3 2	Clear item temporary details.
	Reorganise	Item file.
	Setup Days SD2 0a	Clear workcentre capacity calculations.
	Setup Days SD2 0b	Clear item operation capacity calculations.
	Setup Days SD2 0c	Clear cost centre capacity calculations.

Appendix 2.4 - K+ Simulation - Scenario Modelling Menu.

Menu Option **Program Name**	**Function**
Calculate Scenario Limits.	
Model Days Base 0	Controls logic flow.
Model Days Base 0a	Clear old period order day classes, days per annum and inventory holding rate (i).
Model Days Base 0b	Set up new values for old period order day classes, days per annum and inventory holding rate (i).
Model Days Base 0c	Clear Model Item file.
Model Days Base 0d	Create new Model Item file from Item file.
Model Days Base 1	Identify Driver / Slaves at level 1.
Model Days Base 2	Identify Driver / Slaves at level 2.
Model Days Base 3	Set high and low values for period order days.
Model Days Base 4	Clear Model Operation file.
Model Days Base 5	Create new Model Operation file from Item Operation file.
Model Days Base 5a	Determine batch set-up times.
Model Days Base 6	Calculate set-up costs.
Model Days Base 7	Save high and low limits for number of orders and average inventory value.
Model Days Base 8	Save high and low limits for capacity used.
Model Days Base 9	Display limits on orders, inventory and capacity.
Model Item Enquiry.	
Model Item	Display results.
Model Operation Enquiry.	
Model Operation	Display results.
Model Environment Enquiry.	
Model Static Data	Display results.

Appendix 2.4 - K+ Simulation - Scenario Modelling Menu continued.

Menu Option **Program Name**	**Function**
Match on # Orders.	
Model Match Order 0	Controls logic flow.
Model Match Order 1	Clear this / last scenario, start at K = 2048.
Model Match Order 2	Calculate K+ for each model item.
Model Match Order 3	Calculate period order days for each model item.
Model Match Order 3a	Reset period order days at level 1.
Model Match Order 3b	Reset period order days at level 2.
Model Match Order 4	Calculate total average inventory £ and number of orders.
Model Match Order 5	Clear model operation capacity calculations.
Model Match Order 6	Calculate model operation capacity usage.
Model Match Order 7	Calculate total capacity usage.
Model Search Order X	Runs first loop of match with binary chop through values of K from 1 through 4095 for (v) = 1
Model Loop 0	Control logic flow for improvement factor (v) from 0.9 through 0.1 with binary chop through values of K from 1 through 4095 for each value of (v).
Programs called from Model Search Order X:	
Model Search Order 0	Controls logic flow of binary chop for K values from 1 through 4095.
Model Search Order 1	Retrieve order match and results of last run. If exact match found, stop search.
Model Search Order 1a	Half the last difference in K, move current results to previous results.
Model Search Order 2	If # orders on last run was less than required number, add the difference to the previous value of K.
Model Search Order 3	If # orders on last run was greater than required number, subtract the difference to the previous value of K.
Model Search Order 4	Roll over model item file and calculate K+.
Model Search Order 5	Calculate period order days for model item file.
Model Search Order 5a	Reset period order days at level 1.
Model Search Order 5a	Reset period order days at level 2.
Model Search Order 6	Calculate total average inventory £ and number of orders.
Model Search Order 7	For model operation file move current results to previous and calculate new current capacity usage.
Model Search Order 8	Calculate total capacity usage.

Appendix 2.4 - K+ Simulation - Scenario Modelling Menu continued.

Menu Option Program Name	Function
Match on # Orders continued.	
Programs called from Model Loop 0:	
Model Loop 1	Retrieve order match and results of last and last -1 run. If required value between the last and last -1 results, stop search.
Model Loop 2	Move last order match results to last -1 results, set improvement factor (v) = (v-0.1).
Model Match Order 2	Calculate K+ for each model item.
Model Match Order 3	Calculate period order days for each model item.
Model Match Order 3a	Reset period order days at level 1.
Model Match Order 3b	Reset period order days at level 2.
Model Match Order 4	Calculate total average inventory £ and number of orders.
Model Match Order 5	Clear model operation capacity calculations.
Model Match Order 6	Calculate model operation capacity usage.
Model Match Order 7	Calculate total capacity usage.
Model Search Order X	Runs next loop of match with binary chop through values of K from 1 through 4095 for next lower value of (v).

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.4 - K+ Simulation - Scenario Modelling Menu continued.

Menu Option **Program Name**	**Function**
Match on # Average Inventory Value.	
Model Match Inv 0	Controls logic flow.
Model Match Inv 1	Clear this / last scenario, start at K = 2048.
Model Match Order 2	Calculate K+ for each model item.
Model Match Order 3	Calculate period order days for each model item.
Model Match Order 3a	Reset period order days at level 1.
Model Match Order 3b	Reset period order days at level 2.
Model Match Order 4	Calculate total average inventory £ and number of orders.
Model Match Order 5	Clear model operation capacity calculations.
Model Match Order 6	Calculate model operation capacity usage.
Model Match Order 7	Calculate total capacity usage.
Model Search Inv X	Runs first loop of match with binary chop through values of K from 1 through 4095 for (v) = 1
Model Inv Loop 0	Control logic flow for improvement factor (v) from 0.9 through 0.1 with binary chop through values of K from 1 through 4095 for each value of (v).
Programs called from Model Search Inv X:	
Model Search Inv 0	Controls logic flow of binary chop for K values from 1 through 4095.
Model Search Inv 1	Retrieve capacity match and results of last run. If exact match found, stop search.
Model Search Order 1a	Half the last difference in K, move current results to previous results.
Model Search Order 2	If inventory £ on last run was greater than required value, add the difference to the previous value of K.
Model Search Order 3	If inventory £ on last run was less than required value, subtract the difference to the previous value of K.
Model Search Order 4	Roll over model item file and calculate K+.
Model Search Order 5	Calculate period order days for model item file.
Model Search Order 5a	Reset period order days at level 1.
Model Search Order 5a	Reset period order days at level 2.
Model Search Order 6	Calculate total average inventory £ and number of orders.
Model Search Order 7	For model operation file move current results to previous and calculate new current capacity usage.
Model Search Order 8	Calculate total capacity usage.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.4 - K+ Simulation - Scenario Modelling Menu continued.

Menu Option **Program Name**	**Function**
Match on # Average Inventory Value continued.	
Programs called from Model Inv Loop 0:	
Model Inv Loop 1	Retrieve capacity match and results of last and last -1 run. If required value between the last and last -1 results, stop search.
Model Loop 2	Move last capacity match results to last -1 results, set improvement factor (v) = (v-0.1).
Model Match Order 2	Calculate K+ for each model item.
Model Match Order 3	Calculate period order days for each model item.
Model Match Order 3a	Reset period order days at level 1.
Model Match Order 3b	Reset period order days at level 2.
Model Match Order 4	Calculate total average inventory £ and number of orders.
Model Match Order 5	Clear model operation capacity calculations.
Model Match Order 6	Calculate model operation capacity usage.
Model Match Order 7	Calculate total capacity usage.
Model Search Inv X	Runs next loop of match with binary chop through values of K from 1 through 4095 for next lower value of (v).

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.4 - K+ Simulation - Scenario Modelling Menu continued.

Menu Option **Program Name**	**Function**
Match on Capacity.	
Model Match Cap 0	Controls logic flow.
Model Match Cap 1	Clear this / last scenario, start at K = 2048.
Model Match Order 2	Calculate K+ for each model item.
Model Match Order 3	Calculate period order days for each model item.
Model Match Order 3a	Reset period order days at level 1.
Model Match Order 3b	Reset period order days at level 2.
Model Match Order 4	Calculate total average inventory £ and number of orders.
Model Match Order 5	Clear model operation capacity calculations.
Model Match Order 6	Calculate model operation capacity usage.
Model Match Order 7	Calculate total capacity usage.
Model Search Cap X	Runs first loop of match with binary chop through values of K from 1 through 4095 for (v) = 1
Model Loop Cap 0	Control logic flow for improvement factor (v) from 0.9 through 0.1 with binary chop through values of K from 1 through 4095 for each value of (v).
Programs called from Model Search Cap X:	
Model Search Cap 0	Controls logic flow of binary chop for K values from 1 through 4095.
Model Search Cap 1	Retrieve capacity match and results of last run. If exact match found, stop search.
Model Search Order 1a	Half the last difference in K, move current results to previous results.
Model Search Order 2	If capacity on last run was less than required number, add the difference to the previous value of K.
Model Search Order 3	If capacity on last run was greater than required number, subtract the difference to the previous value of K.
Model Search Order 4	Roll over model item file and calculate K+.
Model Search Order 5	Calculate period order days for model item file.
Model Search Order 5a	Reset period order days at level 1.
Model Search Order 5a	Reset period order days at level 2.
Model Search Order 6	Calculate total average inventory £ and number of orders.
Model Search Order 7	For model operation file move current results to previous and calculate new current capacity usage.
Model Search Order 8	Calculate total capacity usage.

Appendix 2.4 - K+ Simulation - Scenario Modelling Menu continued.

Menu Option **Program Name**	**Function**
Match on Capacity continued.	
Programs called from Model Loop Cap 0:	
Model Loop Cap 1	Retrieve capacity match and results of last and last -1 run. If required value between the last and last -1 results, stop search.
Model Loop 2	Move last capacity match results to last -1 results, set improvement factor (v) = (v-0.1).
Model Match Order 2	Calculate K+ for each model item.
Model Match Order 3	Calculate period order days for each model item.
Model Match Order 3a	Reset period order days at level 1.
Model Match Order 3b	Reset period order days at level 2.
Model Match Order 4	Calculate total average inventory £ and number of orders.
Model Match Order 5	Clear model operation capacity calculations.
Model Match Order 6	Calculate model operation capacity usage.
Model Match Order 7	Calculate total capacity usage.
Model Search Cap X	Runs next loop of match with binary chop through values of K from 1 through 4095 for next lower value of (v).

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.5 - K+ Simulation - Import / Export Menu.

Menu Option	**Program Name**	**Function**
Import Item Details from Lotus 123.		
	Import Item 0	Controls logic flow.
	Delete Items	Clears current item details
	Reorganise	Item file.
	Import	Item details.
Import Operation Details from Lotus 123.		
	Import Item Op 0	Controls logic flow.
	Delete Item Op	Clears current item operation details
	Reorganise	Item operation file.
	Import	Item operation details.
Import Workcentre Details from Lotus 123.		
	Import W-Centre 0	Controls logic flow.
	Delete W-Centre	Clears current workcentre details
	Reorganise	Workcentre file.
	Import	Workcentre details.
Import Cost Centre Details from Lotus 123.		
	Import C-Centre 0	Controls logic flow.
	Delete Cost Centre	Clears current cost centre details
	Reorganise	Cost centre file.
	Import	Cost centre details.
Export Simulation Details to ASCII File.		
	Output Results	Output period order day class by item to file.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.6 - K+ Simulation - Enquiry Menu.

Menu Option Program Name	Function
Class Limits Enquiry.	
Class Limits	Enquiry only option.
Item Maintenance and Enquiry.	
Item	Enquiry and update option.
Item Operation Maintenance and Enquiry.	
Item Operation	Enquiry and update option.
Workcentre Maintenance and Enquiry.	
Workcentre	Enquiry and update option.
Cost Centre Maintenance and Enquiry.	
Cost Centre	Enquiry and update option.
Item Temporary Maintenance and Enquiry.	
Item Temporary	Enquiry and update option.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.7 - K+ Simulation - Modify Setup Menu.

Menu Option	Program Name	Function
Modify Setup Costs and Times by % factor.		
	Modify Setup 0	Control logic flow and input % modifiers.
	Modify Setup 1	Modify item file set-up costs by % factor.
	Modify Setup 2	Modify item operation file set-up costs by % factor.
	Setup Days SD2 0a	Clear workcentre capacity calculations.
	Setup Days SD2 0b	Clear item operation capacity calculations.
	Setup Days SD2 0c	Clear cost centre capacity calculations.
	Replace Setup 2	Clear item file calculations.
Replace Setup Costs.		
	Replace Setup 0	Control logic flow and input replacement values.
	Replace Setup 1	Replace item set-up costs.
	Replace Setup 2	Clear item file calculations.
	Setup Days SD2 0a	Clear workcentre capacity calculations.
	Setup Days SD2 0b	Clear item operation capacity calculations.
	Setup Days SD2 0c	Clear cost centre capacity calculations.
Replace Setup Times.		
	Replace Setup Op 0	Control logic flow and input replacement values.
	Replace Setup Op 1	Replace item operation set-up times.
	Setup Days SD2 0a	Clear workcentre capacity calculations.
	Setup Days SD2 0b	Clear item operation capacity calculations.
	Setup Days SD2 0c	Clear cost centre capacity calculations.

Appendix 2 - Software Logic Flow by Program.

Appendix 2.8 - K+ Simulation - Save Simulation Details Menu.

Menu Option	Program Name	Function
Save Simulation Details.		
	Save Item 0	Control logic flow and input of backup identifier.
	Save Item 1	Delete any old simulation details with same backup identifier in item backup file.
	Save Item 2	Save item details in item backup file.
	Reorganise	Item backup file.
	Save Item 3	Delete any old simulation details with same backup identifier in item op backup file.
	Save Item 4	Save item op details in item op backup file.
	Reorganise	Item op backup file.
	Save Item 5	Delete any old simulation details with same backup identifier in workcentre backup file.
	Save Item 6	Save workcentre details in workcentre backup file.
	Reorganise	Workcentre backup file.
	Save Item 7	Delete any old simulation details with same backup identifier in item temp backup file.
	Save Item 8	Save item temp details in item temp backup file.
	Reorganise	Item temp backup file.
	Save Item 9	Delete any old simulation details with same backup identifier in cost centre backup file.
	Save Item 10	Save cost centre details in cost centre backup file.
	Reorganise	Cost centre
	Save Item 11	Delete any old simulation details with same backup identifier in static data backup file.
	Save Item 12	Save static data details in static data backup file.
	Reorganise	Static data backup file.
Enquire on Saved Environment.		
	Static Data Backup	Enquiry option.
Enquire on Saved Item Operation Details.		
	Item Op Backup	Enquiry option.
Enquire on Saved Workcentre Details.		
	Workcentre Backup	Enquiry option.
Enquire on Saved Cost Centre Details.		
	Cost Centre Backup	Enquiry option.
Enquire on Saved Item Details.		
	Item Backup	Enquiry option.

Appendix 2.8 - K+ Simulation - Save Simulation Details Menu continued.

Menu Option Program Name	Function
Restore Saved Simulations.	
Restore Item 0	Controls logic flow and input of backup identifier to be restored.
Delete Items	Clear item file.
Reorganise	Item file.
Restore Item 1	Restore item backup file to item file for required backup identifier.
Delete Item Op	Clear item operation file.
Reorganise	Item operation file.
Restore Item 2	Restore item operation backup file to item operation file for required backup identifier.
Delete Workcentre	Clear workcentre file.
Reorganise	Workcentre file.
Restore Item 3	Restore workcentre backup file to workcentre file for required backup identifier.
Delete Item Temp	Clear item temporary file.
Reorganise	Item temporary file.
Restore Item 4	Restore item temporary backup file to item temporary file for required backup identifier.
Delete Cost Centre	Clear cost centre file.
Reorganise	Cost centre file.
Restore Item 5	Restore cost centre backup file to cost centre file for required backup identifier.
Delete Static Data	Clear static data file.
Reorganise	Static data file.
Restore Item 6	Restore static data backup file to static data file for required backup identifier.

Appendix 2.8 - K+ Simulation - Save Simulation Details Menu continued.

Menu Option **Program Name**	**Function**
Delete Saved Simulations.	
Delete Backup 0	Control logic flow and input backup identifier to be deleted.
Delete Backup 1	Delete item backup for required backup identifier.
Reorganise	Item backup file.
Delete Backup 2	Delete item operation backup for required backup identifier.
Reorganise	Item operation backup file.
Delete Backup 3	Delete workcentre backup for required backup identifier.
Reorganise	Workcentre backup file.
Delete Backup 4	Delete item temporary backup for required backup identifier.
Reorganise	Item temporary backup file.
Delete Backup 5	Delete cost centre backup for required backup identifier.
Reorganise	Cost centre backup file.
Delete Backup 6	Delete static data backup for required backup identifier.
Reorganise	Static data backup file.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.9 - Schedule Overall Capacity Planning Menu.

Menu Option **Program Name**	**Function**
Schedule Maintenance.	
Schedule Maintenance	
Schedule Capacity Load.	
Schedule Days 0	Control logic flow.
Schedule Days 0a	Clear driver / slave flags on schedule maintenance file.
Schedule Days 0b	Delete schedule operation for year / period.
Schedule Days 0c	Delete schedule temporary for year / period.
Schedule Days 0d	Delete schedule workcentre for year / period.
Schedule Days 0e	Delete schedule cost centre for year / period.
Schedule Days 0f	Delete schedule op temp for year / period.
Schedule Days 1	Set non grouped items to driver.
Schedule Days 2	Set driver / slave level 1.
Schedule Days 3	Set driver / slave level 2.
Schedule Days 4	Copy schedule maintenance to schedule temporary for year / period.
Schedule Days 5a	Set up operations for all schedules for year / period from schedule maintenance and item op master.
123	Read file output from *Schedule Days 5a* and re output.
Import	Import file output from *Lotus 123* to schedule op temp.
Schedule Days 5b	Create schedule operation from schedule op temp for year / period.
Schedule Days 6	Calculate schedule operation times.
Schedule Days 7	Copy workcentre to schedule workcentre for year / period.
Schedule Days 8	Calculate schedule workcentre times.
Schedule Days 9	Copy cost centre to schedule cost centre for year / period.
Schedule Days 10	Calculate schedule cost centre times.

Appendix 2.9 - Schedule Overall Capacity Planning Menu continued.

Menu Option **Program Name**	**Function**
Schedule Operation Enquiry.	
Schedule Operation	Enquiry only option.
Schedule Workcentre Enquiry.	
Schedule Workcentre	Enquiry only option.
Schedule Cost Centre Enquiry.	
Schedule Cost Centre	Enquiry only option.
Delete Schedule for Year / Period.	
Schedule Delete 0	Controls logic flow.
Schedule Delete 1	Delete schedule maintenance for year / period.
Schedule Delete 2	Delete schedule workcentre for year / period.
Schedule Delete 3	Delete schedule operation for year / period.
Schedule Delete 4	Delete schedule cost centre for year / period.
Schedule Delete 5	Delete schedule temporary for year / period.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.10 - Schedule Reports Menu.

Menu Option Program Name	Function
Schedule Workcentre Capacity.	
Schedule WC Cap 0	Controls logic flow.
Schedule WC Cap 1	Output workcentre capacity load to screen.
Schedule WC Cap 2	Output workcentre capacity load to report.
Schedule Group List.	
Schedule Group 0	Controls logic flow.
Schedule Group 1	Output schedule group list to screen.
Schedule Group 2	Output schedule group list to report.
Schedule List by Order Number.	
Schedule List 0	Controls logic flow.
Schedule List 1	Output schedule order list to screen.
Schedule List 2	Output schedule order list to report.
Schedule Operation Load.	
Schedule Op Group 0	Controls logic flow.
Schedule Op Group 1	Output schedule operation load to screen.
Schedule Op Group 2	Output schedule operation load to report.

APPENDIX 2 - SOFTWARE LOGIC FLOW BY PROGRAM.

Appendix 2.11 - Operation Master Menu.

Menu Option **Program Name**	**Function**
Import Item Operation Master from Lotus 123	
Import Item Op Mas 0	Controls logic flow.
Delete Item Op Mas	Clears current item operation master details
Reorganise	Item operation master file.
Import	Item operation master details.
Maintain Operation Details.	
Item Op Master	Enquiry and update option.
Copy Prime Routes to Item Operation.	
Copy Item Op Master0	Controls logic flow.
Copy Item Op Master0	Clears current item operation details.
Copy Item Op Master0	Copy prime routes from item op master file to item operation file.

APPENDIX 3 – PUBLISHED PAPERS.

Appendix 3.0 – British Production and Inventory Control Society Control – August / September 1995.

Competitive Advantage for Batch Manufacturing using Capacitated Batch Sizing within MRP.

COMPETITIVE ADVANTAGE FOR BATCH MANUFACTURING USING CAPACITATED BATCH SIZING WITHIN MRP

An application of the K-Curve Methodology (KCM).

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Geoffrey Relph MBPICS, IBM Consulting

OVERVIEW.

In the increasingly competitive world of the 1990s, the ability to predict and control the behaviour of an inventory management system can have an important effect on the overall business performance of a manufacturing organisation.

The earlier in the planning cycle that this predictive ability can be applied, the better the chance will be of taking effective remedial action.

The power of this methodology is not solely in the ability to calculate the business performance passively and then compare this against current performance measures, or in the ability to leap forward from MRP and provide true capacitated batch sizing, but the key to its success lies in the ability of the underlying modelling software to perform experiments which can help to predict the likely behaviour of the business in a variety of categories.

It is the predictive ability of the modelling software (used in conjunction with its goal searching capability) that provides the key to the power of this approach.

The methodology has the ability to help to answer these sorts of questions.

- What would be the effect on inventory and administration of decreasing all set-up times by 10% whilst loading the Work Centres to the same level?
- What would be the effect on inventory and capacity if our administrative system could cope with double the order workload?
- Where should we concentrate our Set-Up reduction programme? Is a set-up reduction programme what is required, or do our administration systems need improving first?
- Is the continuous improvement programme focused on the bottleneck resource(s)?
- How much money will be tied up in stock?
- If we can achieve a Single Minute Exchange of Dies (SMED) on a bottleneck resource will we still require a new machine?
- Which resources are bottlenecks?

INTRODUCTION

This paper describes a method of applying the K-Curve Methodology (KCM) [1] to the setting of the inventory control system parameters (typically MRP policy codes) within a batch manufacturing environment, by taking account of identified constraints in Inventory Holding Value, Administrative Workload and Machine Capacity.

It simplifies the assumptions made about inventory behaviour by concentrating solely on the values which would be generated against each of the three constraints by the forecasted demand.

It then details how the performance measures are derived and explains the need for identifying where reductions to set-up times should be made, and how they can be identified.

It then re-iterates how the K-Curve methodology is applied to purchased items, and outlines the details of how it is applied to batch manufactured items with set-up costs.

The philosophy behind the modelling process is then explained, and the results of the optimised schedules discussed.

The methodology is illustrated with worked examples and details are given of the assumptions made, and the scheduling environment.

CURRENT PERFORMANCE MEASURES

The first task in the modelling process is to establish the current and desired performance limits. The modelling process takes two sets of parameters as the guide to the calculation of these:

1. The stated limits on Finance (£ average inventory value), Administrative Workload (number of orders per annum) and Work Centre Capacity (shift patterns, machine availability etc.).
2. The load that the current working practices place on these three constraints is calculated from the forecasted annualised demand, the current MRP (or other planning system) parameter settings and the routing information. The forecasted annualised demand should be stated as a gross demand, ignoring any current stock, work in progress, or policy stocks currently within the system.

   This is then validated against the actual performance history, where available, to identify where the parameters are being overridden.

By taking both the theoretical limits and the current working practices into account at this stage, mis-matches in information can be easily identified and rectified.

HOW TO CALCULATE THE CURRENT WORKLOAD

The load that the current working practices generate can be calculated as follows for each item and then accumulated for the business:

For Items with a stated period order days:

$$\textbf{Number of orders per annum} = \frac{\text{Working Days per Annum}}{\text{Period Order Days}}$$

$$\textbf{Average inventory value} = \frac{\text{Demand per Annum} \times \text{Standard Cost}}{\text{Number of Orders per Annum} \times 2}$$

Standard minutes per annum = Run Time per Annum + Set-Up Time per Annum

Run time per annum = Demand per Annum x Run mins per Operation per Item

Set-up time per annum = Number of Orders per Annum x Set-Up mins per Operation

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From this it is possible to calculate an initial estimate of the load placed on the three constraints. This will tend to over estimate the required work centre capacity, as no account is taken of items with common set-up characteristics. This may be the 'worst case' identifiable from the information obtained from the planning parameters. However, it may actually be an underestimate of the load where batch splitting occurs.

ITEMS USING COMMON SET-UPS

The next step is to identify where it is possible for items with common work centre set-up characteristics to be scheduled and run sequentially.

To do this, those items with common set-ups need to be identified into set-up groups, with sub-groups to identify minor set-up changes.

From this, it is possible to construct a 'best case', assuming that wherever it is possible for items within a set-up group to be scheduled together, they will be, with a major set-up incurred by only one of the items within the group, and minor set-ups incurred by the remaining members of the group concurrently scheduled.

As an example, take a manufacturer of extruded curtain rail. This can be manufactured in a variety of profiles, colours and lengths. The extrusion and cutting are performed by a pair of close coupled machines, the rail is then immediately packaged. The extrusion machine is fed with granules via a hopper. To change the profile of the extrusion takes 120 minutes, to change colour takes 30 minutes, and to change the length takes 15 minutes. The changes can be performed in parallel, the time taken being the time for the longest change (eg. to change profile, colour and length will take 120 minutes).

The above example illustrates a hierarchy of set-ups, the levels of which can be identified by a series of analysis codes, as follows:

Level 1	Profile
Level 2	Colour
Level 3	Length

The following 7 items will illustrate the method used to assess which set-up is used and why:

FIGURE 1

ITEMS USED TO ILLUSTRATE METHOD

Item Code	Profile	Colour	Length	Order Days
A120	Budget	White	1m	5
A121	Budget	Gold	1m	40
A122	Budget	White	2m	5
A123	Budget	Brown	2m	40
A124	Budget	Gold	2m	40
A125	Budget	White	3m	10
A126	Budget	Gold	3m	40

Within the set-up group, both Items A122 and A120 are currently ordered every 5 days. Only one of these (A122) will require a change of profile (from a previous profile to budget). All the other budget/white rails (A120 & A125) will require a length change once A122 is running.

Both Brown and Gold colours appear every 40 days.

To change to Brown (A123) will require a change of colour once A122 is running.

To change to Gold (A124) likewise will require a change of colour once A122 is running. All the other budget/gold rails (A121 & A126) will only require a length change once A124 is running.

The annual minutes spent on set-ups can be calculated, as follows, assuming 240 working days per year:

FIGURE 2

ANNUAL MINUTES SPENT ON SET-UPS

Item Code	Set-Up	Mins	Orders/ Year	Annual Mins
A120	Length	15	48	720 m
A121	Length	15	6	90 m
A122	Profile	120	48	5,760 m
A123	Colour	30	6	180 m
A124	Colour	30	6	180 m
A125	Length	15	24	360 m
A126	Length	15	6	90 m
			144	7,380 m

The original calculation (the 'worst case') would have assumed a 120 minute profile change between each item, with 144 orders per year, totalling 17,280 minutes per annum set-up. This is standard MRP.

The 'best case' calculated by taking account of possible set-up reductions, comes out with 7,380 minutes set-up for the 144 orders, a potential saving of 9,900 minutes (17,280 m - 7,380 m) over the year. Experienced planners and/or shop floor personnel may already be able to obtain this benefit through historical scheduling practices.

The run time load for each work centre for the year can be calculated by simply multiplying the annual quantity for each item by the run minutes for the operation. This is repeated for each operation.

Each of the items being considered has only one operation, through the same work centre. The timings are as follows:

FIGURE 3

RUN TIME PER ANNUM

Item Code	Run Time	Annual Usage Value	Standard Cost	Quantity /Year	Run Time /Year
A120	0.25 mins	£1.2m	£4.00	300,000	75,000m
A121	0.25 mins	£0.2m	£4.00	50,000	12,500m
A122	0.50 mins	£2.5m	£8.00	312,500	156,250m
A123	0.50 mins	£0.5m	£8.00	62,500	31,250m
A124	0.50 mins	£0.5m	£8.00	62,500	31,250m
A125	0.75 mins	£1.0m	£12.00	83,333	62,500m
A126	0.75 mins	£0.2m	£12.00	16,667	12,500m
					381,250m

From this it can be seen that the proposed schedule would generate a run-time load of 381,250 minutes on the work centre over the course of the year.

We now need to calculate the average inventory value for the current parameters, using the formula described earlier:

FIGURE 4

AVERAGE INVENTORY VALUE

Item Code	Orders/ Year	Annual Usage Value	Average Inventory
A120	48	£1.2m	£12,500
A121	6	£0.2m	£16,667
A122	48	£2.5m	£26,042
A123	6	£0.5m	£41,667
A124	6	£0.5m	£41,667
A125	24	£1.0m	£20,833
A126	6	£0.2m	£16,667
	144		£176,042

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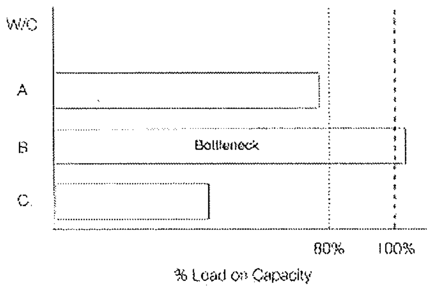
We now have a clear picture of how the business currently performs in relation to each of the three constraints. We also know the contribution that each item makes to the load on each of the constraints, and, importantly in the case of capacity, whether this load is attributable to set-up or run minutes. By stating the capacity of each work centre it is possible to identify the bottlenecks that the current policy would create.

FIGURE 5

IDENTIFICATION OF BOTTLENECKS



The importance of firstly being able to identify the bottlenecks and secondly to attribute the load to both set-up and run minutes is that it can be clearly shown where to focus the set-up reduction process, and where a process improvement or extra capacity would alleviate the constraint.

THE K-CURVE METHODOLOGY MODIFIED FOR SET-UP COSTS

To determine optimal ordering frequencies for manufactured parts, it is necessary to be able to take account of set-up or other one-off charges which add cost to each manufacturing run of a particular item. It is no longer appropriate to consider purely an ordering cost: allowances should be made for the existence of both costs, ordering and set-up, where they exist.

This section attempts to explain a proposed methodology for dealing with these identified costs in a unified manner.

The standard *EOQ* formula for purchased items is:

$$EOQ = \sqrt{\frac{2.A.C_o}{i.C_m}}$$

where

A	Annual usage quantity
C_o	Cost of ordering and delivery per occasion
i	Annual stockholding interest rate
C_m	Item cost

The *EOQ* can be rearranged firstly in terms of the economic ordering or delivery frequency *(F)*:

$$F = \frac{A}{EOQ}$$

And then eventually rearranged again in terms of the Annual Usage Value (AUV), as follows:

$$F^2 = \frac{A^2}{EOQ^2}$$

$$F^2 = \frac{i}{2.C_o}(A.C_m)$$

$$A.C_m = \left(\frac{2.C_o}{i}\right)F^2$$

Therefore the Annual Usage Value *(Annual Usage Quantity * Item Cost)* is related to the square of the ordering or delivery frequency *(F)* by a factor which could be called K.

K is the ratio of twice the ordering or delivery cost *(Co)* to the annual stockholding interest rate *(i)*.

$$K = \frac{2C_o}{i}$$

Which leaves us with the following equation:

$$A.C_m = K.F^2$$

Which can be re-arranged as follows, in terms of the delivery frequency:

$$F = \sqrt{\frac{A.C_m}{K}}$$

When modified to take account of set-up costs the *EOQ* formula becomes the economic batch quantity formula *(EBQ)*, which is:

$$EBQ = \sqrt{\frac{2.A(C_o + S_u)}{i.C_m}}$$

where

A	Annual usage
C_o	Cost of internal ordering per occasion
i	Annual stockholding interest rate
C_m	Item cost
S_u	Set-up cost per occasion

The *EBQ* can be rearranged in exactly the same way as the standard *EOQ* formula in terms of the *AUV*, as follows:

$$F^2 = \frac{i}{2(C_o + S_u)}(A.C_m)$$

$$A.C_m = \left(\frac{2(C_o + S_u)}{i}\right)F^2$$

$$AUV = \left(\frac{2.(C_o + S_u)}{i}\right)F^2$$

$$K^1 = \frac{2.(C_o + S_u)}{i}$$

What does not now come out of the formula is a standard cost ratio *(K)* which is applicable to large group of parts, as it is difficult to argue convincingly that Set-Up costs are the same for all the parts being considered, when they could easily be demonstrated to be different.

Taking the original formula, research [1][2] has already proven that, when taken at the macro level, the ratio of the ordering cost to the inventory holding rate can be considered constant for a range of purchased parts. This is the basic premise of the K-Curve Methodology.

For manufactured parts, it can be argued with equal validity [3][4] that if the Set-Up costs were zero, that is, only considering internal ordering costs, a constant value for *K* could be derived for the group of parts being considered.

It can also be argued that, having established a value of *K* assuming that Set-Up costs are zero, an educated estimate of the inventory holding rate *(i)*, or range of values that the rate was likely to be within, could likewise be established for the enterprise.

Having established these values, a value, or range of values, for the cost of internal ordering or delivery per occasion *(Co)* can likewise be inferred.

By using this technique, and slotting in the relevant Set-Up cost it is possible to rationally allocate manufactured items into scheduling frequencies optimised for the business as a whole.

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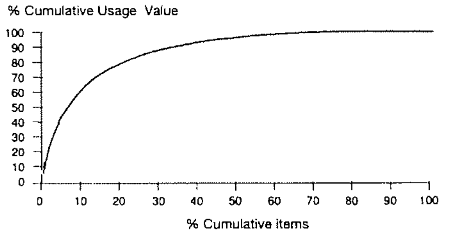
HOW THE MODEL WORKS

The way the model works is that by taking certain assumptions about the business (eg. Inventory Holding Rate, Values of K to be Modelled) and the details of the Set-Up groups, it is possible to rationally allocate items to scheduling frequencies based on Pareto analysis, modified to take account of Set-Up costs. In effect a separate Pareto curve is developed for each group of parts having common Set-Up costs.

FIGURE 6.

PARETO CURVE



It firstly allocates each of the items being considered into one of the period order days classes (eg. 5, 10, 20 days). Having allocated each of the items in this way the load against each of the constraints (Capacity, Finance, Administration) can be directly calculated.

The calculated load generated by the parameter set can then be compared with the stated limits and the current load. By altering the parameters it is possible to flex the generated load on all three constraints and to, firstly, quantify the degree of match against each of the constraints and, secondly, identify and quantify resource bottlenecks (in capacity, finance or administration).

Having identified the bottlenecks (if any) it is then possible to clarify what remedial action is required to bring the system within due bounds, or to re-establish the criteria so that it is possible to satisfy them.

The results of the modelling process will also serve to illustrate the sensitivity of the parameter set, by clearly showing the difference between the desired performance and the theoretical performance of using the suggested ordering cycles. This can be used to clearly focus the business improvement programme on the areas most likely to provide benefit first.

The model relies on the scheduling frequencies being a geometric progression [2] (eg. 5, 10, 20, 40, 80, 160 days) so that the item with the lowest period order days within each group can be scheduled each time less frequently scheduled items are manufactured.

Within each set-up group (in this case Budget rails) the items are firstly ranked according to annual usage value, and the highest AUV item, A122, is allocated the profile change set-up cost, in this case £30.00 (120 minutes at £15 per hour).

All the other white budget rails will incur a length change set-up cost of £3.75 (15 minutes at £15 per hour).

The highest AUV item left for the next colour (Brown), A123, will incur a colour change set-up cost of £7.50 (30 minutes at £15 per hour).

All the other brown budget rails will incur a length change set-up cost of £3.75 (15 minutes at £15 per hour).

The highest AUV item left for the next colour (Gold), A124, will incur a colour change set-up cost of £7.50 (30 minutes at £15 per hour).

FIGURE 7

ALLOCATION OF SET-UP COSTS

Item Code	Colour	Length	Annual Usage/ Value	Set-Up Cost
A120	White	1m	£1.2m	£3.75
A121	Gold	1m	£0.2m	£3.75
A122	White	2m	£2.5m	£30.00
A123	Brown	2m	£0.5m	£7.50
A124	Gold	2m	£0.5m	£7.50
A125	White	3m	£1.0m	£3.75
A126	Gold	3m	£0.2m	£3.75

Having allocated the set-up costs in a coherent manner to the items, the next step is to set the scheduling frequencies.

This is done by using the formula discussed earlier,

$$F = \sqrt{\frac{A.C_m}{K}}$$

with the following modification:

$$K^{\cdot} = \frac{2.(C_o+(S_u \text{ x } v))}{i}$$

The sensitivity factor (v) is used to modify the set-up costs, as the figure of £15 per hour used may not be particularly accurate, especially if the Set-Ups are performed by a setter who has spare capacity. It may then be possible to double the number of set-ups without incurring further costs if the setter is only setting 50% of the time. This factor modifies the Set-Up costs in the same way that flexing the value of K flexes the order cost for purchased parts.

The modifiers for the rest of the modelling process are the values of K ($2.C_o/i$).

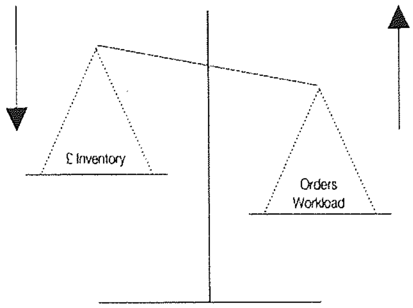
The effect that the sensitivity factor (v) has is to change the set-up costs allocated to each item, by effectively modifying the yield rate used to calculate the set-up costs from the timings.

The value of K used is an indicator of the speed of the business. The lower the value of K, the smaller the implied order cost.

It is possible, using these two modifiers to focus the attention of the modelling process onto the degree of fit possible against the three constraints (financial, administrative and capacity) and away from the detailed discussions on the veracity of the underlying costs (always a topic of much debate).

FIGURE 8

UNDERSTANDING THE BUSINESS EQUILIBRIUM



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The only modification to the raw results obtained from the modelling process that the system performs is to ensure that items with an AUV lower than or equal to the highest AUV item in the group are not scheduled more frequently than the highest AUV item. An example of this could be 2 parts in the same Set-Up group with near identical AUV's. One would be allocated the Major Set-Up cost of £30, and the other a minor set-up cost of £7.50. The period order days for the item with the £30 set-up cost may be calculated at 20 days. By virtue of the lower set-up cost, the class for the other item may be calculated at 10 days. The 10 day item would be re-classified to 20 days.

OPTIMISING THE SCHEDULE

Having clearly defined the starting position both in terms of the theoretical limits and load that the current policy will generate, comparisons against other solutions can be performed.

The items being considered were

FIGURE 9

ITEMS CONSIDERED

Item Code	Colour	Length	Annual Usage Value
A120	White	1m	£1.2m
A121	Gold	1m	£0.2m
A122	White	2m	£2.5m
A123	Brown	2m	£0.5m
A124	Gold	2m	£0.5m
A125	White	3m	£1.0m
A126	Gold	3m	£0.2m

The current inventory policy generated the following load on the three constraints over the course of the year:

FIGURE 10

RESULTS OF CURRENT POLICY

Constraint	'Best case'	'Worst Case'
Number of Orders	144	144
Average Inventory Value	£176,042	£176,042
Work Centre Load - Set-Up	7,380m	17,280m
- Run	381,250m	381,250m

Match on Number of Orders

Taking the current position as a starting point, it is possible to re-class the items so that a match on the Number of orders is found. This generates the following load on the constraints:

FIGURE 11

RESULTS OF MATCH ON # ORDERS

Constraint	'Best case'	Match on Orders
Number of Orders	144	144
Average Inventory Value	£176,042	£130,208
Work Centre Load - Set-Up	7,380 m	7,560 m
- Run	381,250 m	381,250 m

The number of orders generated over the year was the same for both scenarios.

The set-up times over the year have increased slightly from 7,380 minutes to 7,560 minutes (180 minutes or + 2.5%).

The average inventory value has decreased from £176,042 to £130,208 (£45,834 or - 26%).

The run time will obviously be the same for all scenarios as this is calculated directly from the routing information and based on the annual scheduled quantity per item, which is constant.

The detailed breakdown of the figures is as follows:

FIGURE 12

DETAILED BREAKDOWN BY ITEM FOR MATCH ON # ORDERS

Item Code	Order Days	Orders/ Year	Annual Set-Up mins	Average Inventory Value
A120	10	24	360 m	£25,000
A121	20	12	180 m	£8,333
A122	5	48	5,760 m	£26,042
A123	20	12	360 m	£20,833
A124	20	12	360 m	£20,833
A125	10	24	360 m	£20,833
A126	20	12	180 m	£8,333
		144	7,560 m	£130,208

Although the number of orders generated per year has remained the same, all but two of the items (A122 and A125) have been moved into different period order day classes.

This scenario also provides the nearest match on set-up time.

Match on Inventory Value

Taking the current position as a starting point, it is possible to re-class the items so that a match on the average inventory value is found. This generates the following load on the constraints:

FIGURE 13

RESULTS OF MATCH ON INVENTORY VALUE

Constraint	'Best case'	Match on Inventory £
Number of Orders	144	108
Average Inventory Value	£176,042	£172,906
Work Centre Load - Set-Up	7,380m	4,500m
- Run	381,250m	381,250m

This scenario manages to improve on all three constraints.

The set-up times over the year have decreased from 7,380 minutes to 4,500 minutes (2,880 minutes or - 39%).

The average inventory value has slightly decreased from £176,042 to £172,906 (£3,136 or - 1.7%).

The number of orders generated has decreased from 144 per year to 108 per year (36 or - 25%).

The detailed breakdown of the figures is as follows:

FIGURE 14

DETAILED BREAKDOWN BY ITEM FOR MATCH ON INVENTORY VALUE

Item Code	Order days	Orders / Year	Annual Set-Up mins	Average Inventory Value
A120	10	24	360 m	£25,000
A121	40	6	90 m	£16,667
A122	10	24	2,880 m	£52,083
A123	20	12	360 m	£20,833
A124	20	12	360 m	£20,833
A125	10	24	360 m	£20,833
A126	40	6	90 m	£16,667
		108	4,500 m	£172,906

In this scenario all but two of the items (A121 and A125) have been moved into different period order day classes.

Reduce Inventory to 50% of current level.

Assume that management have decided that Inventory is to be reduced by 50%. This would generate the following load on the constraints:

FIGURE 15

RESULTS OF INVENTORY % REDUCTION

Constraint	'Best case'	Inventory % Reduction
Number of Orders	144	216
Average Inventory Value	£176,042	£86,459
Work Centre Load - Set-Up	7,380m	9,000m
- Run	381,250m	381,250m

The number of orders generated has increased from 144 per year to 216 per year (72 or 50%).

The average inventory value has decreased from £176,042 to £86,459 (£89,583 or - 51%).

The set-up times over the year have increased from 7,380 minutes to 9,000 minutes (1,620 minutes or 22%).

The detailed breakdown of the figures is as follows:

FIGURE 16

DETAILED BREAKDOWN BY ITEM FOR INVENTORY % REDUCTION

Item Code	Order Days	Orders / Year	Annual Set-Up mins	Average Inventory Value
A120	5	48	720 m	£12,500
A121	20	12	180 m	£8,333
A122	5	48	5,760 m	£26,042
A123	10	24	720 m	£10,417
A124	10	24	720 m	£10,417
A125	5	48	720 m	£10,417
A126	20	12	180 m	£8,333
		216	9,000 m	£86,459

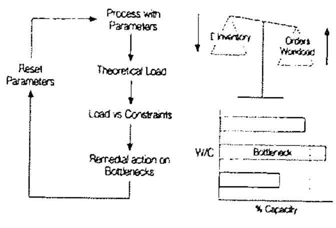
In this scenario all but three of the items (A121, A122 and A126) have been moved into different period order day classes.

CONCLUSION

What this paper has attempted to illustrate is a simple method for, firstly, setting MRP parameters in a rational manner for manufactured items, secondly, providing a mechanism whereby the parameter set can be ratified in three constrained dimensions (capacity, administration and finance) and, finally, to show how it can be used to focus the continuous improvement programme into those areas where maximum benefit will first accrue.

FIGURE 17

CONTINUOUS IMPROVEMENT CYCLE



What the process does is to link the three business pressures of capacity, inventory and orders in such a way that they can be modelled, so allowing for more informed decisions to be made.

It uses data straight from the existing planning and control system, typically MRP; part numbers, costs, routes, work centre details etc. The accuracy of this data will directly contribute to the validity of the results obtained from the underlying modelling process.

The only extra information required by the system is the constitution of the set-up groups and the values for the minor set-ups and associated set-up costs.

It overcomes the limitations associated with MRP in the area of sequence dependent set-ups, and provides a simple methodology for setting planning parameters taking this effect into account.

This methodology has been trialled with companies involved in Plastic Extrusion, Plastic Moulding and Drug Manufacturing. The common attribute of these businesses is that they all have one or two operation steps. The Plastics Companies basically Mould or Extrude and then sell the goods. The Pharmaceutical Company formulates and encapsulates the drugs and then packs and sells them.

The research project described in this paper is funded by the EPSRC and sponsored by the IBM Consulting Group.

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About the Authors

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Appendix 3.1 – Integrated Manufacturing Systems – Volume 6 Number 4 1995.

Managing the Business Constraints of Inventory, Capacity and Orders within Repetitive Batch Manufacturing.

Research note

Managing the business constraints of inventory, capacity and orders within repetitive batch manufacturing

Peter Burcher, Simon Dupernex and Geoffrey Relph

Proposes a methodology to simplify the effort required to control the business

Introduction

In the increasingly competitive world of the 1990s, the ability to predict and control the behaviour of an inventory management system can have an important effect on the overall business performance of a manufacturing organization. The earlier in the planning cycle that this predictive ability can be applied, the better the chance will be of taking effective remedial action.

This note describes a proposed methodology aimed at batch manufacturers with, essentially, single operation manufacturing processes such as plastic extrusion or moulding. It is split into two initial phases, phase one dealing with the planning system (MRP) parameter setting, and phase two dealing with the operational matching of the load to the available capacity.

The main emphasis of the methodology is to provide a means to assist traditional batch manufacturers in a route to continual improvement, by providing modelling tools, and by simplifying the effort required to control the business. The methodology can be described as way of simply understanding and balancing the three main business pressures, capacity, finance and administrative workloads (Figure 1).

By understanding their interrelationships it is possible to bring the business parameters into an equilibrium which is in line with the enterprise objectives.

Phase one

What this note describes is the use in a batch manufacturing environment of a Pareto-based capacitated batch sizing tool using a modified economic batch quantity (EBQ) equation to determine the period order days class of each item being considered.

The Pareto principle is extended so that a separate Pareto curve is produced for each group of items incurring a particular set-up cost (Figure 2).

By using a geometric progression (e.g. 5, 10, 20, 40, 80, 160 days supply) for the period order days series, it is possible to make allowances for set-up reductions when items incurring identical workcentre set-up characteristics are scheduled together.

The common set-up groups are identified within a multi-level set-up group hierarchy and a "best case" constructed. This assumes that wherever it is possible to schedule items within a set-up group together, they will be.

Within each set-up group the items are first allocated set-up costs (of the appropriate value for the level of the item within the set-up hierarchy) based on the annual usage value (AUV) of each item. That is because, using Pareto analysis, the higher the AUV, the more frequently the item would be scheduled.

Once each item is allocated to a period order day class, each set-up group is validated to ensure that items with low AUVs are not scheduled more frequently than those with higher AUVs. This may happen where items with near identical AUVs within a set-up group are allocated different set-up costs and are allocated to different period order day classes.

Having validated the class allocation of each item, the load in terms of finance (average inventory value),

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This research is funded by the EPSRC with sponsorship from the IBM Consulting Group.

Figure 1. *Controlling the business equilibrium*

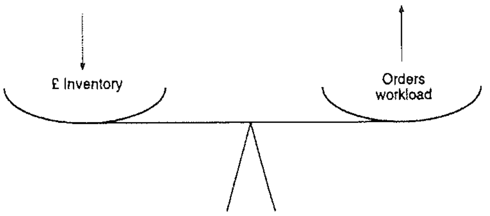


Figure 2. *A Pareto curve*

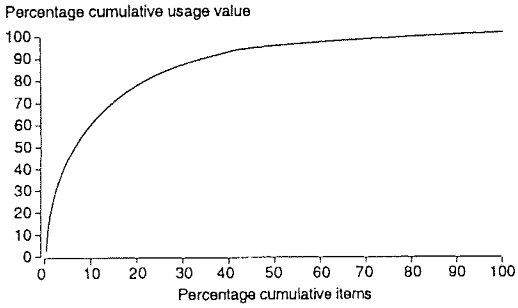
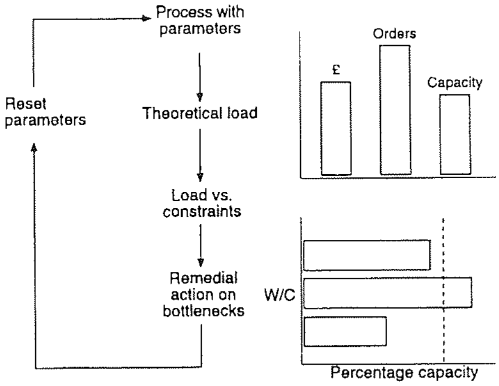


Figure 3. *Continuous improvement cycle*



administration (orders per year) and capacity (workcentre load) can be directly calculated and compared with the stated limits in each area to identify potential constraints. Comparisons with the load that the current policy would generate are also made.

The modelling is greatly simplified by concentrating on the theoretical load that the inventory policy would generate, and ignoring the effects of any current or planned inventory overage such as safety stock.

Having derived an inventory policy that broadly satisfies the limits within which the enterprise wishes to operate, other operational considerations particular to individual items (e.g. space) can be considered, and the parameters generated by modifying the modelling accordingly.

The output from this first phase is the setting of the order policy codes, validated in three dimensions, for the planning system (typically MRP). The modelling process used has been developed to help to overcome one of the important criticisms of MRP, namely that MRP accepts the set-up times and lead times etc. as given and does not provide a mechanism for continual improvement (Figure 3).

The facilities provided within the modelling process address this issue by: first, providing the feedback on the constraint load vs. constraint limits in the three measured dimensions; second, by scenario modelling the effects of changing the limits of the constraints; third, by scenario modelling the effects of changing operational parameters (set-up times etc.); fourth, by assisting multi-dimensional goal searching; and finally, by automatic goal searching for the "best fit" when constrained in one dimension.

Phase two

Following on from the setting of the order policy codes, the next step is to assist in the initial capacity matching of the workload generated by the planning system, or "capacity requirements planning" (CRP). Having set the items being considered within a period order day class (PODC), when each item is reviewed by the planning system, the batch size will be essentially determined by the demand within the period order day horizon less any current stock, and an order generated to cover the net demand.

For the sake of understanding, let us assume that the period order day classes are 5 ,10, 20, 40, 80, and 160 days and that the planning system (MRP) is run on a weekly (five day) cycle.

The main simplifying assumption made in the initial parameter setting phase, namely that the item with the highest AUV within each set-up group will always be scheduled when other items within the set-up group are scheduled, will be shown to be somewhat optimistic! For instance, if the highest AUV item is set to a PODC of ten days, it is possible that items within the set-up group will be scheduled every week, with each week containing differing elements of the set-up group. This could be caused by customer orders being received for delivery within the PODC for the item which cannot be satisfied by any forecast. An instance of this could be where the PODC is 40 days and extra demand over that planned for is required for shipment at day 30 of the 40-day cycle which is not covered by policy stock (Figure 4).

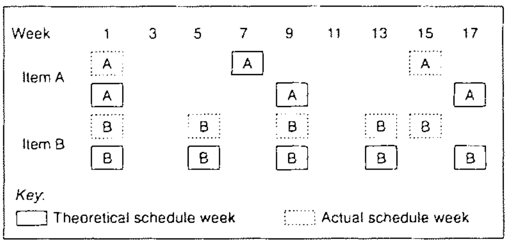
What is now required is a method for re-forming a set-up group each week, based on the items being scheduled that week, initially assuming that all the items scheduled this week are required at the end of the week. The reason for doing this is that while the run times of an item using a particular route can basically be thought of as fixed, the set-up times will differ according to the relationship of the predecessor item to the successor item. Where items within a set-up group can be scheduled sequentially, reductions in the set-up times can be gained.

The first step is to validate the overall work centre capacity ☐

Once each set-up group is reformed using those items scheduled in the current week (which may well include items left over from previous weeks), the set-up times can be recalculated, and a sequenced scheduleable set-up group formed. This group will represent the minimum time it is possible to schedule the items within the group. Each partial set-up group re-formed in this way is independent, and the sequence in which each of the partial set-up groups are loaded has no effect on the overall workcentre load. The groups are reformed in the same manner as that adopted in phase one, but only including those items which are scheduled this week.

What can now be compared against the available capacity is the "best case" load, that is, the load with the minimum possible set-up content. It is assumed that the available capacity is calculated by work centre for the planning period (e.g. one week).

Figure 4. *Theoretical vs actual schedule*



The first step is to validate the overall work centre capacity against the load generated by the partial set-up groups. The resulting capacity plan (CRP) will highlight any immediate capacity shortfalls at a work centre level, using the prime route.

If this check is not OK, the set-up groups can be split across alternative routeings, moving the load from the overloaded work centres to those with spare capacity. The partial set-up groups will then be re-formed and the set-up times and run times recalculated using the revised routeing information.

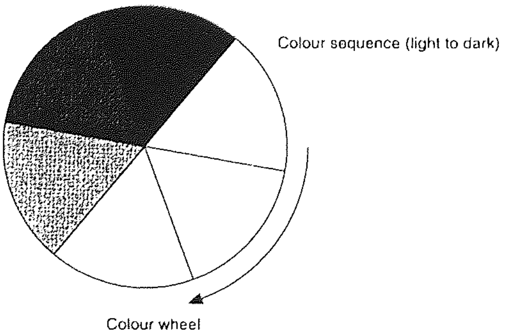
Once a satisfactory CRP is achieved, either by moving items to alternative routeings, or increasing capacity by overtime, or both, the next stage is to load at a machine level. If a work centre is synonymous with a machine, the CRP load will only need to be refined to take account of any priorities within the weekly load.

Where a work centre consists of multiple machines, the output from the CRP will need to be spread across the machines while retaining the integrity of the groups and satisfying individual priorities. This is performed by re-iterating the process described in the CRP procedure, that is, by splitting and re-forming partial set-up groups by machine.

By feeding back the completed work and information on breakdowns, it is possible to use the principles outlined above to re-plan the remaining workload as the week progresses to take account of changing circumstances (Figure 5).

The sequencing element within each set-up group is made possible by simply allocating a priority sorting sequence. For example, it may be desirable to sequence

Figure 5. *Colour wheel*



colours from light to dark. White could be allocated a sequence of 10, grey 20, and black 30. By sorting the items by the set-up sequence within the set-up hierarchy it is possible to accommodate the optimal sequencing for each group.

Conclusion

The power of this methodology is not solely in the ability to calculate the business performance passively and then compare this with current performance measures, or in the ability to leap forward from MRP and provide true capacitated batch sizing, but the key to its success lies in the ability of the underlying modelling process to perform experiments which can help to predict the likely behaviour of the business in a variety of categories. It is the predictive ability of the modelling process (used in conjunction with its goal searching capability) that provides the key to the power of this approach.

The methodology has the ability to help to answer these kinds of questions:

- What would be the effect on inventory and administration of decreasing all set-up times by 10 per cent while loading the work centres to the same level?
- What would be the effect on inventory and capacity if our administrative system could cope with double the order workload?
- Where should we concentrate our set-up reduction programme?
- Is a set-up reduction programme required, or do our administration systems need improving first?
- Is the continuous improvement programme focused on the bottleneck resource(s)?
- How much money will be tied up in stock?
- If we can achieve a single minute exchange of dies (SMED) on a bottleneck resource will we still require a new machine?
- Which resources are bottlenecks?

If you would like further information on the methodology outlined in this note or would like to participate in the research, please contact Dr Peter Burcher, at Aston Business School, Aston University, Birmingham B4 7ET, or telephone him on +44 121 359 3611 ext. 5095.

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Appendix 3.2 – International Journal of Operations and Production Management – Volume 16 Number 2 1996.

The Road to Lean Repetitive Batch Manufacturing.

The road to lean repetitive batch manufacturing

Modelling planning system performance

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Geoffrey Relph
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Introduction

In the current marketplace, which is characterized by frequent design changes, smaller production runs of greater variety and fluctuating demand, the Japanese have succeeded by the use of methodology rather than technology to compete[1] through co-ordinated team work, a systems approach, and attention to detail.

Four recent reports[2-5] on worldwide manufacturing competitiveness have highlighted several features which are consistent among firms achieving world-class manufacturing performance. Although two of these studies[2,3] are focused on the motor industry, valuable lessons are there to be learned by all manufacturers.

The main prerequisites for world-class manufacturing were found to be close management of the supply chain and process control.

Taking the second of these prerequisites, process control was found to be tighter and plants more space efficient. Low capacity utilization was seen to have a damaging effect on productivity, and it was claimed that the high performance of the Japanese plants stemmed from their historically high capacity utilization. The findings confirmed that capacity utilization affected productivity, and that the world-class plants were those operating at, or near, average capacity.

World-class plants were also able to operate with one-seventh the amount of inventory of their non-world-class competitors. Obviously, to be a world-class manufacturer requires more than high capacity utilization and low inventory levels, but what help is available to the repetitive batch manufacturer in these areas?

By gradually decreasing batch sizes in a systematic fashion, inventory will be reduced. By reducing the uncertainty in the forward capacity load profile through modelling the planned level at which the capacity can be loaded can be increased. This will allow for higher planned capacity utilization. Lead time can

International Journal of Operations & Production Management, Vol. 16 No. 2 1996, pp. 210-220. © MCB University Press, 0144-3577

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then be reduced through higher capacity utilization and smaller batch sizes. This article describes a methodology relevant to manufacturers of repetitive batches, to assist them in their journey to world-class manufacturing in these two important areas.

World-class manufacturing and lean production

World-class manufacturing[6] essentially means "having the right production capability to make money from totally satisfying the customer, with high quality services and products at the right price delivered at the right time". Just-in-time, manufacturing resource planning, and total quality management are all techniques which help to achieve world-class manufacturing.

Lean production was a phrase coined by Krafcik (see [7]) and used to describe what Toyota initially called the Toyota production system. It was called "lean" because it used less when compared to mass production techniques – half the labour hours, half the factory space, half the tooling investment, and developed new products in half the time using half the engineering hours, while requiring under half the on-site inventory, producing fewer defects, and a greater variety of products.

The philosophy of lean production can be illustrated by using the Toyota production system as an example. The Toyota production system[8] is a way of reducing the cost of production to increase profits. Because the car market in which Toyota operates is sensitive to selling price increases, the alternative strategy of increasing the selling price to maintain profitability was ruled out by market forces.

Motor vehicle manufacturers basically have the same production facilities, and use the same basic raw materials to produce their vehicles. Toyota had to use those facilities and materials as economically as possible to remain competitive.

Within Toyota there is a great emphasis placed on training and problem solving. The problem-solving exercises are based on an intuitive, pragmatic approach to the problems associated with quality and productivity, the ethos of hard work, the quest for continuous performance improvement, and a stress on self-reliance and responsibility[9]. The intuitive ideas are then compared with the mechanistic model of how the business currently performs (the standard working sheets) and where a process improvement results, it can then be implemented, and the standard method revised accordingly.

At Toyota there is a great emphasis placed on worker awareness of, involvement in, and responsibility for, the production processes. Team leaders are expected to participate actively in process improvements by identifying and eradicating non-value-adding activities, and to encourage their fellow workers to do the same. Team leaders are asked to take ownership and responsibility for their actions, to think about potential process problems before they occur, and stop them from occurring pro-actively. This level of responsibility is at a much lower level than in the traditional hierarchical structures. Each operator is capable of stopping production, using the Andon system. It is, however, the responsibility of the team leader to prevent this by prior preventive actions. Each team leader is expected to have an understanding of the logistics control system, and to be responsible for seeing that capacity is provided in the proportion required by the planned load. Where this differs from the actual load, workers are expected to be moved to the bottlenecks. Each worker is expected to be able to perform more than one task, each of which will be clearly defined and structured via standard working sheets. This may be summarized[7] as follows:

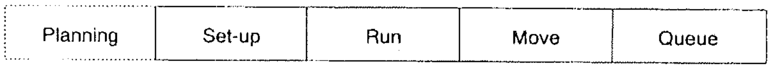
- Integrated single-piece production flow, with low inventories, and small batches made just in time.
- Defect prevention instead of rectification.
- Production pulled by the customer, employing level scheduling, rather than pushed to suit machine loading.
- Team-based work organization with flexible multi-skilled operators and few indirect staff.
- Active involvement in root cause problem solving to eliminate all non-value-adding steps, interruptions and variability.
- Close integration of the whole value stream from raw material to finished customer, through partnerships with suppliers and customers.

Lead time reduction

Having described the essential attributes of world-class manufacturing and lean production, how do these concepts relate to the repetitive batch manufacturer? Let us now take one element of the lean production approach: lead time reduction.

The *APICS Dictionary*[10] defines lead time as "A span of time required to perform an activity. In a logistics context, the time between recognition of the need for an order and the receipt of goods. Individual components of lead time can include: order preparation time, queue time, move or transportation time, receiving and inspection time". Lead time is therefore the total time required to manufacture an item and consists of the elements shown in Figure 1[11].

Figure 1.
Elements of lead time



Planning time is the activity concerned with obtaining the materials, writing the orders or schedules, sending the materials to the first operation and planning the production.

Set-up time is the time taken from producing the last item of a particular batch to producing the first item of the next batch.

Run time is the time taken to produce a batch of items. Reducing the batch size, justified by lower set-up times, directly reduces the batch run time as will process improvements.

Move time is the time taken to move the items from one process to the next process. A move to product-oriented manufacturing (group technology) rather than process orientation will reduce the move time owing to the proximity of the machines and the product focus of the cell.

In repetitive batch manufacturing, queue time is generally the longest element and often represents 80 per cent of the total throughput time[12]. Queues occur because jobs wait before being processed. The queue time is proportional to the amount of work in progress (WIP). To reduce the queue it is necessary to reduce the WIP. As set-ups are reduced to zero, so the batch size may be reduced to one. With the batch size minimized, enabling the WIP to be reduced, the processes become available as required and the queues disappear. For example, if the WIP in Figure 2 could be reduced from 1,000 hours to 300 hours, the lead time would decrease from ten weeks to three weeks.

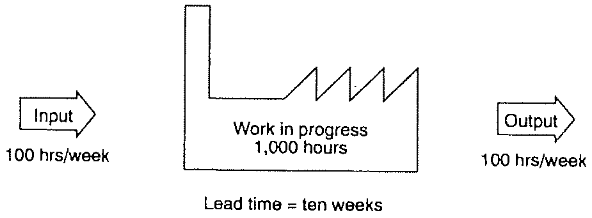


Figure 2. The effect of WIP on lead time

Set-up times have a great impact on the way in which a business behaves in terms of inventory holding and manufacturing flexibility[13] and is one of the key elements in the just-in-time (JIT) approach.

The key to manufacturing flexibility is in reducing the batch sizes. Smaller batches minimize inventory and make planning easier through reducing the unpredictability of capacity bottlenecks and therefore allow for the use of simple production control techniques. Frequent set-ups are necessary to produce a variety of goods in small lots[14].

A way of achieving this is through minimizing the set-up times. Set-up times have for too long been treated as a given[15], and therefore have not been subjected to the same level of scrutiny as large obvious costs such as direct labour, run time, scrap or rework.

Set-up has two elements, internal and external. Internal set-ups consume capacity, and therefore affect output. To reduce the effective set-up time you need either to remove the need for the set-up entirely (e.g. by using dedicated machines) or move from internal to external set-ups.

There are also different types of set-up. When a machine is set up to produce a particular item it may require a change of tool. When another item using the same tool but using a different material is scheduled next, only a change of material is required. If the next item uses the same material and tool, but a different colour, only a change of colour is required. What this means is that the set-up time is not fixed, but is dependent on the relationship of the predecessor to the successor batch. It is possible to minimize the time spent setting up by

Appendix 3.2 – International Journal of Operations and Production Management – Volume 16 Number 2 1996 continued.

planning the appropriate processing sequence. This can be described as a hierarchy, where (in the foregoing example) level 1 is the tool change, level 2 is the material change and level 3 the colour change.

By identifying the bottleneck resources it is possible to focus on the most beneficial set-up time to reduce first. Reductions in set-up times or cycle times on a bottleneck resource will show immediate benefits. Bottlenecks constrain business performance by adversely affecting cost through increased inventory, extended lead times and reduced throughput. Bottleneck identification depends on two factors product volumes, and product mix.

In summary: batch size reduction requires the identification of bottlenecks and their elimination through a systematic set-up reduction programme allowing a decrease in work in progress which reduces the lead time. The benefits of lead time reduction through smaller batch sizes are:

- the feasibility of increasing product variety without excessive cost penalties;
- increased manufacturing flexibility;
- lower cost base;
- increased competitiveness.

The pressures on repetitive batch manufacturers

The ability to predict and control the behaviour of an inventory management system can have an important effect on the overall business performance of a manufacturing organization. The earlier the stage in the planning cycle at which this predictive ability can be applied, the better the chance will be of taking effective remedial action.

The purpose of this research is to study the performance of repetitive batch manufacturers and to see what benefits can be gained over existing practices by using a simple Pareto analysis technique which places manufactured items into period order day classes while taking into account constraint limits in finance, administration and manufacturing. It also incorporates the interrelationship with sequence-dependent set-ups.

The principles outlined address only a very small, but important, part of lean production as applied in the context of repetitive batch manufacturing. The cultural changes required by firms in their relationships with their customers, suppliers and staff are still of paramount importance. The methodology proposed is an enabler, not an end in itself, and needs to be considered in the context of continuous improvement coupled with good manufacturing and logistics practices.

What the methodology provides is a means of helping traditional batch manufacturers along a route to continuous improvement, by providing modelling tools, and by simplifying the effort required to control the business. It is split into two phases, phase 1 dealing with the planning system material requirements planning (MRP) parameter setting, and phase 2 dealing with the operational matching of the load to the available capacity.

Part of the outcome of the current research can be described as a way of balancing and understanding the three main business pressures: inventory value, the number of orders generated and the shopfloor workload[16]. To reduce inventory value, you can decrease the batch size (or increase the ordering frequency), so increasing the number of orders to be processed by the administrative system. Where processes require setting-up time, this will also result in increased shopfloor workload caused by the extra set-ups (see Figure 3).

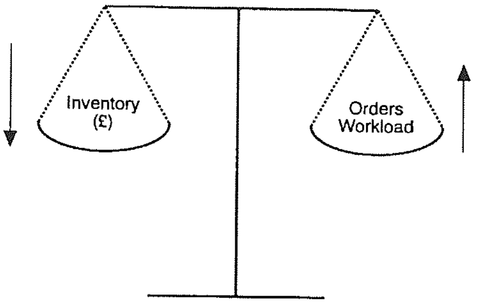


Figure 3.
Balancing the business pressures

By understanding the interrelationships of the *capacity, finance* and *administrative* workloads, it should be possible to bring the business pressures into an equilibrium which is in line with the company's objectives and takes account of the limits in these three areas. The modelling process thus allows for more informed decisions to be made.

The manufacturers being targeted by the research fall uncomfortably between being able to use flow lines, and project-based control techniques. The items manufactured are not prolific enough to justify the move to pull systems or highly engineered lines and are too repetitive to warrant a discrete approach.

Currently what tends to be used varies from manual methods (for low complexity and mix) through spreadsheets to periodic control, MRP and manufacturing resources planning (MRPII), order process time (OPT) and finite capacity planners (for high complexity and product mix).

Reductions in set-up times or cycle times on a bottleneck resource will show immediate benefits. Bottleneck identification depends on two factors: product volumes, and product mix.

By providing a modelling process to identify bottlenecks, and the items which contribute to the load, it is possible to focus the continual improvement programme clearly onto the area of highest benefit first. By passing the results of the modelling process back to the MRP parameter setting process, the predictability of the manufacturing system will be increased.

At the operational level, the identification of set-up reductions to be gained through sequence dependencies can have a great impact on the operational effectiveness of a plant.

By identifying those items which are due to be manufactured with similar set-ups, it is possible to reduce the time required to manufacture these items by scheduling them sequentially. This is because although the run times are essentially fixed in the short term, it is possible to reduce the set-up times according to the relationship of the successor to the predecessor on a particular machine. When items within a tooling family are sequenced logically, reductions in the set-up times will be made and the batch sizes can be reduced accordingly.

Phase 1: parameter setting and capacity matching

The sizing of lots and the sequencing of batches are recognized problems. What is needed is a departure from the traditional approach of taking lot sizing and sequencing as separate issues, to be tackled at separate stages in the planning process. Lot sizing is usually tackled in the planning stage, and sequencing at execution time. If the two areas can be brought together at an earlier stage in the planning process, the complexity of the problems which may arise later, in manufacturing, should decrease.

One way of approaching this is to identify tooling families of parts made on the same machine, which can be processed one after another within the same major set-up. By using a geometric progression (e.g. 5, 10, 20, 40, 80, 160 days supply) for the period order day series, it is possible to make allowances for set-up reductions when items from the same tooling family are scheduled together. Thus a "best case" can be constructed which assumes that wherever it is possible to schedule items within a tooling family together, this will be done.

Within each tooling family the items are first allocated the appropriate batch set-up cost. Then, using an approach which combines Pareto analysis with a modified economic batch quantity (EBQ) calculation, each item is allocated to a period order day class based on the annual usage value (AUV) of each item. From this, the load in terms of finance (average inventory value), administration (orders per year) and capacity (workcentre load) can be directly calculated and compared against the stated limits in each area to identify potential constraints. Comparisons with the load which the current policies would generate are also made. The modelling is greatly simplified by concentrating on the theoretical load which the inventory policy would generate, and ignoring the effects of any current or planned inventory overage such as safety stock.

Having derived batching rules that broadly satisfy the limits within which the enterprise wishes to operate, other operational considerations particular to individual items (e.g. space) can be considered, and the parameters generated by modifying the modelling accordingly.

The output from this first phase is the setting of the batching rules, validated in three dimensions, for the planning system (typically MRP). The initial study state design simplifies the assumptions and calculations. The ratification against the current planning parameters in use assists in identifying achieveable load limits. It is possible to remodel the batching rules until the extra load generated by the increased number of batches consumes the free capacity, or the number of orders generated reach the limits of the administrative system, or the desired average inventory value is reached. The output from the modelling process is detailed and relies on the steady state assumptions.

Constraints can now be identified in all three areas, as well as details of the load generated. The methodology also validates the viability of the constraint limits.

Figure 4 illustrates the structure of the continuous improvement cycle derived from the methodology[17].

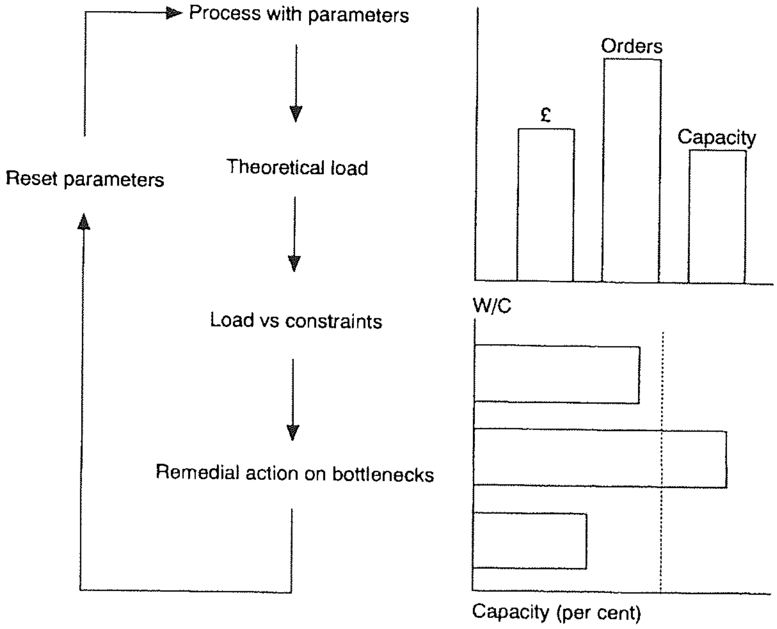


Figure 4. The continuous improvement cycle

The modelling process used has been developed to help to overcome one of the important criticisms of MRP, namely that MRP accepts set-up times and batch sizes as given and does not provide a mechanism for continuous improvement. The facilities provided within the modelling process address this issue by:

- the systematic identification of bottlenecks;
- recognizing that resource bottlenecks occur not only in terms of manufacturing capacity, but also in other areas such as finance and administration;
- the ability to focus the continuous improvement programme on the bottleneck resource(s) in any of the three measured areas;
- balancing of the workload to the bottleneck resource(s) by systematically decreasing the batch size until the spare capacity is consumed;

- providing the feedback on the constraint load vs constraint limits in the three measured dimensions;
- scenario modelling the effects of changing the limits of the constraints;
- scenario modelling the effects of changing operational parameters (set-up times, etc.);
- assisting multidimensional goal searching and, finally, by automatic goal searching for the best fit when constrained in one dimension (e.g. inventory value).

Phase 2: the execution cycle – minimizing the set-ups

Following on from the setting of the batch policy codes, the next step is to assist in the initial capacity matching of the workload generated by the planning system. This is analogous to capacity requirements planning (CRP).

Having set the items being considered within a period order day class (PODC), when each item is reviewed by the planning system, the batch size will be essentially determined by the demand within the period order day horizon less any current stock, and an order generated to cover the net demand.

For the sake of understanding, let us assume that the planning system (MRP) is run on a weekly (five day) cycle. What is now required is a method for re-forming tooling families each week, based on the items actually being scheduled that week. The reason for doing this is that, just as in Phase 1, while the run times of a batch using a particular route can be thought of basically as fixed, the set-up times will differ according to the relationship of the predecessor batch to the successor batch. Where batches within a tooling family can be scheduled sequentially, reductions in the set-up times can be gained.

Once each tooling family is re-formed using those batches scheduled in the current week, the set-up times can be recalculated, and a sequenced schedulable tooling family formed. This group will represent the minimum time within which it is possible to schedule the batches within the family. Each partial tooling family re-formed in this way is independent, and the sequence in which each of the partial tooling families are loaded has no effect on the overall workcentre load.

The "best case" load at the execution phase, that is, the load with the minimum possible set-up content, can now be compared against the available capacity. The next step is to validate the overall workcentre capacity against the load generated. The resulting capacity plan (CRP) will highlight any immediate capacity shortfalls. If the result of this check is not satisfactory, it may be possible to split the tooling families across alternative routeings, moving the load from the overloaded work centres to those with spare capacity. This process can be reiterated until the loading is acceptable.

By feeding back the completion of batches, and information on breakdowns, it is possible to use the principles outlined above to replan the remaining workload as the week progresses to take account of changing circumstances.

At the execution stage, the modelling features:

- bottleneck identification based on actual product mix and volume being planned;
- the set-up minimization approach;
- capacity validation against sequenced schedule taking account of set-up reductions gained through sequence dependencies;
- batch splitting;
- multi-operation;
- alternative routeings.

Conclusions

Lean production is not just the Toyota production system. The underlying philosophy can be applied universally within manufacturing, but the tools used to enable the philosophy need to be applied in a context-sensitive manner. For repetitive batch manufacturers, the *kanban* approach may not be appropriate. Toyota itself does not manufacture cars using *kanbans*, it uses highly engineered production lines. The items controlled by *kanbans* are generally for line side production replenishment.

What is appropriate for repetitive manufacturers is the encouragement of innovation through the use of technology and methodology. The lean production methodology encompasses the organizational structure, systematic education and training, and the use of Japanese manufacturing principles[18], such as:

- systems design;
- supplier integration;
- teamwork for continuous improvement;
- flexible and simple systems;
- attention to detail;
- inventory elimination;
- set-up reduction to facilitate batch size reduction;
- systematic de-bottlenecking;
- total quality;
- preventive maintenance to eliminate unscheduled breakdowns;
- eradication of non-value-adding activities.

This article has proposed a methodology to assist repetitive batch manufacturers in the adoption of certain aspects of the lean production principles. The methodology concentrates on the reduction of inventory through the setting of appropriate batch sizes, taking account of the effect of sequence-dependent set-ups and the identification and elimination of bottlenecks. It uses a simple Pareto and modified EBQ-based analysis technique to allocate items to PODCs based

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on a combination of each item's annual usage value and set-up cost. The PODCs to which the items are allocated are determined by the constraint limits in the three measured dimensions: capacity, administration, and finance.

In recent trials of phase 1, the planning system parameter setting phase, using actual company data, the approach has been able to demonstrate a 20 per cent reduction in base inventory value, when compared with the situation under the company's current planning parameters, while still keeping the capacity and administration constraints at their existing loading levels.

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Appendix 3.3 – The Institute of Operations Management –Conference Proceedings 1996.

Improved Business Performance for Repetitive Batch Manufacturers.

IMPROVED BUSINESS PERFORMANCE FOR REPETITIVE BATCH MANUFACTURERS

Peter Burcher, Simon Dupernex, Aston Business School
Geoffrey Relph, IBM Consulting
Gillian Perkins

For the past two and a half years researchers at Aston University, in collaboration with IBM Consulting, and repetitive batch manufacturers in a variety of industry sectors, have been trialling a methodology to help companies on the road to world class manufacturing by adopting appropriate lean production techniques.

INTRODUCTION

The purpose of this paper is to tell you about the research objectives, the results to date, and the future use of the methodology. The structure of the paper is as follows:

- **Research Perspective.**
  To explain the context of the research.
- **Industrial Collaboration Perspective.**
  To highlight the concerns and aspirations of the industrial collaborators.
- **Consultancy Perspective.**
  To see how the methodology resulting from research is used in a consultancy practice.
- **Conclusions.**
  To discuss the results and applicability of the research.

RESEARCH PERSPECTIVE

This research at Aston Business School is funded by the Engineering and Physical Sciences Research Council, through a CASE award, a Collaborative Award in Science and Engineering, so an industrial collaborator was required who was willing to not only collaborate, but also provide additional funding. The IBM Consulting practice have acted in this role.

The more detailed area of investigation was to see if it was possible to improve the inventory performance of repetitive batch manufacturers through lead time reduction through the use of relatively simple modelling tools, which would, hopefully, be suitable for future use within the Consultancy practice. IBM hoped that this would provide it with a competitive advantage over other consultancies through having the benefit of early access to the results of the research.

But what pressures are there on repetitive batch manufacturers?

Being able to predict and control the behaviour of an inventory management system will obviously have an important effect on the overall business performance. The earlier you can apply this predictive ability, the better the chance will be of taking effective remedial action.

Having defined lead time reduction as an aim of the research, how can 'lead time' be best defined. The APICS dictionary (1) defines Lead Time as "A span of time required to perform an activity. In a logistics context, the time between recognition of the need for an order and the receipt of goods. Individual components of lead time can include: order preparation time, queue time, move or transportation time, receiving and inspection time."

Manufacturing lead time is therefore the total time required to manufacture an item and may consist of the following elements:

Planning	Set-Up	Run	Move	Queue

Figure 1. Elements of Lead Time (2).

Planning time is the activity concerned with obtaining the materials, writing the orders or schedules, sending the materials to the first operation and planning the production.

Set-up time is the time taken from the producing the last item of a particular batch to producing the first item of the next batch.

Run time is the time taken to produce a batch of items. Reducing the batch size, justified by lower Set-up times, directly reduces the batch run time as will process improvements.

Move time is the time taken to move the items from one process to the next process. A move to product orientated manufacturing (Group Technology) rather than process orientation will reduce the move time due to the proximity of the machines and the product focus of the cell.

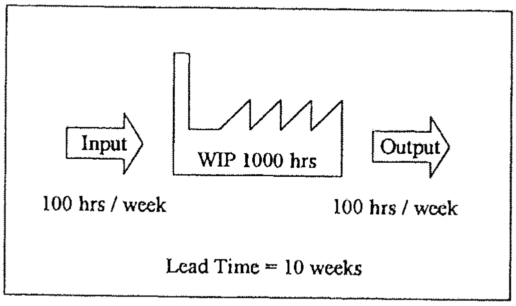

Figure 2. The effect of WIP on Lead Time.

In repetitive batch manufacturing, queue time is generally the longest element and often represents 80% of the total throughput time (3). Queues occur because jobs wait before being processed. The queue time is proportional to the amount of Work in Progress. To reduce the queue you need to reduce the WIP. As Set-ups reduce to zero, so the batch size may be reduced to 1. With the batch size minimised, enabling the WIP to reduce, the processes become available as required and the queues disappear. For example, if the WIP in Figure 2 could be reduced from 1000 hours to 300 hours, the Lead Time would reduce from 10 weeks to 3 weeks.

Set-up times have a great impact on the way that a business behaves in terms of inventory holding and manufacturing flexibility (4) and they are one of the key elements in the JIT approach.

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The key to manufacturing flexibility is in reducing the batch sizes. Smaller batches minimise inventory and make planning easier through reducing the unpredictability of capacity bottlenecks and therefore allow for the use of simple production control techniques. Frequent set-ups are necessary to produce a variety of goods in small lots (5).

A way of achieving this is through minimising the set-up times. Set-up times have for too long been treated as a given (6), and therefore have not been subjected to the same level of scrutiny as large obvious costs such as direct labour, run time, scrap or rework.

Set-up has two elements, internal and external. Internal set-ups consume capacity, and therefore affect output. To reduce the effective set-up time you need either to remove the need for the set-up entirely (e.g. by using dedicated machines) or move from internal to external set-ups.

There are also different types of set-ups. When a machine is set-up to produce a particular item it may require a change of tool. When another item using the same tool but using a different material is scheduled next, only a change of material is required. If the next item uses the same material and tool, but a different colour, only a change of colour is required. What this means is that the set-up time is not fixed, but is dependent upon the relationship of the predecessor to the successor batch. It is possible to minimise the time spent setting up by planning the appropriate processing sequence. This can be described as a hierarchy, where (in the above example) level 1 is the tool change, level 2 is the material change and level 3 the colour change.

Also by identifying the bottleneck resources it is possible to focus on the most beneficial set-up to reduce first. Reductions in set-up times or cycle times on a bottleneck resource will show immediate benefits. Bottlenecks constrain business performance by adversely affecting cost through increased inventory, extended lead times and reduced throughput. Bottleneck identification depends on two factors, product volumes and product mix.

In summary:

- **Batch size reduction** requires the
- **Identification of bottlenecks and their elimination** through a
- **Systematic set-up reduction programme** allowing a
- **Decrease in Work in Progress** which
- **Reduces the Lead Time.**

The benefits of Lead Time reduction through smaller batch sizes are:

- The feasibility of increasing product variety without excessive cost penalties.
- Increased manufacturing flexibility.
- Lower cost base.
- Increased competitiveness.

The purpose of this research is to address this issue by studying the inventory performance of repetitive batch manufacturers and to see what benefits can be gained over existing practices by using a Pareto analysis technique which places manufactured items into period order day classes whilst taking into account constraint limits in finance, administration and manufacturing and incorporating the inter-relationship with sequence dependent set-ups.

So the research is to do with:

- Repetitive batch manufacturers

- Inventory performance
- Computer modelling
- Modified Pareto Analysis
- Sequence dependent set-ups

After developing the theoretical model and accompanying software, what was needed was the application of the research in a live environment, and to study the effects of making any proposed changes.

As the IBM Consulting practice does not manufacture anything itself, nor does IBM manufacture in a way which makes it suitable for study as part of this research, the involvement of third party collaborating firms was required who would allow access to their data, and be willing to implement the findings of the modelling, if of benefit, and not be worried about being involved with public domain research.

INDUSTRIAL COLLABORATION PERSPECTIVE

Besides discussing the findings, this section of the paper will attempt to elaborate briefly on why the collaborating firms decided to get involved with the research.

Many firms are asked to collaborate with academic research. The relationship needs to be of benefit to both parties. The question that all the collaborating firms have asked is:

- **What's in it for me?**

It may not be stated so baldly as this, but it is always asked in one form, or another. Firms today are not generally willing to be involved in collaborative ventures which they get nothing out of.

Also they are not willing to put time, effort and resources into providing commercially sensitive information to a third party just to have the warm glow of having helped an academic for the sake of pure research. So, once the general principle that the modelling is appropriate has been established, the next question that tends to be asked is:

- **What will it cost me?**

Luckily, because of the sponsorship, there has been no direct cost to the collaborating companies.

The interest level is now raised sufficiently for firms to think of a way of selling the idea of collaborative research within the company. So they ask the next question, which is:

- **What are the benefits to me?**

This can be difficult to answer. If they (the collaborating companies) are perfect in everything they do, it will be nothing. If they are not perfect, there is a reasonable probability that they will be able to benefit from going through the modelling process.

By modelling inventory behaviour earlier, there is a greater possibility of being able to cope with the unexpected. You can assess the sensitivity of the system, and therefore the likelihood of coping with changing circumstances without causing major disruption.

Once inventory parameters are set, they don't tend to be reviewed very often. Often they are set based on historical work patterns, rather than relating to true demand.

The modelling provides a simple way of controlling the business, allowing informed decisions to be made about the implications of different planning policies. It focuses attention on the bottleneck resource(s) and provides a benchmark for assessing the viability of alternative strategies.

This leads to the next question:

- **How does it work, what information do you need?**

It uses simple steady state modelling techniques to construct various scenarios of future inventory performance, based on enhanced Pareto analysis, the economic batch quantity algorithm, and the theory behind the exchange curve. ***references***

The modelling uses as its base the information contained on the routes and bills of material of the organisations current planning system, together with the work centre capacities and demand patterns.

- **What does the output look like?**

From the above information a model of the theoretical current base inventory performance is constructed. This shows what the average constraint loads are, an example of the summary output for one part of the business could look like this:

Summary Output	(example)
Capacity	91,000 mins
Run Load	58,240. mins
% Run	64%
Set-up Load	11,682 mins
% Set-up	13%
Total Load	69,922 mins
Available	21,078 mins
% Load	77%
Annual Usage Value	£5,620,962
Orders	165.5
Average Inventory Value	£748,197
Stock Turns	7.5

Figure 3. Summary of Current Performance.

Having validated the Steady State model of the current operating conditions, the next stage is to model the process to see if performance improvements are there to be had by better scheduling practice. This involves matching or improving on the current agreed performance in each of the following three areas:

- **Finance** - £ Average Inventory Value.
- **Administrative Workload** - Number of Orders to be processed.
- **Work Centre Capacity** - Shift Patterns, Machine Availability etc.

These first two models define the limits of the 'free' benefits available without process or work flow improvements. It also serves to quantify the amount of available but unused 'capacity' in each of the three constraints which could, perhaps, be used to increase the flexibility of the business. A third benefit is to focus attention on the areas where an improvement programme would give the most benefit, that is, it can rank the items that use the constraints, and quantify the use by item.

The businesses involved in this research were all involved in a re-appraisal of their manufacturing, operations, and customer service areas, so this led on to a further question:

- **Of the improvements that I have already identified, which bring the greatest benefits?**

The next step is to model the effects that the proposed changes could have. As a simple example, a set-up reduction programme could reduce some set-up times by 50%, and others by 30%. The model can quantify the benefits of using the set-up reduction gains to decrease the batch sizes, whilst keeping within the work centre capacity limits, calculating the increase in administrative workload caused by the extra batches, and the resulting inventory reduction.

Another question which could also be phrased is:

- **What do I need to do to reduce base inventory by 50%?**

By entering the desired limits into the model, the software will calculate the operational requirements for capacity and administration. So what you have is a flexible modelling tool, capable of scenario modelling, and able to construct a theoretical 'best case'.

- **What are the results to date?**

By comparing inventory performance against the current system performance, the research has demonstrated that gains of up to 40% in base inventory performance are possible for some firms, just by altering the scheduling frequencies based on the research model.

On top of this, there are obvious benefits in validating the routes, costs etc. which have uncovered shortfalls in the current operations.

Perhaps the greatest benefit is that of promoting an informed dialogue regarding the courses of action open to a business by quantifying the loads on the three constraints, Finance, Inventory and Administration, and being able to do this quickly using existing data.

CONSULTANCY PERSPECTIVE

Consultancy is becoming more results based with more clients wanting to see tangible benefits. The client's are under pressure to improve the key business performance measures, often the human resource is the easiest to reduce, this can leave the company dangerously low in skills. It also means that he does not have time for some of the administrative workload that goes along with complex stock management and bottleneck management tools. Consultancies are under the same resource pressure when delivering solutions to the client, and the client is looking for pragmatic solutions that recognise this situation.

The work of the IBM consulting practice with the K curve methodology since 1989 has convinced us of the merits of a simplified approach. The initial work was directed towards purchased items, and was not generally applicable to manufactured items where set-up times (and therefore costs) could be easily demonstrated to vary considerably between items.

The current research addresses this weakness in the current approach, and is exciting because by striving for a simple solution a remarkably effective analysis tool has been created, which requires only a moderate amount of data to enable serious analysis.

Business Process Re-engineering (BPR) is aimed at radical change and in most cases the client needs to be sure that the changes are going to bring the benefits and the key o satisfying this need is the ability to focus on the important areas.

The consultant needs an effective approach to get to the heart of the problem and identify where these focus areas are, identify the bottlenecks, and to prioritise the proposed actions. All of the recommendations can now not only be based on the judgmental skills of the consultant, but also on hard evidence based on the clients own operational data. The process allows for 'what ifs' to be played out giving depth to any solutions offered to the client.

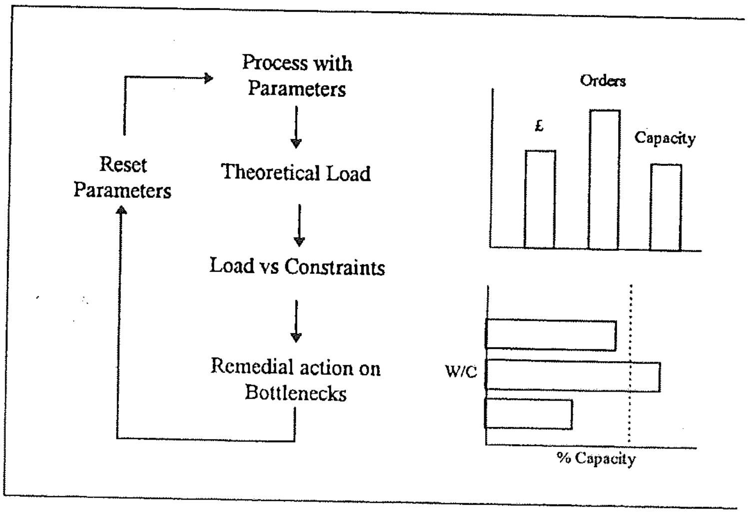

Figure 4 The Continuous Improvement Cycle (8)

The Continuous Improvement Cycle (Figure **) shows the outline process flow. In the initial stage the aim is to reduce all three efficiency drivers, and the focus is on the workload created on the administration and capacity constraints when driving inventory down. The approach allows the modelling to go beyond the theoretical constraint capacities, and then examine the detail loading, (e.g.) to view a,specific theoretical work centre or machine load on a constraint.

The modelling can then go on and assume that remedial action has been taken, so removing the constraint, and calculate the benefits gained. If the benefit analysis is viable, the parameters are reset and the cycle is repeated to identify the next bottleneck constraint. By using this cyclic approach a prioritised list of cost justified improvements is obtained, clearly focused, (e.g.) on key work centres and machines.

As part of a BPR or Continuous Improvement Plan it leaves the client with a tangible deliverable which is supported by client based evidence.

CONCLUSIONS

The methodology can be shown to provide a simple, cheap, and effective way of modelling base inventory performance by:

- **Modelling the current performance to provide a benchmark.**
- **Highlighting those areas where change would bring the greatest**

benefits.

- **Modelling the effect of proposed changes**
- **Quantifying the benefits that could be gained through implementing the proposed changes.**
- **Simplifying the effort required to perform the modelling process.**

It has been successfully applied as part of BPR at firms involved in repetitive batch manufacturing in Pharmaceutical, Plastic Extrusion and Moulding and FMCG, and has been able to show gains in inventory performance of up to 40% in the downstream inventory holding.

The common features of the manufacturers were that they were all constrained by finance (they wanted to reduce the amount of money tied up in inventory), constrained by capacity (they all had bottleneck resources, and long set-up times), and in some cases constrained by administration (e.g. if the ordering frequency was increased, more kits would have to be assembled, requiring extra warehousing staff).

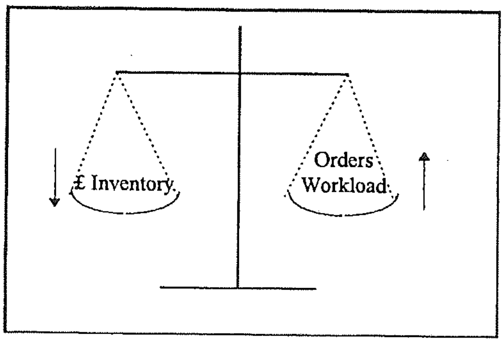

Figure 5. Understanding the Business Equilibrium [(8)].

So the research can be described as a way of balancing and understanding the three main business pressures: Inventory Value, the number of Orders generated and the Shop Floor Workload.

To reduce inventory value, you can decrease the batch size (or increase the ordering frequency), so increasing the number of orders to be processed by the administrative system. Where processes require setting up time, this will also result in increased shop floor workload caused by the extra set-up's. (See Figure 3)

By understanding the inter relationships of the Capacity, Finance and Administrative workloads, it should be possible to bring the business pressures into an equilibrium which is in line with the company's objectives and takes account of the limits in these three areas. The modelling process thus allows for more informed decisions to be made.

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