ASPECTS OF DESIGN FOR A SPARE PARTS PROVISIONING SYSTEM

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ASPECTS OF CONTROL FOR A SPARE PARTS

PROVISIONING SYSTEM

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S U M M A R Y

This thesis describes an investigation by the author into the spares operation of CompAir BroomWade Ltd. Whilst the complete system, including the warehousing and distribution functions, was investigated, the thesis concentrates on the provisioning aspect of the spares supply problem.

Analysis of the historical data showed the presence of significant fluctuations in all the measures of system performance. Two Industrial Dynamics simulation models were developed to study this phenomena. The models showed that any fluctuation in end customer demand would be amplified as it passed through the distributor and warehouse stock control systems. The evidence from the historical data available supported this view of the system's operation.

The models were utilised to determine which parts of the total system could be expected to exert a critical influence on its performance. The lead time parameters of the supply sector were found to be critical and further study showed that the manner in which the lead time changed with work in progress levels was also an important factor. The problem therefore resolved into the design of a spares manufacturing system which exhibited the appropriate dynamic performance characteristics.

The gross level of entity presentation, inherent in the Industrial Dynamics methodology, was found to limit the value of these models in the development of detail design proposals. Accordingly, an interacting job shop simulation package was developed to allow detailed evaluation of organisational factors on the performance characteristics of a manufacturing system. The package was used to develop a design for a pilot spares production unit.

The need for a manufacturing system to perform successfully under conditions of fluctuating demand is not limited to the spares field. Thus, although the spares exercise provides an example of the approach, the concepts and techniques developed can be considered to have broad application throughout batch manufacturing industry.

Key Words:-

Spares Provisioning
Industrial Dynamics
Job Shops
Simulation

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DECLARATION

The work described in this thesis which was performed in collaboration is described as such, and none of the work has been submitted in support of a degree or other award at this or any other institution.

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Chapter 1. Introduction

1.1 The Spares Problem

The CompAir Group of companies are the largest manufacturers of compressors, air tools and associated equipment in the UK and are one of the top four companies engaged in such activities in the world.

The production of the Group's industrial compressors and equipment is mainly concentrated at CompAir Industrial Ltd., previously known as Broom and Wade Ltd., prior to the merger. Broom and Wade had been engaged in the manufacture of compressors since the beginning of this century and had established a sound reputation for the longevity of its reciprocating compressors and the quality of its after sales service.

These machines are normally installed to provide a compressed air supply to production or process plant. The continuous availability of the compressor is therefore vital to the operation of the customer's manufacturing facility. Breakdowns or excessive servicing delays can result in lost production and hence have serious financial implications for the customer. Thus, success in the industrial market demands not only competitive product pricing, performance and delivery, but also the assurance of a high quality after sales service. The quality of the after sales service is primarily dependant on the availability of spare parts. Customers can obtain compressor spares only from the company or its agents since, at present, 'pirate' manufacture of components is very rare. The performance of the company's parts division therefore has a direct impact on the reputation of the product in the field and thus may be expected to influence the company's future market penetration.

The development of the industrial product range, prior to the merger, was based, essentially, on the enhancement of existing reciprocating designs. During this period the designs were characterised by very long production and working lives. It was not uncommon for a machine to remain in production with only detailed design changes, for in excess of twenty years. Working lives of thirty or forty years may also be achieved by the older, slow running, reciprocating designs. These factors led to a spares component range which, although broad (over twelve thousand unique parts), was relatively stable in composition and could normally be sourced with batches of parts required for the current compressor build programme. Components which are sourced in this manner are therefore known as 'current' parts, whilst those unique to spares (ie parts which fit obsolete machines) are identified as 'non current'.

The industrial market has become more competitive during the last fifteen years with increased penetration of the home and overseas markets by the other international compressor manufacturers. This has tended to accelerate the development of new designs and has led to the dominance of the reciprocating machine being challenged by the screw compressor. The small size of the screw compressor unit (or 'air-end') allows these machines to be marketed as a complete package which includes the motor, receiver and control gear, all contained within a single cabinet. The rotors run in a bath of oil and exhibit perfect rotational balance thus reducing wear and leading to an increase in servicing intervals.

The company recognised that the emergence of the screw compressor was likely to threaten the quality of service offered by the Parts Division; anticipated developments included:-

i) The need to support a broader spares component range since, although many of the existing reciprocating designs would quickly become obsolete, company policy (and market conditions) dictated that the supply of spare parts should continue for at least fifteen years after obsolescence.

ii) The acceleration in the rate at which the reciprocating designs would be withdrawn from production would lead to a rapid increase in the proportion of 'non - current' parts which would have to be sourced separately of the compressor build programme.

iii) The nature of the main manufacturing facility would change to meet the needs of the screw compressor. The higher proportion of bought out, or proprietary components, and the different process requirements of the air-end could well make a large proportion of the medium and heavy machine tools redundant. Much of the spares range, including some existing non-current parts, are manufactured on this plant.

In the light of these developments, the company included a proposal to review the activity of the Parts Division in the 1973 version of its rolling five year corporate plan. Subsequently, discussions with the Department of Industry and the University of

Aston suggested that the review would form a suitable basis for the first Science Research Council Teaching Company Scheme.

A small project team was later appointed under the aegis of the Teaching Company Scheme to investigate the total spares operation of CompAir BroomWade Ltd.

1.2 Project Terms of Reference

The company initially defined the team's terms of reference as being:

> " To determine the nature of the facilities and the manner in which they are organised to enable the company to provide an efficient service to customers for its continuously changing product range."

Once the team had been properly constituted and some initial investigations had been completed, joint discussions with the company management yielded a more specific list of project objectives:-

i) To obtain a clear understanding of the way the spares system operated.

ii) To identify, from study of the historical performance of the Parts Division, those factors which affect the performance, and obtain an understanding of how their influence is exerted.

iii) To identify those areas within the company where action is likely to be most effective.

iv) To decide on what action is necessary to improve or maintain the performance of the division, bearing in mind those factors which have exerted influence in the past, and also taking into account the implications of the changes envisaged in the company's product range.

1.3 Development of the Project

The initial study of the historical performance of the spares system and the subsequent development of the basic industrial dynamics model was undertaken jointly by both members of the project team. The investigation of the provisioning solution to the spares problem (reported from Chapter 4 onwards) was the sole responsibility of the author, whilst the investigation of the stock control areas was carried out by D.I.Peckett and is reported in his PhD thesis (Peckett 1979).

Chapter 2 The Existing System

2.1 The Company

CompAir BroomWade produce a wide range of industrial air equipment including compressors, air tools, receivers, air filters, coolers and associated control gear and fittings. The range is sufficiently broad to ensure complete coverage of the industrial market.

The range of compressors, by far the most significant element of the product range, extends from small portable machines, commonly used in garages to supply air for tyre inflation, to the large 'V major' series capable of meeting the needs of a complete manufacturing plant. Examples of a representative selection of the compressor range are shown in Figure 2.1.

The company maintains a dominant position in the U.K. market and exports over 40% of it's products.

The operational centre of the company is located at High Wycombe in Buckinghamshire. The bulk of the site is devoted to manufacturing and storage facilities but also contains the offices and workshops of the main service functions such as product design and development, sales and general administration. The production facility is comprehensive and includes a ferrous foundry from which virtually all the company's casting requirements are met, three large machine shops, and areas for compressor assembly, testing, and inspection.

The company employs a total of 1400 people of whom 450 are directly engaged in manufacturing activities.

2.2 Parts Division

The Parts Division operates as a semi - autonomous unit within CompAir BroomWade and employs a total of 94 people of whom 42 are directly concerned with the supply of spare parts. The division makes a major contribution to the company's turnover and profitability. Turnover of the division in the year ended 31st October, 1977 reached £6.7M.

The company operates it's own warehouse on the High Wycombe site and bears sole responsibility for the associated sales and marketing functions. The spares, stock and procurement control systems are fully integrated with those for original equipment production, although the relevant parameters are modified for spares items. The influence of the Parts Division on these activities is therefore limited by the need to operate within the constraints imposed by the original equipment requirements.

The organisation chart shown in Figure 2.2 reflects the main functions of the division. The spares establishment is for 46 people, 15 on sales and order processing, 7 in stock control and procurement and 23 in the warehouse. The sales manager controls the sales and warehousing areas whilst the procurement manager's responsibility is limited to the provisioning function. The director and general manager is responsible to the Board for the operation of the complete division.

The longevity of both the product design and the working machine means that regular demand for spares can be expected even for designs first produced in the 1930's. The company policy in relation to obsolescent components was recently defined as:-

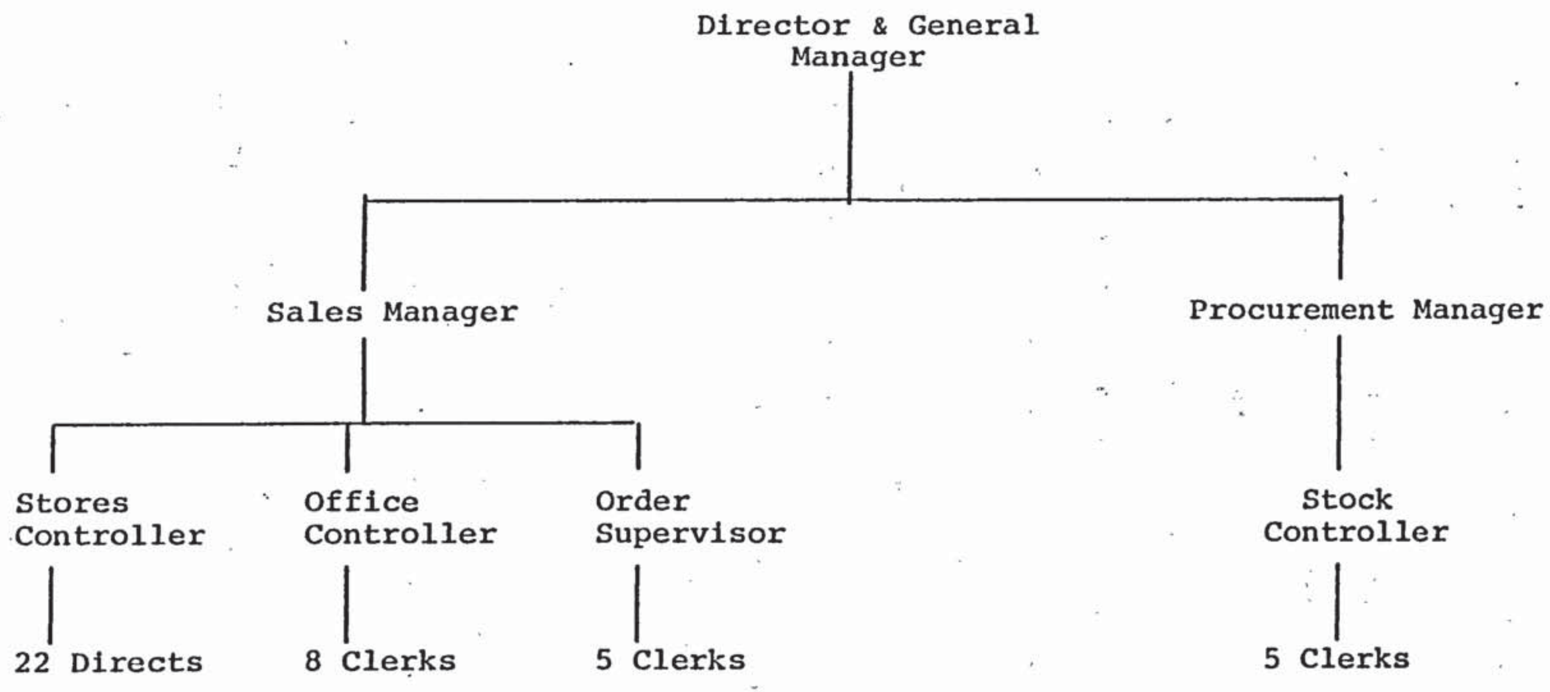


Figure 2.2 ORGANISATION OF PARTS DIVISION

"provision of spares for at least 15 years after cessation of the production of the parent machine."

Parts may continue to be made available after this period if the level of demand remains high and continued supply proves to be economically sensible. A consequence of this situation is the need for the Parts Division to stock or be prepared to supply approximately 12000 different parts.

The components supplied vary in size from small fastenings to large and intricate castings, and in unit price from pence to over £1000. A wide range of demand levels is also evident for piece parts, for example the demand for a particular valve spring exceeded 38000 during 1976 whilst sales of over half the parts range failed to reach more than a single unit during the same period. A breakdown of the range by value turnover showed a very strong 'Pareto' type distribution with only 10% of the parts accounting for over 80% of the business. A similar analysis on the basis of unit demands showed that only 2.4% of the total range exhibited demands exceeding 1000 units per annum.

Historically, demand trends have shown high variability both for individual components and at a gross level, the latter fluctuating by as much as 17.5% about the mean over an eight year period.

2.3 Marketing and Distribution

With few exceptions the company does not sell spare parts directly to the end user, nor does it engage in any form of repair or servicing work. Independant companies, both in the U.K. and overseas, are granted franchises for these activities and the sale of spare parts.

There are 25 main distributors in the U.K. who, between them, account for 90% of total home spares sales. They may be divided, on the basis of annual turnover (1976-1977) into the groups shown in Table 2.1.

The project team visited six of the U.K distributors in order to elicit comment on the quality of the service offered by the Parts Division and to investigate the manner of their operation.

Many of the distributors are part of larger groups and most engage in additional business activities, such as plant hire, or hold spares and service franchises for other manufacturers.

The majority, but not all, of the distributors maintain proper stock records and follow, at least in principle, formal stock control routines. Although several of the larger companies were investigating the installation of computer systems, all used manual processing at the time of the visit. Most distributors modified their stock holding policies and ordering patterns in response to their subjective assessment of the trends in service offered by High Wycombe. They also utilised their knowledge of the composition of the local compressor population to anticipate major changes in demand, such as occur during factory shut down periods.

The number of lines held as policy stock varies at each distributor but normally lies between 2000 and 8000 items.

In general the distributors praised the attitude and flexibility of the staff at High Wycombe and were satisfied with the rapid turnround of breakdown orders, but felt that more information could be provided on the progress of regular stock orders.

NUMBER OF DISTRIBUTORS	ANNUAL TURNOVER
3	OVER £250,000
8	£100,000 to £250,000
3	£50,000 to £100,000
6	£25,000 to £50,000
5	LESS THAN £25,000

TABLE 2.1 DISTRIBUTOR TURNOVER

There are over 100 export outlets which accounted for 35% of the total parts business in 1976. Of these, only 25 handle volumes comparable to the U.K. distributors, with overseas members of the CompAir Group taking one third of the total exported.

2.4 Order Processing and Warehousing

Incoming orders from distributors are classified into three catagories.

i) Bulk Orders

These are raised monthly or fortnightly by the distributor for his policy stock items. They may therefore be for relatively large quantities of many different parts. The distributor receives the maximum discount of 30% against the list price for items ordered in this way.

ii) Stock Orders

These may be raised at any time by the distributor and are normally for a small number of items. As no special priority applies to small orders the distributor receives a 20% discount.

iii) Breakdown Orders

As the name implies items ordered under this catagory must be urgently required for machines which are out of service due to a breakdown. The order is given special priority and would normally be fulfilled within 48 hours. The discount for such orders is also 20%.

The order processing system is relatively sophisticated and makes extensive use of the Company's I.C.L. 1902 computer. The items on an order are first verified and translated by the sales staff into CompAir terminology. Bulk orders are sent to the Data Processing department for overnight entry to the computerised stock control/order processing system. Stock and breakdown orders are entered directly into the system using V.D.U.'s located in the sales office.

The direct entry system also allows the Stock Controller to examine and, if desired, to allocate free stock against a particular item.

Overnight the computer processes all the orders entered (from whichever source), adjusts the stock position for each item, and generates the necessary paperwork for picking, packing and despatch.

The parts are picked by the storemen against the documentation and then passed to the packing department for collation and despatch.

Any order which has only been partially satisfied is recycled through the system and a part-delivery made to the customer.

In contrast to the computerised processing system the handling techniques used in the warehouse are relatively primitive. The main storage area and associated offices cover 17000 square feet, small components are stored in bins and large items on open racks. Material is transported using fork lift and hand trucks. The area is generally crowded, the lighting levels low, and the standard of decoration poor. The warehouse handles over 2.5M parts per year and receives over 330 orders every week for approximately 3500 lines

2.5 Sources of Supply

The complete parts range is classified into two main supply catagories, bought-out and production sourced. Parts may be sourced from the Production Division if:

i) It is a current component and can therefore be sourced as part of a batch being manufactured or brought in for original equipment purposes.

or ii) It is non current but can be economically manufactured on the production facility.

The production division may exercise a further option, that of sub-contracting, particularly during periods of peak demand. The decision to sub-contract a spares batch is taken by the Production Control Manager without reference to the Parts Division. In February 1977 20% of the spares manufacturing load, in standard hours, was subcontracted.

A summary of the provisioning routes for spares is given in Table 2.2.

The allocation of a production sourced batch is controlled by the Production Control department whose priority tends to be the satisfaction of the original equipment requirements.

The Parts Division can exercise little direct control over the process of component provisioning, the allocation of a component to a particular source of supply being determined mainly by its' commonality with Original Equipment build requirements.

SOURCE	% of TOTAL BY VALUE	TYPE of COMPONENT	PROVISIONING ROUTE
BOUGHT OUT	26	Proprietary Items Unique to Spares	Parts Division -Central Purchasing
PRODUCTION (Bought out)	44	Proprietary Items Common to Spares and Original Equipment	Parts Division -Production Control -Central Purchasing
PRODUCTION (Manufactured)	30	All Manufactured Items	Parts Division -Production Control -Machine Shop/ Sub-contract

TABLE 2.2 SPARE PARTS PROVISIONING ROUTES

2.6 Production and Stock Control Systems

The company's production control and spares stock control functions are integrated into a single coherent computerised system. From a manufacturing viewpoint the spares demands are integrated with the compressor build requirements and composite batches manufactured.

During manufacture it is not possible to identify a batch of components as being destined for spares (excepting non- current items). Allocation of components to O.E. build or spares is determined after manufacture has been completed. It is therefore not possible to identify a batch as being destined for spares during the manufacturing process.

The demand for each spares item is monitored and a forecast demand calculated using a simple 12 month moving average. The usage value of each item (Av. monthly usage x unit cost) is used to determine a target stock objective. Comparison of the current stock position, forecast demand and the target stock objective may result in the calculation of a deficit for each month of the forward planning horizon. The deficits are carried across and added to the original equipment build requirement for each month.

For each item the production planning system carries a target stock objective, calculated on the basis of different value categories, a nominal lead time and the various floats to be included at each stage of the production cycle. The system compares the total forward requirement (stock objective + lead + floats) x (forecast demand for build) + (spares) with current free stock and work in progress. If a deficit arises a factory order or purchase requisition is raised by the computer. This process is performed once per month, but more urgent action can be taken manually, in the intervening period.

All orders and requisitions are checked and approved by the Production Control Department prior to issue. As manufacture proceeds, progress is monitored by the return of documents to the computer at the completion of each operation. The process of reviewing the need for a batch of components continues (monthly) until manufacture is complete. Each batch has an associated total float time which is defined as the difference between the time to the required completion date and the remaining process time (machining time + an allowance for queueing). Scheduling of batches at each machining centre is calculated by the computer on the basis of minimum 'float' time. If the need for the batch changes after issue, revision of the completion date automatically adjusts the 'float' and thus the priority of the batch.

The supply of components to spares is not directly associated with particular batches, the system assumes that when spares stock falls to the replenishment level, material will be available from production to make up the deficit. An 'issue to spares' note is raised by the computer when the spares stock reaches a minimum level plus one month's float. This note authorises the factory production controller, at his discretion, to release some, or all, of the parts in a batch to spares. From the production control department's point of view, the satisfaction of spares requirements tends to be secondary to that of fulfilling the original equipment demand.

2.7. Management Controls

The performance objectives set for the Parts Division by the company are defined in terms of the 'first pick rate' and order turnround times. The first pick rate is defined as the ratio of the number of items picked at the first attempt in any month to the total number of items ordered during that month. The present target is 95% for regularly used parts. The order turnround time is the period which elapses between receipt and despatch of an order. Different objectives are set for each order category:-

24 hours U.K. breakdown orders

48 hours Export breakdown orders

5 days stock orders

15 days for Bulk Orders.

Formal measurement of the division's performance against the above objectives is undertaken on a monthly basis, and the results forwarded to CompAir Group headquarters at Slough.

Other statistics monitored by the spares management include the order intake rate, stock levels, receipts into stock and stock and customer shortages. These figures are normally expressed as line items and/or by value.

More detailed reports are also prepared by the computer to indicate:-

i) Items which have changed their average monthly usage.

ii) Items having less than 4 weeks stock, and therefore indicating a prospective shortage of supply.

iii) Items overdue against particular customer orders, giving the value and duration of the shortage.

It should be noted that the spares division only indirectly monitors the performance of its suppliers via the low stock and customer shortage reports.

In addition the service objectives and monitoring only applies to the performance seen by the distributor. The parts division have no way of monitoring the service offered by the distributors to the true end customers.

Chapter 3 Analysis of the Existing System

3.1 Spares Literature Survey

Examination of the literature demonstrates that spares provisioning problems are recognised as being significant in most of the industrialised countries of the world, examples include the U.K. (Robertson 1974), Germany (Kamper 1975), USA (Whitaker 1974), USSR (Khanin 1973), France (Melese) India (Bhattacharya 1979), Australia (Lanford 1977) and Japan (Nakagawa 1976). Papers which deal with the supply of spares from the manufacturer's viewpoint are rarely of an analytical nature. The popular technical press do occasionally carry reports of solutions to the data processing or warehousing aspects of the problem. Several of these were associated with the automotive industry and include descriptions of stock control systems for Ford UK distributors (Anon 1968), Vauxhall dealers (Anon 1971), Suzuki motor cycle spares (Churchill 1973) and Daimler Benz service agents (Lester 1971). Systems relating to wholesalers of spares and associated equipment are also described for agricultural (Anon 1976) and construction plant (Hollingum 1972). Other articles discuss the materials handling aspects of spares provisioning for domestic products (Anon 1974), aircraft (Anon 1972), and gas appliances (Anon 1976).

Whilst many of these articles describe interesting solutions to a particular company's problems, the treatment is generally too superficial to be of direct relevance to the task at CompAir. The relevance of case studies of this type is also dependant on the correspondence of operating conditions between the application being considered and the example cited. Unfortunately all the examples found related to companies engaged in the manufacture of a different class of product or having access to a much larger spares market.

In contrast to the large number of papers which utilise operational research techniques to study the maintainance inventory problem, few were located which were concerned with the levels of stock that should be held by the manufacturer or distributor. Perowne (1963) presents a review of the application of operational research techniques to the spares provisioning problem but the treatment is superficial and ignores the practical problems attendant on use of the techniques proposed. Cohen (1958) reports an early use of computer simulation to explore the appropriate level of stocks for the central and branch warehouses of an automotive parts wholesaler in the USA. The paper provides limited information on the form of the simulation model used but the implication is that the system was represented only by the operation of a single branch inventory. The simplistic approach casts suspicion on the validity of the conclusion that the relationship between service levels and stockholding can be adequately defined by a series of curves drawn for different levels of average damand.

A paper by a group of workers at the University of Lancaster (Ekanayake 1977) reports a study of spares inventory control problèms in a company producing domestic and industrial machines. The dimensions of the problem are comparable to those at CompAir, although the distribution of parts is carried out directly from a central warehouse. Although they eventually recommended the use of conventional forecasting and stock control procedures the team did investigate the possibility of forecasting part demand from analysis of the parent machine field populations. Whilst they report encouraging results for some components, the complexity of the calculations involved and the problems of commonality and interchangeability of parts eventually defeated implementation of the approach. The influence of lead time variability on the level of safety stocks was recognised and the system installed made provision for manual intervention to reset targets in the light of advanced knowledge of changes in the lead time performance of the suppliers.

In addition closer co-operation was suggested with subsidiary overseas companies to aleviate the effects of surges in demand on the amount of stock required to maintain adequate service levels. Housman and Thomas (1972) developed a mathematical model to minimise costs for a situation in which components required for original equipment and spares are withdrawn from a single inventory. Neither the assumption of deterministic original equipment demand nor the single inventory organisation are applicable to the position at CompAir BroomWade.

Studies of the manufacture of spares are especially rare. Astrop (1979) describes the use of numerically controlled pipe bending machines to manufacture automotive exhaust system components and another article (Anon 1974) deals with the general application of NC to the production of spare parts. These papers highlight the flexibility of NC machine tools and their ability to produce small batches economically.

The problem of forecasting the demand for spare parts has also received some attention, noteably by Kendrick (1961) and Moore (1971).

Kendrick's work was associated with automotive products and sought to establish a relationship between past production levels, service life and replacement demand. The analysis was assisted by access to components returned to the manufacturer from a service exchange scheme. The components had been date stamped during the manufacturing process and this, combined with analysis of service life data gathered from fleet vehicle users, allowed the probability of failure at any time after production to be established. Forward demands could then be forecast by applying the probability distributions to past production records. This approach by-passed the complexities inherent in the analysis of parent machine populations but required access to accurate past production data and a reliable method of determining service lives. Neither of these requirements could be satisfied by the conditions at CompAir BroomWade. In addition a comparison with other forecasting techniques presented in the paper shows that Kendrick's approach does not offer a consistently superior performance to that obtained by conventional time series analysis.

The paper by Moore (1971) shows that the use of conventional forecasting methods will result in over-stocking during the decaying process of a component's life cycle. Moore concentrates on the design of an 'all-time requirements' production policy. The viability of this approach is heavily dependant on the accuracy of the forecast demand, since errors would result in losses accruing from stock-outs or the disposal of obsolescent stocks. Moore shows that, for the majority of parts examined, the decay in demand always followed one of three characteristic trends. The method has the merit of requiring only the analysis of component demand histories, but it's viability is dependant on achieving a satisfactory fit to the theoretical curves. Unfortunately Moore mentions that the exceptions to the rule were parts for commercial vehicles which could, intuitively, be expected to show some commonality with the demand patterns for compressor spares.

Papers which consider the problems of the end user are far more numerous than those concentrating on the difficulties of the supplier. Military applications are the subject of many studies which seek to optimise the relationship between inventory or repair costs and operational efficiency. Examples of studies of this type. may be seen by reference to Bhattacharya (1979), Muckstadt (1973), Powell and Lutz (1970), Judge and Luetjen (1979), Brown and Rogers (1973), Spence (-) and Gross (1977 and 1979).

Methods of deriving the economic level of spares inventory to be held by industrial plants are described by Fox (1974), Gelders and Van Looy (1978), Hefter (1978), Gaganov (1969), Harris (1975 and 1979), Apte (1979) and Mitchell (1962). A few papers present the problem in terms of optimising the ordering pattern for spares, for example see Kaio (May '78 and Oct '78) and Nakagawa (1976).

The orientation of this literature towards the end user limits the relevance of the objectives considered to the situation at CompAir. For example, the study by Mitchell which explores the control of slow-moving spares in the National Coal Board is concerned to balance the cost of the inconvenience and lost production that results from a stock out with that incurred by holding stocks of spares.

In other cases the data utilised to derive the demand for spares would only be available to the end user. Apte (1969) describes a probabilistic economic analysis of spares requirements for industrial plant that uses the experience of maintainance engineers to determine likely failure rates.

The generally poor contribution offered by the literature to the analysis of the CompAir problem prompted the decision to visit a number of other spares organisations in order to allow some comparative assessment of the performance of the Parts Division.

3.2 Comparison with other Spares Organisations

The tables given in Appendix 1 show the detailed comparison of the company's spares operation with those of:

Compair C & M

Ford

Leyland

J.C.B.

Aveling Barford

The data for this exercise were derived from a series of visits made to the companies concerned by members of the project team and Mr. H.C. Craig the company's project manager. The breadth of the comparison was considerable covering turnover, claimed and target service levels, staffing, warehousing techniques, buildings, distribution, sourcing, current/non-current policy, and distributor support. Several others were also visited but insufficient data were gathered to justify inclusion in the Appendix. The main conclusions which can be drawn from the exercise were:

- The warehouse was small and relatively inefficient
- The service targets and achievements were lower than all the other companies.
- The warehouse storage and handling systems were outdated and the level of mechanisation low by comparison with the other companies.
- Distributor back up services were limited.

The comparison of the systems used for stock control, sourcing and by distributors was difficult to quantify but in general CompAir's basic stock control system appeared to be no less sophisticated than those used by the majority of the companies. Some improvements were seen in the speed and efficiency of the order processing and picking systems at Ford and Holmans. At several companies visited it was evident that future developments were likely to include more direct data links with distributors and Ford already offered a bureau based stock control system to those distributors who requested it. The degree of involvement with distributors varied considerably from little to complete definition of the stock control, ordering, and storage systems that must be used.

In general it was concluded that the study identified potential for improvement in:

- Customer Service levels
- Warehousing hardware and order processing systems
- The relationship with distributors.

3.3 Historical Performance

The analysis of the historical performance of the Parts Division can be considered in two stages:

i) The examination of gross measures of the inputs and outputs to the Parts Division e.g. order intake, shortages etc.

ii) The detailed investigation of aspects of the performance of each constituent part of the organisation (i.e. Distribution, Provisioning etc.) not covered by the gross measures mentioned above.

3.3.1. Overall Performance of the Parts Division

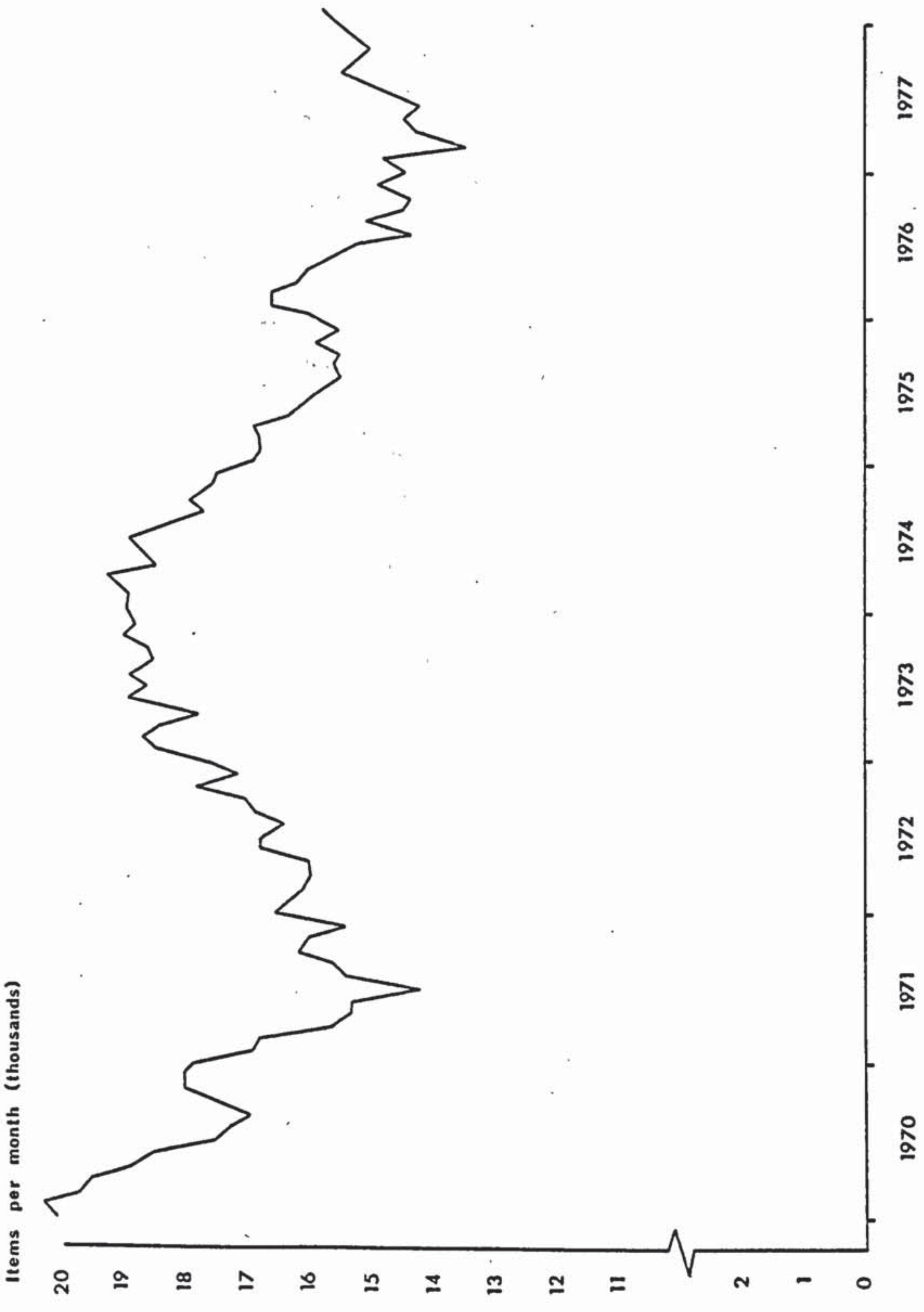
The key input to the company sectors of the system is the order intake received from distributors. This is shown for a period 1970 - 77 expressed as 6 month moving average of the total number of items ordered in Figure 3.1. The demand is seen to be of a cyclic nature and varies from a minimum of 13,000 items/month to a maximum of 20,000 items/month. The variation about the average value for the whole period is ± 17.5%.

Data giving order intake by value were also examined but proved more difficult to evaluate due to the influence of inflation and the attendant increases in the company's standard costs. Three month moving averages of the order intake and stock receipts, expressed at basic standard costs, are contrasted in Figure 3.2. The relationship shown in the figure suggests that the system is very slow to respond to changes in the level of order intake.

Stock levels were also seen to vary considerably from a minimum of 3 months to a maximum of 8 months over the same period. Figure 3.3 gives the stockholding expressed as a function of the order intake for the period 1968-77.

The performance of the division in satisfying the distributor's demand is reflected in two measures, the first pick success rate (defined above) and the level of customer shortages.

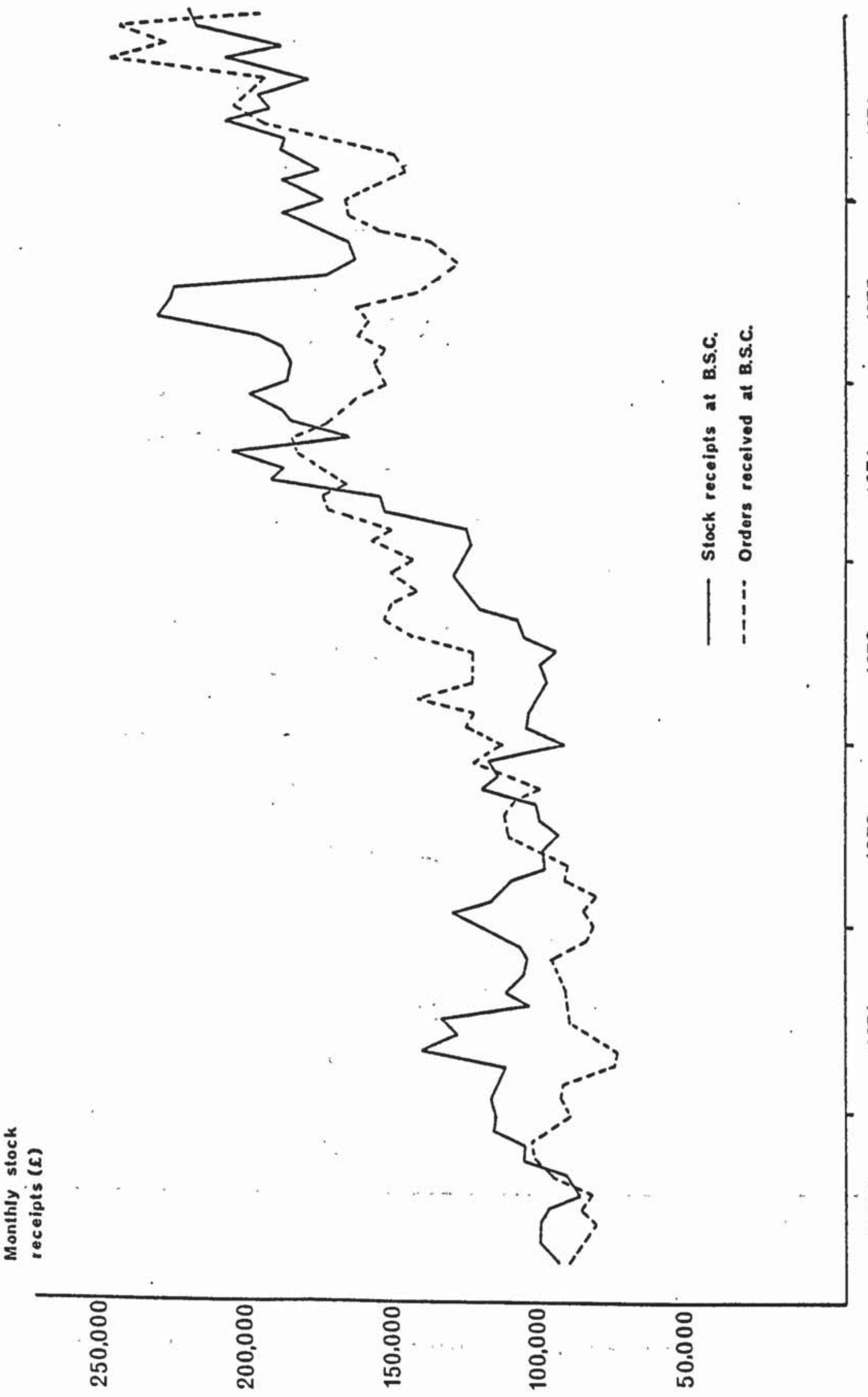
Figures for the first pick rate were only available for the period 1973-1977. Figure 3.4 shows the first pick rate contrasted with the order intake for this period. The improvement in



SPARES ORDER INTAKE

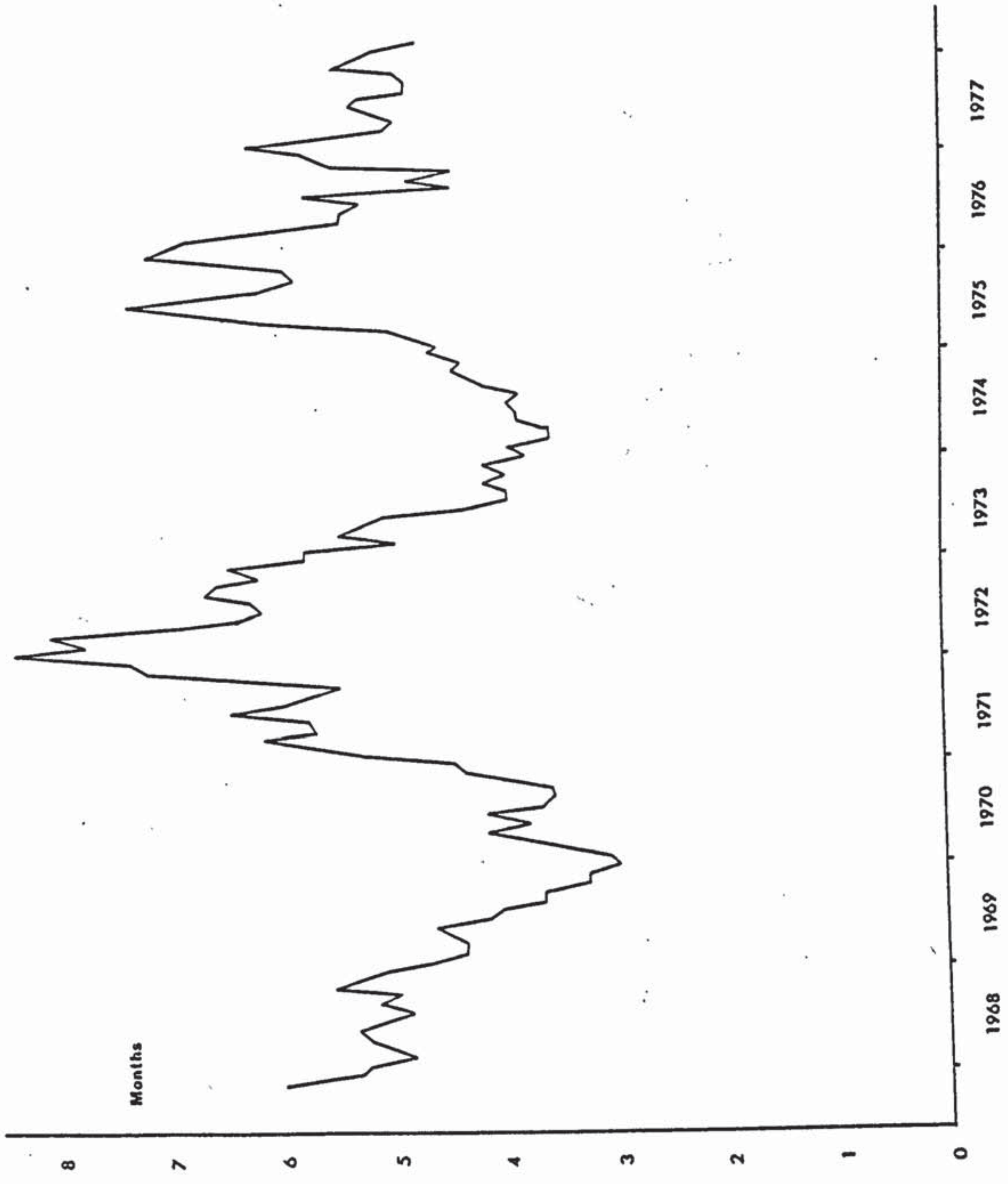
(6 MONTH MOVING AVERAGE)

Figure 3.1



STOCK RECEIPTS AND ORDER INTAKE
(3 MONTH MOVING AVERAGES)

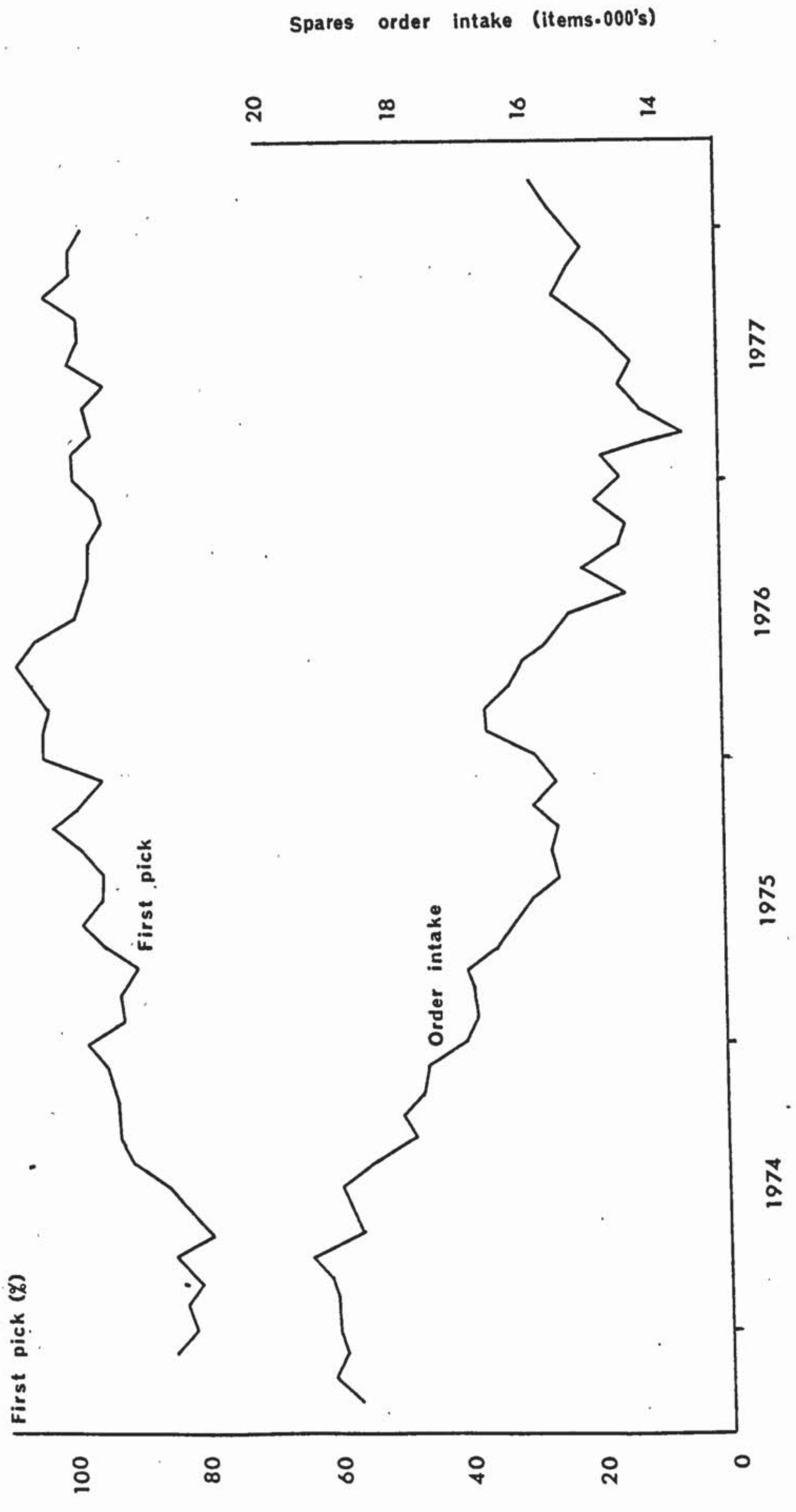
Figure 3.2



STOCK VALUE IN TERMS OF ORDER INTAKE

(RATIO OF 3 MONTH MOVING AVERAGES)

Figure 3.3



FIRST PICK ACHIEVEMENT AND ORDER INTAKE
(6 MONTH MOVING AVERAGES)

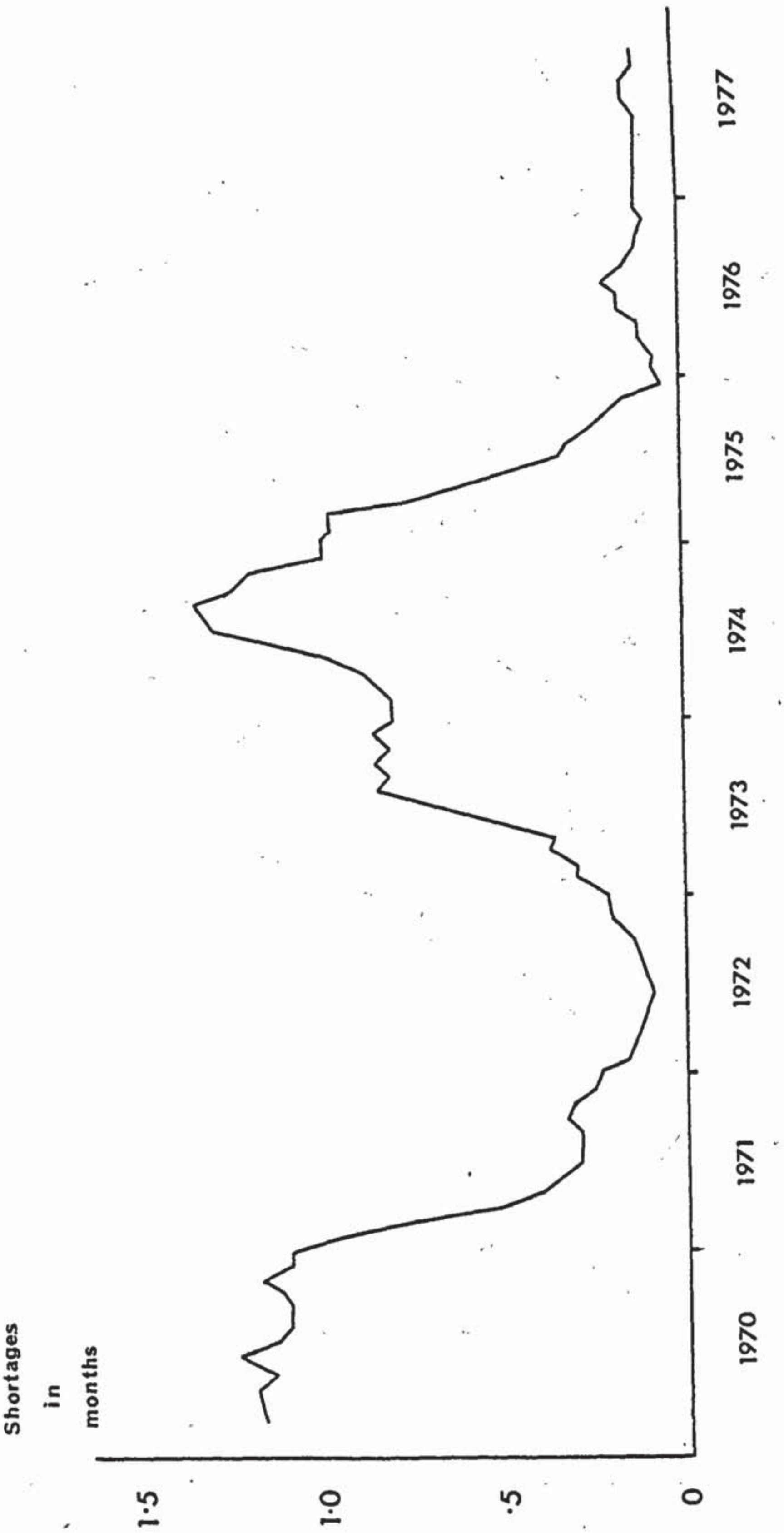
Figure 3.4

performance during recent years is seen to be accompanied by a decline in the level of order intake.

The data for shortages are fortunately available for a longer period (1970-1977). Figure 3.5 shows the value of customer shortages expressed in terms of the order intake rate and demonstrates a fluctuation through this period from 0.1 month to a maximum of 1.3 months. Comparison with the order intake curve shown in Figure 3.1 indicates that, after a short lag, shortages generally followed the order intake trend.

An attempt was made to determine if shortage trends varied between different sources of supply. Figure 3.6 shows that little difference exists between the trend for bought out and factory sourced parts. A similar analysis of shortages of factory sourced components split by product group is shown in Figure 3.7. Again no significant difference in trends can be seen.

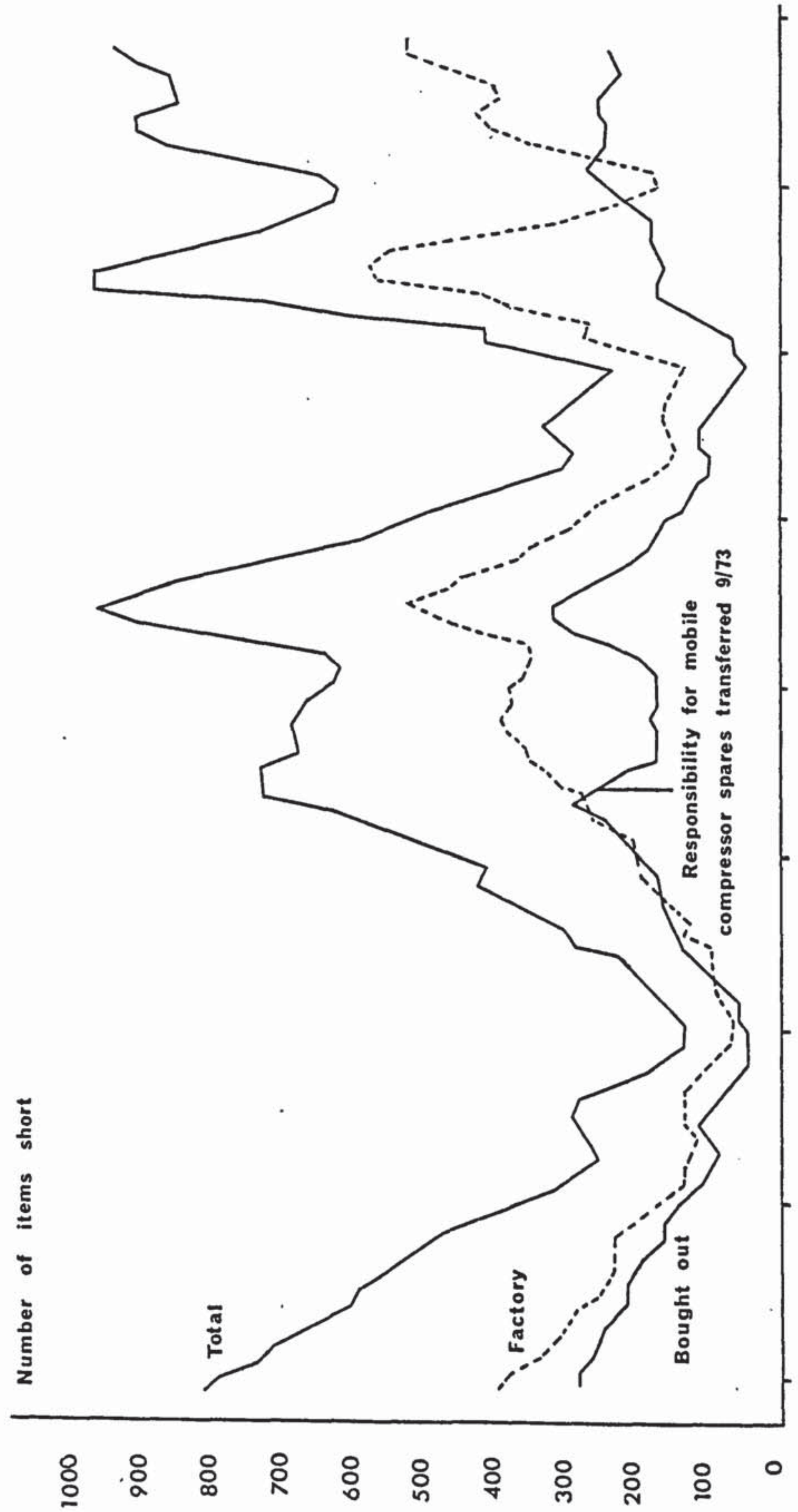
Comparison of the shortage levels shown by value, in Figure 3.5, and by quantity in Figure 3.6, indicates that both measures follow a consistent response up to the end of 1975. Thereafter the latter measure shows a rapid increase in shortage quantities during 1976/7, whilst the value of shortages during that period remained low. This apparent contradiction arose partly from the form of analysis used, since the value shortages were not expressed in absolute terms but in relation to the order intake. This rose during 1977 and thus tended to mask the quantity of items in arrears at this time. The main factor, however, was a change in company policy which dictated that shortages should be progressed by value rather than quantity. Consequently, although the number of items in arrears rose, the policy ensured that the majority of the parts involved were of minimal value. Whilst this strategy was clearly designed to improve



SHORTAGES IN TERMS OF ORDERS RECEIVED

(3 MONTH MOVING AVERAGES)

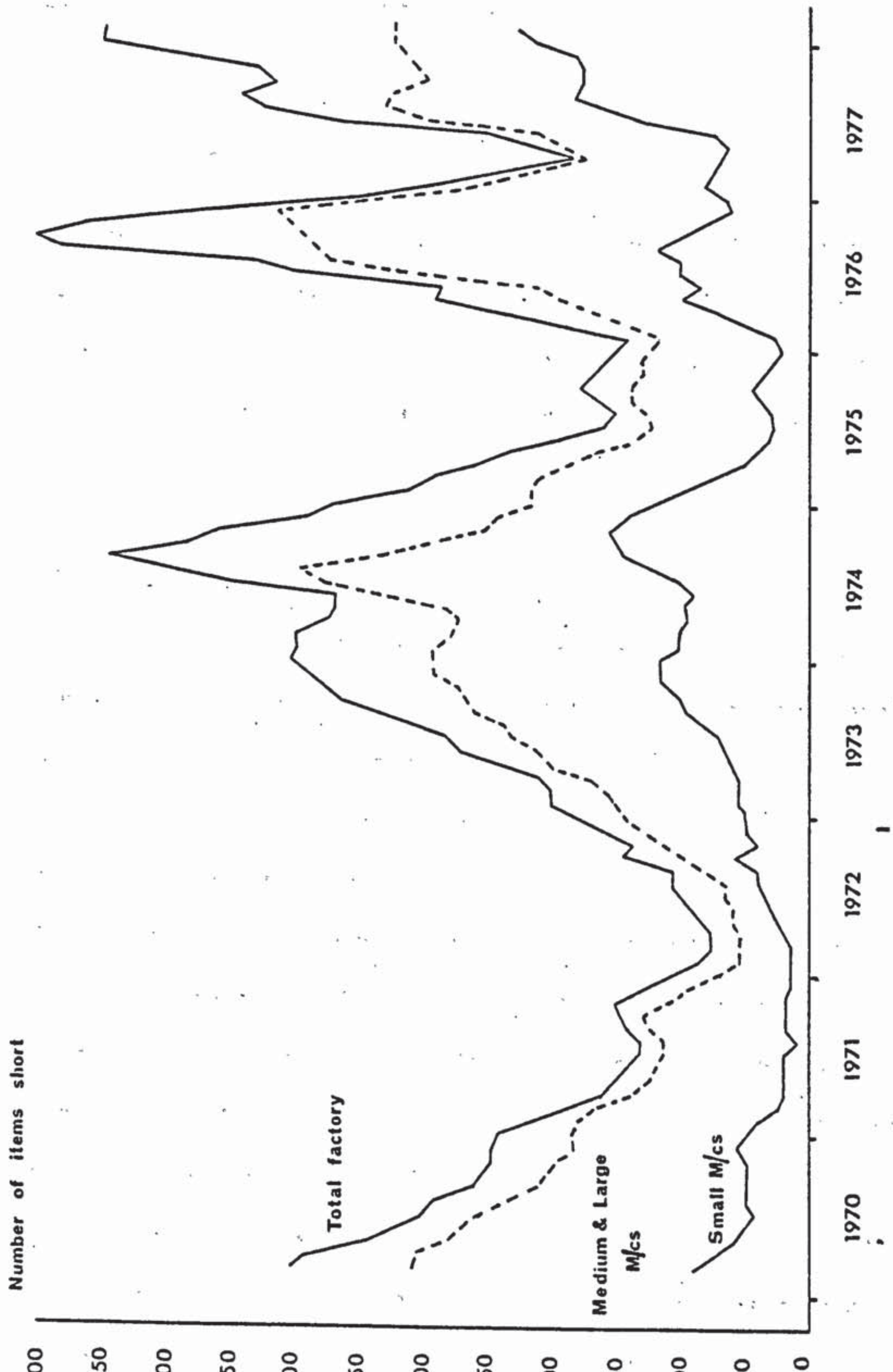
Figure 3.5



SPARES SHORTAGES (ITEMS)

(3 MONTH MOVING AVERAGES)

Figure 3.6



SPARES SHORTAGES (ITEMS) FACTORY SOURCED

(3 MONTH MOVING AVERAGE)

Figure 3.7

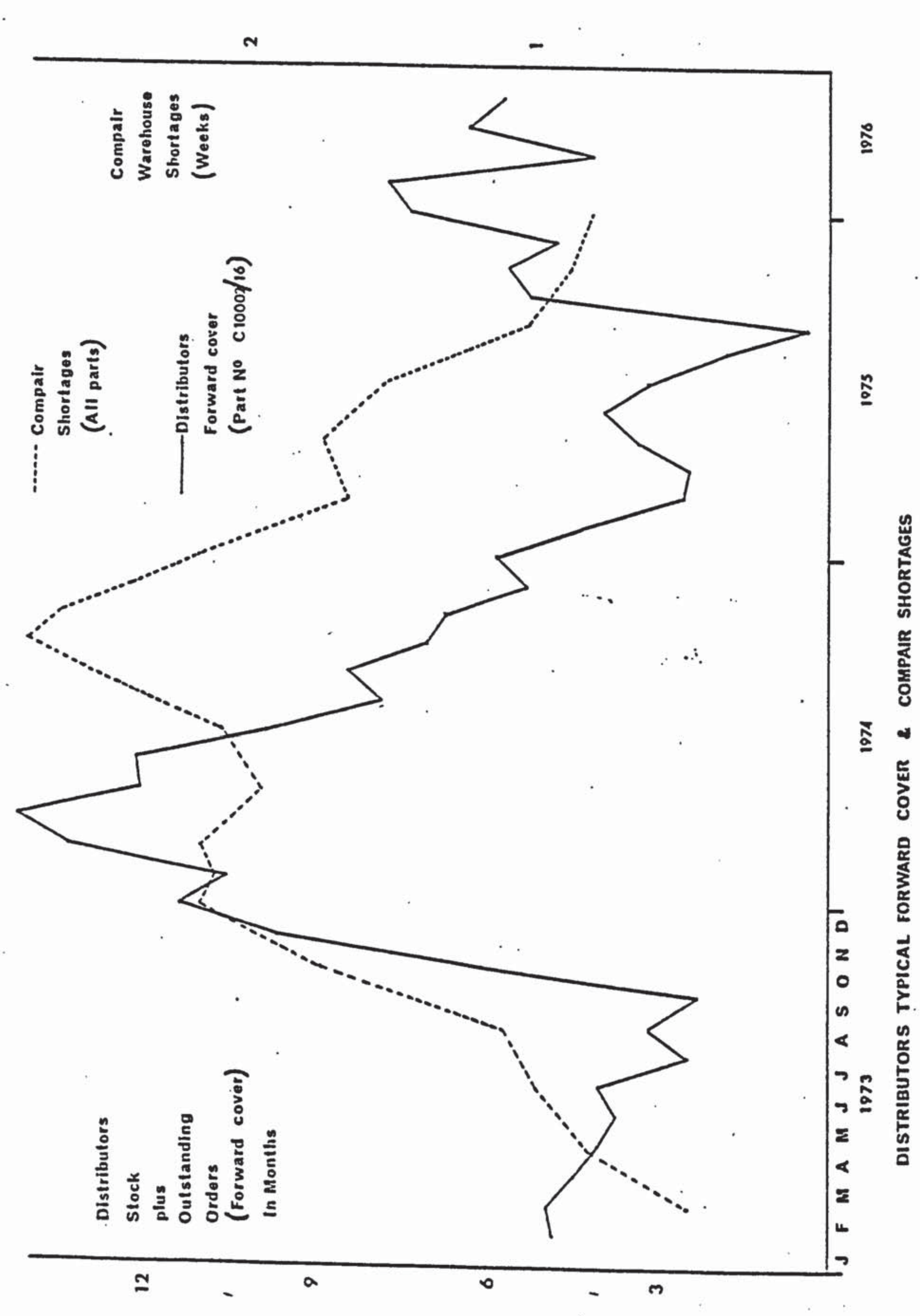
the company's cash flow position, it offered no improvement in the service offered to the customer.

3.3.2. Sub-System Performance

Three areas were investigated in more detail. These were the operation and ordering patterns of distributors, the throughput times for the order processing and warehousing systems and the lead time performance of the various provisioning sources.

3.3.2.1. Distributors

Data were collected from seven U.K. and four overseas distributors describing stock movements and orders generated for a small sample of fast moving items. The individual ordering patterns were examined to determine whether the distributors followed a consistent ordering policy, independant of the service offered by High Wycombe or the general level of business. If this were the case one could expect the distributor's stock plus order cover, when expressed in terms of the demand, to remain essentially constant. Just over half the seventeen parts examined exhibited trends similar to that shown in Figure 3.8.
The sharp rise in stock and order cover anticipates the general increase in shortages at High Wycombe and suggests an over - response by the distributors to a prospective increase in demand. This kind of action would, of course, accentuate any inherent tendancy the distributor's stock control system might have to amplify customer demand trends.



DISTRIBUTORS TYPICAL FORWARD COVER & COMPAIR SHORTAGES
Distributors Stock plus Outstanding Orders (Forward cover) in Months
Compair Warehouse Shortages (Weeks)
----- Compair Shortages (All parts)
——— Distributors Forward cover (Part No C10007/16)
12
9
6
3
2
1
J F M A M J J A S O N D
1973
1974
1975
1976

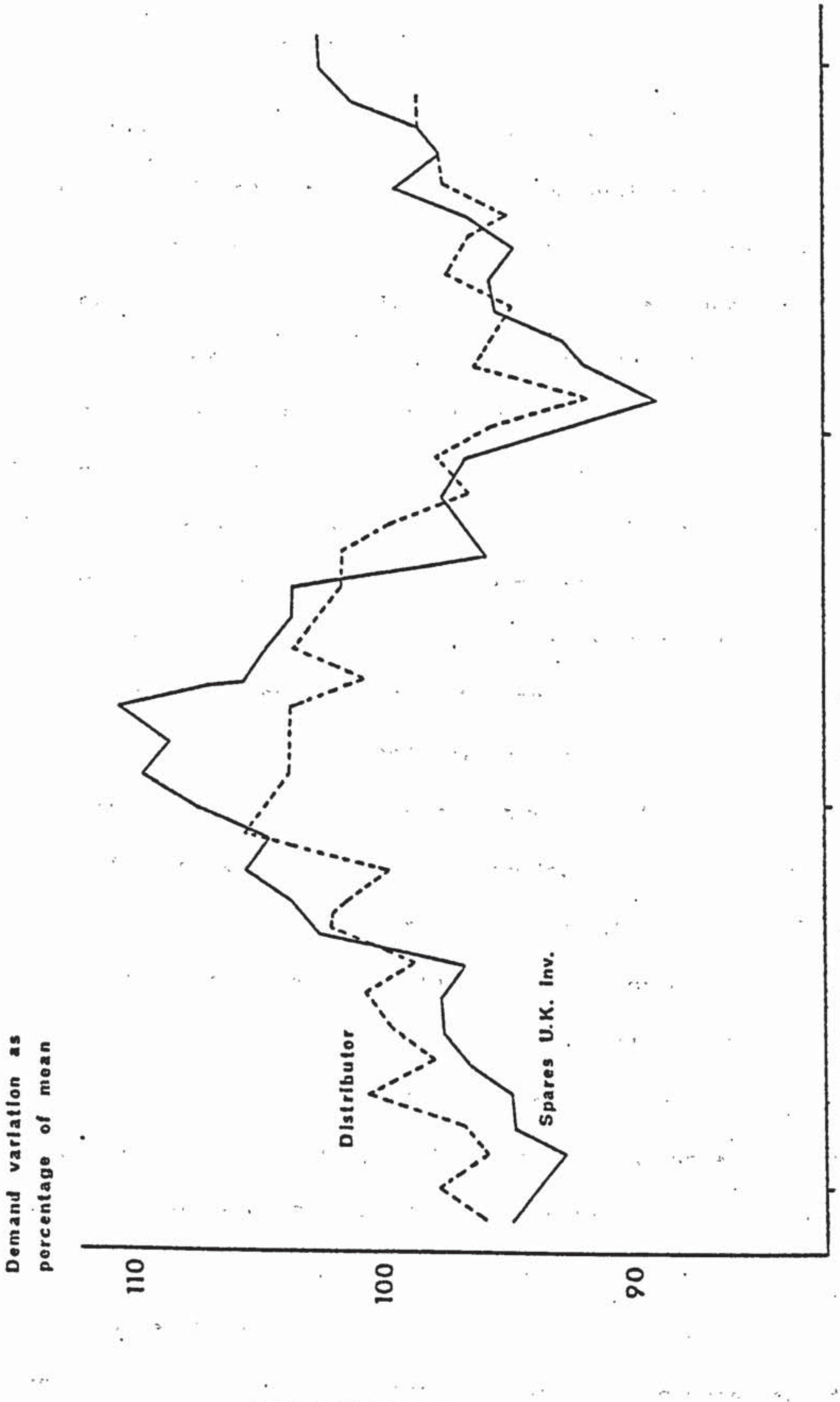
Figure 3.8

The small size of the sample limited the degree of confidence possible in the findings and it was therefore felt necessary to seek additional evidence to support the contention that amplification was present in the system. All the larger U.K. distributors were approached and requested to supply monthly turnover figures for CompAir Industrial spares for as long a history as possible. Only four of the companies were able and willing to supply this data, and then only for a common period of four years. However, they jointly represented 28% of the total U.K. market. Two of the companies were only prepared to supply the information in an indexed form. These data were therefore weighted to reflect the level of spares invoiced to the two companies during 1974/5. During the analysis the data from all the distributors were indexed and adjusted to reflect any price increases which occurred during the period covered. All the data and details of this process are given by D.I.Peckett in Appendix 2 of his PhD Thesis (Peckett 1979).

A comparison between sales invoiced at these distributors and the total U.K. sales invoiced by the Parts Division is shown in Figure 3.9.

Although twelve month smoothing has been applied to the data, it is clear that the fluctuation seen at CompAir is greater than that experienced by the distributors.

Whilst these results are based on sample data covering a relatively short, but important, period of time, the fact that the conclusions are consistent with the results of the earlier piece - part analysis increases confidence that amplification is present in the system. Unfortunately the attitude of the distributors and the poverty of their stock movement records prevented a more comprehensive analysis of this vital aspect of the system



VARIATIONS IN DEMAND

COMPARISON BETWEEN COMPAIR AND DISTRIBUTORS

Figure 3.9

performance.

3.3.2.2 Warehouse and Order Processing

Whilst the level of shortages and the first pick achievement gives a general indication of the service available to distributors, neither allows the delay between receipt and complete satisfaction of an order to be determined. The first pick rate may imply that say 90% of the items ordered are satisfied at the first attempt, but it does not indicate how long the customer has to wait for the balance of the order. Even if the complete order were picked at the first attempt, delays could be expected to occur in the processing, picking, packing and despatch of the material.

A special exercise was mounted in the last quarter of 1976 to measure the time spent by each category of order in each stage of the receipt/warehouse procedure. The data were gathered before the installation of the direct entry system (via VDU's) in the spares office for breakdown and stock orders. For this reason the period the order spent in the Data Processing department is included. The new system has reduced this delay for urgent orders.

Examination of the total throughput times, given in Table 3.1 shows considerable deviation from the target times of 15 days , 48 hours and 24 hours for bulk, export breakdown and U.K.breakdown orders respectively. It should also be noted that the largest delays occur in the picking and packing stages of the process.

In order to establish some estimate of the delay distributions involved in the satisfaction of complete orders, an additional exercise was mounted to analyse the processing of all the orders from the largest U.K. distributor during two separate monthly periods. The months were chosen to be representative of periods of

Breakdown of Order Turnround Times

The figures below show the average time in days orders were taking to be processed in the last three months of 1976.

	Spares Office	EDP Department	Picking	Packing	Total
Bulk Orders	2.8	5.2	6.8	3.8	18.6
U.K. Breakdown	0.6	1.58	2.4	2.17	6.75
Overseas Breakdown	0.8	2.33	3.4	3.73	10.26

Table 3.1

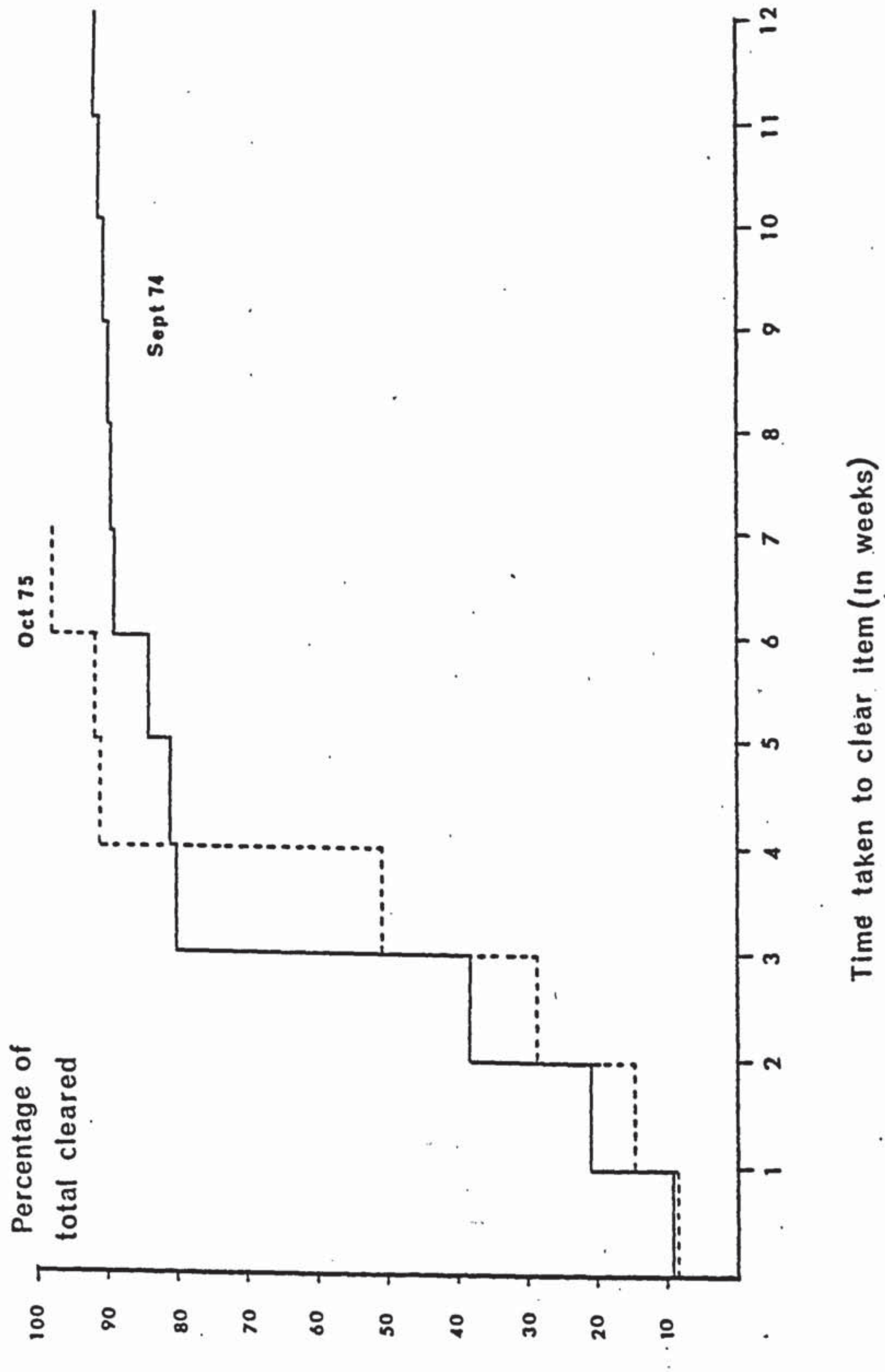
high (September 1974) and low (October 1975) business activity. The time taken to satisfy each item ordered was determined from the picking records
and a cumulative distribution plotted as shown in Figure 3.10. The times shown here relate only to the time between receipt and picking and therefore exclude delays in packing, despatch and transportation to the distributor. Inspection of the distributions shows that clearance of the final 20% of the items took much longer during the period of high activity (September 1974).

3.3.2.3. Sources of Supply

Lead times were analysed for manufactured and bought out components at two different points in the trade cycle, one in September 1974 when activity was high, and one in February 1976 when business was quieter.

For bought out parts the analysis was straight forward. All the buying orders generated in the given month were examined and the actual delivery date achieved was recorded.
The results, shown in Figure 3.11, indicate that delivery of 80% of the outstanding orders was achieved after 20 weeks in the low activity period, but that this extended to 35 weeks in the period of high activity.

However, for factory sourced parts, the analysis was complicated by the fact that an order as such is never raised. The future spares requirements are calculated by the computer and added into the gross forward load on the factory, after taking into account the specified lead time for the part concerned. Four weeks before any given allocation falls due, a note is automatically raised by the computer and is issued to the Spares Department. On



VARIATIONS IN SERVICE TO DISTRIBUTORS

Figure 3.10

BOUGHT-OUT LEAD TIME ANALYSIS

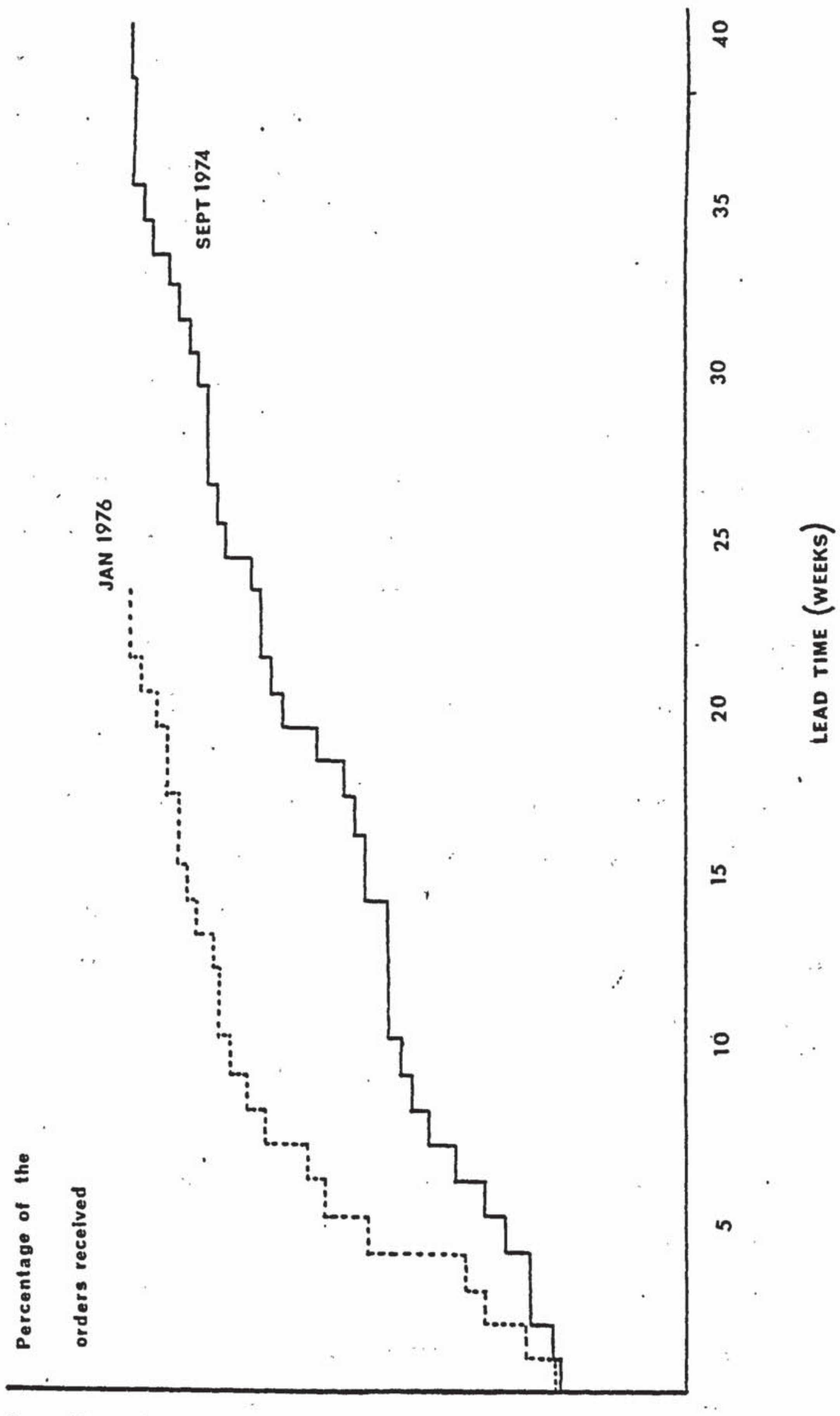


Figure 3.11

presentation of this allocation note to the relevant source department, the parts should, in theory, be available.

Each month the computer prints a tabulation of the outstanding allocation notes against every part number and also lists the numbered quantity of parts which were delivered to spares in the preceding month.

By examination of the allocation notes in existence in the months selected, and perusing subsequent issues to determine the time taken to clear these notes, it was possible, knowing the nominal lead time, to calculate the actual lead time for each delivery of a particular component.

Average lead times were then calculated for each component, for each period. The result is shown in Figure 3.12 as a cumulative distribution of average lead times.

Although the curves come together at the 70%/40 week point, significant differences are evident at lower lead times. For example, in September 1974 (high activity) only 15% of the parts in the sample had lead times less than 20 weeks whereas in February 1976 (low activity) this figure had risen to 45% within 20 weeks.

The influence of the level of activity is further demonstrated by analysis of the lateness, rather than lead times, of factory supplies. Lateness in this context was defined as the period between the nominal allocation date and the time the material was actually made available to the warehouse. The basic data used in the lead time analysis also yielded the cumulative lateness distributions shown in Figure 3.13. In this instance the performance in February 1976 (low activity) was consistently superior to that offered during September 1974 (high activity).

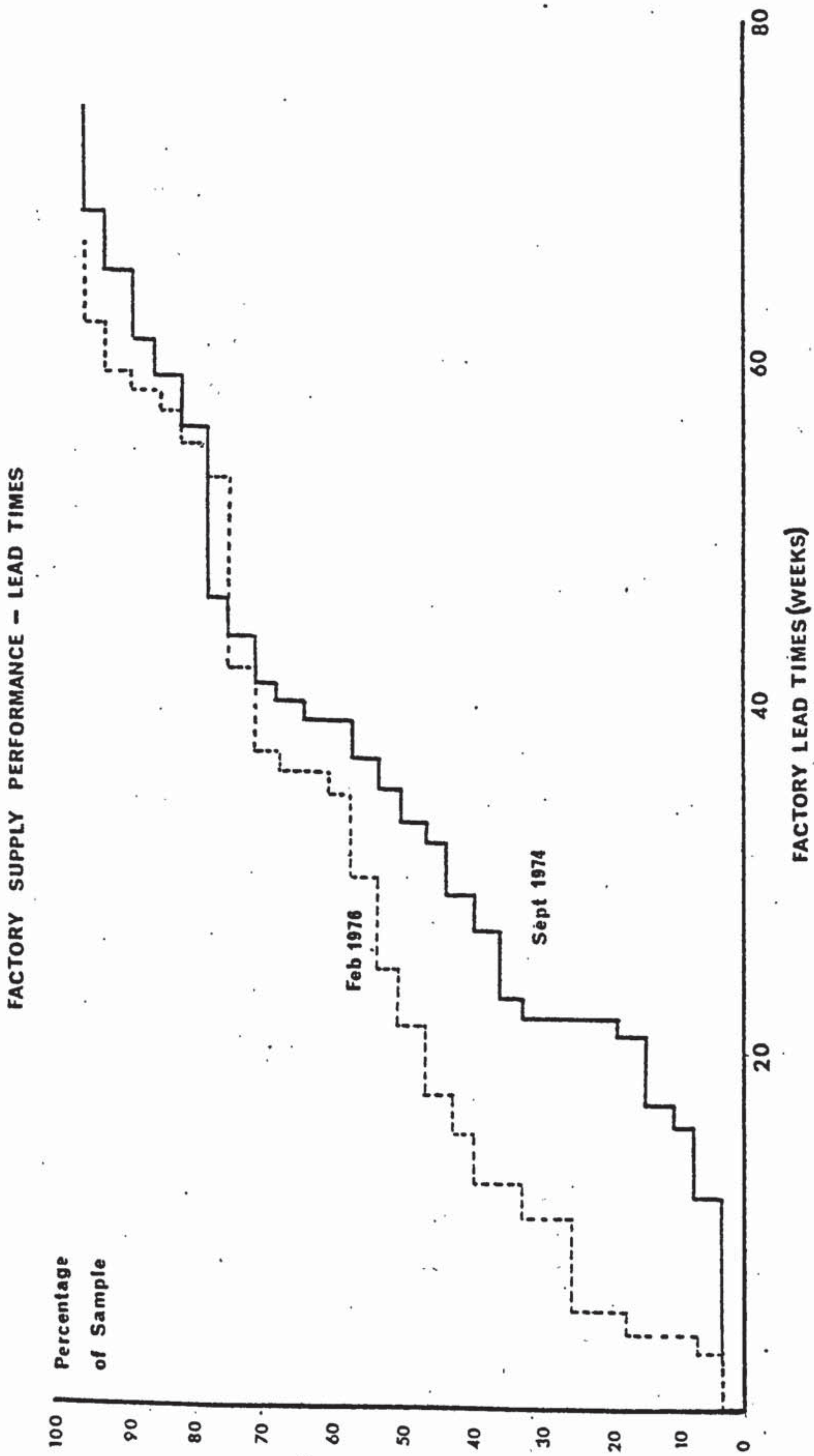

FACTORY SUPPLY PERFORMANCE - LEAD TIMES
Percentage
of Sample
100
90
80
70
60
50
40
30
20
10
0
Feb 1976
Sept 1974
20
40
60
80
FACTORY LEAD TIMES (WEEKS)

Figure 3.12

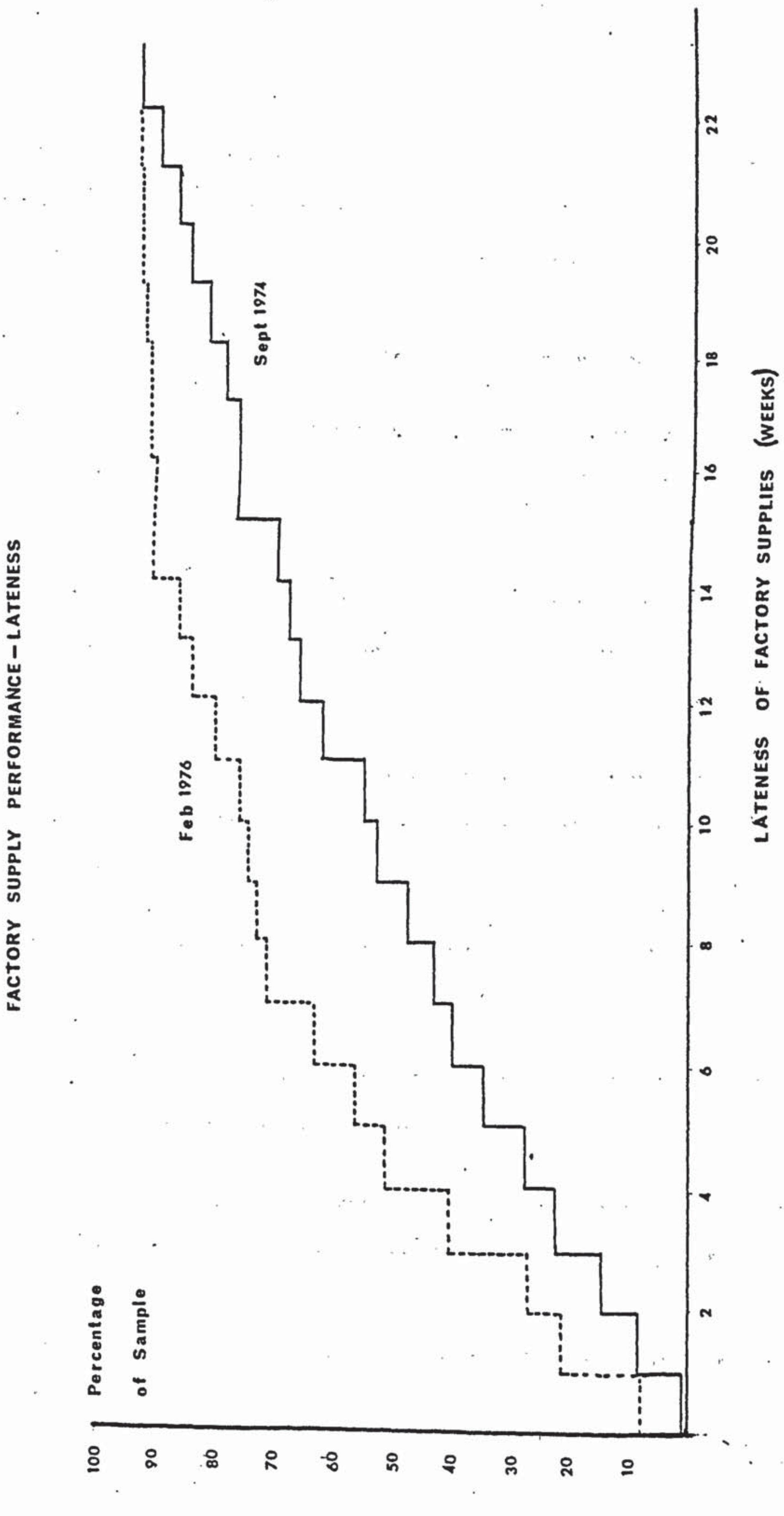

FACTORY SUPPLY PERFORMANCE - LATENESS
Percentage
of Sample
100
90
80
70
60
50
40
30
20
10
Feb 1976
Sept 1974
2
4
6
8
10
12
14
16
18
20
22
LATENESS OF FACTORY SUPPLIES (WEEKS)

Figure 3.13

3.4. Forecasting of Long Term Demand

The prospective increase in the proportion of non-current parts in the spares range created a need for more information about demand trends for individual components once the production of parent machines had ceased.

Several approaches to the problem were attempted including:

i) A search for correlation between component demand and the decline of the field population of the parent machines.

ii) A search for a standard type of decay curve to represent the obsolescent demand for all or similar classes of component.

iii) Analysis of the gross revenue generated by groups of parts associated with machines made obsolete several years ago.

Unfortunately the only facts to emerge from the investigations were:

i) The decline in demand for spare parts during obsolescence is difficult to forecast.

ii) For the majority of parts a substantial demand is likely to exist for at least the first seven years of obsolescence.

A more detailed discussion of the exercise is to be found in Appendix 2.

3.5 Conclusions

The two key measures of the service performance of the Parts Division are the order turnround time and first pick success rate.

The first of these is principally dependant upon the customer order processing procedures and the facilities for picking and packing. An analysis of the total order turnround times showed that of all the activities concerned, the order picking and packing operation was the most significant.

The potential for improvement in the methods of storage and handling in the warehouse was apparent from the survey of the parts operations of other companies. It was agreed with the company that a separate project should be initiated, using company personnel, to investigate and report on this area .

The other aspect of performance (first pick) has financial implications in that the rate achieved at a particular time will depend on the characteristics of the demand and the level of stock held, i.e. capital invested.

It is clear from the historical data that the performance of all the major sections of the spares system is affected by significant fluctuation in the level of demand.

It can be seen that, as the demand for spares increases:-

- service at distributors deteriorates and they increase their order cover on High Wycombe.

- service and stock fall at High Wycombe and shortages rise.

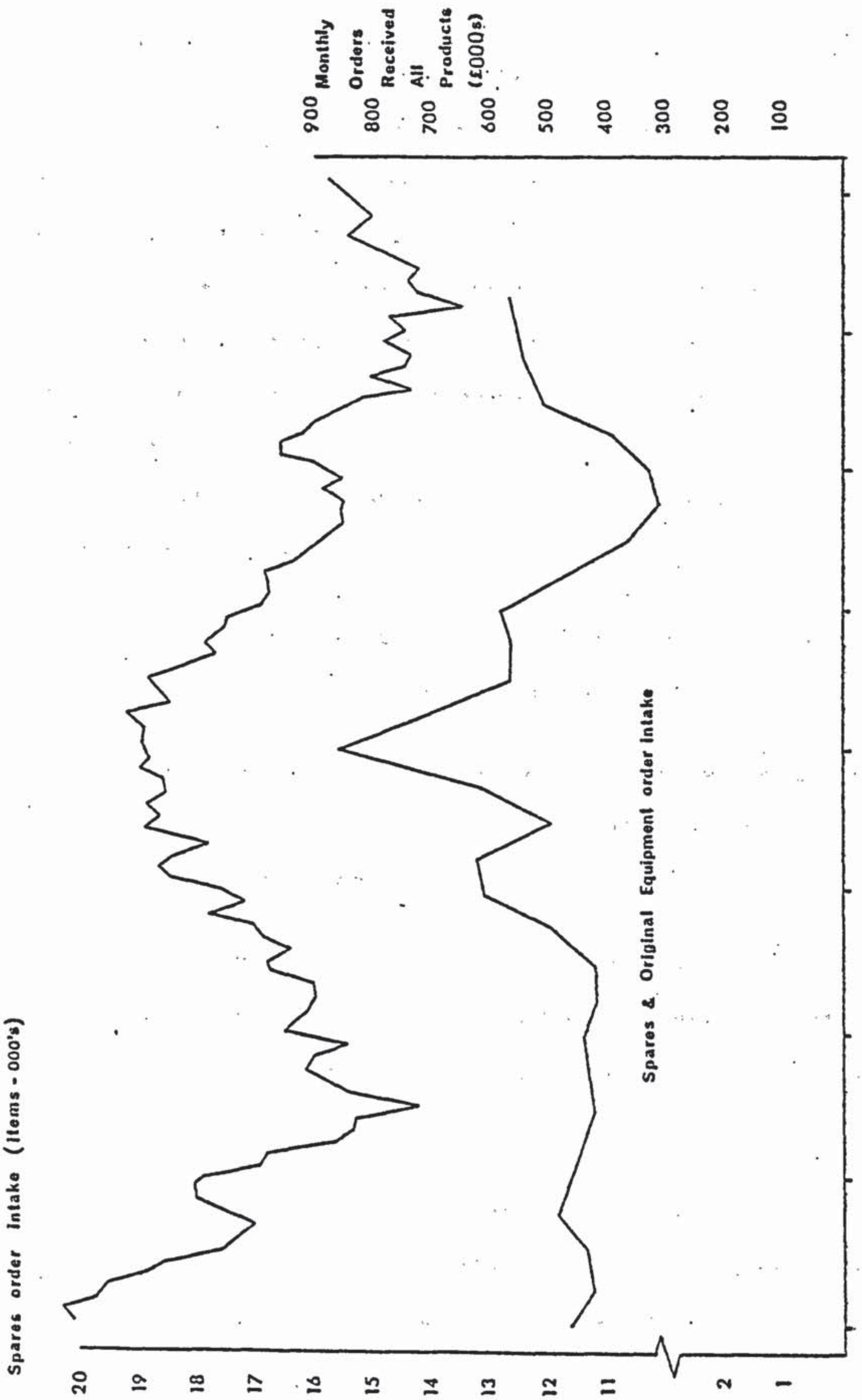
- supply lead times increase for both manufactured and bought out components.

In view of these effects, it is important to establish the timing of the spares demand cycle with respect to both the demand for complete compressors, and to the general level of industrial activity. If, for example, all three were in phase, it would mean that the spares division would be requiring additional capacity at the very time it was being made scarce by the much greater demands of a rising original equipment requirement.

It is, however, commonly believed within the industry that the demand for spare parts seen by the manufacturer rises as demand for original equipment falls, the hypothesis being that during periods of economic recession lack of capital forces users to continue to repair old machines, rather than purchase new replacements.

If this view is correct, the spares order intake should be out of phase with that for original equipment and would smooth the demand on common facilities within the company.

Reference to Figure 3.14 shows clearly that the demand for spares and original equipment rise together disproving the above hypothesis. This view was specifically reinforced in a study of spares and original equipment demand made by Mrs. M. Mabberly of the CompAair Group holding company (1975). A possible explanation may lie in the influence of the general level of economic activity. Service intervals for industrial compressors are normally quoted in terms of running hours. It follows that as industrial activity increases, compressors will be worked harder, and the actual period between services will decrease. The life of wearing components, such as rings, bearings etc. will also be dependant on the hours worked.



Comparison of order Intake for spares and original equipment

(6 month moving average)

Figure 3.14

A rise in general economic activity might therefore lead to an increase in the demand for spare parts. Figure 3.15 shows that the spares order intake is approximately in phase with a plot of manhours worked in industry.

Thus, it is clear that the trade cycle affects the performance of the spares division in two ways, by increasing the demand for spare parts and at the same time decreasing the capacity available to meet it.

The trade cycle is believed to work through the CompAir system in the following way:-

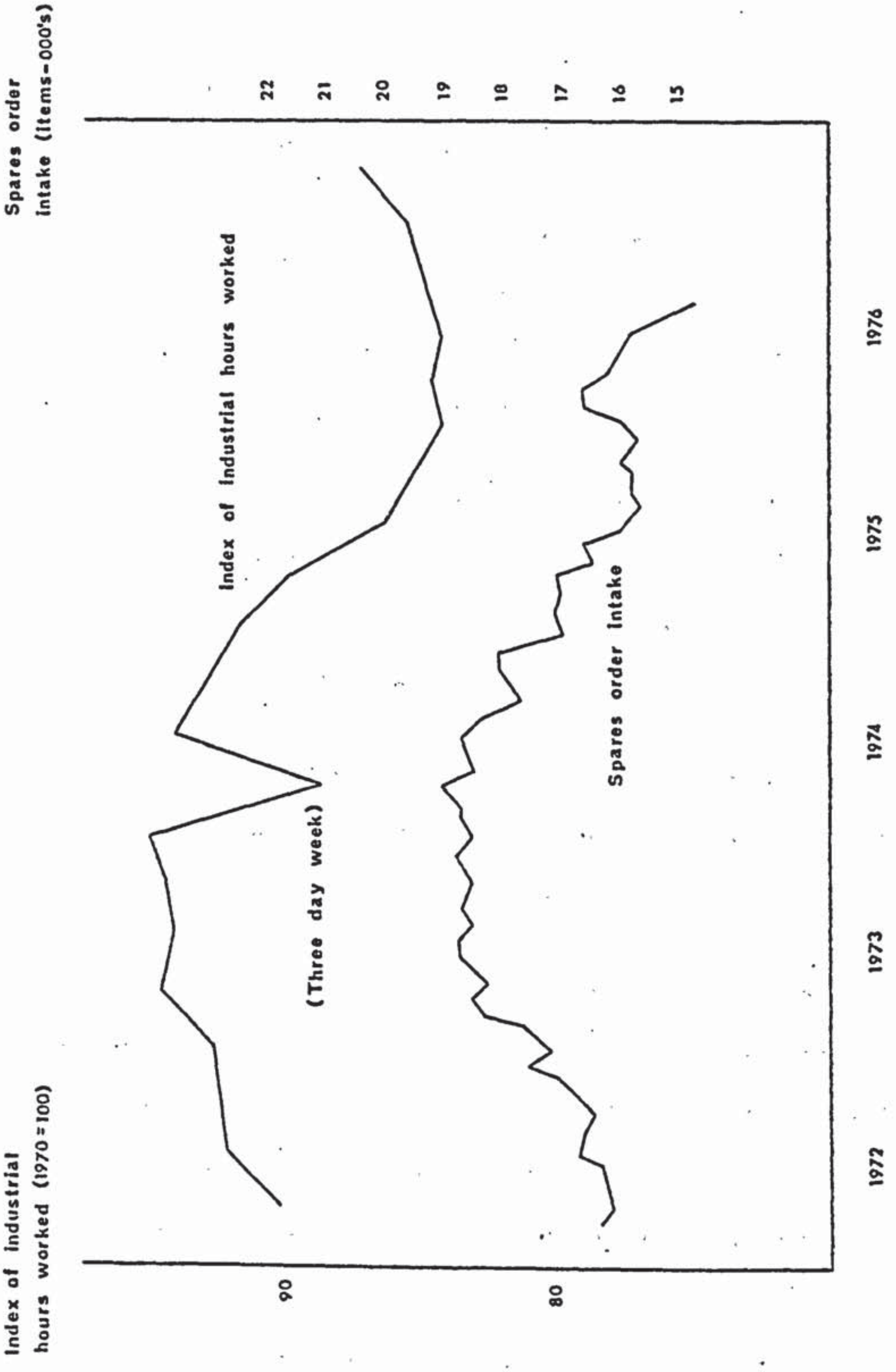
- an upturn in economic activity generates an increase in demand for spares and compressors.

- the distributors stock control system amplifies the true trend in sales and passes this on to High Wycombe.

- the forecasting/stock control system at High Wycombe acts slowly to the increase, but finally passes an even larger demand on to the various sources of supply.

- the increase in demand for compressors reduces the capacity available on the manufacturing facility for spares. The resultant increase in load on the production units leads to longer throughput times.

- with the upturn in industrial activity, lead times of outside suppliers deteriorate rapidly



COMPARISON OF SPARES ORDER INTAKE WITH THE LEVEL OF INDUSTRIAL ACTIVITY

Figure 3.15

- stocks and service, both at High Wycombe and at distributors fall as the supply of parts is delayed. Shortages increase rapidly.

- as lead times increase, order cover is increased by distributors and High Wycombe causing further deterioration in lead times. This cycle may be repeated several times.

- as demand begins to die away and action taken by suppliers to increase output takes effect, supplies improve and an excess order cover situation develops.

- as orders are cancelled or reduced to correct the level of order cover stocks and service rise and shortages fall rapidly.

Although discussion has concentrated on the effects of the trade cycle, this is not the only source of instability of demand. Apart from the stochastic nature of individual demand patterns, there are superimposed trends of growth or decline of new or obsolete components. Because there is no apparent common pattern for non- current spares it is impossible to make a general forecast. (See Appendix 2 and section 3.4). Thus it is important that the system is able to accommodate the variety of trends which will occur at the piece part and gross levels of demand.

Examination of the data suggests that, although the system might work satisfactorily during periods of stable demand, the achievement of the desired levels of service would require an integrated system, designed for better dynamic response under all demand conditions.

Chapter 4 Analysis of the Interaction Between System Elements

4.1 Selection of the Method of Analysis

4.1.1. Introduction

The historical analysis suggested that the system performance was considerably influenced by the fluctuation in demand at distributors. It also implied that significant interaction existed between the main elements of the system. Whilst the company management saw the problem essentially in spares manufacturing terms, the review of the complete operation indicated that potential for development existed in most other areas,including aspects of the warehouse handling,stock control at distributors and central production/ stock control system. It would have been possible to instigate separate development programmes for each area, but it was felt that maximum benefit could only be obtained if any modifications to the system elements were evaluated and directed in the context of the performance of the total system.

A method of investigating the dynamic response of the complete system, and identifying the significance of it's constituent parts was therefore clearly required. It was clear that some form of simulation model would offer the most appropriate vehicle to explore the problem. The use of conventional discrete methods required the system to be modelled at too great a degree of detail if all the components of the operation were to be included. It was felt that such a model would necessitate an excessive development period and would be unwieldy and inefficient in operation. The technique known as 'Industrial Dynamics' offered a more efficient alternative and had originally been developed specifically to study the dynamic operation of large industrial systems. The simplicity of the approach and its obvious relevance to the requirements of the spares project were deciding factors in the decision to build an industrial dynamics model of the complete system.

4.1.2. History and Introduction to Industrial Dynamics

The technique or discipline called industrial dynamics was developed by Jay. W. Forrester at MIT in the late 1950's (see Forrester,1958,1959). Industrial Dynamics, or System Dynamics as it has more recently been called, can be considered to be the application of the principles of feedback control theory to the analysis of organisational problems. Although the presence of feedback control mechanisms in human activity had been recognised much earlier it was not until 1952 that Simon (1952) had proposed the use of conventional servo-mechanism theory in the analysis of a production/inventory system.

Forrester recognised that the organisational systems which had to be studied represented a much higher order than the electromechanical systems which were susceptible to analysis by conventional control theory techniques.

Advances in the power of digital computers allowed Forrester the opportunity to develop his models as a series of simple linear equations which could be repeatedly evaluated for small time increments by the computer. The system can therefore be considered as being represented as a series of integral rather than differential equations. The format is simple in concept yet capable of representing very complicated systems.

Unlike many of the computer based simulation techniques industrial dynamics models do not represent and record the state of individual entities in the system. Rather they model the flow of different classes of entity, orders, material, money etc, through the system.

In addition the models represent many of the decisions in the system in the form of information feed back loops. The flow of information is modelled in the same way as that of orders or material and is usually the most critical feature of any industrial dynamics model.

An example of a simple mechanistic feedback system is shown in Figure 4.1.

To control the level of water in the tank a valve is introduced in the supply line. In order to know by how much the valve should be opened or closed it is necessary to feed information about the water level and output flow back to the valve operator. A delay will occur before the effects of valve movement are felt at the tank and delays will also occur in the feedback of information to the operator

The characteristics of the system, for example how well the level is controlled, will be determined primarily by the information feedback loops (controlled by their respective delays) and the way in which the valve operator responds to that information.

The relevance of this example can be seen by reference to Figure 4.2 where the same basic information feedback system has been used to represent a stock control system.

Forrester developed a unique algebraic notation and a flow charting technique which can be used to represent the relationships of the variables and parameters in a model.

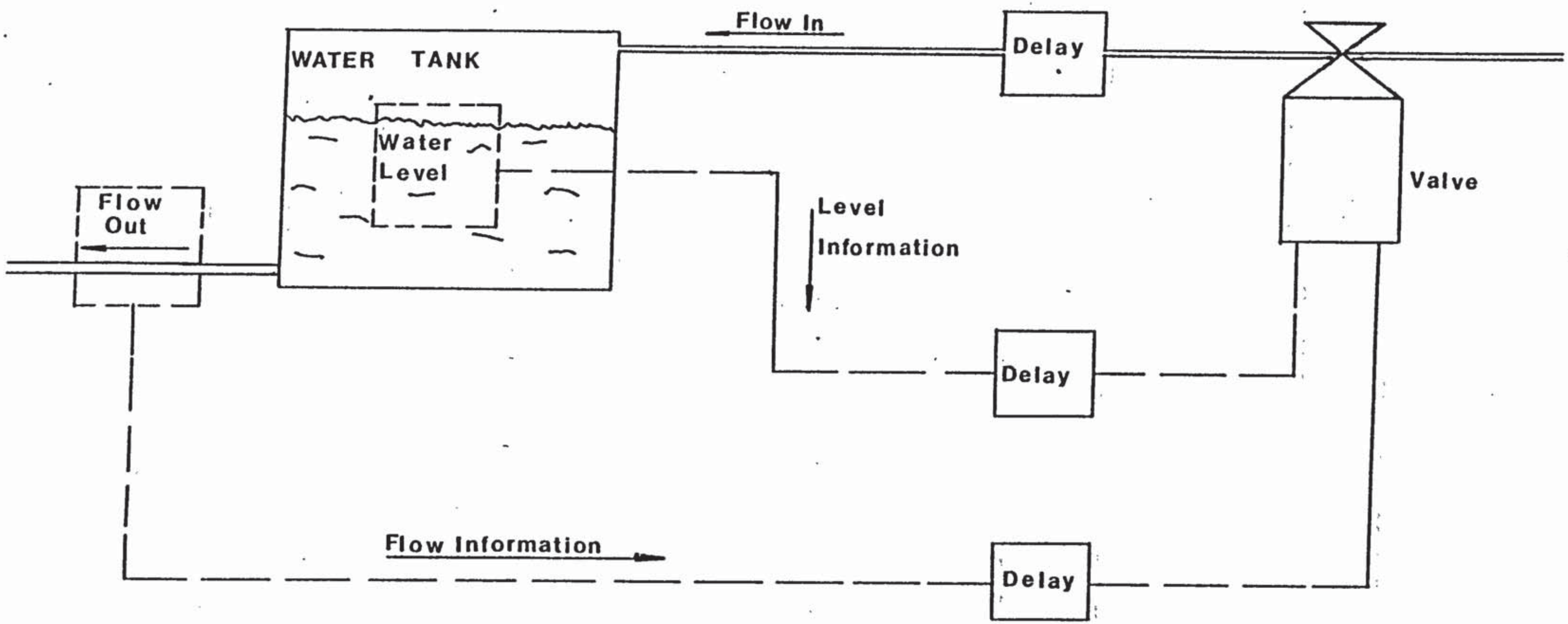


Figure 4.1 Example of an Information Feedback System

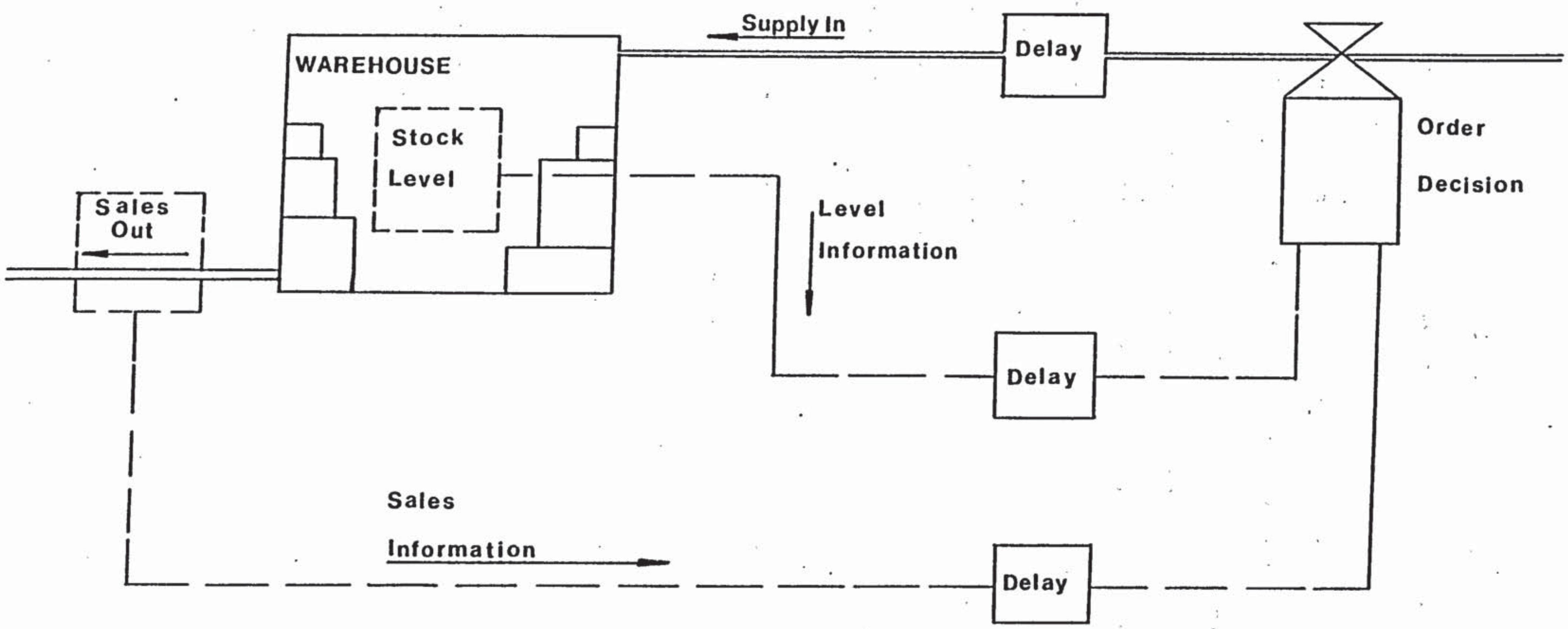


Figure 4.2 Second Example of an Information Feedback System.

Flow charts are used to indicate type and relationship between all the variables in the system. The symbols used are defined in Figure 4.3. The rate and level symbols are used in a manner similar to that in the information feedback example discussed above. Two additional types are also defined - the auxillary variable and the line delay. Although any system could be represented exclusively as levels, rates and delays some of the rate equations could become extremely complex and difficult to conceptualise. Auxillary variables define sub-relationships which feed a rate calculation. For example, in the order rate decision shown in Figure 4.4 the target stock function could be defined as average sales times a constant. The target stock would be calculated as an auxillary variable thus simplifying the form of the order rate equation and allowing better correlation with the operation of the real system.

An example of the algebraic notation used to describe the calculation of actual stock in the warehouse sector of the spares model is shown below and the associated flow chart in Fig 4.5.

$$IAF.k = IAF.j + DT*(SRF.jk - SSF.jk)$$

The three or four letters preceding the period represent the variable (usually chosen as a mnemonic eg IAF - Inventory Actual at the Factory warehouse). The one or two letters following the period are time subscripts. A single letter indicates that the variable takes on its value at the specified time instant ('k' is taken as the present, 'j' the preceding and 'l' the succeeding instants, a constant increment 'DT' separates 'j-k' and 'k-l'). A double letter indicates that the variable takes on and holds its value during the time interval specified.

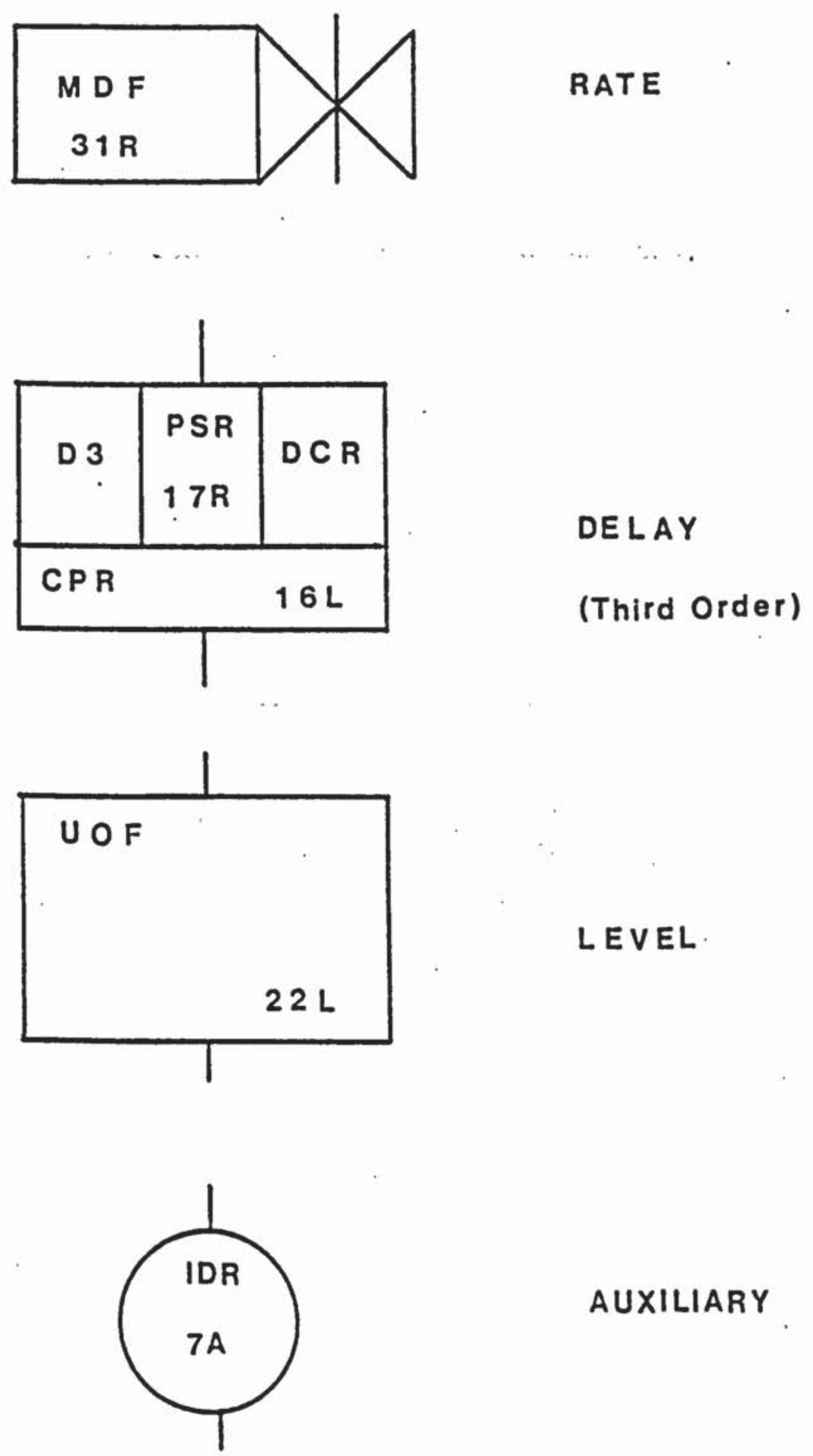


Figure 4.3 Industrial Dynamics Flow Chart Symbols.

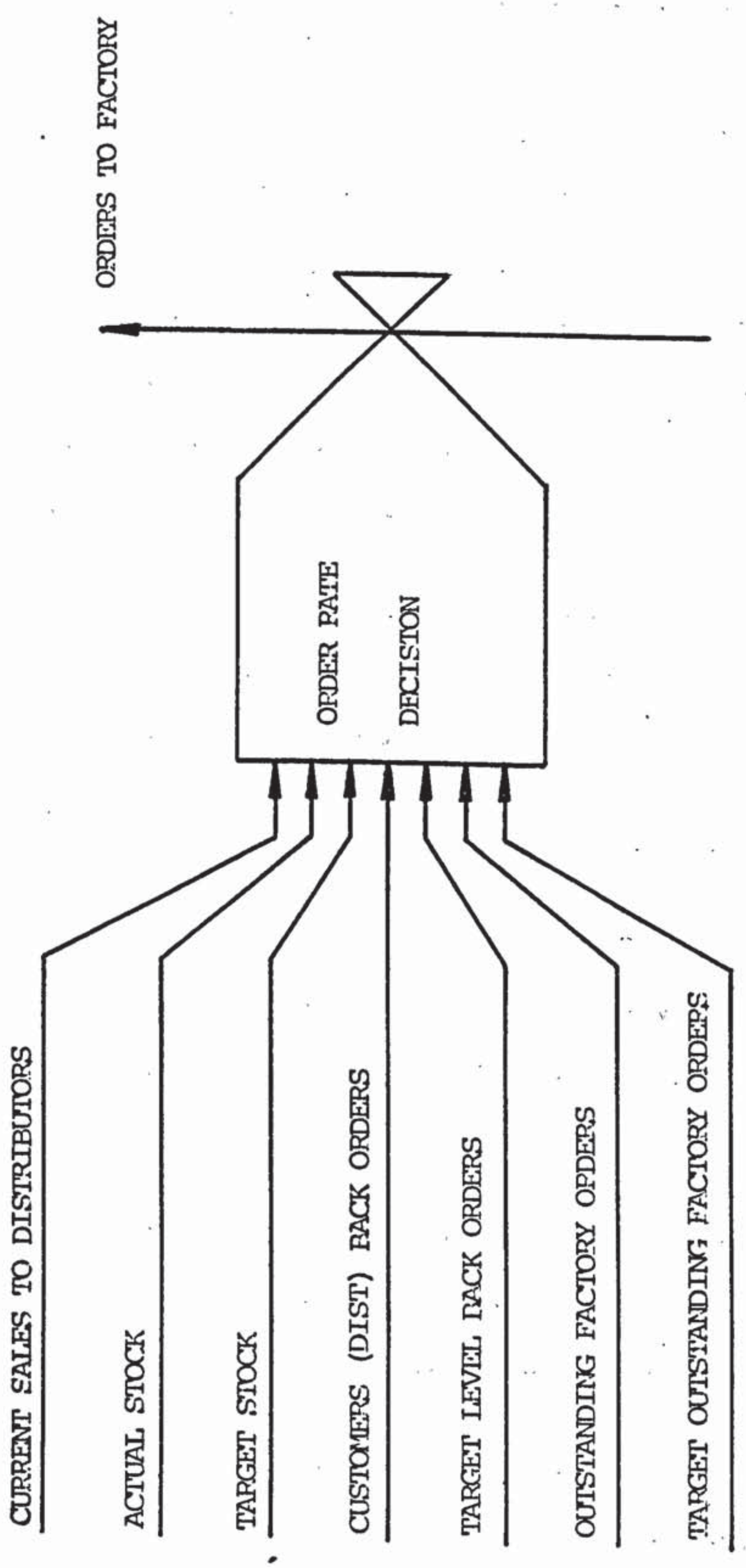


FIGURE 4.4 EXAMPLE OF A RATE CALCULATION

Single letter subscripting indicates the variable is a level and the presence of two letters is characteristic of a rate. Variables with no time subscripts are parameters whose values do not change with time.

The equation given above indicates that the new value of IAF is defined as the old value plus the net flow of material during the calculation time increment DT.

The sector of the model shown in Figure 4.5 also illustrates the interdependance of rates 'and levels in industrial dynamics models. The closed loop defined by : IAF- DFF- STF- SSF- IAF can be explained in the following manner:

- The present value of inventory (IAF.k) is used to calculate the delay in fulfilling orders from the warehouse (DFF.k)

- The delay is used to determine the shipping rate to be tried from the warehouse (STF.kl)

- The shipping rate sent from the warehouse (SSF.kl) is set equal to the trial rate (STF.kl) providing the predetermined maximum (NIF.kl) is not exceeded.

- The value of the inventory in the next time increment is calculated from the net flow of material, i.e. inflow (SRF.kl) minus outflow (SSK.kl).

The interdependance of the calculation of levels and rates is seen throughout all industrial dynamics models. Even simple models will normally be formed from a multitude of feedback loops which lead to the high order characteristic of organisational systems.

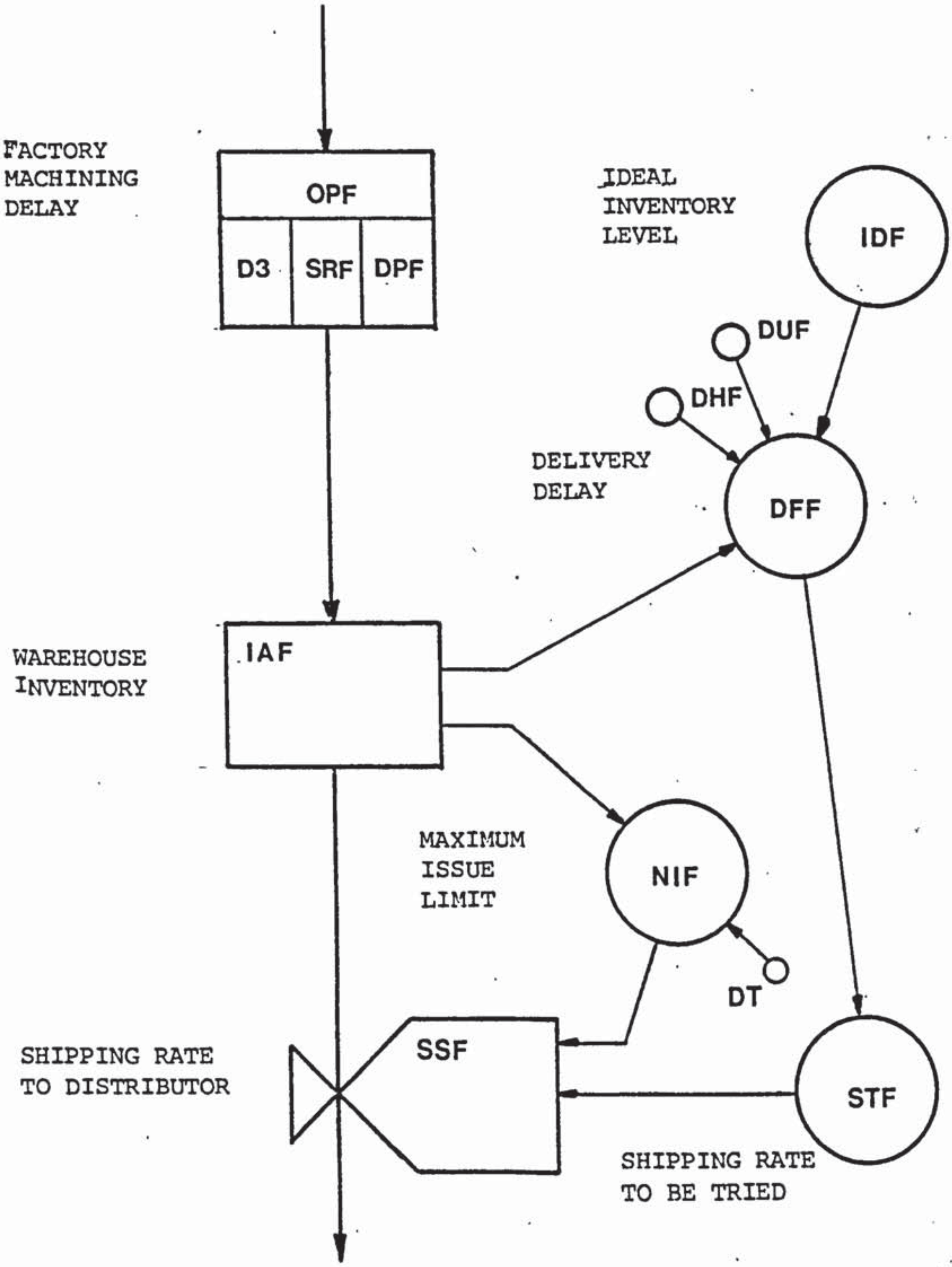


FIGURE 4.5 CALCULATION OF STOCK LEVELS AT THE WAREHOUSE

For a more comprehensive introduction to the principles and techniques of industrial dynamics see Forresters definitive book "Industrial Dynamics" (1961) or Chapter I of "System Dynamics" by Roberts (1978).

4.1.3. Industrial Dynamics - Discussion of Related Applications

In the preface to his book (1978) Edward Roberts states:

> "By the early 60's academia ceased being the breeding ground for industrial usage of system dynamics, and action shifted to the larger corporations and consulting companies. Details of these managerial applications of system dynamics, however, have not been readily available to the interested public".

Even though this book goes some way toward rectifying this situation, reports of the analysis of production/inventory/distribution systems are limited to four papers documenting, in varying detail, five applications, three of which are described in one paper. Three of the papers were previously published in journals during the early 1960's (Fey 1962, Carlson 1964, Schlager 1964).

It would appear that problems of corporate confidentiallity have severely restricted publication of much of the work which Forrester and Roberts insist has been done in the manufacturing area. In the introduction to the manufacturing section of his book (1978), Roberts lists a number of large U.S. companies known (from the MIT System Dynamics Newsletter) to have been active in the application of industrial dynamics to manufacturing problems. No published material has been located connected with these applications.

The first application of industrial dynamics to a practical problem was carried out at the Sprague Electric Company by a team from MIT directed by Forrester. The project was undertaken at a time when work was still proceeding at MIT on the philosophy and methodology. This application could therefore be considered the first practical test of the technique and can be considered important from that aspect alone.

Two papers written by Fey (1962) and Carlson (1964) are supplemented by a detailed description of the model in Forresters book (Chapters 17 and 18, 1961)

Willard R. Fey was a member of the MIT project team and his paper (1962) presents a description of the problem, the development and use of the model and comments on the success of the changes introduced in the organisation of the company.

Fey defines the company's objectives as :

> ".....profits and employment stability for its own sake. The major problems relative to these objectives were the long term cyclic nature of the product's industry and the tendency for wider fluctuations to occur in production than in sales".

The boundaries of the model were set to include the hypothetical activities of the customers and the effects of the labour market. Production capacity was seen essentially in terms of labour as much of the production process was based on manual work. The production/inventory sector of the model was similar to that developed by Forrester, but excluded the multi- echelon distribution and retail levels present in that model.

Analysis of the model results indicated that the cyclic trends could be traced to variation in the delivery delay (or lead time) offered by the company caused by fluctuation in the order backlog. It was found that during periods of increasing demand a proportion of the backlog existed only to enable a higher level of inventory to be achieved (target stock proportional to average sales) rather than as a direct reflection of true customer backorders.

Basically two changes were introduced aimed at using the inventory to absorb some of the long term fluctuation in demand and thus reducing the variation seen in production and employment. A priority system ensured that parts were only made for stock when excess capacity was available, and an employment decision rule was introduced to encourage stability in the workforce.

Fey claimed, after a relatively short period of operation of the new policies, improvements in productivity, employment stability, sales levels and lower inventories. The precise relationships between these improvements and the new policies is not clear from the paper. In a note added in 1965 assessing the results after two years experience the author indicates that after the withdrawal of the MIT personnel the company management lapsed back into its old habits.

Carlson's paper (1964) presented the view of the project from the company's side. In his discussion of the accomplishments of the project four areas of improvement are mentioned, none of which can be completely attributed to the industrial dynamics model. The productivity improvement is said to be "the result of the more stable employment called for by the new decision rule and partly as a result of aggressive methods improvement programs".

The use of an improved scheduling procedure and computer controlled inventory reorder points are also mentioned as contributing to the better system performance.

The main objective of the exercise, the damping out of long term fluctuation in customer ordering, had not been achieved at the time Carlson wrote his paper.

Explanation of this failure seems to depend on the viewpoint of the observer. Forrester, in his reply (May 1968)to Ansoff and Sleven who quoted this point in their critique of industrial dynamics (March 1968) attributes the failure to the management reversion to old employment policies after the first year of operation. Carlson, on the other hand, points out the hypothetical nature of the customer sector of the model and its failure to represent the complete market place. Sprague's competitors were not included in the model and no explicit data were gathered from customers to indicate the <u>actual</u> way their ordering decisions were made.

Given the tenuous links between the claimed improvements and the modelling exercise it is clear from both papers that the company gained a much better understanding of the manner in which their organisation operated. In addition the weakness in the model could be attributed to omission of key areas of influence on the behaviour of the system being studied. The model boundaries were drawn in the wrong place.

The translation of the model results into specific policy rules also seems to have been difficult to achieve. The priority rule could be considered trivial and had been in operation prior to the modelling exercise. The employment rule failed to survive more than the first year of its operation.

The Sprague study emphasises the importance of defining correct model boundaries and the problems of utilising industrial dynamics as the sole form of system analysis. It does also indicate, however, that such an exercise highlights new aspects of system behaviour and allows those involved to gain much greater insight into the key decisions and relationships in an organisation.

Kenneth Schlager, in his paper "How Managers Use Industrial Dynamics" (1964) reports on the use of the technique in three, unnamed, companies. The application in company 'A', a manufacturer of flow meters is the only one reported in any detail.

The model used covered the company's production/inventory/ employment activities and was a development of the Sprague model. It was, however, much more detailed in its representation of the manufacturing (split into four production and three purchasing functions) and marketing sectors.

Schlager also stresses the involvement of company management in the development team and the importance of gathering a comprehensive data base for validation of the model.

In general the application appears to have been more successful than the Sprague study, perhaps because of the greater commitment from company personnel and more rigorous development of the model.

The other applications mentioned in the paper are concerned with product development policies (company "C") and jobbing manufacture (company "B") but neither are described in sufficient detail to permit proper evaluation of their significance.

Another enhancement of the basic Forrester production/distribution model is described by Yurow (1967) who simulated the multi-echelon structure of the tufted carpet industry. The structure of the model, as briefly described, appears to be more complex than the Forrester original, includes five levels of production or distribution, and explicitly models the flow of four classes of product through the system. Unfortunately the author does not present any detailed results or conclusions from the exercise, merely stating that:

> "....continuous representation is useful for obtaining qualitative managerial guidlines."

In chapter 10 of his book "System Dynamics" (1978) Edward Roberts describes an MIT study of employment fluctuations in an engineering company manufacturing high quality machine parts. The development of the model is given in considerable detail, including a full set of equations, and is the only published account of the work.

The company manufactures directly to customer orders, thus eliminating any inventory in the system. The orders are gained by bidding in the market place and the main sectors in the model therefore represent sales and production activities. The production sector includes the effects of overtime working and hiring/firing of the workforce on productivity and thus output. The existing employment decision was based on the length of the current manufacturing lead time. The model showed that a decision based on the average demand plus an allowance for correcting the order backlog would stabilise employment and lead times. This could hardly be considered a surprising result, it merely reflects good production planning practice.

In addition a specific rule was developed to control the proportion of management effort to be devoted to the bidding activity. This model showed that this rule would lead to more stability in demand levels. Quite how a change in effort from 5% to 15% (the maximum increment possible) could be measured or controlled is not explained.

The use of the new rules in the company is not discussed and their success or failure not assessed.

The paper is interesting only for the form of the model structure and the detailed discussion of the development of the new policies.

Sharp (1977) reports briefly on a number of widely divergent applications of the technique by the System Dynamics Group at the University of Bradford. The most relevant of these concern the redesign of a production planning system and an analysis of the export distribution policy of a manufacturing company. The former study is covered in more detail in a paper by Sharp and Coyle (Ref 1976) and is particularly interesting in that a comparison between model and actual system performance data is given. Such an explicit attempt at validation is rare in the applications literature. The problem of correspondence between the model variables and measures of the real system was simplified by limiting the application of the model to a single product. This approach also avoided the aggregation difficulties common in industrial dynamics models.

The study of a manufacturing company's distribution policy is also reported by Coyle (p.282-305, 1977). The analysis showed that excessive stocks were present in the total system and that closer company control over the operation of the independant distributors would result in more robust system performance. The distribution structure studied here is clearly analagous to that used by CompAir, both in the U.K and overseas. The conclusions from this paper accentuate the importance of studying the complete system.

With the exception of the Bradford studies, the application of industrial dynamics to production/inventory systems analagous to the CompAir operation generally occurred early in the development of the technique. Later work in the managerial sphere tended toward examination of marketing (e.g. Forrester 1968, Roberts 1977), corporate growth (e.g. Wright 1977, Roberts et al 1968), research and development strategies (e.g. Roberts, 1964) and the design of information control systems (e.g. Millen, 1972).

The fact that industrial dynamics has more recently become known as System Dynamics reflects the broadening application of the technique to areas far beyond the industrial context. The major published works show the trend away from the industrial area into examination of socio- economic problems culminating in the study of world dynamics in the early 1970's. (Forrester, 1971).

Although this work shows the continued use and acceptance of the industrial dynamics methodology it adds little of direct relevance to the study of the CompAir problem. Reiterating the main observations to be drawn from the literature:

i) The inclusion of all the influential factors inside the boundary of the model is critical to its validity.

ii) The objectives of the models were normally to develop improved policy decision rules.

iii) The use of the model to explore the relative importance of different areas of the organisation is not explicity mentioned, neither is the idea of using the model to guide the direction of detail design effort in such areas.

iv) The translation from model output and terminology to specific, detailed modification of the system seemed difficult to achieve.

v) In some cases the improvements in performance could have resulted from activities not directly linked to the industrial dynamics exercise.

vi) The creation of a comprehensive data base and inclusion of company personnel in the project team was vital to acceptance of the model by management.

An assessment of the structure and applications of production/ inventory models described in the available literature indicates that the development of an industrial dynamics model of the spares system could utilise many of the concepts and formulations which already exist.

4.1.4. Review of Industrial Dynamics in the Literature

Although the publication of Forresters basic texts (1958,1961) caused some controversy at the time, for example see Wagner's book review (1963), comprehensive reviews of the technique are rare. Much space in this section has been devoted to the critique by Ansoff and Slevin (March 1968 and May 1968). This paper presents a comprehensive review of the philosophy and methodology of industrial dynamics and can be considered the definitive criticism of the early period of development.

In the introduction to their paper Ansoff and Slevin state that the review sets out to be impartial and admit to no experience in the use of industrial dynamics. The paper can be judged, overall, as being critical of the technique but one gains the impression that much of the comment is motivated by the all-pervasive way in which Forrester contrasts the merits of his approach with the failure (as he sees it) of conventional management science practise.

The author's most important comments on industrial dynamics can be considered under three headings: structure and philosophy, quantification of system relationships, and problems of model validation.

Structure

All industrial dynamics models are formulated using Forrester's basic concepts, the rate and level, to describe the flow of various classes of entity through the system. By definition, representation of the flow of say, orders, in this manner involves the assumption that the movement of discrete entities can be properly modelled in a continuous fashion. The use of a discrete evaluation interval is merely a computational convenience and does not detract from the esentially continuous form of the model equations.

Further, in most instances the entities involved will be subjected to quite different delays than the average figures used in the model. The justification of this assumption is barely examined by Forrester and not questioned at all by Ansoff and Slevin.

Ansoff and Slevin also barely comment on the validity of the rate/level structure, merely pointing out the necessity for the assumption of incompressability in entity flow and the exclusive dependance of the rate (or decision) calculations on past history. Both comments are accepted by Forrester in his reply to Ansoff and Slevins paper (Forrester May '68).

Ansoff and Slevin are far more concerned with the feedback loop as the basis of system analysis in all situations:

> "...it does not necessarily follow that all aspects of the firm are best studied by means of information feedback systems".

> "This suggests that the appropriateness of the information feedback viewpoint should be determined on the basis of the relative influence of the feedback information on the decision in any given situation".

They further suggest that application to areas which are functionally well defined is likely to prove more successful and quote the results of the Sprague Electric Study as practical evidence of this conclusion.

Forrester responds by defining the generality of the feedback concept in all decisions, a point not specifically questioned by Ansoff and Slevin:

"Various critics have asked that the generality of feedback loop structure be proved. Such a request fails to recognise that this class of theory is not subject to positive proof...... If one can show an important and purposeful decision which is not embedded in a feedback loop structure the generality is destroyed"

but,nevertheless,fails to adequately refute the point made by Ansoff and Slevin.

It could be argued that the questionable success of the technique in the analysis of less well defined areas of an organisation reflects the difficulties in conceptualising the decision factors in such situations, even when using Forrester's technique. The problems of quantifying the relationships and validating the data and results also increases in such cicumstances.

The conclusion by Ansoff and Slevin that the order of appropriate application of the technique is ;

Production and distribution

Marketing

Research and development

and in general management;

Organisational design

Production and marketing strategy

can be said to stand if the criteria to be applied in the judgement is the ease with which the model can be formulated and validated.

Forrester points out that if the criteria is changed to reflect the importance of the results and insight gained the rank order proposed by Ansoff and Slevin would be completely reversed. The expansion of the technique to include models of cities and even the world may reflect Forrester's priorities. However, the spares problem is specifically confined to the production/distribution area and even controversial aspects of a company's operation, such as marketing strategy, are less relevant than in more conventional product retailing situations. This factor allows the boundary of a spares model to be drawn to exclude such controversial areas.

Quantification

Ansoff and Slevin question Forrester's requirement for the quantification of all the variables and relationships in a model, pointing out that there is no facility available for human intervention during the operation of the model. Whilst this requirement is common in all mathematically based simulation techniques it becomes particularly controversial when some of the areas to which industrial dynamics has been applied are considered. The need to express the variable "Pressure for expansion" in a firm on a scale from -5 to +5 units (Roberts 1964) seems somewhat curious and certainly arbitrary.

Forrester asserts that one of the practical advantages of the technique is the correspondence between the model variables and the real system which enables the fundamental relationships of the model to be readily grasped by the management of the company. This could hardly be said to apply to the above example.

The inclusion of such factors in the model does allow the sensitivity of the system to them to be established. If such a factor is established as critical, Forrester then argues that further scrutiny and validation of the associated relationships and parameters becomes essential. He does not, however, indicate precisely how this can be achieved.

Ansoff and Slevin suggest that the facilities offered by the special purpose compiler 'Dynamo' encourage the wide use of such factors. This suggestion implies considerable naivety on the part of the investigator and as Forrester points out:

> "It is hard to see how the inclusion of an explicit table function with it's stated input and output and a graph of its functional relationship can be more hidden than an alternative like omitting the relationships and making no mention of the omission".

As was pointed out in the discussion on the structure of the technique the criticisms voiced above have most validity in applications where functional relationships are not well defined. The spares production/distribution problem cannot be considered to be in that category.

Validation

The whole question of what constitutes validity in a simulation model is subject to considerable discussion (see Chapter 12) and controversy amongst management scientists. The output from a simulation program is often presented in a form analagous to that from the real system. The comprehensive nature of the reporting, for example stock movements, orders generated, back orders at weekly or monthly intervals, encourages comparison with real system data.

There is a tendency to focus on the comparison between model and system data and consider that validation can only be 'proved' by agreement between the two. Much of the literature concentrates on determining the best form of statistical test to be applied to evaluate the respective data streams.

Whilst agreement between historical system data and that generated by a model undoubtably increases confidence in the model, the only point that can be said to be proven is that the parameters in the model are capable of adjustment to produce the desired fit. There can be no absolute guarantee that the response of the model to experimental changes in its structure or parameter values would reflect the response of the real system when subjected to similar change.

Ansoff and Slevin appear to disapprove of the accent which Forrester places on the dynamic characteristics of the model's behaviour, such as intervals between peaks or the form of the transient response at the expense of examination of the correlation between model and system data streams. They also point out that Forrester is a little vague on the particular techniques to be used in examining the dynamic response of the model.

In his reply Forrester makes two points as a basis for his discussion of the subject.

> "First, a model cannot be expected to have absolute validity. A model is constructed for a purpose. It should be valid for that purpose but may be irrelevant or wrong for some other purpose."

and

> "A second essential point in clarifying a discussion of validity is to realise the impossibility of positive proof. The difficulty starts in selecting criteria of validity There is no absolute proof but only a degree of hope and confidence that a particular measure is pertinent in linking together the model, the real system and the purpose".

The industrial dynamics modelling technique is aimed primarily at reaching an understanding of the way in which the components of a system interact rather than creating a predictive tool. To this end Forrester places great emphasis on the structural validation of the model - the output from the model should be in the same class as that from the real system, but above all, it should have resulted from interactions between functions that have demonstrable correlation with those in the real system. Good correlation between model and system output data streams says little about the validity of such structural considerations. Even the increase in confidence it generates in the model builder could still be considered subjective, since it is based on a judgement of the relevance of the test and data streams selected to the purpose of the model, see Forresters consideration of the criteria for model validity (Chapter 13, pgs 126/7, 1961).

An overview of Forrester's approach to validation would be to state that, whilst he accepts that numerical validation can be useful, he asserts the importance of qualitative judgement in assessing the quality of the structure of the model (in terms of system boundaries, interacting variables, parameter values) and the correct nature of the model behaviour with respect to that of the real system (range of values of variables, periods of oscillation form of response to change etc).

The form of the spares system analysis problem is not one of a predictive nature, rather we are seeking better understanding of the mechanics of the operation and a judgement of which parts of the system would repay further work. The industrial dynamics process of parameter sensitivity analysis can be seen as being particularly valuable in this context. For example, how using normal methods would it be possible to determine the relative merits of two or more sub-projects designed to improve the performance of different parts of the system? A review of the mechanical handling methods in the warehouse, aimed at reducing the picking and packing delays, would clearly involve considerable expenditure in terms of personnel and financial resources, both of which could be considered to be of limited availability. Alternatively the resources could be directed at improving the performance of the central and/or distributors stock control systems. Industrial dynamics appeared to offer the opportunity to evaluate the likely impact of such projects on the performance of the total system. In fact, although the problem was conceived at the time in this format, a superior approach would be to allow the sensitivity tests of the model to identify those areas which could be considered critical in their impact on the system behaviour.

Further there was the prospect of the model identifying the mode and direction which improvements in sub-system behaviour could best take.

The hypothesis outlined at the end of the previous chapter describing the manner in which the trade cycle was seen to work through the system could be tested against model behaviour when subjected to similar excitation.

The results of several of the manufacturing industrial dynamics studies (e.g Fey 1962) also suggested the possibility that part, or all, of the oscillation in the spares division's performance could be self-generated. A model specific to the spares organisation could test such a possibility.

4.2 Model Development

4.2.1. Purpose

As was mentioned in the last section the purpose of developing an industrial dynamics model of the spares system was threefold:

i) To generate a deeper understanding of the mechanisms at work in the spares system both amongst the project team and company management.

ii) To highlight those areas which could be considered critical in improving the service or financial performance of the spares operation.

iii) To indicate the direction which detailed sub-system development should take and explore the sources of instability evident in the real system data.

It should be stressed that the model was not intended to be used as a forecasting tool, other than in the context of the points mentioned above.

4.2.2. Model Boundary.

The choice of the appropriate model boundary was established by examination of the literature (see section 4.1.4) as being critical to the utility of the model.

The spares market, at least for most capital equipment manufacturers, differs from that of other products in that little or no competition exists for the customer's business. A customer has no choice but to approach the original manufacturer or his agent to obtain replacement parts.

This leads to the conclusion that demand will, in the long term, always be equal to sales and that back orders can be assumed with no 'lost opportunity' costs.

The implication of the captive spares market is that the market forces implied by the activity of competitors and end customers can be ignored in the model.

None of the existing sources of supply of spares components were exclusive to the division. Indeed in most cases spares represented only a small proportion of their total demand. The study of the influence of policies controlling employment and aquisition of plant or spares supply could therefore be considered of limited value. The factory sector of the first model (see Chapter 5 for discussion of later developments) was therefore modelled purely in terms of material flow.

The boundaries of the model were defined as enclosing the production, warehousing, and distribution functions and specifically excluded the operation of the market.

4.2.3. Model Equations

Each variable, parameter and relationship in the model was carefully considered in relation to the operation of the real system. The information culled from extensive discussion with company management and visits to the six largest UK distributors was compared with the data gathered during the historical analysis phase of the project.

The production/inventory/distribution model described by Forrester in his book "Industrial Dynamics" (1961) was used as the basis of the spares model. The literature survey had shown that all the manufacturing applications models had used the same concepts to represent the inventory and distribution sectors. Forrester's model included the activity of retailers, as well as the warehouse and distributors. The extra retailer distribution level was clearly redundant in the spares model.

Forrester describes his model in considerable detail in Chapter 2 of his book "Industrial Dynamics" (1961) giving each equation and the rational behind its development. The similarity between the two models makes a detailed description of the spares model redundant in this text. An overview of the model is given below and deviations from the Forrester model are discussed, in detail, in the next section.

The flow diagram of the basic spares model is given in Figure 4.6 and a summary list of the equations provided in Appendix 3.

Given the boundaries of the model, the only exogenous influence on the system is the input of customers orders to the distributors. These orders are received into a pool of unfilled orders (a level) and after a suitable delay are satisfied from the distributors'

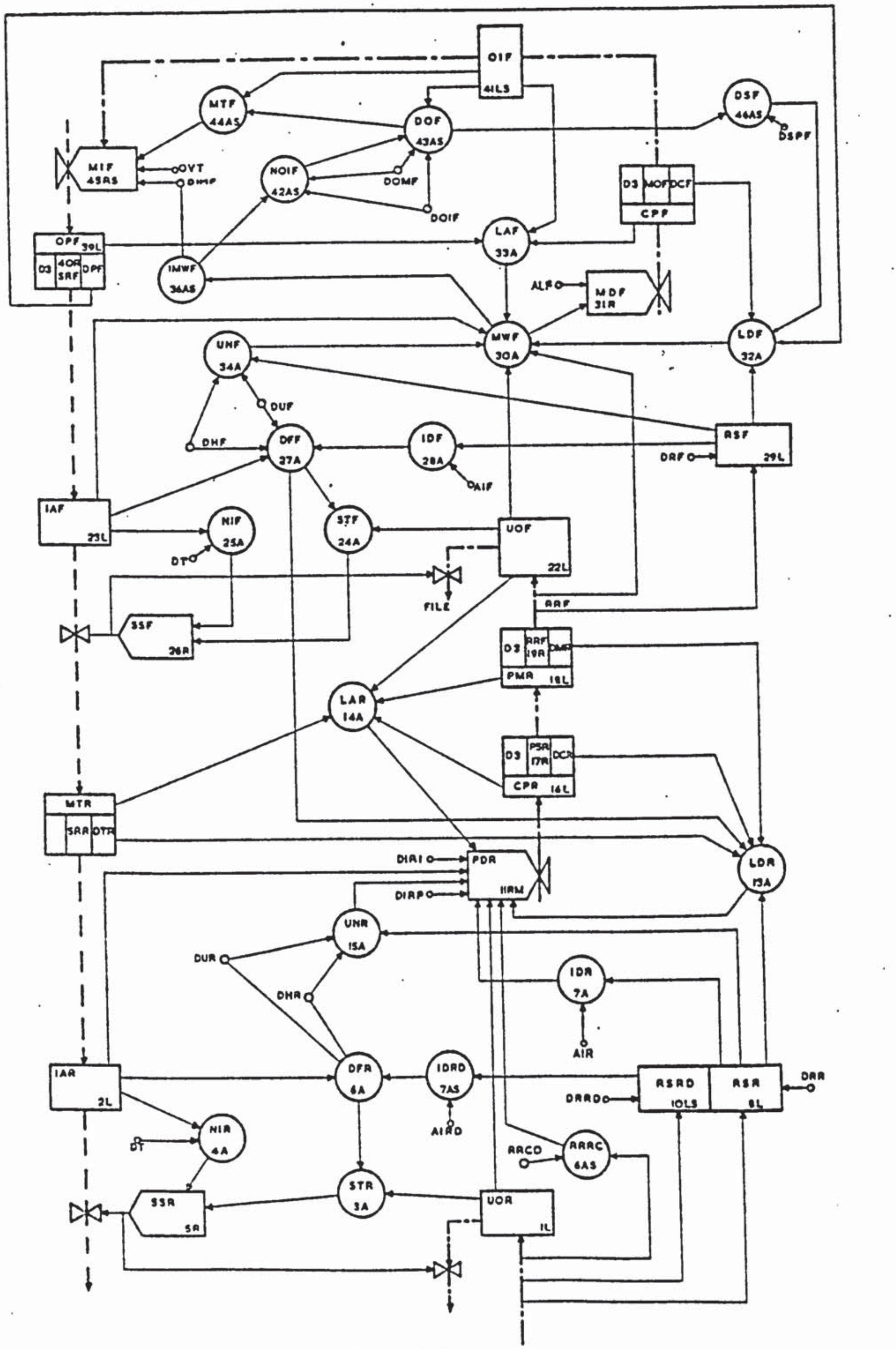


Figure 4.6 Flow Diagram of Basic Model

inventory. The distributors generate orders on the factory warehouse in proportion to the customer demand, and deficits between target and actual levels of stock, unfilled customer orders, and outstanding orders on the warehouse.

The warehouse orders are subjected to clerical and mailing delays before being received into the unfilled order pool at the warehouse. After a suitable delay material is shipped from the warehouse and received into stock at the distributors after a delay representing the period in transit.

The delays at the distributors and warehouse in fulfilling orders are composed of two elements. The first represents the time to process the order and pick, pack and despatch the goods whilst the second reflects additional delays introduced by a component being out of stock. As the ratio of actual to target stock decreases the larger the second element of the delay becomes.

The production sector of the model is quite different to that of the Forrester model. Factory orders are generated in the warehouse in a manner analagous to that at the distributors, by consideration of demand and deficits in stocks, work in progress and unfilled orders. After a clerical delay factory orders join an awaiting issue pool. The issue rate from the pool is dependant on the factory capacity at that time and an issue delay. The issue delay rises as work in progress levels increase and factory capacity is slowly increased or decreased to correspond with factory order intake trends.

Following issue the material is subjected to a third order delay representing processing time, and shipped directly to the warehouse inventory.

4.2.4 Model Development - Deviations from Forrester

4.2.4.1 Retail Sector (Distributors)

The principle of an 'ideal inventory' is applied by Forrester to two distinct areas of the distributors operation :-

i) In determining the shipping rate from the distributors to the customer and thus the service offered via calculation of the delay in fulfilling orders.

ii) In establishing one function of the distributors ordering decision. This function represents the distributors perceived deviation from his target stock level (represented by IDR.)

It can be argued that whilst the actual service offered by the system will react rapidly to a change in the trend of order intake, the response of the ordering system will not. The response to such a change in the Forrester model is determined partially by the value of the smoothing delay (DRR) acting on the intake rate to calculate the 'ideal' level of inventory.

The use of the same delay to control two such separate functions is especially difficult to justify in the distribution sector where our experience indicated that most systems were based on fixed targets, reviewed only occasionally.

The two functions are therefore separated in the model. Two smoothed versions of the order intake RSR and RSRD (Equations 8L and 10L) are generated, using delays DRR and DRRD, and used to calculate IDR and IDRD respectively (Equations 7A and 9A). IDR is utilised in the ordering calculation to yield PDR (Equation 11R) and IDRD to modify the shipping delay DFR (Equation 6A).

Using different values for the two controlling delays (or smoothing constants) enables the effects of the response of each function on the total system to be explored separately.

Forresters distributor ordering calculation which generates PDR (Purchasing Decision Rate) has two distinct components:

i) The replacement of all goods sold in the preceding interval (= RRR)

ii) A term to correct for deviations between desired (or normal) and actual levels of items in stock, orders in the pipeline, and unfulfilled orders. This term is modified by a delay (DIR) to represent the rate at which distributors act to correct such deficits. A value of DIR = 4 weeks would equate to a rate of correction of 1/4 the net deficit per week.

This form of the equation makes two assumptions. Firstly, that the whole of the sales made in one time increment are carried forward in their entirety, with no delay, to the order rate in the next period. Conversely it ignores the possibility that the distributors ordering mechanism could disregard the direct order intake and derive the order rate only from the resultant stock deficit.

Secondly the use of a single delay assumes that the distributor's response in correcting the deficits is identical for each of the terms. This is equivalent to stating that he will take action to correct a stock deficit at the same rate as he would adjust for excessive over-ordering.

The form of the basic equation was therefore modified by the introduction of two delays which separately control the response to stock and unfilled order deficits (via DIRI) and over/under ordering (DIRP). In addition the order intake is fed via a filter equation which allows the proportion of the direct sales (RRR) incorporated in the ordering decision to be adjusted from 0 to 100%

Warehouse Sector

No deviation from the Forrester equations was felt to be needed or justified in the warehouse sector. This might appear curious given the apparent similarity between the functions of the warehouse and distributors and the extent of the changes introduced in the latter sector.

The ordering routines at the warehouse are well defined and, unlike the distributors, of a mechanistic nature. The computerised routines generate orders in a manner (Section 2.4 refers) which can be considered to be analagous to that represented by the basic Forrester equations.

Factory Sector

It is in this area that it was felt most necessary to modify the structure of Forresters model.

In the original the activities of the supply source were represented by a simple structure of a limited rate and two third order delays. In his description of this part of the model Forrester recognises the limitations of this simple approach and later in his book describes an extension of the model to include (amongst other factors) the influence of employment policies on the system. The extended version is considerably more complicated and ventures into such nebulous areas as the labour market which are clearly outside the boundaries of the spares system.

It was felt that the most unrealistic assumption in the simple model was the constant nature of the production and clerical delays (DPF and DCF) and the absence of any levels to provide a compressible characteristic in the system. It was manifestly evident both from experience and the historical data that lead times vary and that levels of work in progress fluctuate.

Clearly the capacity of a production unit does change in response to long term trends in demand. Plant is purchased, additional operatives are hired and trained in times of increasing demand and conversely capacity is trimmed as the work load falls.

In the short term an increase in demand will lead, in most production/ distribution systems, to a backlog of orders in paper and material form appearing inside the manufacturing sector.

Given that the purpose of the model was primarily to study the performance of the system under conditions of fluctuating demand it was felt that the structure of the factory sector of the model should be able to mirror the effects described above. This implied firstly that the production available should react, albeit slowly, to changes in order levels and secondly that a queueing element should be introduced in the order path through the factory.

The original manufacturing decision equations are retained (MWF - 33A, and MDF - 35R) although the maximum limit on the issued rate used by Forrester in the calculation of MDF was later dispensed with. As in the original version the manufacturing rate wanted from the factory is first subjected to a clerical delay, represented by the third order delay based on the constant DCF.

From this point manufacturing orders pass into a queue awaiting issue represented by the level OIF. They are removed from OIF under the control of the rate MIF (Material Issue Rate) and then subjected to a second third order delay representing the machining process controlled by DPF.

The level OIF and its associated delay DOF may be considered as representing all the queueing activity in the process (including that on the shop floor) whilst the second third order delay DPF equates to the machining or process delays.

The form of the OIF equation is the standard one for a level (see Equation 37L). The calculation of the issue rate, MIF, involves several other new variables. In much the same way as issues from stock are calculated in the warehouse sector, a manufacturing issue rate to be tried (MTF) is determined from the instantaneous values of OIF and its associated delay DOF -

Material issues to be Tried at Factory

MTF.kl = OIF.k/DOF.k.

The calculation of the delay DOF is dependant on two components, DOMF the minimum handling delay (constant) and DOIF the queueing delay which is modified by the ratio of actual (OIF) to normal (NOIF) levels of orders awaiting issue:-

Delay in Order issue at Factory

DOF.k = DOMF + DOIF (OIF.k/NOIF.k)

The normal level of orders awaiting issue, NOIF is made a function of the factory capacity at that moment (known as the Ideal Manufacturing Wanted at the Factory) IMWF:

NOrmal level of orders awaiting Issue at the Factory

NOIF.k = (DOIF + DOMF) IMWF.k

The current factory capacity (IMWF) is calculated as a smoothed version of the historical desired manufacturing rate (MWF):

Ideal Manufacturing rate Wanted at the Factory

IMWF.kl = IMWF.jk + DT/DIMF (MWF.kl-IMWFjk)

The delay constant DIMF therefore controls the rapidity with which the factory capacity is adjusted to suit a changing demand trend.

Finally, to arrive at the actual material issue rate at the factory (MIF), the rate to be tried (MTF) is compared to the current capacity (IMWF) and the lesser of the two selected. Thus:

MIF.kl = MTF.kl

if MTF.kl < OVT X IMWF.kl

or

MIF.kl = OVTxIMWF.kl

if MTF.kl > OVT X IMWF.kl

The constant OVT allows the factory capacity to be increased to represent the effect of overtime being worked at short notice, i.e. it assumes that, if required, the order issue rate can exceed the basic capacity of the factory by a small amount (e.g. 10%).

The remaining adjustments to the Forrester model reflect the need to include the effects of the new structure on the calculation of the level of the desired and actual orders in the pipeline (LDF and LAF).

The effects of the changes are to allow the factory capacity (and therefore the maximum issue rate of orders to the factory) to follow the long term demand trend and to make the manufacturing lead time (DPF + DOF + DCF) a variable dependant on the size of order backlog present in the factory.

4.2.5. Programming Considerations

Although much has been made in the literature of the benefits and influence of the 'Dynamo' special purpose compiler (Ansoff and Slevin,1968a; Forrester,1961; Schlager,1964; Coyle,1977) its use is in no way essential to the formulation and evaluation of an industrial dynamics model. 'Dynamo' accepts the model equations directly in the Forrester notation and also provides some useful utilities, such as a lineprinter plotting routine and standard delay functions.

The use of this compiler would have been convenient but it was not available on any computer accessible from Aston. The prospect of running the model on the company's ICL computer also influenced the decision to use ICL 1900 Extended Fortran IV as the programming language of the model.

Fortran allows the basic form of the model equations and variable names to be retained and the use of variable arrays enables subscripting to be introduced.

The full text of the program is given in appendix 4. During development of the program it was found that by careful ordering of the equations the necessity for subscripted arrays could be eliminated and the core occupied by the program was greatly reduced.

More recent developments in the power of mini and micro-computers and their wider availability would make their use a practical proposition today. The use of Basic as an alternative to Fortran is entirely practicable and the dedicated nature of the machines offsets their lower speed of computation.

4.2.6 Determination of Parameter Values

Each of the parameters will be discussed in turn and their standard value given. The significance of these initial estimates is considered in section 4.3 which describes the sensitivity analysis performed on the model.

4.2.6.1. Distributors

The values assigned to parameters in this area were intended to represent a composite view of all the individual distributors procedures. The information used for the assessments was based on the analysis of detailed demand and order pattern data for a restricted range of components culled from the records of seven UK and four overseas distributors. In addition six U.K. distributors were visited who between them accounted for 28% of the total U.K. spares business. During these visits the stock recording and ordering procedures were inspected and senior and junior management of the companies interviewed. The parameters to be considered in this sector of the model are:-

DHR

Delay in Handling orders at retail = 0.0 weeks

Most of the distributors business is conducted across the spares counter involving no appreciable delay.

DUR

Delay due to Unfilled orders at Retail = 0.6 weeks

This figure is derived from an assumed distributor service level of 90% for the complete range of 12000 parts. A study of 160 parts at two distributors (Evans 1978) revealed service levels in excess of 95% for stocked items but distributors rarely stocked more than 25% of the total range.

A service level of 90% implies that the remaining 10% of orders will be subjected to the warehouse lead time delays specified in section 3.3.2.2. The effects of these delays expressed across the whole range results in an average delay of 0.6 weeks.

DRR

Delay in smoothing Requisions at retail = 10 weeks.

This delay controls the 'average' demand figure used to calculate the target levels of stock, unfilled orders, and outstanding warehouses orders in the ordering decision. Distributors generally estimated demand trends by consideration of the last two or three months sales. This process was usually of an intuitive rather than mathematical nature. A value of ten weeks was considered to reasonably reflect this practice.

DRRD

Delay in smoothing Requisitions at Retail, = 3.33 weeks.

This delay controls the calculation of the target level of inventory in relation to the service offered from the distributor. It was considered that the response to changes in order intake would be more rapid in this area than in the odering decision. The delay was therefore set at 1/3 the value of DRR.

DIRI

Delay in Inventory and unfilled order adjustment at Retail = 4 weeks.

Although bulk orders may be raised by distributors twice in any month each order will cover only part of their range of stocked items. Review of the complete range takes approximately two months, giving an average delay of 4 weeks.

DIRP

Delay in Inventory adjustment at Retail for Pipeline orders = 8 weeks.

A distributor will not normally detect a change in warehouse lead times until at least two delivery delays have elapsed. Correction of any resulting deficit will take a further two months, giving an average response time of 8 weeks.

<u>DCR</u>

Delay in Clerical processing of orders at Retail = 1 week

Discussion with distributors showed that the time taken to perform a review was approximately one week.

<u>DMR</u>

Delay in order Mailing from Retail = 0.6 weeks

Three days was considered to adequately reflect the combined effect of mailing delays for the different classes of U.K. and Export orders.

<u>DTR</u>

Delay in Transporting material to Retail = 2 weeks

This figure includes an allowance for packing and awaiting transport as well as for the actual movement between the warehouse and the distributor.

4.2.6.2. Warehouse Sector

Data used in setting parameter values for this part of the model were more plentiful and all the relevant members of the management team were available for detailed discussion. The computerised nature of the stock control system allowed more confident estimates of the order intake smoothing delay (DRF) and review period delay (DIF) to be established.

DHF

Delay in Handling orders at the Factory = 2.9 weeks

The analysis of order processing times (see section 3.3.2.) indicated that the clerical and picking delays totalled an average of 2.9 weeks during the period studied.

DUF

Delay due to Unfilled orders at the Factory warehouse = 2.8 weeks

This represents that part of the warehouse lead time introduced by items being out of stock.

The warehouse first pick performance averaged 82.6% over the period 1973-1977, indicating that 17.4% of ordered parts had to await material from the supply sources. As 50% of the spares range has monthly usages less than one, it is reasonable to suppose that for most shortaged items a full supply lead time would elapse before the order could be fulfilled. Given a ratio of bought out, to manufactured, to assembled items of 64/26/10 a composite average lead time can be calculated from the individual source lead time performances. (see section 3.3). The average composite lead time is 16.3 weeks and thus the overall delay can be calculated at 2.8 weeks.

DRF

Delay in smoothing Requisitions at the Factory = 24.5 weeks

The model uses an exponential form smoothing equation whereas the real system uses a 12 month moving average. A figure of 24.5 weeks represents the nearest approximation, for an exponential method to a 12 month moving average.

DIF

Delay in Inventory adjustment at the Factory warehouse = 1.6 weeks

The review periods differ for bought out and production sourced components being weekly and monthly, respectively. Weighting these average delays (0.5 and 2 weeks) in proportion to turnover (1 : 2, bought-out : production) results in an overall delay of 1.6 weeks, including an allowance for clerical delays of one day.

AIF

Constant between Inventory and average sales at the Factory = 20 weeks.

For a typical mix of orders, the warehouse target stock level averages out at about 3 months.

The actual stock levels vary, depending on the level of activity, between 3 and 8 months. (See Section 3.3). and averaged 5.13 months.

The discrepancy between the target and actual levels can be partially explained by over delivery by the factory and policy intervention ordering by the stock controller. As neither of these factors are incorporated in the model the target objective was set at approximately the average stock holding of 5 months.

DCF

Delay in Clerical processing at the Factory = 1 week.

This period is the time between the computer raising a factory order and material being made available to the shop floor, or supplier.

4.2.6.3 Factory Sector

DOMF

Delay in Order issue, minimum, at the Factory = 0.2 weeks

This delay represents the minimum time an order would spend queueing in the factory. The estimate of one day was derived from consideration of the factory 'crash' production procedures.

DPF

Delay in Processing orders at the Factory = 4 weeks

An analysis of setting and machining times for sixteen of the most popular manufactured items gave an average total process time per batch of 4.8 weeks. Sub-contract process times are likely to be of the same order, but some bought out material, being available ex stock, would be subject to much shorter delays. A composite value of one month was therefore chosen as being representative of all sources.

DOIF

Delay in Order Issue at the Factory = 11.1 weeks

Discounting the values of DCF, DPF and DOIF (total 5.2 weeks) from the overall average lead time of 16.3 weeks gives a value of 11.1 weeks for this delay.

DIMF

Delay controlling Ideal manufacturing rate at the Factory = 50 weeks

Adjustment of factory capacity to changes in the level of order intake takes several forms. In the short term overtime working may be authorised and the supply from existing sub-contractors increased. Long term adjustment involves the acquisition/disposal of plant, major changes in employment levels, and acquisition of new sub contractors. The short term effects are represented by the overload constant OVT described below.

It is considered by company management that the process of bringing a new subcontractor on stream takes approximately 16 weeks. To this value must be added the sub-contractors manufacturing lead time giving an overall delay of approximately 5-6 months. Acquisition of plant is likely to involve delays of up to 1 or 2 years before the new plant realises its full capacity. The hiring and training of substantial numbers of new employees is likely to take at least 6 months.

The value of 50 weeks used here is an estimate of the combined effect of such actions.

<u>OVT</u>

Overtime overload constant controlling short term factory capacity = 1.2

It was estimated that the maximum increase in capacity which would result from short term action such as overtime working would be unlikely to exceed 20%

DSPF

DSPF = Delay in Smoothing issue delay to feed pipeline calculation = 24.0 weeks.

This delay controls the smoothing of the actual issue delay to provide an average value for use in the calculation desired work in progress levels. This parameter controls the rate at which changes in the performance of the source of supply are reflected by adjustment of the work in progress policy targets used in the ordering decision. The production control system float and lead time parameters are reviewed very infrequently and thus a large value of 24 weeks was chosen for the smoothing delay.

4.2.6.4. General Comment

Two major problems beset the process of establishing parameter values.

In many instances the data histories available were too short. This was particularly true of distributors, some of whom carried records only for the previous years transactions.

Where data were available the second problem frequently arose, that of correspondence between the model parameter and any in the real system.

It was particularly difficult to derive and justify values for gross flow delays from data tied to individual or groups of components. For example, whereas the company's spares stock control system sets different target stock levels for each of five value classes of components, a single estimate had to be derived for use in the model (AIF = 20 weeks)

In a few extreme cases no real correspondence exists between the concept in the model and any measure of the real system. This was especially true of the factory lead time parameters, only by substitution of other parameter values was the queueing element (DOIF) derived from the overall factory lead times.

Much of the Forrester modelling involves the concept of 'normal' or 'ideal' levels at which the values of controlling delays can be defined. When considering actual data it is difficult to establish at what times the stock or work in progress levels are in an 'ideal' state, and thus what values of the attendant delays should be taken. The factory lead time was established by taking the mid-point between the maximum and minimum average lead times that corresponded to periods of high and low activity. It was a reasonable, but not rigorous, assumption that the mid-point between high and low levels of activity represented the 'normal' or 'ideal' state.

4.2.7. Input to the Model

As was indicated above (section 4.2.3.) the only exogenous influence on the model was the intake of customers orders at the distributors. In general such an input can either be generated artificially inside the computer program, or use can be made of historical data from the real system. The latter option was not available as the distributors records could not provide data covering a sufficient period of time. Even if comprehensive records had existed the model required the input in a gross form. Given the number of export outlets and the size of the component range, deriving gross totals from individual component sales records would not have been practicable.

It was therefore decided to follow normal industrial dynamics practice and arrange the following kinds of time series to be generated by the program:

- Step increase/decrease
- Ramp increase/decrase
- Random fluctuation about a mean
- Sine wave
- Steady state

The programming allowed composite inputs to be generated, e.g. Sine wave and Noise, and the amplitude and timing of the fluctuations to be controlled.

4.2.8 Model Validity

The tests used to establish confidence in the validity of this model are described and discussed in Chapter 12, which is devoted to consideration of the validity of all the models developed during the project.

4.3 Sensitivity Analysis

4.3.1 Introduction to the Experiment

The purpose of the development of an industrial dynamics model was defined in Section 4.2.1. as being threefold:

i) To improve understanding of the mechanisms at work in the spares system.

ii) To highlight the critical aspects of the system.

iii) To guide future sub-system development.

The sensitivity analysis was aimed primarily at the second of these, although it could also be expected to yield some information relevant to the other criteria.

The experiment proceeds by varying all the parameters of the model one at a time, between extreme values and recording the effects of such changes on the total system behaviour. If changes in the value of a particular parameter elicits a significant response in the models behaviour then that parameter can be considered as critical or sensitive.

Identification of critical parameters in the model instantly highlights areas of the operation which can be considered worthy of further investigation. At this stage the significance of the results lies less in the form of the response to a parameter value change than in its presence.

4.3.2. Background Considerations

4.3.2.1. Run length and Input Characteristics

This type of experiment is likely to be relatively expensive in computer time - varying each parameter in the model over three values results in a need for over 70 individual model runs for each input form. Clearly the length of the simulated timespan of each run directly affects the amount of computation and thus computer time required.

Thus before performing the sensitivity experiments it was necessary to investigate the effect of the simulated timespan, or run length on the reliability of the results.

The spares model was designed to allow a variety of characteristics to be generated in the single exogenous model input customer - demand at distributors. Step noise and sine wave forms, or combinations of these, could be generated at will.

The step input yields information about the basic response of the system - degree of damping or stability, natural frequencies of oscillation and the degree of amplification present are all indicated.

The systems ability to damp out high frequency variation in demand is tested by noise inputs which can also be expected to highlight the effects of the natural frequencies of oscillation on the systems performance. The sine wave input, analogous to the trade cycle variation in demand, evident in the real system data, tests the systems ability to cope with longer term fluctuation in demand trends.

The choice of an appropriate run length is dependant on the form of the input being used in the experiment.

The standard model's response to a 10% step increase in week 4 of the run is shown, graphically, in Figure 4.7. The diagram illustrates that the response of the majority of the key variables is contained within the first 50 weeks of the run. The choice of a run length much greater than 50 weeks would cause the means and standard deviations of the key variables to be depressed, and information lost.

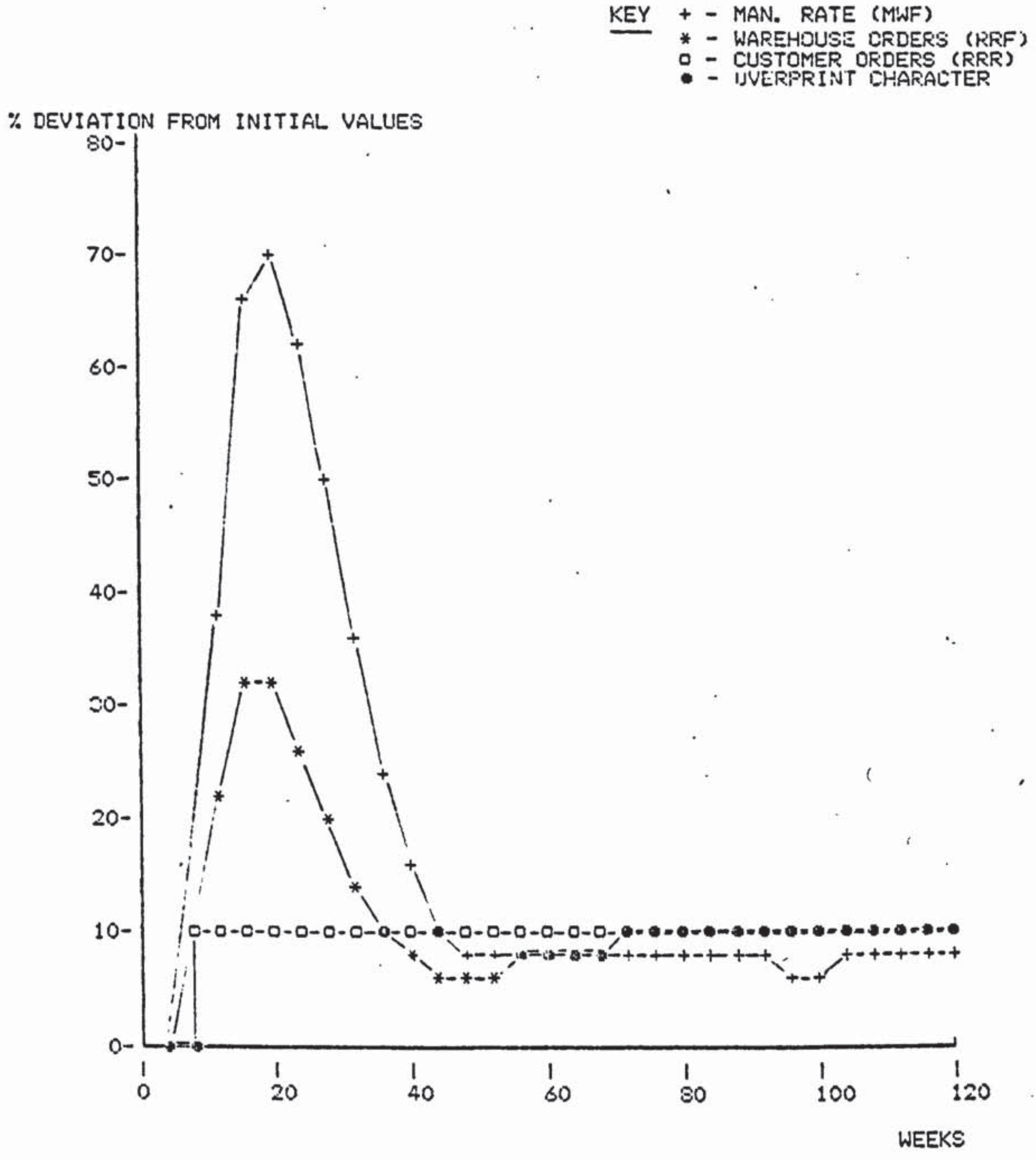


Figure 4.7 RESPONSE OF THE BASIC SPARES MODEL TO A 10% STEP INPUT

	IN	VAL	UOF MN	UOF SD	IAF MN	IAF SD	SRF MN	SRF SD	MUF MN	MUF SD	SSF MN	SSF SD	RATIO VALUES
1	29	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0=STD VAL
2	5	2.0	1.0	7.1	1.0	8.6	1.0	11.5	1.0	4.7	1.0	5.4	16.0=STD VAL
3	5	8.0	1.0	1.2	1.0	1.6	1.0	2.0	1.0	1.0	1.0	1.1	16.0=STD VAL
4	5	32.0	1.0	1.6	1.0	1.5	1.0	1.8	1.0	1.5	1.0	1.6	16.0=STD VAL
5	6	2.0	1.0	1.3	1.0	1.6	1.0	1.8	1.0	1.2	1.0	1.3	16.0=STD VAL
6	6	8.0	1.0	1.1	1.0	1.2	1.0	1.3	1.0	1.1	1.0	1.1	16.0=STD VAL
7	6	32.0	1.0	1.3	1.0	1.7	1.0	2.0	1.0	1.1	1.0	1.2	16.0=STD VAL
8	8	5.0	1.0	1.3	1.0	1.1	1.0	1.3	1.0	1.4	1.0	1.4	10.0=STD VAL
9	8	20.0	1.0	0.8	1.0	0.9	1.0	0.8	1.0	0.8	1.0	0.7	10.0=STD VAL
10	8	50.0	1.0	0.6	1.0	0.9	1.0	0.8	1.0	0.6	1.0	0.6	10.0=STD VAL
11	9	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.3=STD VAL
12	9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.3=STD VAL
13	9	5.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	3.3=STD VAL
14	10	0.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0=STD VAL
15	10	0.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0=STD VAL
16	10	2.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.0=STD VAL
17	11	0.1	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	0.6=STD VAL
18	11	0.3	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	0.6=STD VAL
19	11	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.6=STD VAL
20	12	2.0	1.0	2.4	1.0	1.6	1.0	2.2	1.0	2.4	1.0	2.5	4.0=STD VAL
21	12	8.0	1.0	0.6	1.0	0.9	1.0	0.8	1.0	0.6	1.0	0.6	4.0=STD VAL
22	13	1.0	1.0	0.5	1.0	0.8	1.0	0.7	1.0	0.6	1.0	0.4	8.0=STD VAL
23	13	4.0	1.0	0.8	1.0	0.9	1.0	0.8	1.0	0.5	1.0	0.5	8.0=STD VAL
24	13	16.0	1.0	1.3	1.0	1.1	1.0	1.3	1.0	1.2	1.0	1.3	8.0=STD VAL
25	14	0.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0=STD VAL
26	14	0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0=STD VAL
27	14	2.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0	0.9	1.0	1.0	1.0=STD VAL
28	15	0.3	1.0	0.9	1.0	1.0	1.0	1.0	1.0	0.7	1.0	0.9	2.0=STD VAL
29	15	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	2.0=STD VAL
30	15	4.0	1.0	1.1	1.0	1.1	1.0	1.2	1.0	1.0	1.0	1.1	2.0=STD VAL
31	16	0.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.6=STD VAL
32	16	1.2	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	0.6=STD VAL
33	17	6.5	1.0	1.4	1.0	0.8	1.0	2.2	1.0	2.3	1.0	1.0	24.5=STD VAL
34	17	12.5	1.0	1.1	1.0	0.9	1.0	1.5	1.0	1.5	1.0	0.9	24.5=STD VAL
35	17	49.0	1.0	0.9	1.0	1.1	1.0	0.8	1.0	0.7	1.0	1.1	24.5=STD VAL
36	18	2.0	1.0	1.5	0.1	0.5	1.0	1.0	1.0	0.7	1.0	0.6	20.0=STD VAL
37	18	10.0	1.0	1.0	0.5	0.8	1.0	0.3	1.0	0.8	1.0	0.9	20.0=STD VAL
38	18	40.0	1.0	1.0	2.0	1.3	1.0	1.5	1.0	1.3	1.0	1.1	20.0=STD VAL
39	19	0.1	0.5	0.6	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.5	2.8=STD VAL
40	19	1.4	0.8	0.8	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.2	2.8=STD VAL
41	19	5.6	1.5	1.3	1.0	0.8	1.0	1.2	1.0	1.0	1.0	0.7	2.8=STD VAL
42	20	0.3	0.5	0.7	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.2	2.9=STD VAL
43	20	1.5	0.8	0.9	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.1	2.9=STD VAL
44	20	6.0	1.5	1.2	1.0	0.9	1.0	1.2	1.0	1.0	1.0	0.8	2.9=STD VAL
45	21	1.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	1.6=STD VAL
46	21	3.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.6=STD VAL
47	21	12.0	1.0	1.0	1.0	1.2	1.0	0.8	1.0	0.6	1.0	1.0	1.6=STD VAL
48	22	120.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	999.0=STD VAL
49	23	0.5	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	1.0=STD VAL
50	23	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0=STD VAL
51	23	10.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0=STD VAL
52	24	12.0	1.0	1.1	1.0	0.2	1.0	3.3	1.0	1.0	1.0	1.1	50.0=STD VAL
53	24	25.0	1.0	1.0	1.0	0.9	1.0	1.8	1.0	1.0	1.0	1.0	50.0=STD VAL
54	24	100.0	1.0	1.0	1.0	1.4	1.0	0.8	1.0	1.0	1.0	1.0	50.0=STD VAL
55	25	2.0	1.0	1.0	1.0	0.9	1.0	1.2	1.0	1.0	1.0	1.0	4.0=STD VAL
56	25	8.0	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0	1.0	4.0=STD VAL
57	25	20.0	1.0	1.0	1.0	1.3	1.0	0.8	1.0	1.2	1.0	1.0	4.0=STD VAL
58	26	1.3	1.0	1.0	1.0	1.0	1.0	1.3	1.0	1.0	1.0	1.0	0.2=STD VAL
59	26	5.0	1.0	1.0	1.0	0.9	1.0	1.7	1.0	1.1	1.0	1.0	0.2=STD VAL
60	26	10.0	1.0	1.0	1.0	0.9	1.0	1.8	1.0	1.2	1.0	1.0	0.2=STD VAL
61	27	5.5	1.0	1.0	1.0	1.0	1.0	1.2	1.0	0.9	1.0	1.0	11.1=STD VAL
62	27	22.0	1.0	1.0	1.0	0.9	1.0	1.2	1.0	1.2	1.0	1.0	11.1=STD VAL
63	27	50.0	1.0	1.0	1.0	0.8	1.0	1.5	1.0	1.7	1.0	1.0	11.1=STD VAL
64	28	12.0	1.0	1.0	1.0	1.0	1.0	1.2	1.0	1.0	1.0	1.0	24.0=STD VAL
65	28	48.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	24.0=STD VAL
66	28	96.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	24.0=STD VAL
67	38	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2=STD VAL
68	38	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.2=STD VAL
69	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0=STD VAL

Figure 4.10. Example of Analysis Program Output.

A series of runs were performed to determine the appropriate runlength for the noise input sensitivity analysis. Ten different values of runlength were selected, ranging from 5 to 400 weeks, and for each runlength ten runs were performed with different random number seeds.

The mean values were extracted for several key variables from each run and grouped into batches; one for each of the various runlengths tested. The batch means were then derived and the deviation calculated of each of these from the ultimate value achieved by the 400 week runs. The absolute deviations of each runlength mean for desired manufacturing rate (MWF), factory unfilled orders, (UOR), are shown plotted against runlength in Figure 4.8. Inspection of the figure shows that all the variables had stabilised by 200 weeks and, with the exception of MWF, very low deviations (less than 0.5%) were displayed for all runlengths over 25 weeks. Given the significance of the desired manufacturing rate it was decided that the behaviour of this variable should be the determining factor in the selection of an appropriate runlength. Accordingly, a runlength of 200 weeks was chosen for all the noise sensitivity analysis runs.

The use of a cyclical input, such as a sine wave, introduces phasing problems in the interpretation of results. If the response of all the model variables was exactly in phase with the input fluctuation, then runlengths could be chosen as multiples of the period of the input sine wave. Some phase differences are, however, evident in the models response, and moreover the phasing varies with the values chosen for critical parameters.

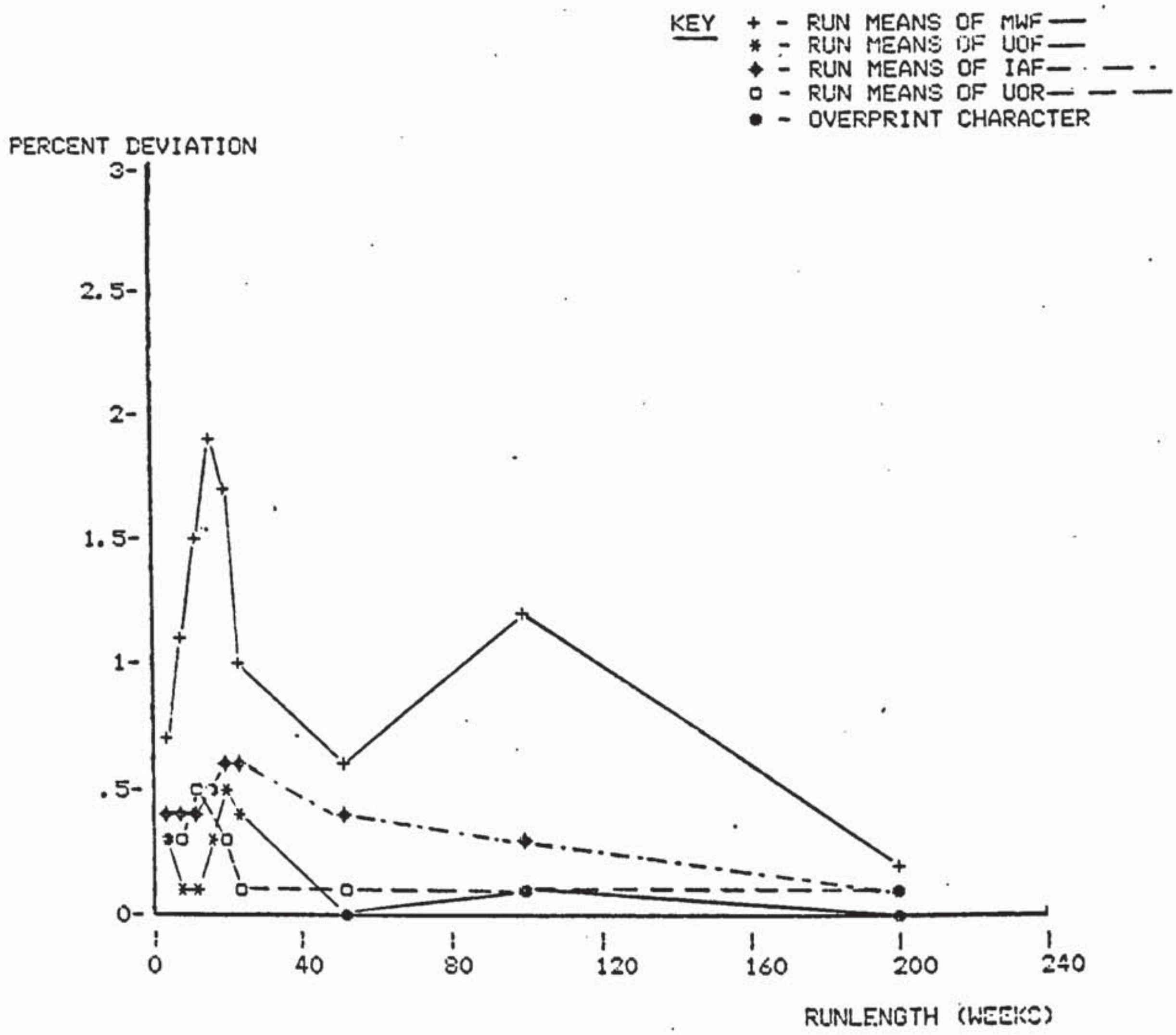


Figure 4.8 <u>RUN LENGTH TESTS - DEVIATION FROM THE RESULTS FOR A 400 WEEK RUN</u>

In such circumstances an error could result from comparison of the means and standard deviations of the measured variable with those from the 'standard parameter' model. Figure 4.9 demonstrates the risk of measuring results over a single cycle. Two responses, for the same variable, are shown, one from a 'standard parameter' run and the other after the value of a phase sensitive parameter has been changed. Although, phase differences apart, both responses are identical the means and standard deviations would be different.

It can, of course, be argued that the presence of such a difference is always significant as an indication of phase <u>or</u> amplitude sensitivity. The potential error lies in mistaking one cause for the other. In sensitivity analysis the prime concern is to establish a significant difference, whatever the cause, and short runlengths remain legitimate providing no conclusions are drawn regarding the type of response. In such circumstances a smaller mean level of unfilled orders, for example, would not necessarily indicate the presence of consistently better service.

In order to limit computing costs the sine wave sensitivity runs were restricted to 220 weeks, or one input cycle. Later work which investigated the response of critical factory parameters in more detail, utilised much longer runlengths (See Chapter 5 for further discussion of this point).

4.3.2.2. Measurement and Evaluation of the Results

In order to simplify the analysis of results the model program calculates the means and standard deviations of all the variables for each individual run. Used carefully, this facility greatly eases

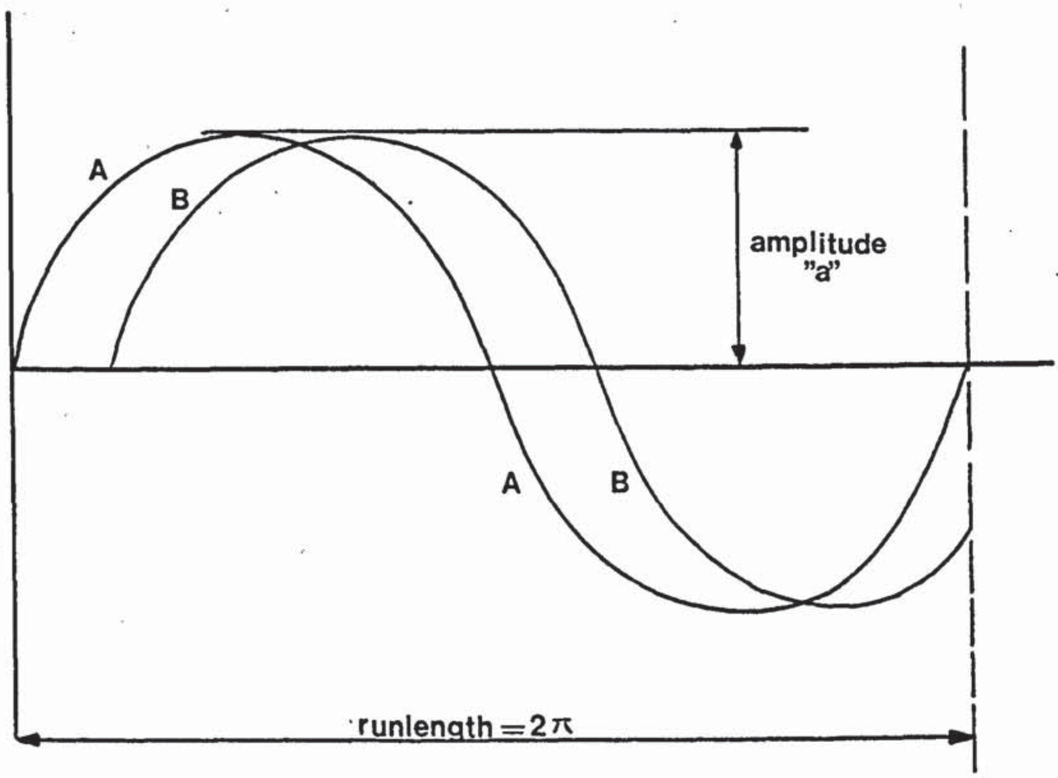


Figure 4.9 Effect of Phasing on the Reliability of Means and Standard Deviations as Measures of System Response.

the analysis of the considerable amount of data generated by the sensitivity experiments.

Whilst the detailed form of the model response to a particular parameter value change may be of general interest, the sensitivity analysis is primarily concerned with its' relative significance. Detail analysis of the model response to changes in values of the critical parameters was a subsequent task. The use of the variable means to reflect overall levels and the standard deviations to indicate the degree of variability present was therefore considered adequate for the prime purpose of the experiment.

The program outputs the means and standard deviations of all model variables after each run (there is one run per parameter change) to a holding file. This is later read by a second program which summarises the results for key variables. In addition to printing the actual means and standard deviations for each parameter change the program also calculates the ratio:

$$\frac{\text{Mean of 4th variable for the ith run}}{\text{Mean of 4th variable for the standard run}}$$

This calculation is repeated for the standard deviations and the ratios printed in the form shown in Figure 4.10. The first column gives the number of the run, the second column a code number which indicates the parameter changed during that run, the third column the new value of the parameter, and the remaining columns the appropriate ratios for the means and standard deviations of the variables named across the top of the sheet. Inspection of the output shows readily which parameter changes resulted in a significant alteration in the models response.

It was felt desirable that some method be used to quantify the amount of influence each parameter exerted on the system. It was also felt necessary to be able to determine the extent to which parameters affected the performance of different parts of the system.

A ranking technique was therefore utilised based on a points score derived from the ratio summary. A parameter received one point for each occasion upon which the ratio of the means or standard deviations of key variables differed by more than 10% from the standard values. A high score indicated that the relevant parameter exerted influence over many of the key variables or that the response over a few variables was acute.

Points scores were calculated for each input type for sub-groups of key variables from the three sectors of the model; the factory, warehouse, and the distributors. Using this approach it was also possible to produce a combined ranking for all input types and/or all sectors of the model.

4.3.3. Parameter Values

In general each parameter was tried with three values, twice and half the standard figure plus an extreme value.

The extreme value chosen (either very large or very small) depended on the nature of the parameter and the range covered by the other changes. For example, in the case of the stock review delays (DIRI, DIRP and DIF) a very small value was chosen to test the concept of continuous stock monitoring.

In a few instances the range of values was limited by experience of the real world, (mailing delays for example) or by instability of the model. The latter was generally caused by specifying the value of a third order delay too close to the calculation interval leading to a breakdown of the validity of the delay equations .

The range of values used for all the parameters is given in Table 4.1

4.3.4. Results of Sensitivity Analysis

The results will be presented and discussed for each input form (step, noise, sine, and sine + noise) in turn and the overall conclusions covered in the final section.

4.3.4.1. Step Input

The step input demonstrates the systems response to sudden changes in demand and the parameters identified as being critical are therefore likely to be those which control either the transmission speed or amplitude of the pulse fed through the system.

The critical parameters are shown in Table 4.2, ranked in descending order of the influence each had on the three sectors of the model.

Examination of the overall response column in the table confirms the critical nature of transmission delays (DTR,DPF,DUF) and amplitude related constants (AIR, AIF, DIRI, DIRP). The smoothing delays (DRR,DRF) also influence the timing and amplitude of the pulse transmitted as does DIMF which controls the rate of change of factory capacity.

Parameter	Parameter Number	Parameter Values Used. Extreme	Half	Twice	Standard
AIR	5	2.0	8.0	32.0	16.0
AIRD	6	2.0	8.0	32.0	16.0
DRR	8	5.0	20.0	50.0	10.0
DRRD	9	0.1	1.0	5.0	3.3
DHR	10	0.1	0.2	2.0	0.0
DUR	11	0.1	0.3	1.2	0.6
DIRI	12	0.5	2.0	8.0	4.0
DIRP	13	1.0	4.0	16.0	8.0
DCR	14	0.3	0.5	2.0	1.0
DTR	15	0.3	1.0	4.0	2.0
DMR	16	0.3	1.2	-	0.6
DRF	17	6.5	12.5	49.0	24.5
AIF	18	2.0	10.0	40.0	20.0
DUF	19	0.1	1.4	5.6	2.8
DHF	20	0.3	1.5	6.0	2.9
DIF	21	1.0	3.2	12.0	1.6
ALF	22	120.0	-	-	999
DCF	23	0.5	2.0	10.0	1.0
DIMF	24	12.0	25.0	100.0	50.0
DPF	25	2.0	8.0	20.0	4.0
DOMF	26	1.3	5.0	10.0	0.2
DOIF	27	5.5	22.0	50.0	11.1
DSPF	28	12.0	48.0	96.0	24.0
OVT	38	1.0	1.5	-	1.2

Table 4.1 Parameter Sensitivity Values

Factory		Warehouse		Distributors		Overall	
Rank	Param	Rank	Param	Rank	Param	Rank	Param
1	DIMF	1	DIRI	1	AIR	1	DIRI
2	DPF	2	AIR	2	DIRI	2	AIR
3=	AIR	3=	DRR	3=	DTR	3=	DIMF
3=	DIRI	3=	DIRP	3=	DUR	3=	DRF
3=	DUF	5=	DTR	5=	DIRP	5	DUF
6	DRF	5=	DRF	5=	DRF	6	DIRP
7	DSPF	5=	DIMF	5=	DHF	7=	DRR
8	AIF	8	DPF	8	DRR	7=	DTR
9	DOMF	9	AIF	9	AIRD	9	DPF
10	DIRP	10	DCR	10=	DRRD	10	AIF
				10=	AIF	11=	DSPF
						11=	DOMF
						13	DHF
						14	AIRD
						15=	DCR
						15=	DHR
						15=	DIF
						18	DCF
						19=	DRRD
						19=	DOIF
						21	DUR

Table 4.2 Sensitivity Analysis - Parameter Rank Order.

(10% Step Input Runlength 56 weeks.)

The dominant nature of the distributor parameters should be noted two of which (AIR, DIRI) appear in the top four parameters which affect the factory performance.

The column showing overall ranking confirms the importance of the distributor parameters. The prominent factory and warehouse parameters are those which control the factory capacity response (DIMF), the production delay (DPF) and warehouse policy stock levels (AIF).

4.3.4.2 Noise Input

Table 4.3 shows the parameter rank order for the noise input. The distributor parameters are again dominant in their influence on all sectors of the model. The parameters controlling stock levels and ordering frequency at the distributors (AIR, DRR, DIRI etc.) are particularly critical.

The factory parameters, as a group, are relatively more critical than was demonstrated by the step input. The high frequency of the noise input naturally led to a lower rank position for the factory capacity response parameter (DIMF).

The handling and clerical delays throughout the system (DHF, DAR, DCF , DCR) exhibited little influence on the models behaviour.

4.3.4.3. Sine Input

The parameter rank order for a sine input is shown in Table 4.4.

The most significant difference between the response to this input form and those discussed above is the increased importance of the factory parameters and the corresponding decrease in the

Factory		Warehouse		Distributors		Overall	
Rank	Param	Rank	Param	Rank	Param	Rank	Param
1=	AIR	1=	AIR	1	AIRD	1	AIRD
1=	AIRD	1=	AIRD	2	AIR	2	AIR
3=	DRF	1=	DRR	3=	DIRP	3	DRR
3=	DRR	1=	DIRI	3=	DIRI	4=	DIRI
5=	DIRI	1=	DIRP	3=	DRR	4=	DIRP
5=	DIRP	6	DRF	6	DUR	6	DRF
7=	DOIF	7=	DTR	7=	DRRD	7	DTR
7=	AIF	7=	DUF	7=	DHR	8=	AIF
9=	DIMF	7=	DHF	7=	DCR	8=	DIMF
9=	DPF	10	DIMF	10	DTR	10	DUF
9=	DOMF					11=	DPF
						11=	DOIF
						13	DOMF
						14	DUR
						15	DCR
						16=	DIF
						16=	DHR
						16=	DHF
						19=	DRRD
						19=	DSPF
						21=	DMR
						21=	DCF

Table 4.3 Sensitivity Analysis - Parameter Rank Order
Noise Input (Standard Deviation 20%)

Factory		Warehouse		Distributors		Overall	
Rank	Param	Rank	Param	Rank	Param	Rank	Param
1=	AIF	1	AIR	1	AIR	1	AIR
1=	DIMF	2	DIMF	2	AIRD	2	DIMF
3	DSPF	3=	DPF	3=	DRR	3	AIF
4	DPF	3=	DOMF	3=	DUF	4	DSPF
5	AIR	3=	DSPF	5	DIRP	5	DPF
6	DOMF	6=	DOIF	6=	DHF	6	DOMF
7	DOIF	6=	AIF	6=	DIRI	7	DOIF
8	DCF	8	DRF	8	DIMF	8	DUF
9=	DRF	9=	DHF			9=	DIRI
9=	DIRI	9=	DIF			9=	DRR
		9=	DCF			11=	AIRD
						11=	DRF
						11=	DCF
						14	DIRP
						15=	DHF
						15=	DIF

Table 4.4 Sensitivity Analysis - Parameter Rank Order

Sine Input (10% period 220 weeks)

influence of the distributor sector on the remaining areas of the model.

The distributor stock policy parameter (AIR) remains super - critical but no other parameters from this area are represented in the top eight of the overall response list.

All the main factory parameters (DIMF, DPF, DOMF, DOIF etc) are represented in the top group as is AIF which controls policy stock levels at the warehouse.

4.3.4.4. Sine Plus Noise Input

The sensitivity tests were additionally performed with a combined sine plus noise input primarily because this form of order intake was seen to most closely approximate that evident from analysis of the real system data.

The rank of critical parameters is shown in Table 4.5.

Comparison with the results for a pure sine input, shown in Table 4.4, show only minor differences in rank, particularly in the 'overall' column.

Factory and distributor parameters dominate the first ten overall positions although the warehouse stock policy parameter (AIF) is also clearly critical. The distributor stock policy and reorder delay (AIR and DIRI) are seen to significantly influence the performance of the factory sector, whilst the converse is not established.

In general the handling, clerical and transport delays are not seen to be critical. The distributor pipeline ordering delay (DIRP), which proved difficult to estimate, was also non critical.

Factory		Warehouse		Distributors		Overall	
Rank	Param	Rank	Param	Rank	Param	Rank	Param
1	DIMF	1	AIR	1	AIR	1	AIR
2=	DPF	2	DIMF	2	DRR	2	DIMF
2=	DSPF	3=	DPF	3	AIRD	3	AIF
2=	AIF	3=	DOMF	4=	DIRP	4=	DPF
5	AIR	3=	DSPF	4=	DUF	4=	DSPF
6	DOMF	6=	AIF	6	DIRI	6	DOMF
7=	DOIF	6=	DOIF	7=	DRRD	7=	DOIF
7=	DIRI	8=	DCF	7=	AIF	7=	DRR
9=	DRF	8=	DUF	7=	DHF	7=	DIRI
9=	DUF	8=	DRF	10	DUR	10=	AIRD
		8=	DRR			10=	DUF
						12=	DCF
						12=	DRF
						12=	DIRP
						15=	DRRD
						15=	DHF
						15=	DIF
						18	DUR

Table 4.5 Sensitivity Analysis - Parameter Rank Order
Sine + Noise Input

4.3.4.5. Sensitivity Analysis - Summary of Results

The conclusions from the sensitivity analysis can be summarised as follows:

i) The distributor parameters, particularly those associated with the ordering decision (AIR, AIRD, DIRI, DIRP) exert an influence on the performance of all sectors of the model, even the factory.

ii) The factory parameters do not significantly affect the performance of distributors sector of the model, but are a critical influence on the warehouse performance.

iii) The warehouse stock control parameters influence both distributor and factory performances.

iv) In general the handling, unfilled order, clerical and transport delays are not a significant influence on the system performance.

4.4 Results and Conclusions

The results of the sensitivity analysis confirmed the importance of looking at the complete spares manufacturing, warehousing and distribution system. The model demonstrates that significant interaction exists between the main sectors and implies that significant gains in performance can only be achieved by coordinated development work in all sensitive areas.

It is worth reiterating the main purpose of the modelling exercise - to define the areas on which the project team should concentrate their effort and possibly suggest the direction which that work should take.

The sensitivity analysis, as one might expect, confirmed the importance of all the main areas on the performance of the system. However, the conclusion that handling and unfilled orders do not exert a significant influence on the system performance is less expected. This conclusion implies that the development and installation of sophisticated order processing and materials handling techniques cannot be justified on the basis of improved customer service but would have to rely on savings made in labour costs.

The all - pervasive influence of the distributors was also less expected, as the conventional view of the warehouse function is to decouple the customer from the supplier. This view might hold for small fluctuations in demand about a steady state value but in none of the runs performed with the model was the variation in the manufacturing rate (MWF) seen to be <u>less</u> than that of the true demand at distributors. Examination at a detailed level of various individual model runs allowed the mechanism at work in the system to be clarified.

The response of key model variables to a step input is shown in Figure 4.7. It is clear from the diagram that the original disturbance to the system is amplified as it passes forward through the distributor and warehouse stock control routines. The same effect is evident in the models response to the sine wave input, shown in Figure 4.11.

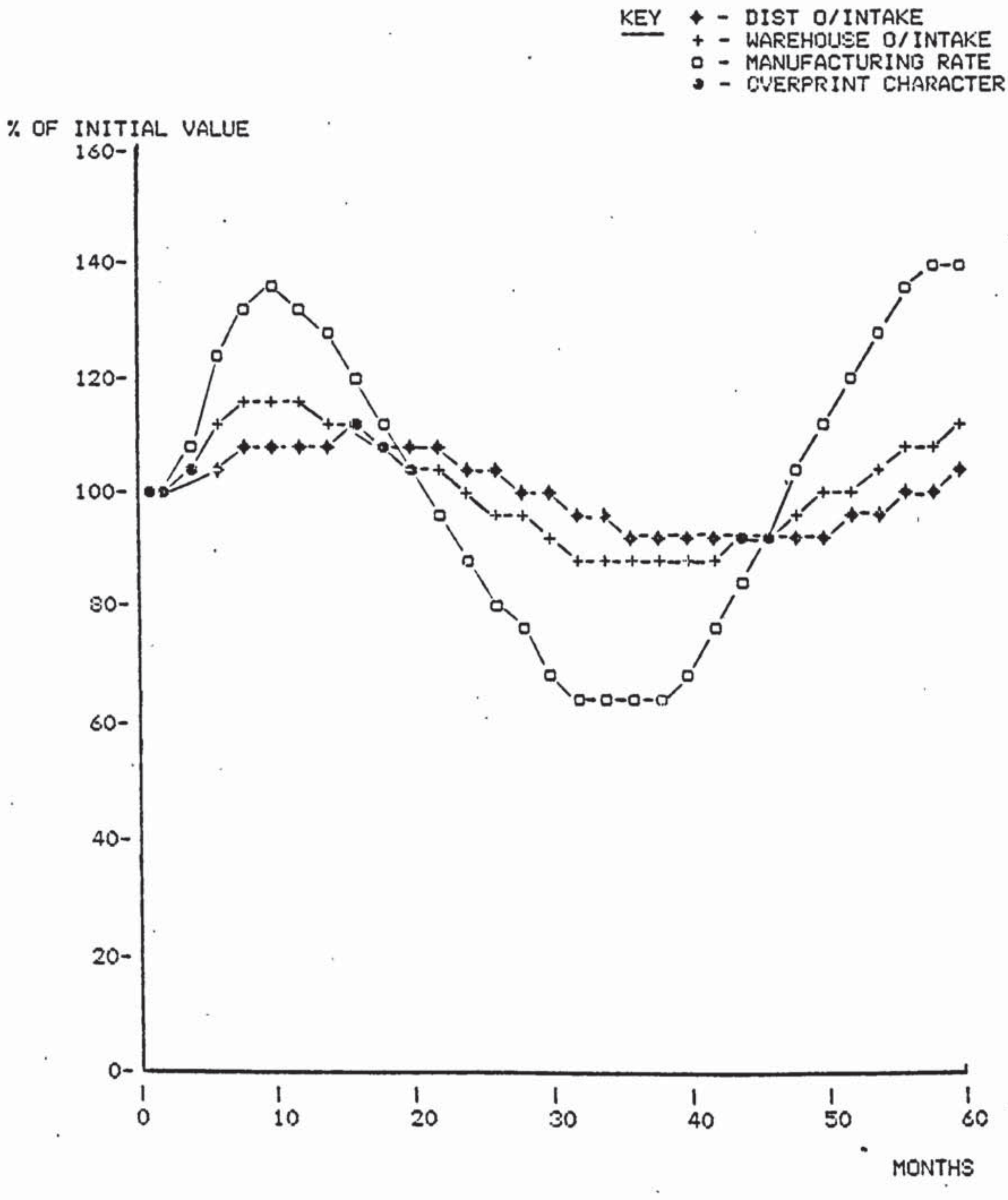


Figure 4.11 RESPONSE OF THE BASIC SPARES MODEL TO A SINE WAVE INPUT

The stock control algorithms in both sectors use the difference between target and actual levels of stock, work in progress, and unfilled orders to arrive at the appropriate order rate. As the order intake begins to rise the target levels are reassessed from the formula:

Target = Demand x Policy Holding (in weeks)

Thus the amount by which the target is incremented is dependant on the policy holding (AIF or AIR) as well as the actual increase in demand. The increment in target levels, and thus order issue rates, will therefore be several times the value of the actual increase in demand. This kind of stock control routine guarantees the presence of amplification in the system and explains the dominance of the distributors parameters in influencing system performance. It also explains the critical nature of all the parameters directly concerned with the ordering routines (e.g. AIF, DIRI etc). This subject is explored in considerably more detail in D.I. Peckett's Ph.D thesis (Peckett 1979), which concentrates on the stock control aspects of the project.

The critical nature of the factory parameters, particularly to a low frequency input, can also be explained. If the factory responds very slowly to increases in demand, for example if the capacity response is slow (ie DIMF is large) or lead times excessive, then a large backlog of orders will accumulate in the factory sector. The increasing factory lead time will stimulate the ordering routines to demand progressively higher rates of order issue, which, of course, further aggravate the position. When material does begin to arrive in large quantities, the warehouse and distributor sectors over compensate by rapidly reducing their demand, and starving the factory of work. The parameters identified as critical are those which either control the rate at which capacity is modified to suit changes in demand trends or have a direct influence on the factory lead time.

This modelling approach highlights the significance of the system's dynamic performance and the problem therefore resolves into the translation of these conclusions into specific detailed design proposals. The model's results clearly indicated a need to review, and preferably for the company to influence, the stock control practice at distributors. Stock or capacity policy decisions made by the company should be made with a knowledge of the true end customer demand rather than that subject to distortion by the distributor's stock control system.

A review of the warehouse stock control system was also suggested by the analysis, particularly to examine the efficiency with which it decouples distributor demand from the factory and copes with low frequency changes in base demand levels.

The prospective changes in the company's product range implied a need to develop an alternative source for manufactured spares. The interaction analysis indicated that such a production unit should be designed so as to optimise it's dynamic response to long term fluctuation in demand as well as meeting conventional technical and financial targets.

The limited resources available to the project team dictated a sub-contract approach to further development work. Accordingly the company assumed responsibility for the development of an enhanced distributors stock control system which would encompass appropriate information links with the company's warehouse system.

The specification of these data links and enhancement of the warehouse control systems was undertaken by D.I. Peckett and is reported in his Ph.D thesis (Peckett 1979).

The author assumed responsibility for the development of the manufacturing/sourcing function to which the remainder of this thesis is devoted.

Chapter 5 Effect of Compressor Demand on Sources of Supply

5.1 Background

Those spares components sourced from the factory are manufactured alongside parts destined for compressor assembly and thus competition for capacity exists. Variation in demand in one market directly affects manufacturing capacity available to the other.

The demand for compressors fluctuates widely, as is demonstrated by the graph of demand for the years 1970-77 shown previously in Figure 3.14 . The magnitude of the variation suggests that significant changes in the capacity available to spares can be anticipated at the factory. The factory reacts to a prospective overload by increasing the amount of material sub-contracted to outside manufacturing companies. In selecting the particular components to be sent out the Production Control Department will normally give priority to non-current spares items. Such action reflects the dominant position of the compressor build requirement in the capacity planning decisions of the Production Division.

It was established previously (see section 3.5) that the demand for spares varied approximately in phase with that for compressors. This correlation implies that the increase in demand for spares occurs at just the time when the capacity available is being constricted further by an upturn in compressor demand.

This view depends on the assumption that the demand for spares, as seen at the warehouse, is independant of the performance of the factory or other sources of supply. The sensitivity analysis established that significant levels of feedback exist in the system.

The possibility therefore exists that the influence of the compressor demand on the factory capacity could be fedback through the system to generate an apparent fluctuation in the demand seen by the warehouse. It was felt necessary to determine whether, in conditions of static end customer demand, this mechanism could generate fluctuation in warehouse demand similar to that seen in the historical data.

Although the analysis of distributor sales figures in section 3.3.2 implied that a considerable degree of fluctuation in end customer demand did exist, it should be realised that this analysis depended on sales rather than demand data. It was possible that the effect of the feedback mechanisms could be to regulate the supply of material in such a way that sales would follow a fluctuating path, whilst the true underlying demand remained essentially stable.

The factory sector of the basic model was therefore extended to more faithfully represent the various sources of spares supply and to incorporate the influence of compressor demand on the factory capacity and thus allow the hypothesis to be tested.

In addition a more realistic representation of the provisioning sector was felt to be necessary to allow a deeper analysis of the relevant capacity response parameters since these could be expected to differ in value between the various sources of supply.

5.2 Multi-Source Model Development and Description

5.2.1 Introduction

The warehouse and distribution sectors of the original model were considered satisfactory and development was therefore concentrated on the 'factory' part of the model.

The existing system sourced components from either outside manufacturers (for proprietary parts) or from the Production Division (for manufactured parts). The Production Division may in turn sub-contract all, or part, of the manufacturing process to small outside suppliers. The level of sub-contracting depends on the size of the deficit resulting from the comparison of the combined compressor and spares manufacturing load with available capacity. The management indicated that spares batches, particularly for non-current items, tended to be selected for sub-contract first, ie compressor requirements are satisfied in preference to those for spares.

The new source sector of the model clearly had to incorporate the sub-contracting decision as this could be considered one of the key factors in the systems response to an increase in compressor demand. In addition the sector had to include a separate source of supply for proprietary parts. The model also included an alternative manufacturing source of supply which corresponded to an independant spares production unit, although this facility was not utilised during the system feedback experiments.

5.2.2 Model Equations.

A diagram showing the new capacity decision sector of the model is shown in Figure 5.1.

The total spares requirement from all sources (MWF) is calculated in the normal way by the warehouse routines. The proportion of this to be allocated to each source is determined by the value of the proportional parameter PS(1-3).The calculation of the Manufacturing

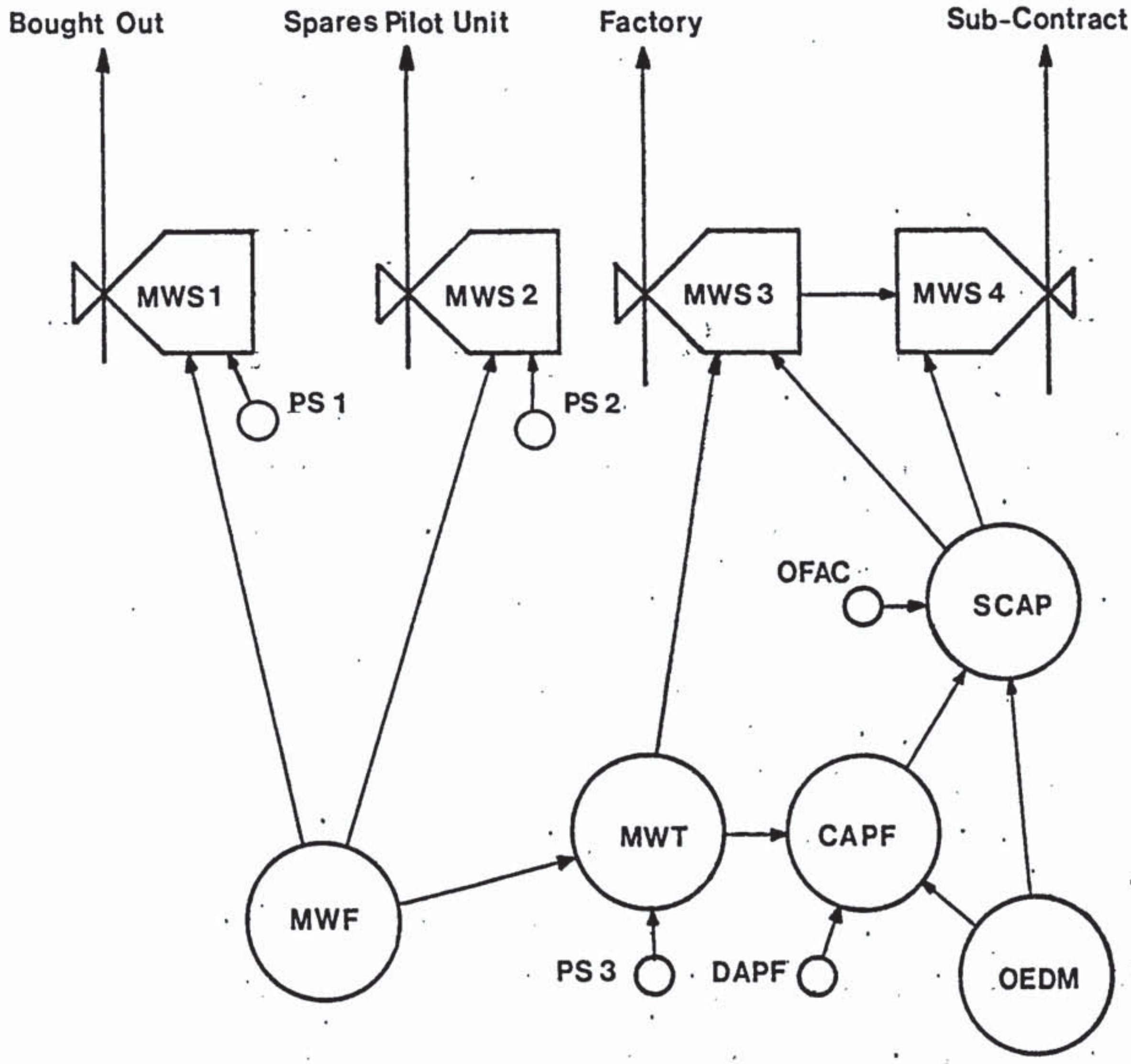


Figure 5.1 Factory Capacity Decision Sector of the Multi-Source Model

rate Wanted at each Source uses an equation of the following form:

MWS(T) = PS(1,2,3) x MWF

and the total spares manufacturing rate (MWT) from;

MWT = MWS(1) + MWS(2) + MWS(3)

where PS(1,2,3) is a proportional factor.

The factory manufacturing capacity (CAPF) is calculated from a smoothed average of the combined spares (MWT) and compressor demands (OEDM). thus:

CAPF = CAPF + DT/DAPF((MWT+OEDM)-CAPF)

The smoothing delay DAPF controls the capacity response in a similar manner to DIMF in the simple model.

The current capacity is compared with current compressor demand to derive the capacity available to spares (SCAP). An overload factor (OFAC) allows the facility to be loaded beyond its theoretical capacity, if necessary, thus:

SCAP = (OFAC. CAPF) - OEDM

The total spares manufacturing rate wanted from the division is then compared with the available capacity to determine the level of sub-contracting, (MWS(4) for sub contract, MWS(3) for manufactured). The equations follow:-

if MWT is less than SCAP then:

MWS(3) = MWT

if MWT is greater than SCAP then:

MWS(3) = SCAP and the sub-contract rate:

MWS(4) = MWT - MWS(3)

The modelling of each source closely follows the format developed for the single source in the basic model. The structure of a source is

shown in Figure 5.2. All four sources have identical structures, the variable name suffix merely changes. A complete set of equations, following the Forrester conventions is given in Appendix 5.

5.2.3 Parameter Values

The parameters associated with the hypothetical spares manufacturing unit were set to nominal values as this facility was not required in the experiment. All orders were therefore diverted to either the bought out or factory sources of supply.

The values of the parameters associated with the calculation of the source loads and those which control the influence of the compressor demand will be discussed first.

5.2.3.1 Capacity Parameters

OECAP

This parameter sets the base level of compressor demand in relation to that for spares. A study showed that the compressor factory load was approximately

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seven times that generated by spares orders. This parameter was therefore given a value of 210 units/week (the spares demand is normally set at 100 units/week of which 30% is manufactured by the factory).

OEPER

The variation in compressor demand was simulated using a sine wave generator in the program. The period of the cycle was controlled by this parameter. Although the actual data available could not be considered adequate to allow true cyclic behaviour to be established, it did suggest that a period of 220 weeks could be considered representative for experimental purposes.

OESH

This parameter determines the amplitude of the compressor demand and a variety of values were used ranging from 10% to 50% of the mean level.

PS(1-3)

The model divides the total demand generated by the warehouse between the alternative sources of supply using this parameter as a proportional factor. PS(2) which controls the load generated on the spares manufacturing unit was set equal to zero. Seventy percent of the total demand was directed to outside suppliers (PS(1) = 0.7) whilst the remainder was

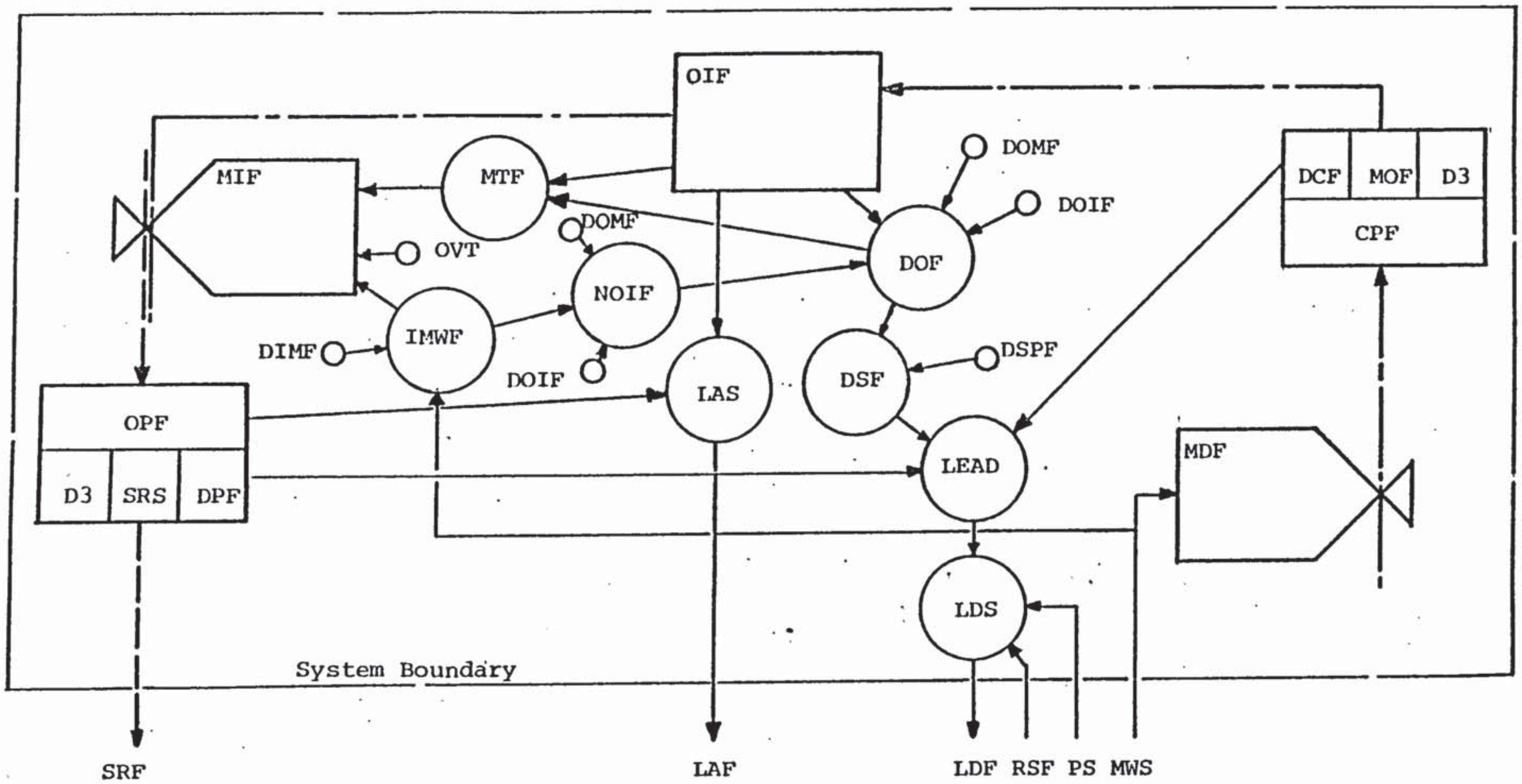

Figure 5.2 Supply Sector Structure of the Multi-Source Model

sourced on the factory (PS(3) = 0.3). These figures were derived from analysis of current provisioning policy, described in Section 2.4 above.

DAPF

The delay in adjusting the production capacity at the factory determines the rate at which the total capacity of the factory is perceived to change in relation to the sub-contracting decision and the calculation of the available spares capacity. Similar considerations apply to the estimation of DIMF in the basic model (see Section 4.2.6, above) and consequently an identical value of 50.0 weeks was used for DAPF here.

OFAC

This parameter allows the factory to be overloaded,if desired, above it's nominal current capacity. Values corresponding to zero and ten percent overloads were both tried.

5.2.3.2 Source Parameters

A limited amount of data were available for either bought out or sub-contracted suppliers which could be utilised to derive appropriate values for some of the parameters in those sectors of the model. It was therefore necessary,in such instances,to use values felt to be 'typical' by informed members of the company management team.

Each of the parameters will,again,be discussed in turn :

DCF

The clerical delays at the factory and for outside suppliers were considered to be one week (as in the basic model) but a longer delay of two weeks was defined for sub-contracted items to reflect the time needed to prepare additional paperwork and to ship material to and from the supplier.

DOMF

This parameter was defined in the basic model as equal to 0.2 weeks from consideration of the minimum queueing time possible at the factory. This value was retained for the factory sector of the multi-source model and was also used for the bought out sector reflecting the ex-stock service available from some suppliers. Sub-contracting companies were generally smaller and could therefore be expected to be able to offer even shorter minimum queueing times than the factory - a value of 0.1 weeks was therefore chosen for this sector of the model.

DOIF

This parameter was previously derived by comparison of the historical average overall lead time with the values chosen for the other model parameters which directly affect the source lead time thus:

DOIF = Overall Lead - (DPF + DOMF + DCF)

The overall lead time for bought out components was, on average, 12 weeks (see Section 3.2), substitution in the above equation yields a value of 8.8 weeks.

The average figure for the factory lead time used in the basic model included the effects of sub-contracting. In order to minimise the influence of this activity on the value used in the multi-source model the average overall lead time for the period of slack demand (1976) was substituted in the DOIF equation. A value of 22 weeks was used giving 15.8 weeks for the factory DOIF.

The lead time data available for sub-contracted items was not sufficiently reliable to allow proper analysis but turn-round times of two months are common for existing sub-contractors. Since this value does not include delays of the type represented by DCF substitution of the appropriate values yielded a figure of 2.9 weeks for DOIF in this sector of the model.

DPF

The value derived from process data for the basic model was 4.8 weeks. This value was considered to remain valid for both the factory and sub-contractor sectors of the new model. The influence of ex-stock service from bought out supliers led to an assumption of a smaller process delay, of two weeks, for this sector of the model.

DIMF

The value derived for use in the original model took into account the Production Division's ability to bring additional capacity on stream by the use of sub-contractors (see Section 4.2.6). This process was considered to take approximately four months. Adjustment of the capacity of the manufacturing plant itself by the acquisition of new plant and/or labour can be expected to take considerably longer. In recognition of this a value of 70 weeks was used for the factory sector of the new model.

The time to organise additional sub-contract capacity was, as mentioned above, defined as 16 weeks.

The response of outside suppliers to changes in demand is more difficult to determine since it would appear to depend on a number of factors outside the knowledge or control of CompAir Ltd. However, even in cases where the CompAir call is a small proportion of the suppliers total business (piston ring manufacturers for example), it is unlikely that increases in demand will be easily satisfied since these will be most likely to occur in times of increasing economic activity (see Section 3.5). For this reason the bought out DIMF was set, initially, equal to 50 weeks although later runs were performed with values of 10, 25, and 100 weeks to test the sensitivity of the results to this assumption.

DSPF

This parameter is primarily defined by the characteristics of the CompAir production/stock control systems which can be considered common to all sources of supply. Separate values were included in the model mainly for reasons of programming convenience. An identical value to that used in the basic model, of 24 weeks, was therefore defined for all sectors of the model.

5.3 Experimental Results

5.3.1 Feedback Experiment

The prime purpose of this experiment was to determine the presence , or otherwise, of significant levels of feedback between the factory and other sectors of the model. In particular it was intended to determine if such feedback could, alone, generate the fluctuation evident in the historical warehouse order intake data. Consequently the amplitude of the fluctuation in demand for compressors could be expected to be a key element in such a mechanism. Part of the series of computer runs was therefore dedicated to exploring the influence of this factor on the performance of the system. The amplitude of the compressor demand was varied between 10% and 50% of the steady state level in steps of 10%.

As was mentioned above, the value of DIMF proved difficult to define particularly for the bought out source. A series of runs were performed varying the value of this parameter form 10 to 100 weeks for bought out suppliers and from 50 to 100 weeks for the factory.

It was necessary to determine a basis of comparison between the historical system performance and that generated by the model.

The variables in the model associated with the warehouse order intake are the reqisitions received at the factory warehouse (RRF) and the requisitions smoothed at the factory warehouse (RSF). The latter (RSF) being an exponentially smoothed version of RRF.

The historical order intake figures presented and discussed in Section 3.3 correspond most closely to RSF, as moving averages were used to analyse the data.

These variables were monitored through the length of each model run and the minimum, mean, and maximum values they attained, recorded. The results for a range of compressor demand amplitudes are shown below in
Table 5.1.

In all cases the model was initially run over a simulated period of 400 weeks. In order to check on the influence of run length on the results, the last run was repeated over a period of 1100 weeks.

The results clearly fail to sustain the hypothesis that fluctuation in the compressor demand is sufficient to generate the variation in the demand for spares seen at the warehouse. In no case did the induced fluctuation in the RRF exceed ± 3% or RSF ± 2%.

The influence of an error in the estimation of the value of the bought out and factory capacity response parameters (DIMF) were checked by another series of runs and found to be minimal. The

Compressor Demand		Spares Orders Received at the Warehouse					
Amplitude		Rate (RRF) Units/Week			Smoothed Rate (RSF) U/Wk		
Units per Week	% of Mean	Minimum	Mean	Maximum	Minimum	Mean	Maximum
21	10%	99.4	100.1	101.2	99.5	100.11	100.7
42	20%	98.8	100.1	102.4	99.1	100.12	100.2
63	30%	98.5	100.1	102.7	98.9	100.13	101.6
84	40%	98.4	100.1	102.7	98.9	100.14	101.8
105	50%	98.4	100.1	102.8	98.8	100.1	101.8
105	50%*	98.2	100.0	102.8	98.7	100.0	101.9
Steady State		100	----------	----------	----------	----------	100

* Over 1100 Weeks

Table 5.1 Results of the Feedback Experiment results for this series are shown below in Table 5.2. These, and later runs of the multi-source model, were performed with the fluctuation in original equipment demand set at ±40% of the mean level. This figure was derived from analysis of the demand levels, shown in Figure 3.14, which indicated a peak to trough fluctuation of 80% of the mean level for the years 1969-77.

In no case did the maximum, mean or minimum values of RRF or RSF vary by more than 1% from the results yielded by the 'standard' parameter values. It was concluded therefore that an error in the estimate of the capacity response parameter would not significantly affect the result.

5.3.2. Introduction of Fluctuating Spares Demand

The failure of the inherent system feedback to generate the fluctuation evident in the real system naturally raises the question of whether a true fluctuation in customer demand could result in behaviour typical in the real system demand.

A series of runs were therefore set up over 1100 weeks in which a sinusoidal form was selected for end customer demand. The amplitude of the demand was varied between 10% and 30% of the mean value.

Comparison of the historical model data for stocks, shortages and warehouse order intake showed that the 20% and 25% demand amplitudes gave results closest to the historical data. Table 5.3 and Figures 5.3 and 5.4 give detailed coverage of the results.

Parameter Values Weeks	Spares Orders Received at the Warehouse					
	Smoothed Rate (RSF) U/Wk			Rate (RRF) Units/Week		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
Bought Out DIMF						
10.0	99.2	100.03	101.2	98.7	100.0	102.3
25.0	99.1	100.07	101.5	98.6	100.0	102.6
50.0*	98.4	100.1	102.7	98.9	100.1	101.8
100.0	98.5	100.2	102.1	98.0	100.0	102.6
Factory DIMF						
50.0	99.1	100.11	101.6	98.7	100.1	102.4
70.0*	98.4	100.1	102.7	98.9	100.1	101.8
100.0	98.7	100.17	101.7	98.2	100.1	103.0

*Standard Values

Table 5.2 Sensitivity of Results to Estimates of the Value of the Capacity Response Parameter (DIMF)

Variable	Historical Values	Model Values	
		Spares Demand 20%	Amplitude 25%
Stocks (Wks)			
Maximum	29.0/27.5	27.5/28.0	31.0/32.0
Minimum	12.5/15.0	15.0	14.0
Mean	≃ 21.0	20.4	20.1
Period	3.5/4.5	4.0/4.5	4.0/4.5
*Shortages Months			
Maximum	1.2/1.3	1.03/1.1	1.2/1.25
Minimum	0.1	0.35/0.38	0.28/0.3
Mean	0.66	0.7	0.73
Period Yrs.	4.0/4.5yrs	4.0/4.5yrs	4.0/4.5yrs
Order Intake			
Maximum	116/110	119/120	125/126
Minimum	87/94	78/79	73.
Mean	100	100	100
Period	4.0/5.5	4.0/4.5	4.0/4.5

Note. Successive Peaks or Troughs are indicated by 2 values
*January 1970, all other figures relate to 1971-7

Table 5.3 Comparison of Model and Real System Performance

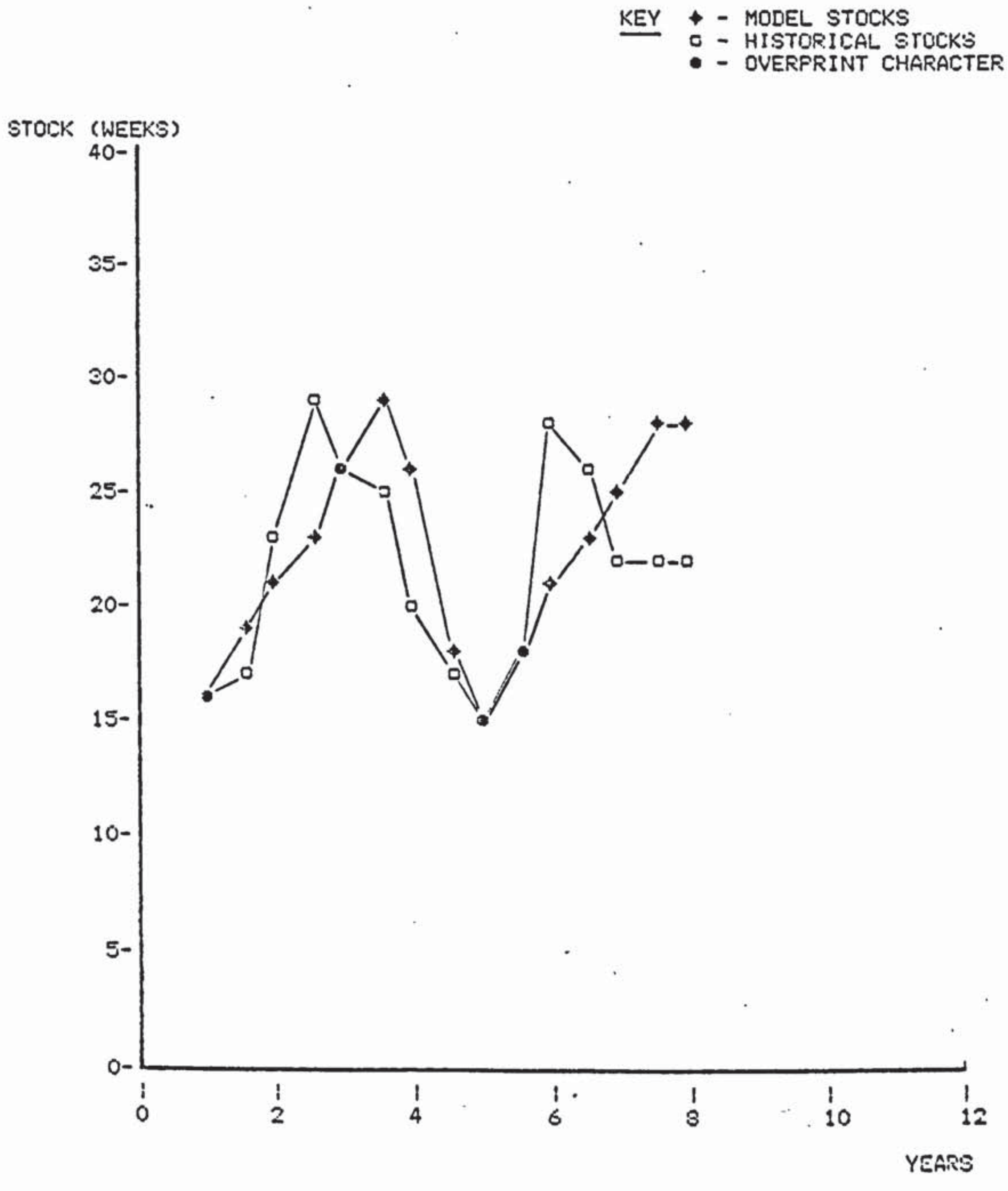

Figure 5.3 COMPARISON OF HISTORICAL STOCK LEVELS WITH THE MULTI-SOURCE MODEL RESULTS

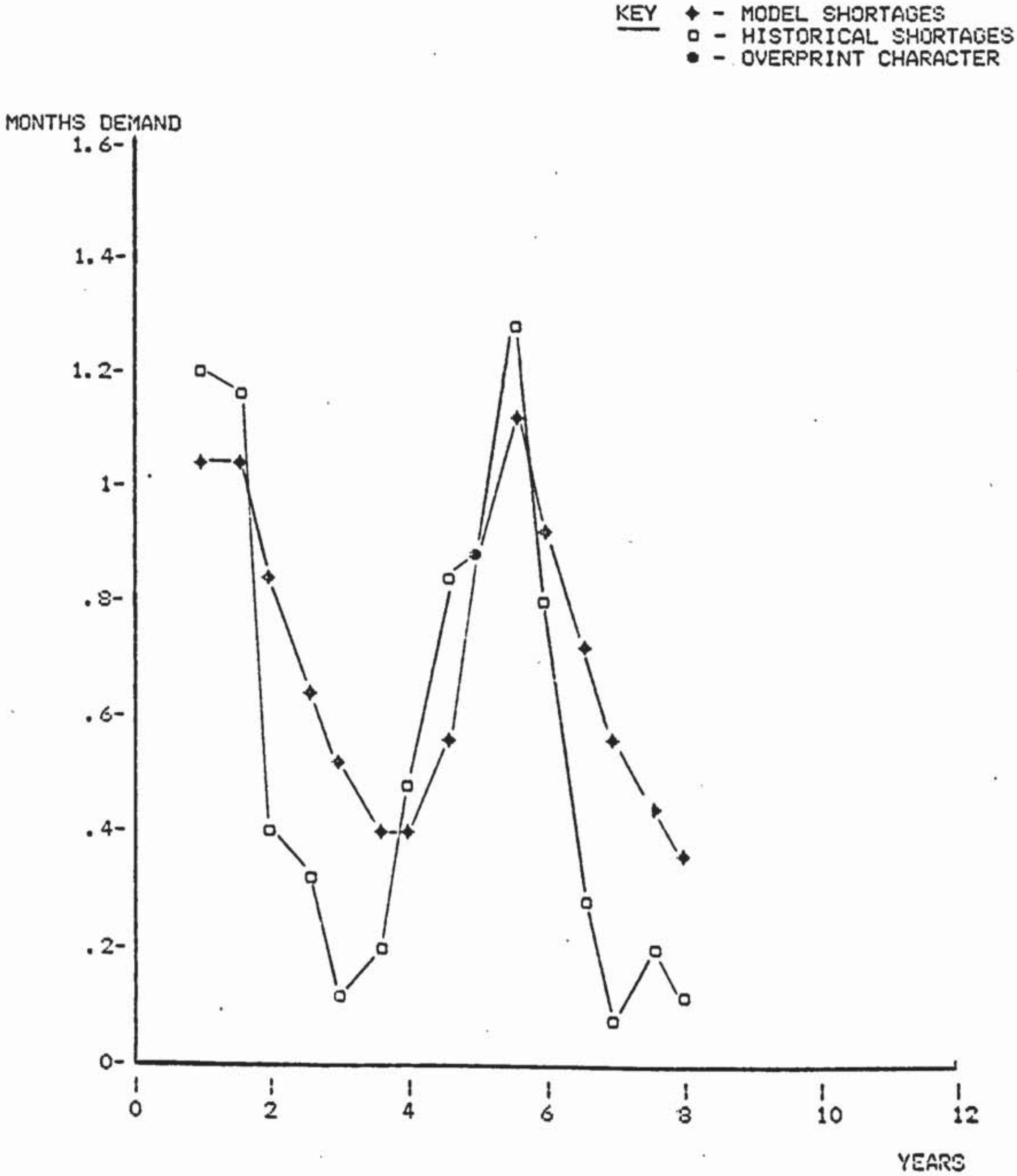

Figure 5.4 <u>COMPARISON OF HISTORICAL SHORTAGE LEVELS WITH MULTI-SOURCE MODEL RESULTS</u>

The historical data covers the period from June 1970 to June 1977 (ie year 1 is equivalent to June 1970). The historical order intake figures were smoothed in a similar manner to that used in the model to allow a proper comparison to be made.

The similarity established between the historical and model data particularly for stocks and shortages suggests that the introduction of variation in spares demand at distributors, in phase with that for compressors, does result in a model performances typical of the real system.

These results also, necessarily, enhance confidence in the validity of the model.

Some discrepancies do occur between the model and the real system in relation to the model's higher minimum stocks and shortage levels which probably stem from the non-symmetrical form of the real system input (as measured at the warehouse). In addition, the model shows a higher degree of fluctuation in the warehouse order intake than that evident in the real system. This, coupled with the agreement achieved for stocks and shortages, suggests that the gain of the warehouse and provisioning parts of the real system is greater than that demonstrated by the model. This view is reinforced by the study of distributor sales figures (see section 3.3.2) which implied that the true fluctuation in end customer demand is less than the 20% level used as the basis of this comparison.

The implications of the experimental results are therefore that the real system is very sensitive to even small fluctuations in end customer demand and that this sensitivity exceeds that demonstrated by the model.

Chapter 6. Development of Criteria for a Provisioning Solution

6.1 Introduction

The sensitivity analysis indicated that the parameters controlling the rate at which source capacity changes to suit demand (DIMF) and those which dictate the form of the lead time response (DOIF, DOMF, DPF) were critical in determining system performance. The feedback analysis suggested that the fluctuation in the sytem is probably externally driven implying a need for the provisioning solution to be evaluated primarily on the basis of its dynamic performance.

Since such fluctuation could not be eliminated by changes in the system parameter values, exploration of the influence of these parameters was necessary to determine the kind of response characteristic which would be desirable in the existing,or alternatively any new, sources of supply. Specifically this implied detailed study of the systems behaviour as changes were made in the values of the relevant parameters DIMF, DOIF, DOMF and DPF.

6.2 Analysis of the Influence of the Capacity Response

6.2.1. Experimental Design - Introduction

In the real system the manufacturing capacity is adjusted to meet the demand in several ways:

i) By increasing/decreasing the number of suppliers of proprietary parts. The opportunity to take this kind of action may be limited both by the nature of the component, and market conditions at the time. The effect on the system is analagous to the acquisition/disposal of a sub- contractor.

ii) By increasing demand on existing suppliers and assuming that they will take appropriate action to increase capacity themselves.

iii) By hiring and training additional operatives where manufacturing capacity is limited by labour constraints.

iv) By the purchase and installation of new plant to supplement existing machine capacity.

v) By increasing the amount of material sub-contracted both to existing and new companies.

The use of overtime working can be considered viable only as a short-term balancing device.

The cost of adopting a policy aimed at achieving especially rapid response, either through excessive hiring/firing of operatives and purchase/disposal of plant or extensive multi-sourcing of proprietary parts, is likely to be high. It is therefore necessary to establish that such a policy would result in real benefits in terms of better service.

The use of sub-contractors as a variable source of supply for manufactured parts is clearly an attractive alternative when set against the problems inherent in achieving significant changes in factory labour or plant capacity.

This series of experimental runs were therefore aimed at exploring the effect on system performance of an increasingly rapid capacity response in each of the sourcing sectors of the model. In addition, the effect on the system of removing the sub-contract facility was also explored.

6.2.2. Experimental Design - Parameter Changes

The response series of runs utilised the multi- source model. The value of DIMFwas changed successively, [illegible] for each source of supply, across the range of values shown in Table 6.1.

A runlength of 1100 weeks was adopted to ensure that the initial conditions would not significantly influence the results.

The compressor demand level was set at that used in the feedback experiments and end customer demand defined as being of sinusoidal form, with a period of 220 weeks and an amplitude of 20% of the mean level. This combination was found previously (see section 5.3.2) to give the closest fit to historical data for the most relevant sectors of the model (warehouse and factory) using 'standard' parameter values.

6.2.3. Results

The results will be discussed for each source of supply in turn. Consideration of system performance will be based primarily on movements in stocks (IAF, IAR), Unfilled orders (UOF, UOR) and the desired manufacturing rates (MWF, MWS(1-4)).

Source of Supply	Parameter	Range of Values (Weeks)	Standard Value
Bought Out Proprietary Parts	DIMF	10,25,100.200	50
Factory Production Parts	DIMF DAPF	10,25,50,100,200 10,15,25,70,100,200	70 50
Sub - Contract Production Parts	DIMF	5,10,25,50,100 (plus complete removal)	16

Table 6.1. Capacity Response Parameter Values Tested.

6.2.3.1. Bought Out

Table 6.2 summarises the results for key variables. In general it is evident that slower response leads to a deterioration in performance, particularly for unfilled orders (UOF). The distributor variables are little effected but those at the warehouse change significantly. Although the mean value of the desired manufacturing rate (MWF) does not change, the increase in standard deviation implies a considerable increase in the variation of demand seen by the sources of supply. Stocks show an opposite trend becoming more stable as capacity response slows.

6.2.3.2. Factory Capacity Response

Examination of the factory capacity is complicted by the presence of two parameters (DIMF and DAPF) each of which can modify the capacity response of this source. DAPF controls the changes in the total factory capacity, including that for compressor manufacture and acts before the model performs the allocation of orders to sub-contract. Decreasing the value of DAPF will therefore tend to make the available factory capacity follow the combined spares/ compressor demand more closely.

The other parameter, DIMF, applies after the sub-contract decision has been made and acts only on the spares order stream actually processed by the factory. A decrease in the value of this parameter will therefore tend to adjust the spares factory capacity more closely to the demand net of the amount sub-contracted.

The real system capacity response is allied more closely to the control offered by the former parameter DAPF, but experimental runs were performed for both parameters to ensure complete coverage.

Summary of Results - Bought Out Source										
DIMF	UOF		IAF		MWF		UOR		IAR	
Weeks	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
10	561	117	2085	354	100	23.6	60.3	10.9	1604	228
25	568	133	2069	364	100	28.8	60.4	10.9	1603	231
50	577	159	2054	347	100	36.5	60.4	11.0	1602	233
100	585	182	2049	314	100	44.0	60.4	11.1	1602	233
200	588	193	2055	314	100	47.8	60.4	11.3	1603	232

Table 6.2 Summary of Results - Bought Out Capacity Response

The results for changes in the value of DIMF are shown in Table 6.3.

In the interpretation of the results it is important to note that in the model available capacity is tied only to the demand seen by the source and that no account is taken of any backlog of work in progress in the system.

The coincidental rise in spares and compressor demand results in a reduction in the quantity of orders directed to the factory source (ultimately reaching zero) and a corresponding increase in that sub-contracted. The closer the available capacity is made to follow demand the more rapidly and frequently the spares capacity (SCAP) approaches zero. The orders which have accumulated as work in progress (in OIF) cannot then be cleared and the factory lead time rapidly becomes extended. At very low values of DIMF full recovery is not possible before the next demand cycle begins.

Thus the problem of available capacity being low in times of high demand is accentuated by tying the spares capacity directly to net demand. The overall effect, as DIMF is reduced, is to lower the average capacity available from the factory and increase the amount necessarily sub-contracted.

The parameter values used in the model are such that the lead time offered by the sub-contract route is actually lower than that offered by the factory. Consequently, as the utilisation of the factory source increases with higher values of DIMF, the overall performance of the sourcing sector deteriorates.

The overall capacity response parameter DAPF can be expected to have considerable influence on the lag which exists between a change in demand and adjustment of capacity to meet that demand. The effect of increasing values of DAPF on the lag between the capacity

Summary of Results - Factory (DIMF)												
DIMF	UOF		IAF		MWF		UOR		IAR			
Weeks	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD		
10	480	162	3919	1880	100	142	60.4	10.6	1601	236		
25	595	173	1954	319	100	39.6	60.4	11.0	1602	235		
50	581	161	2033	328	100	37.3	60.4	11.0	1602	234		
70	577	159	2053	347	100	36.5	60.4	11.0	1602	233		
100	579	160	2052	376	101	36.5	60.4	11.0	1602	233		
200	590	168	1984	393	101	37.6	60.4	11.0	1602	234		

Table 6.3 Summary of Results - Factory (DIMF)

available to spares (SCAP) and total spares manufacturing rate wanted (MWF) is shown in Table 6.4.

The table also shows the maximum and minimum values attained by SCAP during the third cycle (weeks 660 to 880) of each run. The considerable increase in lag and variation in capacity is clearly evident from the table. When DAPF equals 25 weeks the lag approaches half a period implying that theoretical capacity is completely out of phase with demand.

Table 6.5 shows the effect on stocks, shortages and the manufacturing rate of changes in the value of DAPF.

The influence of this parameter on the distribution sector is limited, but clearly considerable on the warehouse. Values of DAPF between 25 and 70 weeks give the lowest mean and standard deviation of unfilled orders and also yield the most stable stock position.

Detailed inspection of the results data also shows that at the two lowest values of DAPF (10 and 15 weeks) the factory lead time is superior to that offered by sub- contract whilst at higher values the position is reversed.

The lags between demand and the corresponding change in factory or sub-contract response are affected by this parameter. The interaction between these lags leads to a smoothing of the total supply of material from this sector

of the model. This effect is demonstrated in Figure 6.1 which shows the response of the combined supply of material from the factory and sub-contract for several values of the parameter The smoothing effect extends to the variable SRF which represents the flow of material from all sources, including the bought out sector. The mean level of this variable reaches a maximum and it's standard deviation

DAPF Weeks	Spares Capacity Availalable (SCAP)		Lag (Weeks) SCAP after MWF
	Maximum	Minimum	
10	44.8	14.3	65
15	54.5	7.9	78
25	71.1	0	104
50	92.4	0	104
70	98.6	0	143
100	104.6	0	156
200	110.2	0	156

Table 6.4 The Influence of DAPF on the Lag Between the Desired and Actual Manufacturing Rates

Summary of Results - Combined Response Parameter DAPF										
DAPF	UOF		IAF		MWF		UOR		IAR	
Weeks	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
10	619	206	1886	396	100	47.6	60.6	11.1	1598	238
15	612	194	1892	341	100	43.0	60.5	11.1	1598	236
25	588	173	1998	307	101	38.2	60.5	11.0	1599	234
50	579	158	2047	350	101	36.9	60.5	10.9	1599	234
70	579	158	2049	388	101	37.8	60.5	10.9	1599	234
100	582	161	2043	428	101	39.4	60.5	10.9	1599	235
200	589	169	2025	488	101	42.1	60.5	10.9	1598	237

Table 6.5 Summary of Results - Combined Response Parameter

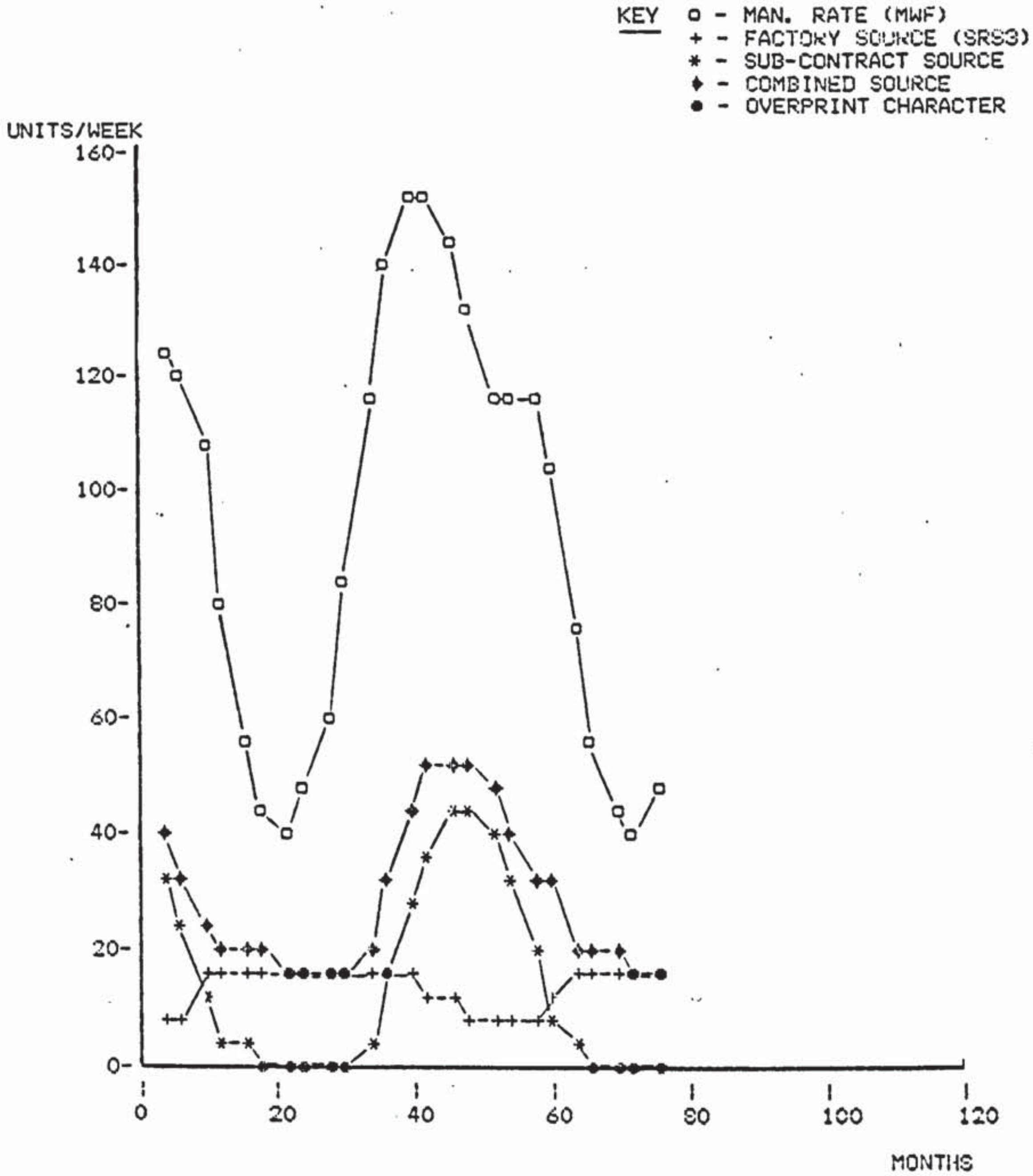

Figure 6.1 EFFECT OF THE LAG BETWEEN SOURCES OF SUPPLY

a minimum when DAPF takes a value of 25 weeks.

Overall the system performance seems to be best for values of DAPF in the range 25 to 70 weeks.

6.2.3.3. Sub-Contract

Table 6.6 shows the results for the sub-contract series of runs.

The general trend evident in the bought-out results is also present here showing a deterioration in system performance as the source becomes less responsive. The deterioration in the shortage and stock positions is, however, more dramatic in this instance. The reduction in stocks is balanced by an increase in the minimum level of work in progress at sub-contract. This level becomes significantly greater than zero at values of DIMF larger than 25 weeks. The lead time offered by sub-contract also increases rapidly at this point, whereupon the service offered by this source can be considered inferior to that provided by the factory.

The effect of the removal of the sub-contract facility from the model is demonstrated below in Table 6.7.

The superior performance given by the run which included a sub-contract facility is evident from an inspection of the table which shows lower unfilled orders, stocks closer to target levels and much less fluctuation in all the variables.

The usefulness of the sub-contract facility is therefore clearly established.

Summary of Results - Sub - Contract.												
DIMF	UOF		IAF		MWF		UOR		IAR			
Weeks	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD		
5	553	133	2202	382	100.	35.9	60.4	10.9	1603	231		
10	563	145	2138	367	100	36.1	60.4	10.9	1603	232		
16	577	159	2054	347	100	36.5	60.4	11.0	1602	233		
25	600	178	1926	318	100	37.4	60.4	11.1	1602	235		
50	675	225	1576	250	100	40.3	60.5	11.4	1601	237		
100	908	312	975	227	101	45.6	60.7	12.0	1600	243		

Table 6.6 Summary of Results - Sub - Contract.

Summary of Results - Sub - Contract Availability										
Sub-Con	UOF		IAF		MWF		UOR		IAR	
	MN	SD	MN	SD	MN	SD	MN	SD	MN	SD
ON	580	158	2043	350	102	37	60.5	10.9	1598	233
OFF	642	239	1851	483	101	56	60.8	11.1	1594	241

Table 6.7 Summary of Results - Sub-Contract Availability

6.2.4. Conclusions

Generally changes in the capacity response of the various sources of supply produced significant effects only on the warehouse and source variables. These effects were felt primarily in the fluctuation of the variable rather than in their mean values.

A steady, significant increase in the standard deviation of unfilled orders and desired manufacturing rate was seen as the bought-out source became less responsive. Over the range of values tested the standard deviations of these variables almost doubled. Mean values were scarcely affected.

The importance of ensuring flexibility of supply aimed at ensuring rapid increases in volume during periods of high demand is clearly evident.

Although the purchasing department may in practise have limited freedom to act in this direction, where such opportunities do exist, the purchase price/prospective delivery performance package offered by a supplier should be evaluated with the above in mind.

The evaluation of the factory sector is complicated by the presence of the sub-contract facility and the influence of the compressor demand. Given the parameter values and demand pattern used in the experiment, optimal performance seems to result from a total capacity response delay (DAPF) in the range 25 to 70 weeks. Values which give more or less responsive configurations upset the interaction between the factory and sub-contract sectors of the model.

The more responsive runs also demonstrate the importance of including backlogs as well as demand in setting capacity levels.

The response delay of the existing system (see section 5.2) lies within the range of values identified as giving optimal system performance. Major efforts to reduce this response time, as well as being expensive, are therefore unlikely to yield any significant improvement in spares performance.

This conclusion may not be robust if significant changes occur in the existing balance of performance between the factory and sub-contract sources of supply.

The results for the sub-contract sector showed its presence to be a positive influence on system performance. In terms of capacity response the trend was similar to but more dramatic than that seen for bought-out suppliers. As the source became less responsive the fluctuation in unfilled orders and desired manufacturing rate increased as did the average level of unfilled orders.

The practical consequences of the results are to underline the importance of the company's existing sub-contractors. Further it suggests that retention of suppliers during periods of low demand may be cost-effective if this would guarantee ready availability of capacity during the next upturn in demand.

6.3 Analysis of Lead Time Characteristic Response

6.3.1. Introduction

The sensitivity analysis identified those parameters directly associated with setting the source lead time as being critical. These were:

DPF - Machining delay

DOIF - The Variable element of the inter-machine delay

DOMF - The fixed element of the inter-machine delay.

The variable element DOIF is modified by the level of orders awaiting machining to give queueing delay thus:

$$\text{Queueing delay} = DOIF \times OIF/NOIF$$

Where OIF is the actual level and NOIF the 'normal' level of orders awaiting machining. The essential elements of the source lead time can then be combined:

$$\text{Lead} = DPF + DOMF + (DOIF \times OIF/NOIF)$$

and can be seen to consist of two fixed and one variable term.

If the lead time is considered in relation to work in progress the model structure can be seen to have defined a simple straight line relationship as shown in Figure 6.2.

In establishing the influence of source lead time on system performance the absolute value of the lead time is clearly important but the possibility also exists that the manner in which it changes with work in progress levels could also be highly significant. For example, although both of the relationships shown in Figure 6.2 would yield similar lead times at the work in progress level marked 'W', it is not possible to state that system performance would be similar for both characteristics.

The problem therefore resolves into determining the influence of both the nominal lead time <u>and</u> the lead time/ work in progress

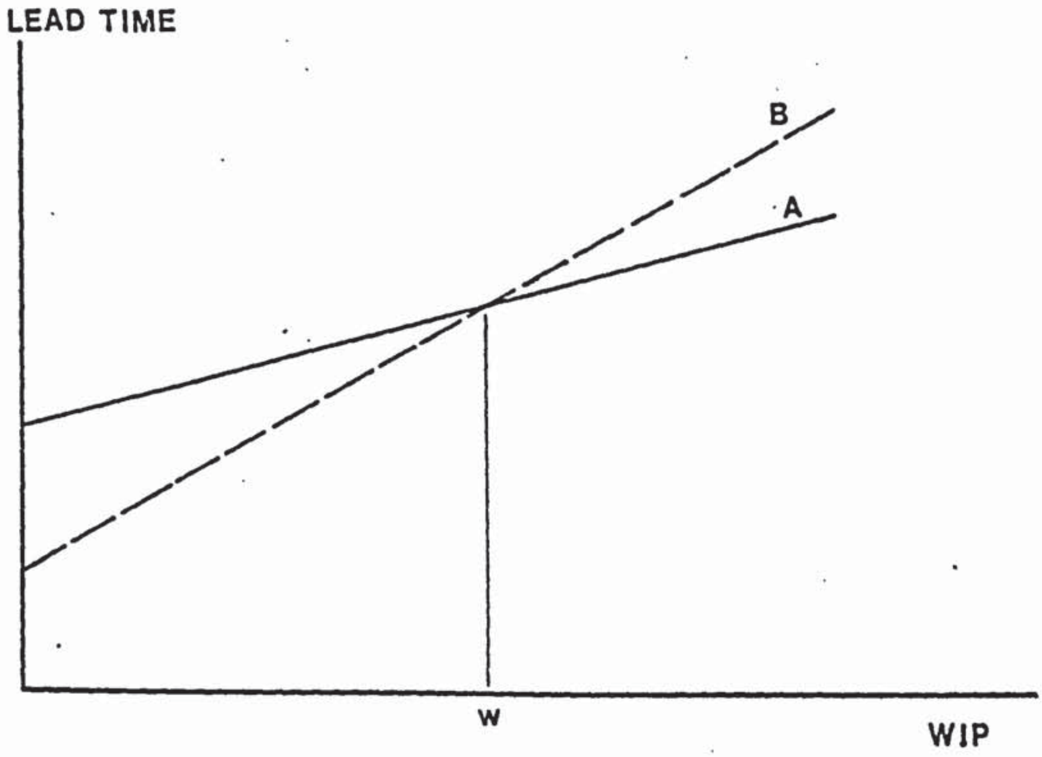

Figure 6.2 Model Lead Time-Work in Progress Response Characteristic

characteristic on system performance.

6.3.2. Experimental Design

In order to conveniently represent the significance of the parameter associated with the variable element in the lead time expression a new relationship was defined as:

$$Pv = \frac{\text{Value of Variable Element Parameter}}{\text{Nominal Lead Time}}$$

thus

$$Pv = \frac{DOIF}{DPF + DOMF + DOIF}$$

Pv therefore represents the proportion of the nominal lead time subjected to variation or can alternatively be considered to be that part directly associated with queueing prior to machining.

Since the significance of the lead time could be considered to apply to any source the basic version of the model was utilised to simplify interpretation and conserve computer running time. A long runlength of 1400 weeks was chosen to eliminate the influence of initial conditions on the results and the form of the end customer demand was again defined as sinusoidal with an amplitude of 20% of the average demand level.

A series of experimental runs were conducted in which Pv was varied between 0.1 and 0.95 for each of a range of lead times from 4 to 48 weeks. Since DOMF could be considered equivalent to the total transport time between operations, was small, and (in relation to the total lead time) could not be altered significantly, the values of DOIF and DPF were adjusted to give the desired values of Pv and lead time.

Lead	4		8		16		24	
Weeks P_v	DOIF	DPF	DOIF	DPF	DOIF	DPF	DOIF	DPF
0.95	3.8	0	7.6	0.2	15.2	0.6	22.8	1.0
0.9	3.6	0.2	7.2	0.6	14.4	1.4	21.6	2.2
0.8	3.2	0.6	6.4	1.4	12.8	3.0	19.2	4.6
0.7	2.8	1.0	5.6	2.2	11.2	4.6	16.8	7.0
0.6	2.4	1.4	4.8	3.0	9.6	6.2	14.4	9.4
0.4	1.6	2.2	3.2	4.6	6.4	9.4	9.6	14.2
0.2	0.8	3.0	1.6	6.2	3.2	12.6	4.8	19.0
0.1	0.4	3.4	0.8	7.0	1.6	14.2	2.4	21.4

Table 6.8a.Lead Time Characteristic Parameter Values

Lead Weeks Pv	32		40		48	
	DOIF	DPF	DOIF	DPF	DOIF	DPF
0.95	30.4	1.4	38	1.8	45.6	2.2
0.9	28.8	3.0	36	3.8	43.2	4.6
0.8	25.6	6.2	32	7.8	38.4	9.4
0.7	22.4	9.4	28	11.8	33.6	14.2
0.6	19.2	12.6	24	15.8	28.8	19.0
0.4	12.8	19.0	16	23.8	19.2	28.6
0.2	6.4	25.4	8	31.8	9.6	38.2
0.1	3.2	28.6	4	35.8	4.8	43.0

Table 6.8b Lead Time Characteristic Parameter Values

The specific parameter values used are given in Table 6.8a and 6.8b.

The structure of the third order delays in the model (of which DPF is one) does not permit values to be specified of less than three times the time increment DT, since the validity of the equations breaks down and instability ensues. No values of DPF were therefore specified of less than 0.2 weeks.

6.3.3. Results and Conclusions

In this experiment the evaluation of the significance of the parameter changes concentrated on the same key measures used in the capacity response exercise. These were unfilled orders and stocks at the warehouse and distributors and the manufacturing rate desired from the factory. In addition to consideration of the mean and standard deviations the maximum and minimum value of each variable during the run were recorded. The trends evident in these latter measures were so similar to those shown by the standard deviation that detailed figures are not included in the data presented here.

The means and standard deviations of the distributor variables are given in Tables 6.9 and 6.10 and those for the warehouse are shown plotted against the nominal lead time in Figures 6.3-6.8 and against Pv in Figures 6.9-6.14.

The trends indicated by the graphs are quite different at extremes of the lead time spectrum. At low lead times improvements in mean and standard deviation consistently follow a reduction in lead time variability whereas for long lead times (32-48 weeks) the trend is completely reversed. In the middle range of lead times a 'hump' effect may be observed yielding superior system performance at extremes of the variability range. This pattern is present in all the variables examined although it is less significant for those in

Lead Time Weeks	Distributor Inventory Levels							
	Run Means				Run Std.Deviations			
	Maximum	Pv	Minimum	Pv	Maximum	Pv	Minimum	Pv
4	1608	0.1	1605	0.8	236	0.8	228	0.1
8	1607	0.1	1603	0.9	240	0.7	230	0.1
16	1603	0.95	1601	0.4	246	0.4	240	0.95
24	1604	0.95	1598	0.2	255	0.2	239	0.95
32	1604	0.95	1593	0.2	267	0.2	236	0.95
40	1605	0.95	1587	0.2	281	0.2	234	0.95
48	1606	0.95	1585	0.1	281	0.1	233	0.95

Table 6.9 Influence of Lead Time Characteristic on Distributor Inventory Levels

Distributor Unfilled Orders								
Lead Time Weeks	Run Means Maximum	Pv	Minimum	Pv	Run Std Deviations Maximum	Pv	Minimum	Pv
4	61.2	0.8	61.1	0.1	11.0	All	11.0	All
8	61.3	0.9	61.1	0.1	11.1	0.9	11.0	0.1
16	61.5	0.4	61.3	0.1	11.2	0.9	11.1	0.1
24	61.7	0.2	61.3	0.95	11.4	0.4	11.2	0.95
32	62.1	0.2	61.3	0.95	12.2	0.2	11.2	0.95
40	62.5	0.1	61.3	0.95	13.3	0.2	11.2	0.95
48	62.7	0.2	61.2	0.95	13.9	0.2	11.2	0.95

Table 6.10 Influence of Lead Time Characteristic on Distributor Unfilled Order Levels.

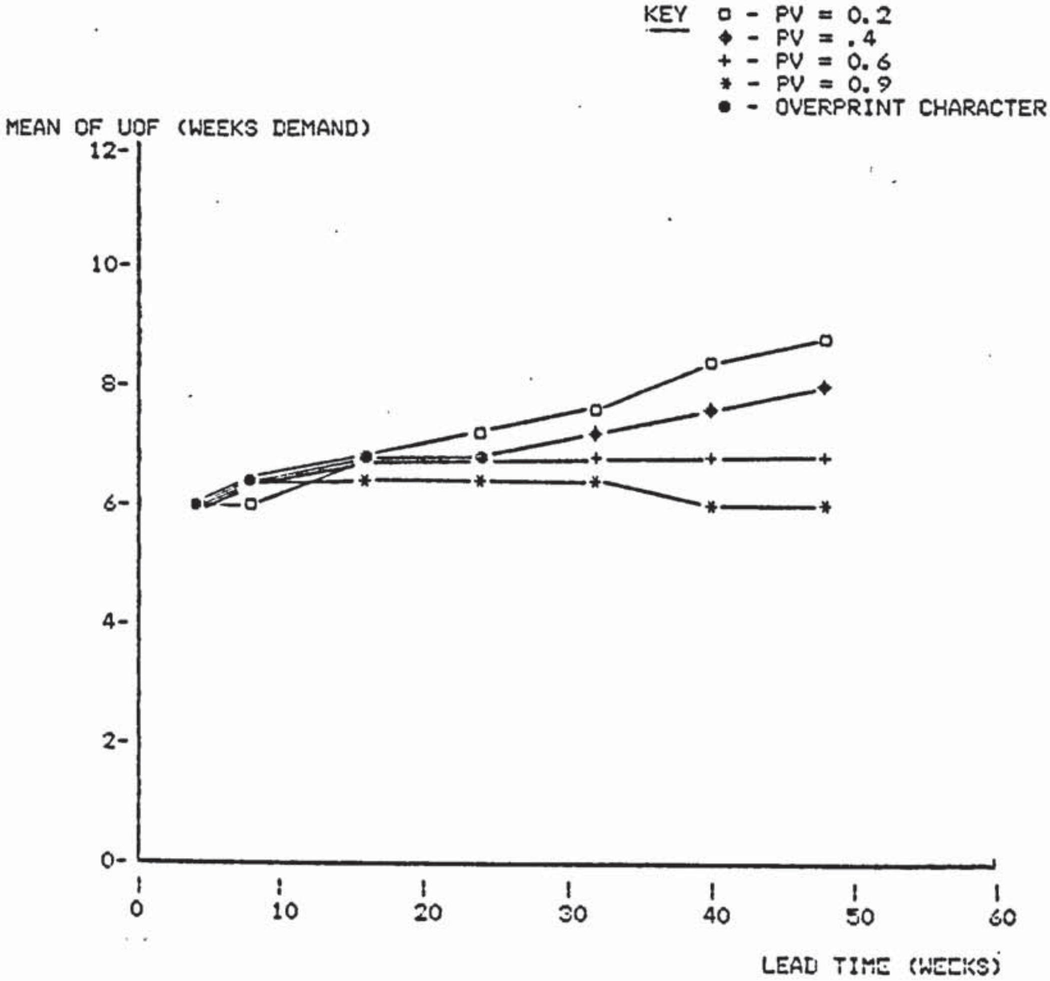

Figure 6.3 MEAN LEVEL OF UNFILLED ORDERS (UOF) V FACTORY LEAD TIME FOR SEVERAL VALUES OF THE VARIABILITY FACTOR (PV)

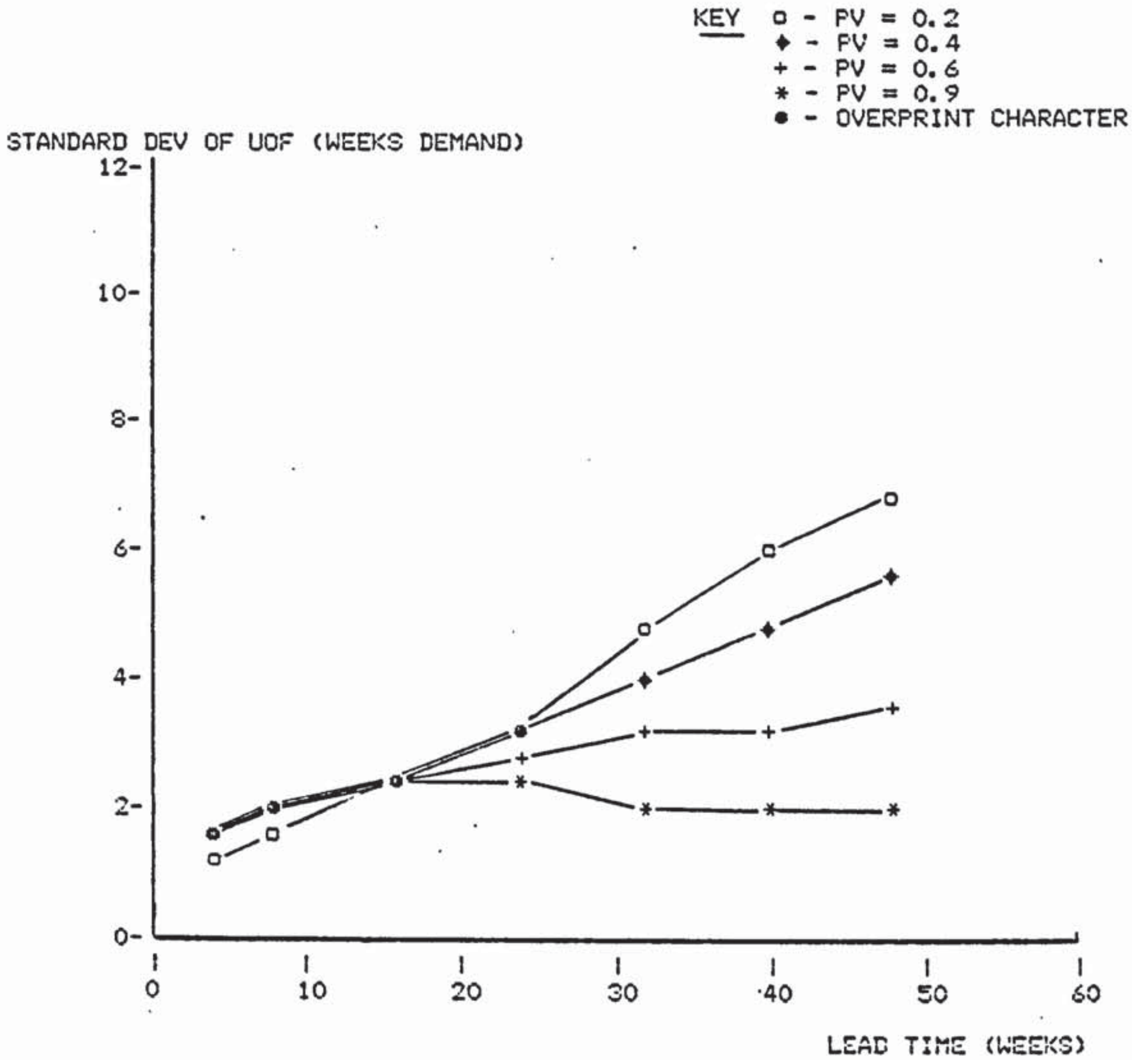

Figure 6.4 **STANDARD DEVIATION OF UNFILLED ORDERS (UOF)V VARIABILITY FACTOR. (PV) FOR SEVERAL VALUES OF FACTORY LEAD TIME**

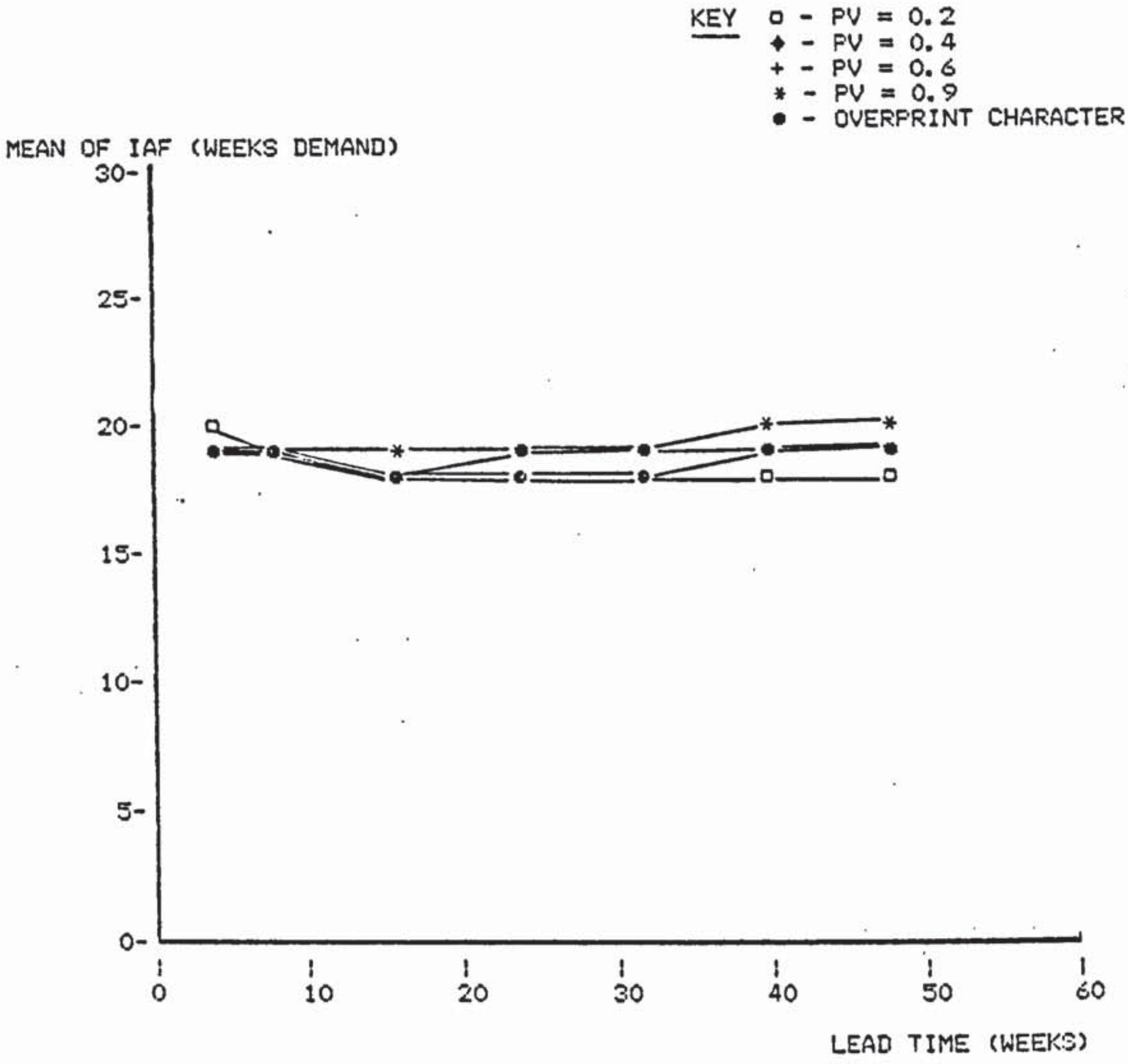

Figure 6.5 <u>MEAN LEVEL OF FACTORY STOCK (IAF)V. FACTORY LEAD TIME FOR SEVERAL VALUES OF THE VARIABILITY FACTOR (PV)</u>

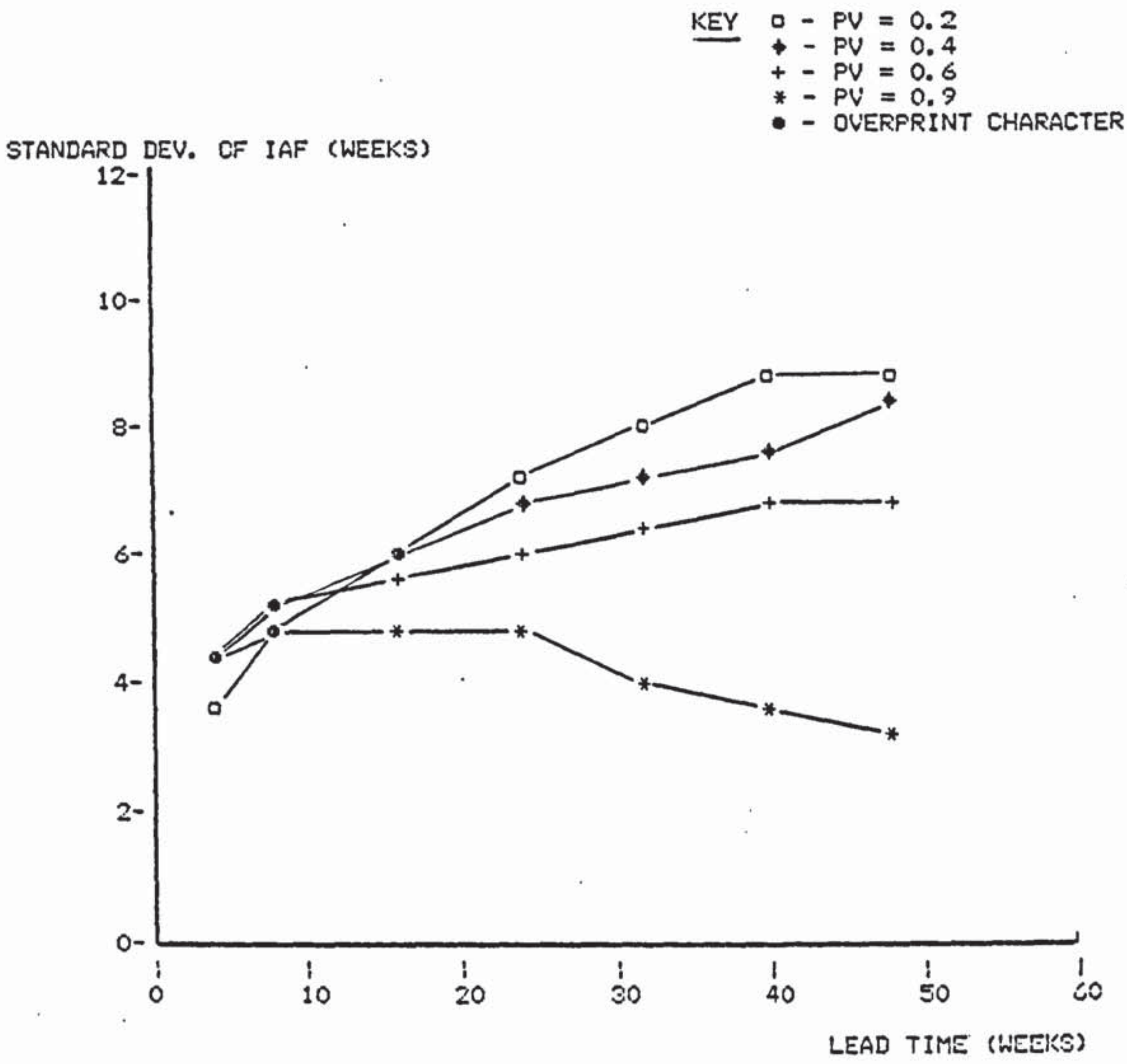

Figure 6.6 STANDARD DEVIATION OF FACTORY STOCK (IAF)V FACTORY LEAD TIME FOR SEVERAL VALUES OF THE VARIABILITY FACTOR (PV)

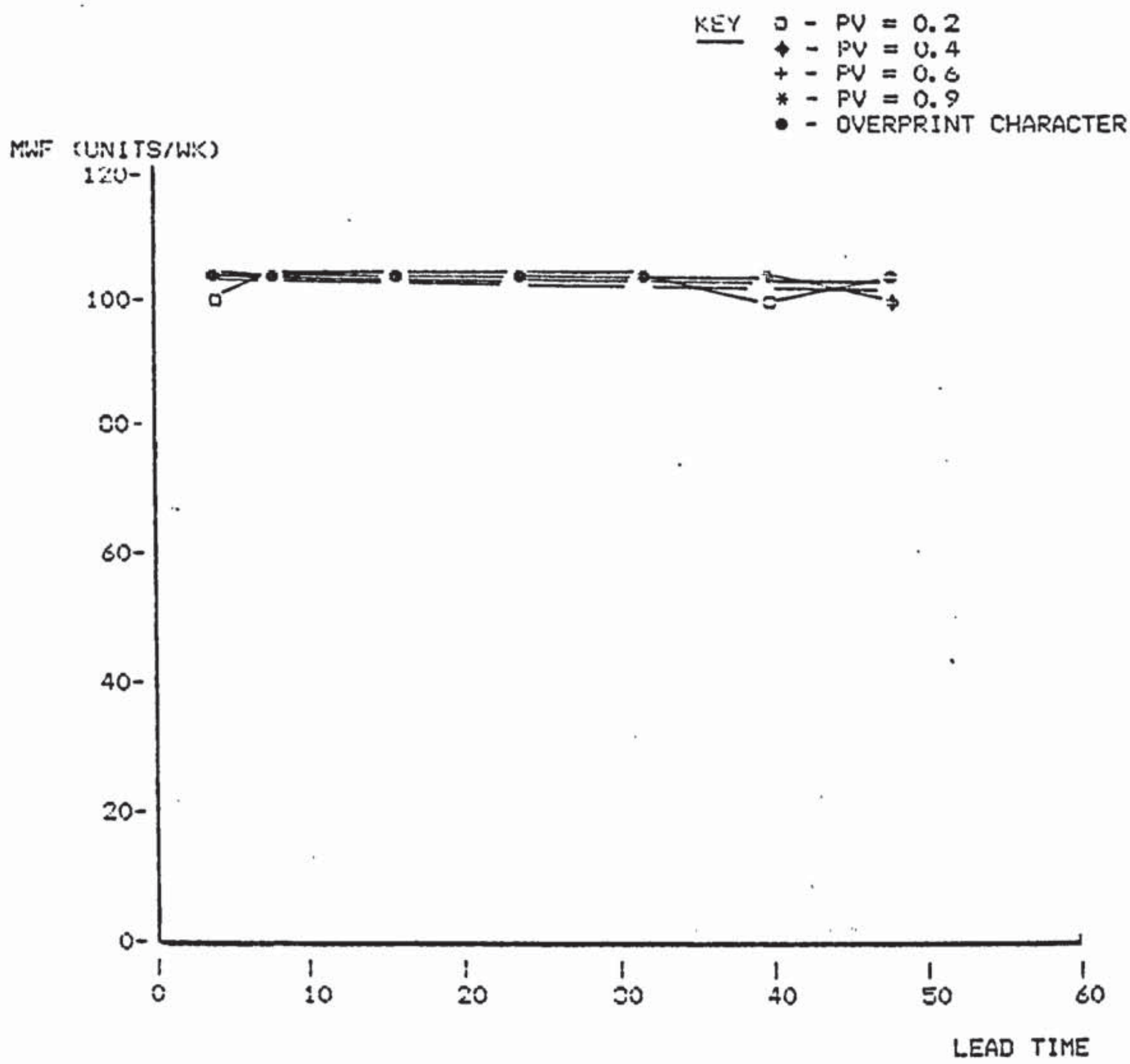

Figure 6.7 MEAN LEVEL OF THE MANUFACTURING RATE WANTED V. FACTORY LEAD TIME FOR SEVERAL VALUES OF THE VARIABILITY FACTOR (PV)

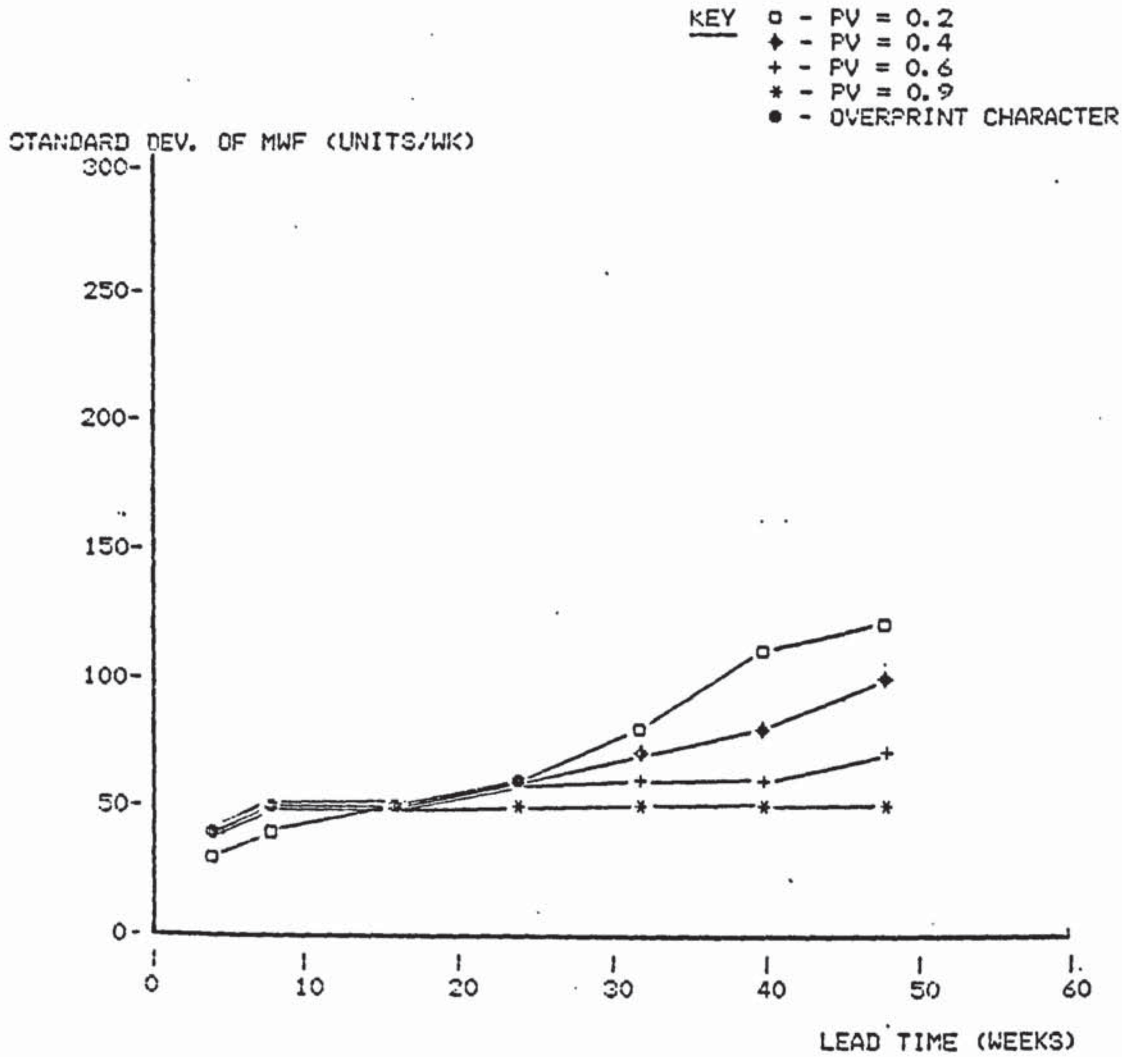

Figure 6.8 STANDARD DEVIATION OF THE MANUFACTURING RATE RATE WANTED V. FACTORY LEAD TIME FOR SEVERAL VALUES OF THE VARIABILITY FACTOR (PV)

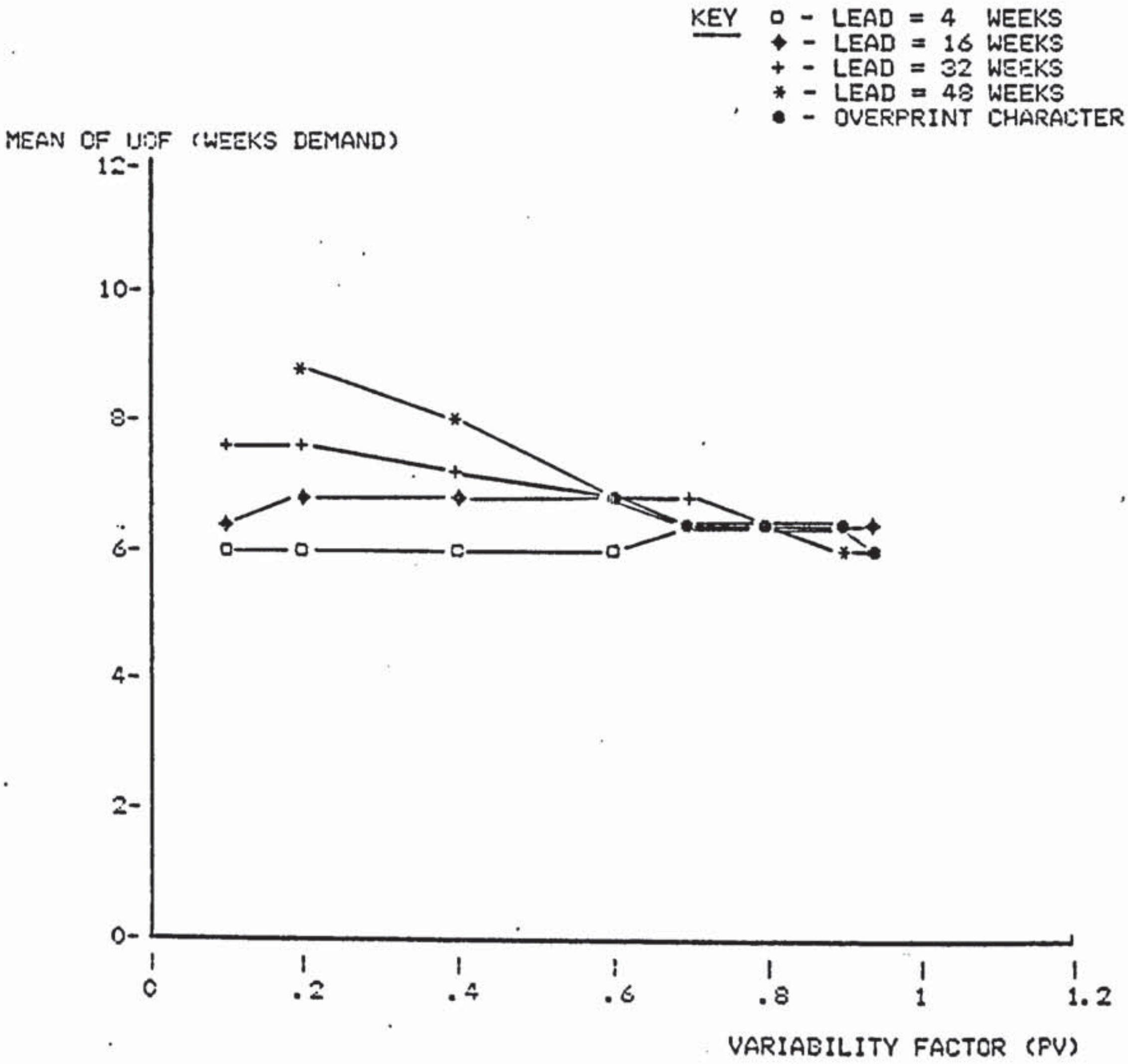

Figure 6.9 MEAN LEVEL OF FACTORY UNFILLED ORDERS (UOF)V VARIABILITY FACTOR (PV) FOR SEVERAL VALUES OF LEAD TIME

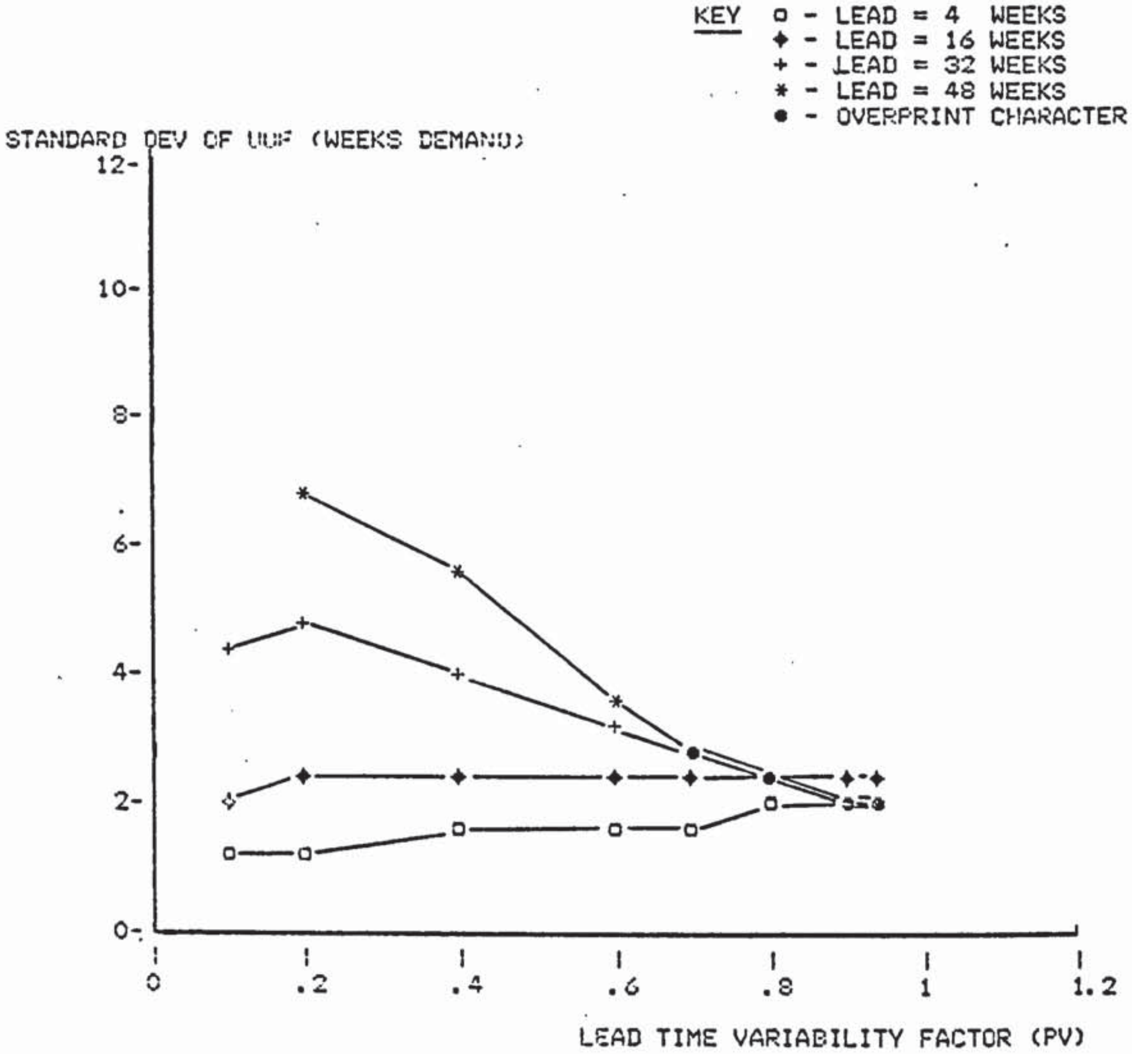

Figure 6.10 STANDARD DEVIATION OF FACTORY UNFILLED ORDERS (UOF)V VARIABILITY FACTOR (PV) FOR SEVERAL VALUES OF FACTORY LEAD TIME

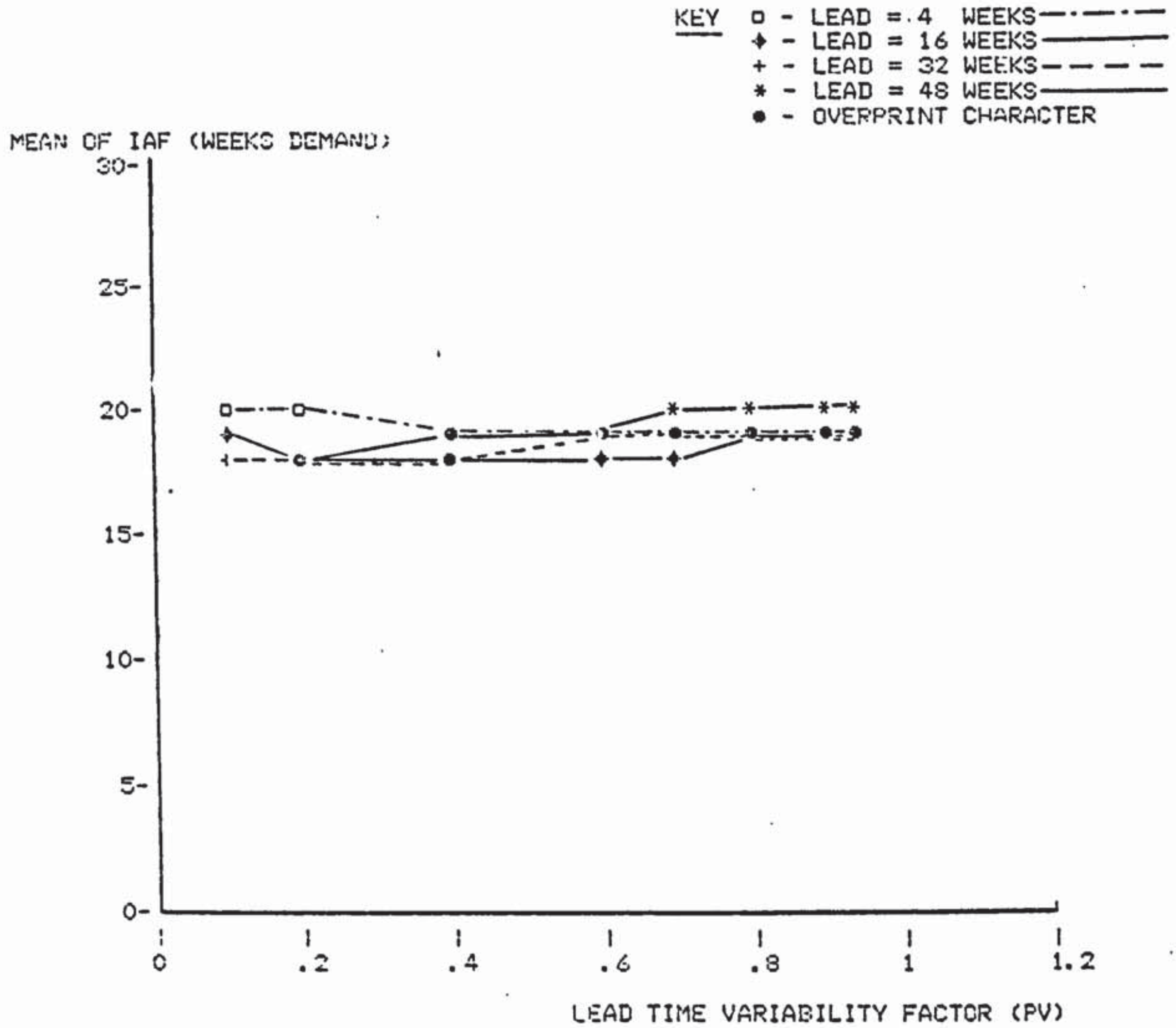

Figure 6.11 MEAN LEVEL OF FACTORY STOCKS (IAF)V VARIABILITY FACTOR (PV) FOR SEVERAL VALUES OF FACTORY LEAD TIME

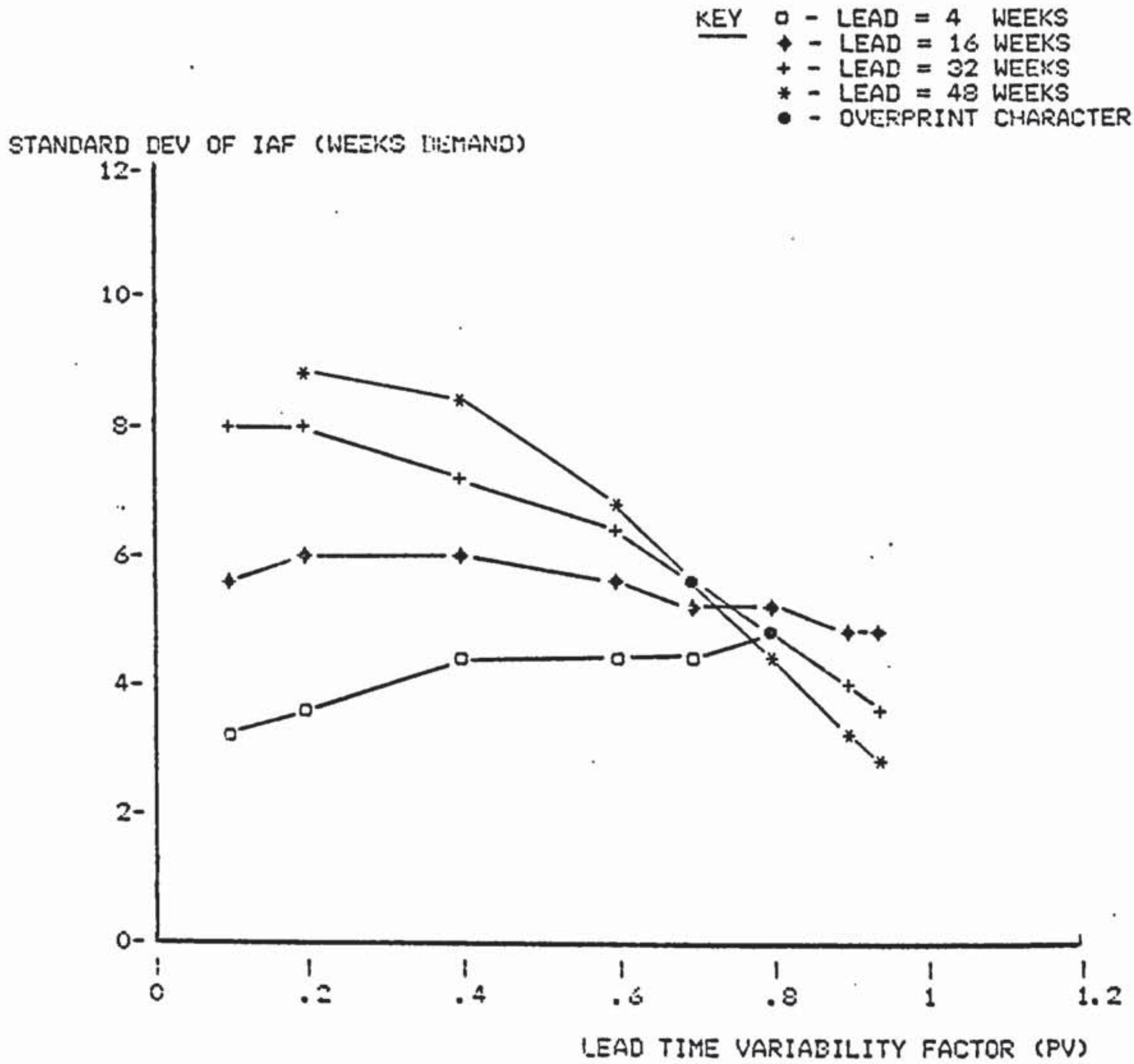

Figure 6.12 STANDARD DEVIATION OF FACTORY STOCKS V VARIABILITY FACTOR (PV) FOR SEVERAL VALUES OF FACTORY LEAD TIME

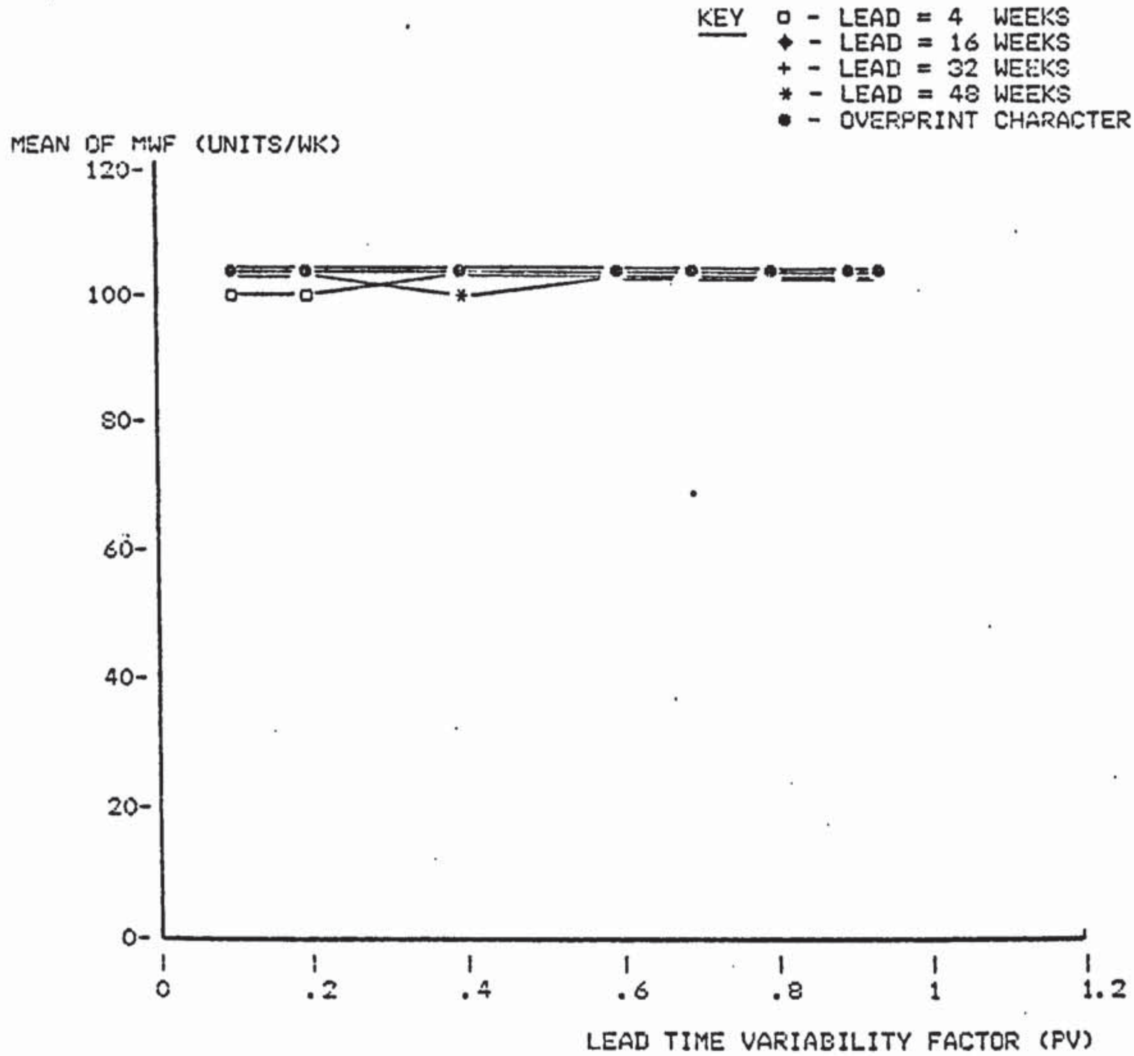

Figure 6.13 MEAN LEVEL OF THE MANUFACTURING RATE WANTED (MWF) V VARIABILITY FOR SEVERAL VALUES OF FACTORY LEAD TIME

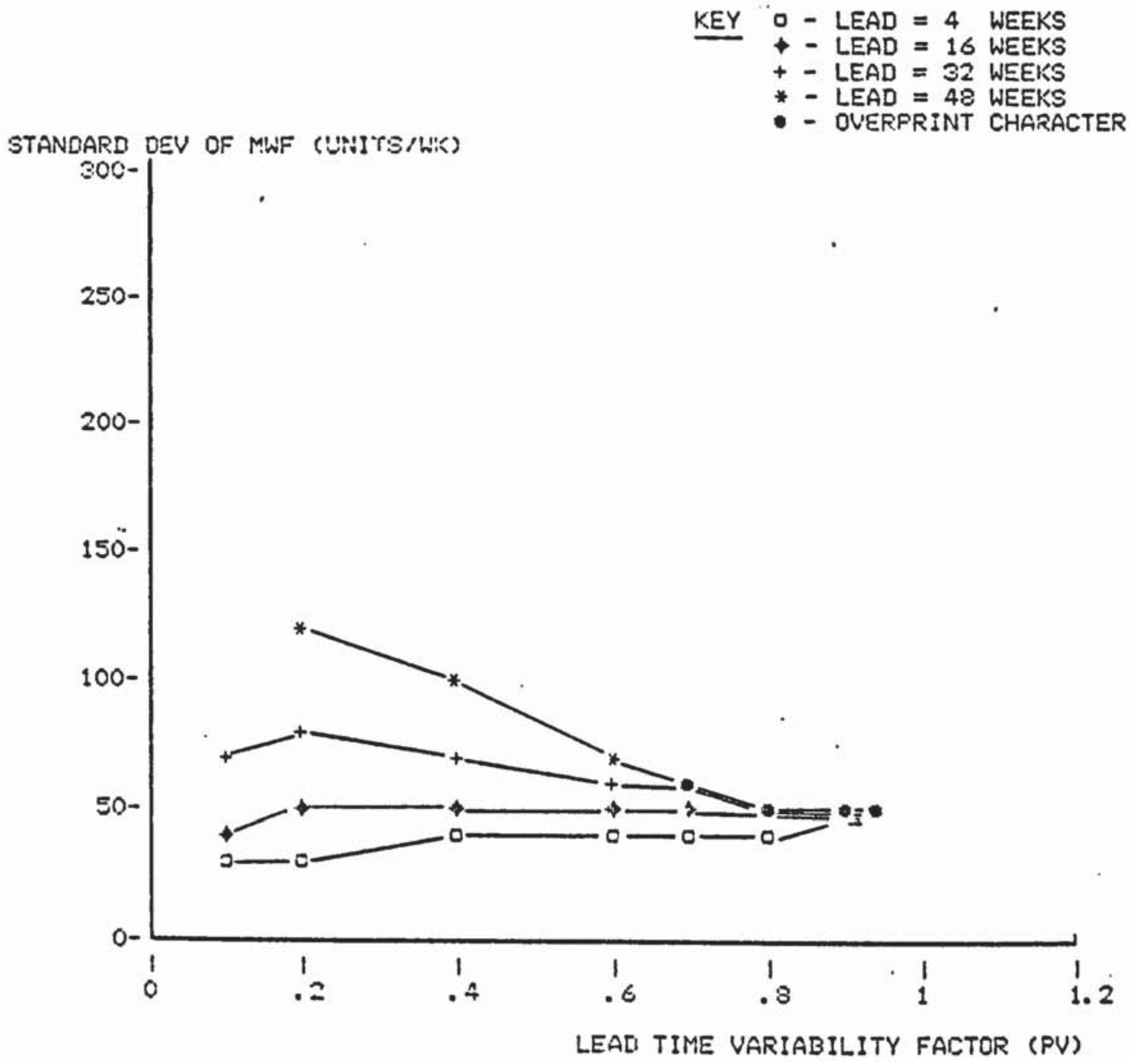

Figure 6.14 STANDARD DEVIATION OF MANUFACTURING RATE WANTED (MWF) V VARIABILITY FACTOR (PV) FOR SEVERAL VALUES OF FACTORY LEAD TIME

the distribution sector of the model.

In general the distributor variables were little affected by the parameter changes.

The mean values of all the variables were more stable than the standard deviations, indeed the only variable to show any sensitivity in this respect was UOF (see Figures 6.3 and 6.9). This performance is consistent with the sinusoidal form of the input. The standard deviations provide a measure of the amplitude of the fluctuation generated in the system and thus lower values of this measure indicate a better controlled system response.

Examination of the figures shows that superior system performance occurs at the lowest values of lead time and that in this area performance is less sensitive to lead time variability. It is worth noting that the standard lead time parameter values yield a nominal lead time of 15.3 weeks and a Pv of 0.73. The opportunity therefore exists of improving the system performance significantly by a reduction in both the length and variability of source lead times.

6.4 Definition of Source Performance Criteria

6.4.1 General Discussion

The results of the two simulation experiments show clearly that the service offered by the warehouse to the distributors is significantly affected by the rate at which manufacturing capacity is brought in line with demand and by the length and variability of the lead time.

Whilst these findings may not appear particularly surprising it should be realised that such characteristics of a supplier or a manufacturing workshop are rarely explicitly considered by production engineers or buyers. In particular performance is normally considered almost solely in terms of cost against steady state or average demand conditions. The dynamic performance of a manufacturing unit especially in terms of lead time variability is not consciously considered when selecting a supplier or designing a production system.

If it were possible to create a single source of supply for spare parts then the following characteristics would be desirable:

i) Capacity adjustment to be achieved with a maximum delay of approximately 25 weeks.

ii) Nominal lead time to be the minimum possible.

iii) Variability of the lead time to be a maximum with a variability factor (Pv) less than 0.3.

The capacity response recommendation is based on the results for the 'bought-out' source (see section 6.2.3) since those for the factory were complicated by the interaction evident with the sub-contract sector. These results indicated that system performance deteriorated markedly for delays greater than 25 weeks. The cost of achieving such capacity adjustments is likely to rise steeply for lower delays and would be unlikely to be justified by a sufficient improvement in service.

The lead time results indicated that good performance could be achieved at both short and very long lead times. Performance at very short times was just superior, however, and significantly less sensitive to the size of variable element in the delay. This latter point is most important since the ability to precisely pre-define the variability factor of a particular production system under all operating conditions must be open to question. Even if the influence of the variability factor has been minimised by the choice of a short lead time it does, however, remain significant. (see Figures 6.3-6.8, Section 6.3.3.). Clearly the identification of those aspects of production system design which can influence the variability factor can be considered an important problem, to which much of the remainder of this thesis is dedicated.

The comments above apply to an 'ideal' state which does not relate to that currently or prospectively faced by the company.

It is to be expected that multi-sourcing of components will necessarily continue for the forseeable future. For example the need to purchase proprietory parts from specialist suppliers will remain and may even increase with the introduction of the screw compressor. There are several options which can be considered in order to achieve improvements in the performance of the provisioning system. These will be discussed in relation to each of existing sources of supply in turn.

6.4.2. Proprietary Components

Selection of suitable suppliers of proprietary components should be made on the basis of historical and prospective delivery performance as well as the normal commercial criteria which apply in such circumstances. Whilst the buyers will normally consider delivery performance in reaching a procurement decision, this consideration is rarely detailed or explicit enough to meet the criteria above. Companies who historically have proved themselves responsive to changes in demand or who can offer this facility in the future should be given priority over others that may offer a more competitive price structure.

The performance of the Parts Division is closely related to the service such suppliers can offer since they provide over 70% of the parts (by value) used by the division. The Parts Division must be in a position to directly affect such policy decisions as those outlined above and on a short term basis be able to take whatever action is necessary to ensure a high supply service level during periods of changing activity. To ensure that the accountability is properly directed for the consequences of such decisions it should be viewed against the total economic performance of the Parts Division.

The current system of purchasing components (often in tandem with compressor requirements) via the Production Purchasing Department prevents such accountability being realised and imposes a long chain of communication between the supplier and end customer. The establishment of a purchasing function within the Parts Division would allow a proper accountability to be realised and a more flexible and responsive purchasing policy to be achieved.

In a few instances the production by the company, of a range of bought out components might prove attractive providing the lead time and unit costs achieved by the manufacturing unit could substantially better those offered by outside suppliers. In terms of lead times the existing production facility would not appear competitive but this situation does not necessarily hold at a detail level. For example the lead time offered by Dienes for valve components was 65 weeks in the time this study was performed and the company agreed to investigate the setting up of a specialised valve component manufacturing unit.

6.4.3. Manufactured Components

The service offered to the Parts Division by the production facility could be improved by a clear statement of policy indicating that priority is to be given to spares whenever conflict arises with a compressor build requirement.

Even if such a policy could be effectively implemented at a detail level the resultant improvement would still be limited by the slow response of the manufacture facility which would remain unchanged. In addition it could be considered that any improvement in spares service would be matched by a corresponding deterioration in that for compressors. Nevertheless a case can be made for applying this policy exclusively to breakdown orders (ie where a compressor is out of action awaiting the part).

A more fundamental approach would be to investigate the possibility of change in the operations of the total manufacturing facility. The performance of the facility is partly a function of the production control system and plant layout. These aspects of the production facility have been designed to satisfy the conditions implied by the adoption of a 12 week fixed, 12 month tentative, compressor build programme. This approach does not optimise on the manufacturing lead time or capacity response which have been seen to be key factors from the spares point of view.

To be effective a change in the company's total manufacturing philosophy would require modification of both the production control system and plant/labour organisation.

Such an exercise would represent a major project in its own right and would be unlikely to represent a cost effective solution to the spares manufacturing problem.

The existing manufacturing practice which uses the same facilities to produce components for both spares and compressor build requirements, was established at a time when the non-current (or unique to spares) proportion of the parts range was small. The case for continued manufacture of current parts may prove economically overwhelming, but this position cannot be said to hold for non-current parts. The proportion of non-current components in the spares range is likely to rise substantially as new spares designs displace older traditional reciprocating machines (estimated to reach 56% by 1985). The type of plant needed to manufacture the new compressors is of a quite different nature to that conventionally required. The prospect is therefore for the need for spares manufacturing to grow as the existing production facility becomes progressively more orientated towards production of the screw compressor.

The present range of spare parts has a sufficiently high made in content to occupy a spares manufacturing facility of approximately 30 direct operatives. However the removal of this load from the main production facility would be unlikely to release more than 25% of the machines required and this, coupled with the variety of processes involved, would lead to a capital investment approaching #0.75 Million in order to establish a self sufficient unit. Such an investment would be unlikely to be justified by savings in stock or work in progress and could not therefore be considered sensible. If the creation of the manufacturing unit could be coordinated with the phasing out of reciprocating compressors, the additional capital investment required takes on more reasonable proportions as much of the plant required could be progressively released from the existing production facility.

These considerations dictate a phased introduction to spares manufacturing and suggest that the first step should be to establish a pilot scheme. Maximum benefit would accrue to both the parts and the production divisions if the unit were designed as an alternative source of supply, offering considerably reduced lead times for those components which are least suited to manufacture by the existing production facility. The range of components selected should therefore include a high proportion of non current items. The unit should be autonomous and should be constituted as a department within the Parts Division.

6.4.4. Sub-Contracted Parts

The useful nature of a responsive sub-contract provisioning option was clearly established by the analysis described in Section 6.2.3. The trend evident there indicated that rapid response to changing demand was especially important in this sector, underlining the importance of the company being able to switch suppliers on or off stream during periods of fluctuating demand. Retention of suppliers during spells of low demand may prove cost-effective if such action would guarantee capacity when the next upturn in business occurred .

As with the purchasing of proprietary components, it is important that the Parts Division should have direct control over such decisions and are seen to be fully accountable for them. It was therefore recommended to the company that sub-contracting should be incorporated in the Parts Division purchasing function mentioned in Section 6.4.2. above.

6.4.5. Summary

The recommendations made to the company at this stage of the project can be summarised as follows:

i) To set up a separate purchasing function within the Parts Division to be responsible for the procurement of all spares unique proprietary or sub-contracted parts.

ii) To establish unequivocal priority during manufacture for parts required for breakdown orders.

iii) To investigate the design and viability of a separate manufacturing facility devoted soley to the production of non-current parts.

All these recommendations were accepted, in principle, by the company and resources were allocated to allow reasonable progress to be made on the design of the spares manufacturing unit.

Chapter 7 Development of an Outline Design for Spares Manufacture

7.1. Overview

The design of the pilot spares manufacturing unit fell into two distinct stages, firstly the derivation of an outline specification following conventional production engineering practice and secondly the refinement of this design to meet the dynamic performance criteria outlined in the previous chapter. This chapter is concerned with the first stage of the design exercise. The basic problem which confronts the designer of any manufacturing unit is the identification of a viable base component range. The normal practise within CompAir BroomWade was to work from the compressor future build requirement, exploding this demand into that for the associated components and then, where necessary, adding in the spares requirement. Calculation of the consequent load on each machining centre (or group) and comparison with existing capacity then identified areas where action to increase or decrease capacity was needed. The machine groups are arranged functionally within each of the major manufacturing departments associated with the various classes of compressor (light, medium, heavy). This approach, whilst allowing use of the Production Control forward loading suite of computer programs to perform the arduous calculations involved, was necessarily tied to the existing types and organisation of machines. In addition this procedure precluded any component based analysis of machining requirements since it could only be carried out in terms of air compressor demand levels.

The engineers in the company did not possess the tools necessary to be able to identify a group of parts whose manufacturing rational might be based on anything other than obvious functional similarity e.g. valve plates or crankshafts. Even in such cases, potential members of such groups could only be identified on the basis of experience or inspection of parts lists.

The design of the spares unit clearly started with a completely different set of requirements to those conventionally assessed within the company. These may be summarised as:

i) The components should ideally be non-current and at present manufactured (or sub-contracted) by the Production Division.

ii) They should require relatively simple machining operations.

iii) They should represent a significant proportion of the existing range of non-current parts manufactured by the Parts Division.

Discussions with the company management at this stage confirmed the view, initially at least, that the case for separate manufacture grew less attractive as the size and complexity of the machine tools required increased (and thus the consequent investment). This approach implied concentration in the initial phase on components which basically required only turning, milling and drilling operations. The component range could be increased later as the heavier plant became redundant from the main production facility.

Having identified, provisionally, the kinds of operation to be included in the manufacturing unit it was necessary to find a technique which would enable a suitable component range to be extracted from all the parts made by the company. Two possibilities were immediately obvious; the use of a coding and classification system or a simple form of Burbidge's Production Flow Analysis.

Production Flow Analysis was developed by J.L.Burbidge (1975) as a means of identifying components having sufficient commonality in process requirements for their manufacture to be organised following Group Technology (GT) principles. Components are sorted into groups on the basis of identical (or very similar) process routes, this information being taken from normal company records. One could envisage a simple variant of this approach in which the parts range process data is inspected to find all the parts which visit turning, and/or milling, and/or drilling machines.

A basic problem with the PFA approach concerns its' reliance on existing methods of manufacture and the underlying assumption that the process route held on the computer file or layout sheets is correct. Although the validity of the process route could be checked at the detail analysis stage the initial process profile of the manufacturing unit could only be expressed in terms of existing machine types rather than component characteristics.

The development of a complex sorting program would also be necessary and expression of the sort conditions would be complicated. This latter point arises from the need to express the search condition in an extended compound manner (eg. Machine Group equals A &/or B &/or C &/or D etc). The number of items in the compound condition would be dependant on the number of relevant machine group names presently used within the Production Division. These total 52 for turning 14 for milling and 25 for drilling, and thus one could expect the search conditions to be extremely complex. In addition it would be impossible to directly identify the parts range for a machine(s) having different operational or dimensional capabilities from those of the existing plant.

This approach is therefore of limited flexibility and would be restricted in application to the spares project rather than offering potential for use elsewhere in the company.

Coding and classification systems allow a component to be described numerically, usually in terms of its dimensions, material, shape, and machining requirements. In relation to the problem in hand it follows therefore, that the capability of a particular, or group of machine tools can be described by a range of code numbers. This range can be considered as a filter through which all the coded components can be passed. Any which have codes falling within the specified range can then be considered for manufacture on the relevant class of machines. A paper by Opitz et al (1969) reports a similar analysis which utilises the concept of a 'code number field' which is analagous to the code filter mentioned above.

Depending on the size and features of the coding system selected, the definition and expression of the sort criteria can be expected to be more straightforward than that envisaged for the PFA approach.

The use of a coding system also had the merit of meeting one of the broader aims of the Teaching Company Scheme; that of encouraging the introduction of new techniques into the company to lead to a general enhancement of the management's expertise. The development and successful application of the technique to one area of the company's operation could be expected to generate interest and enthusiasm for its broader application elsewhere in the company. Such applications could include:

i) Use as a design retrieval facility aimed at reducing component variety.

ii) Use in progress planning to prevent duplication of tooling and standardise methods.

iii) Use in production planning to facilitate reduction of setting times through a sequence scheduling based on family grouping.

iv) To provide a manufacturing data base which could be analysed using many component features as entry or sort keys. Such a data base could be considered almost a prerequisite for optimum plant replacement/resource planning/ production costing.

v) To provide the base data for further investigation of the potential for the setting up of specialised machining units.

The considerable potential for use of a coding and classification system in the company and its suitability for the task in hand led to the adoption of this technique as the basis of the method to be used to identify the potential base component range for the spares manufacturing unit.

The overall approach used to derive provisional design for the unit is shown in Figure 7.1.

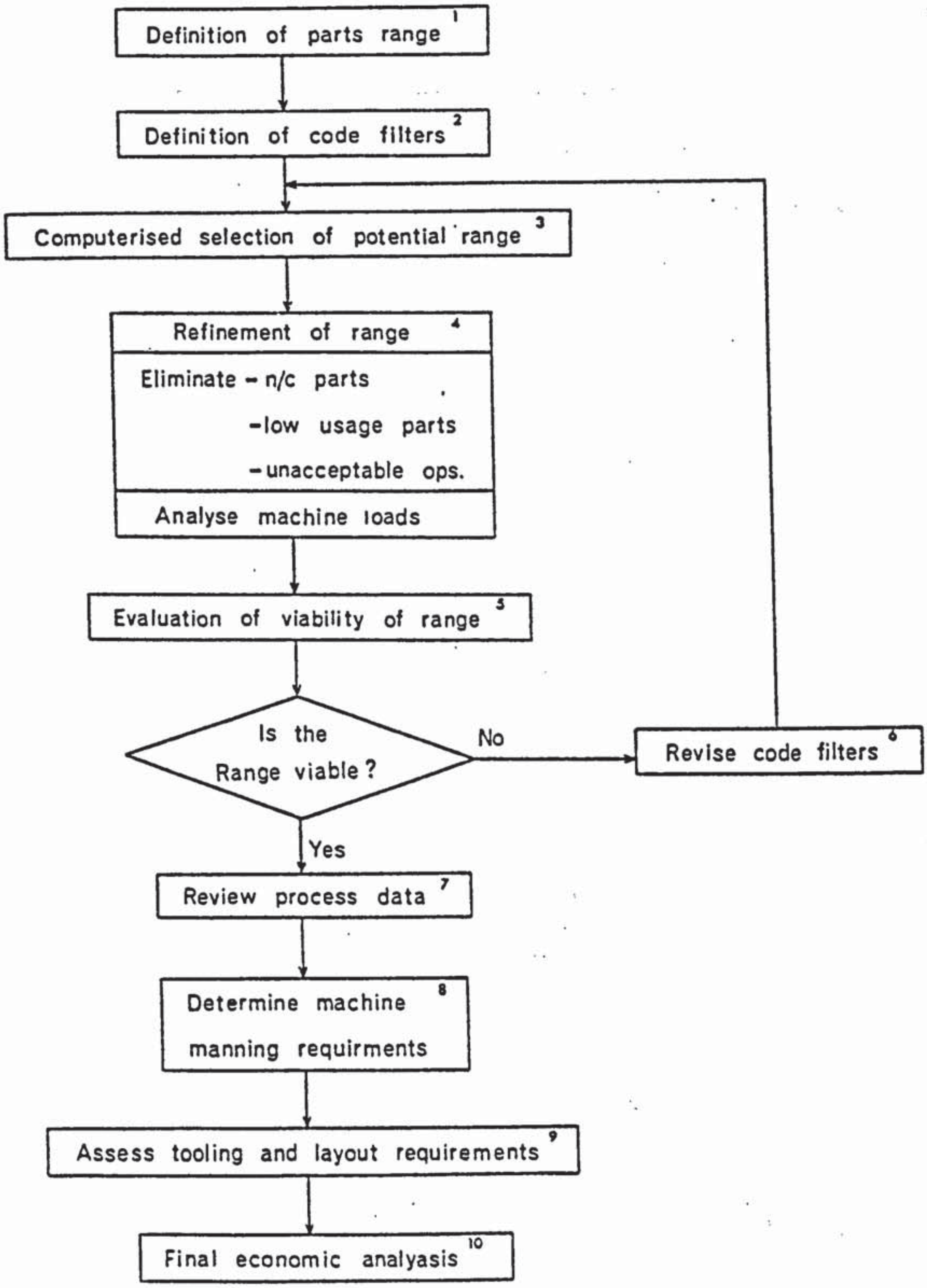

Figure 7.1 ANALYTICAL APPROACH

7.2 Selection and Evaluation of the Coding System

7.2.1. Selection of Coding System

The selection of an appropriate coding system was based on its suitability to both the immediate task of identifying the spares manufacturing unit component range and the wider applications envisaged elsewhere in the company. The implied criteria can be summarised as follows:-

i) The code should exhibit a logical unambiguous structure which could be readily assimilated by people in both the production and design divisions of the company.

ii) A fixed number of digits and a non-hierarchical structure is desirable to ease data processing procedures. Independent digit significance (where a particular digit position always carries the same class of information for all components) is particularly useful in easing the design of feature sorting routines.

iii) The code length be as short as possible, consistent with provision of sufficient detailed information, to allow rapid coding and ready assimilation of the code by company personnel.

iv) The code should contain sufficient information to be potentially useful for design retrieval purposes and to allow identification of machining features either directly or implicitly.

v) The balance of the code structure should fit the company's component range.

vi) The code should preferably, have a proven track record of success in several of the areas of interest.

vii) Full details of the structure and interpretation of the code should be available.

viii) Any cost involved in aquisition of the system should be minimal.

The details of a number of coding systems are given in Table 7.1, including the basic structural format, descriptive abilities, and background data and comment. The data contained in the table were gleaned from various sources, including Knight (1972); Middle et al (1971); Anon (1970); Zimmerman (1967, 1968a and 1968b); Edwards and Fatheldin (1971); Opitz et al (1969, 1971); Gombinski (1964, 1969); Dornbush and Eiche (1969); Brisch and Geoghegan (1957); Gallagher et al (1973); Gallagher and Southern (1973); Gallagher and Knight (1973); Grayson (1967).

All but the Opitz System were rejected for the following reasons:

NAME OF SYSTEM	COUNTRY OF ORIGIN	CODE FORMAT			DESCRIBES						BASIS OF DESIGN	TAILORED OR UNIVERSAL	REPORTED APPLICATIONS/ QUALITY OF DOCUMENTATION	
		LENGTH	DIGIT RANGE	I.D.S.*	SHAPE	FUNCTION NAME	DIMENSIONS	ACCURACY	M/C REQU. + FEATURES	MATERIAL				
BRISCH	UK	Monocode -4 to 6	0-9	Polycode	√H	√H	√P	√P	√P	√P	Code of <u>all</u> items in an organisation	T	Consultants employed	Polycode added to give production data in more accessible form
IAHA	JUGOSLAVIA	8	0-9	After 1st	√		√		√	√		U		Similar to Opitz + information on non-machined parts
OPITZ	W. GER.	5 + 4	0-9	After 1st/ 2nd digit	√		√	√	√	√	Workpiece stats	U	Many/manual available	
PERA	UK													
P.G.M.	SWEDEN	6 + 4	0-9		√		√	√	√	√		U	Limited	Similar to Opitz + extra digit, slightly more biased to prod
STUTTGART	W. GER.	8	0-9	All	Aimed at coding of tooling							T - mc type		Different codes for each type of m/ç tool eg centre lathe
V.U.O.S.O.	CZECH	4	0-9	Last digit only	√		√		√	√	Workpiece stats - m/c tools	U	Pub. papers	Limited detail
V.U.S.T.E.	CZECH	4	0-9	Last 2 digits only	√				√			U	Pub. papers	Biased toward non-rotational
WILLIAMSON	UK	2	0-9	None		√						T	Pub. paper	Classifies only into broad classes of similar function
Z.A.F.O.	W. GER.	20-26	0-9 + Alpha	Mixed	√		√	√	√	√		U	Pub. paper	Very comprehensive but long
ALLIS-CHALMERS "CODE"	USA	8	Hexa-decimal	All	√		√		√		Design retrieval	U	Consultants	Use of Hex novel but no information material or accuracy

* Independent digit significance

Table 7.1 Coding Systems Considered

i) Inadequate descriptive ability - IAMA, VUOSO, V.U.S.T.E. WILLIAMSON, ALLISS-CHALMERS, STUTTGART

ii) Excessive length - Z.A.F.O.

iii) Insufficient documentation or high cost - P.G.M., BRISCH

Details of the opitz system are readily available both in the form of published papers (e.g Opitz et al (1969,1971); Knight (1972); Gallagher and Knight (1973)) and in a comprehensive manual prepared by the Aachen team containing interpretive information and examples of coding conventions. Although originally developed as a vehicle for the study of workpiece statistics, particularly those associated with the machine tool industry, the code has been successfully used in the formation of Group Technology Families (Opitz, 1971), in variety reduction (Gallagher and Knight, 1973; Eversheim, 1974) and in production planning and costing (Gallagher and Southern, 1973). In addition a paper by Opitz, Eversheim and Wiendall (1969) specifically describes its use in an application analagous to that faced here. One of the examples quoted in the paper relates to the selection of a component range for manufacture on a multi-spindle automatic lathe using a technique which Opitz calls a 'Code number field' which is equivalent to the 'code filter' procedure described below.

Criticism has been leveled at the system, notably by Edwards and Fatheldin (1971) and Gombinski (1969) who are proponents of the Brisch system. The 'universal' nature of the Opitz code is questioned, particularly the inherent assumption that the distribution of machined component topology does not change significantly between different companies. The Opitz code effectively assumes a preponderance of rotational components in the distribution since five of the eight first digit positions are devoted to this class of part. The paper by Edwards and Fatheldin throw doubt upon the universal validity of this assumption (and therefore on the code structure) since studies by themselves and PERA showed rotational components to comprise only 39.5% and 44% respectively of the total range. Moreover the proportion of rotational parts associated with the small UMIST sample varied between 14.5 and 89% for different companies.

These comments underline the importance of testing the fit of the code to the user company's component range but ignore the opportunity which clearly exists of utilising the 'spare' digit positions built into the code or of modifying the structure to better fit the needs of the analysis or component topology.

Gombinski (1969) suggests that the requirements of production analysis and design retrieval cannot be satisfactorily contained within a single code and that it is necessary to develop two distinct (but related) code systems. He points out that codes which record the presence of component features (threads, holes, grooves etc) cannot be said to adequately describe machining requirements since many of the features can be produced by a variety of quite different production processes. Only a purpose designed code, such as the Brisch polycode, can provide adequately detailed, unambiguous, production information. These comments are backed by examples from a 'Production Orientated Coding System' (which is clearly Opitz). It should be noted, however that the examples given are especially complicated parts (gears) from a production viewpoint and as such are not likely to form a significant proportion of the component range of many companies (this is certainly true at

CompAir). The difficulty associated with inclusion of such detailed production process information in the code is that it is not a constant attribute of the component (unlike shape and features) and is subject to the same reservations outlined in the discussion of PFA in Section 7.1 above. It is the presence, or otherwise of a particular feature which is important to the designer of a manufacturing unit, since modification of the existing process method may prove desirable from a cost or organisational point of view. Gombinski's criticism of the Opitz code's ability to describe component features is limited.

A brief description of the Opitz code is included in Appendix 6. It was evident from the above review that the use of the Opitz code should be preceded by a check on its fit to the component range and that the possibility of structural modification should also be explored.

7.2.2 Modification of the Opitz Code

Comparison of the sets of coding sheets given in Appendix 6 for the original and modified forms of the Opitz code shows the extent of the changes introduced. A summary review is given below.

i) Rotational Section

Changes were concentrated in the fourth and especially the fifth digits. The ninth position of the fourth digit (plane surface machining) was modified to enable explicit coding of valve components i.e. parts with 'slots or grooves on component face -interrupted'. The absence of drilling information for gears and the complication introduced by attention to drilling patterns were rectified by a simpler structure for the fifth digit.

ii) Rotational with Deviations

Only the fifth digit was modified to give a structure for drilling information consistent with that for rotational parts.

iii) Flat Components

The structure of the second digit (overall shape) did not readily allow parts which were essentially circular (although obviously not turned) to be coded. Positions two and three were modified to rectify this and other changes made to ensure compatability with the new form of the code for cubic components.

iv) Long Components

None except those described below for the third and fifth digit for cubic parts.

v) Cubic Components

The changes to the overall shape digit (second) arose from the need to adequately describe and differentiate the relatively large number of cubic parts in the component range which were hollow and compounded of webs and flanges (e.g. crankcases). The conventional form of the code concentrates on whether such parts are split or not, a feature which was not found amongst the company's components. A simplified structure was therefore introduced which allowed more information on such parts to be coded and also introduced the concept of 'cylindrical' cubic parts. This latter feature was not a contradiction in terms but served to better describe some cylinder and cylinder head components. The structure of the principle bore and rotational machining digit (third) was modified to simplify interpretation and allow information about the shape of the bore to be included (stepped to one or both ends for example). The positions in the fifth digit (one to four) which describe drilling were modified in a similar manner to that mentioned for rotational parts.

vi) Supplementary Code

The main change was the elimination of the digit describing accuracy since it was felt that , at least in this form, the information that it yielded would be of limited practical use. Where this factor was important, additional information would come to light during the detailed analysis stage (when drawings and process layout sheets are studied).

The gap this created was filled by the introduction of an additional dimensional digit which described the length of a rotational part or edge length 'B' of a non-rotational component.

No further changes were felt necessary throughout the remainder of the coding exercise.

7.3 Outline Design Procedure

7.3.1. Initial Coding Exercise

The coding of 2,500 components was completed prior to the start of the analytical phase of the pilot unit design. The exercise was performed over a period of about ten months by a succession of apprentices. The coding rate varied enormously throughout the period for the following reasons:-

i) The code itself was being developed during the early stages.

ii) The use of a succession of apprentices implied lengthy and frequent periods of retraining.

iii) The ability of the apprentices varied considerably.

iv) Microfilms copied specifically for the use of the project team did not become available until towards the end of the exercise.

The maximum coding rate achieved under the improved conditions prevailing at the end of the exercise exceeded 350 parts per week.

All the spares made-in components with monthly usages greater than zero (i.e. less than 6 per year), which were not assemblies, were coded. In addition, a selection of bought out components which were considered as possible candidates for manufacture were also processed.

7.3.2. Analysis of the Coded Information

The greatest attribute of the code is the ease with which it can be manipulated by numerical means. The application of the computer to this task was an obvious step. In conjunction with the EDP Department, it was decided that the best way of bringing all the relevant information about the components together was to add the code number to the component's record in the production stock file. A copy of the current version of the file was obtained exclusively for the use of the project team. The code number for each part was inserted in the area of the record used, normally, to hold the raw material description.

Using standard program, the computer could now be made to sort and print the file on the basis of any combination of the component's attributes. For example; all coded parts could be printed in spares monthly usage order giving such information as:

-monthly usage
-basic standard cost
-delivery time
-part number
-description etc.

The selection of a potential range of components to be manufactured on the spares pilot unit required the ability to select or reject certain of the manufacturing features described by the code. The method of achieving this is described in the next section.

7.3.3. Selection of the Component Range

Once the type of machining operations to be included in the manufacturing unit had been decided upon, a range of code filters were developed to correspond with the desired combinations of:

-physical size and shape

-machining operations

-raw material form and type

Table 7.2 shows a typical code filter which describes components suitable for manufacture on a medium size bar capstan and a simple drill.

The code filters were defined to select parts requiring combinations of the following machine operations:

i) turning

ii) drilling

iii) milling

In addition, the form of the raw material was considered by repeating the filters for:

i) bar sourced parts

ii) casting sourced parts

Three size ranges were also considered:

Accept	Digit Position								
	1	2	3	4	5	6	7	8	9
Either	0 1 2	0 1 2 3 4 5 6	0 1 2 3 4 5 6	0	0 1 2 3 4	0 1 2 3 4	1	0 1 2 3 4 5 6 7 8 9	0 1 3
Or	3 4	0 1 2 8	0 1 2 3 4 5 6 7	0	0 1 2 3 4	0 1 2 3 4	1	0 1 2 3 4 5 6 7 8 9	0 1 3

Digit	Filter Interpretation
1	Rotational component with deviations
2&3	External and internal machining (turning) but tapers unacceptable
4	No plane surface machining (milling)
5	Small holes (drilling) but no gear teeth.
6	Length up to 10".
7	Diameter up to 2"
8	Any material.
9	Round bar, hex bar or tube

TABLE 7.2 Example of a Code Filter

i) Small

- diameter less than 0.8" (bar) or 4" (castings)
- length less than 4" (bar or castings)

ii) Medium

ii)-diameter greater than 0.8" (bar) or 4" (castings)
and less than 2" (bar) 10" (castings)
- length greater than 0.0" and less than 10" (bar and castings).

iii) Large

- diameter greater than 10" and less than 40" (castings only)
- length greater than 0.0" and less than 25" (castings only).

The fourteen computer runs (one per unique filter) resulted in the output of data for 1769 components. This compares with a total of 2500 coded components held on the file. The 2500 coded parts represent all made in spares components with a monthly usage greater than six per year plus a selection of bought out (or permanently sub-contracted parts) which had potential for in-house manufacture.

The later stage of analysis required information about the spares usage,current costs,and process data such as setting and machining times.

A special program was developed by the EDP department which allowed the input of a code filter to generate three print-outs of those components which satisfied the code ranges. These were:-

i) a special print giving part number, code number, spares monthly usage and monthly usage value.

ii) a standard production stock file print which included information about the source of supply, product code, etc.

iii) a special print of the operation layout file for each part giving all the relevant process data.

The later stages of the analysis were performed manually using this data.

<u>7.3.4 Refinement of Range</u>

The first stage of refinement concerned the elimination of all parts with a spares monthly usage value less than £5 which left a total of 487 components. This was necessary in order to minimise the time spent on the manual analysis of machine loads. It was felt that the parts which had low usage values were unlikely to contribute a significant proportion of the total load on the manufacturing unit.

The spares machine load generated by the reduced range of parts was calculated using the existing operation layout data. The number of different machines specified by the current methods was obviously much larger than could be accommodated in the pilot scheme. Further refinement therefore concerned:

i) The elimination of machines (and therefore components) which would clearly be grossly under-utilised (less than 10% of the available time). After this exercise there remained 145 current and 73 non current parts:

ii) The transfer of loads (and components) from a lightly loaded machine to an alternative, which gradually resulted in the emergence in a series of standard machines.

Although, on this occasion, the procedure was performed by manual analysis, the possibility of utilising the computer to perform the routine calculations was investigated and found to be viable.

At this stage it was necessary to make assumptions about setting times and the factors to be applied to process times when a transfer occured between machines having different rates of output. The factor, which equalled the time on the new machine divided by the original process time, was estimated from experience for each class of transfer. For example a factor of 3 was used for transfer between a bar automatic and a bar capstan lathe. This broad approach was necessary because the large number of parts processed in the early stages precluded detailed evaluation.

In the same way, blanket assumptions were made about the setting times, these being:

i) Four batches to be manufactured per year

ii) Setting times were estimated as:

- Capstans and automatics

  - Four hours for the first operation.

  - Two hours for subsequent operations.

- Other machines

  - One hour for all operations.

7.3.5 Evaluation of Viability of Selected Range

Up to this point, current and non-current components had not been considered separately because it was felt necessary that the full potential range should be defined for the class of parts being considered. The two types of component were now divided and the analysis proceeded for non current parts only. This was possible because the non-current part load appeared capable of supporting a viable pilot manufacturing unit. The 'standard' machines and operations which emerged for non-current parts are listed in Table 7.3 The table also gives the load, in actual hours, generated by one years demand for the 73 non-current components which form the core range of parts to be considered for manufacture in the pilot unit.

At this stage, the evaluation was primarily concerned with establishing viable machine loads. The level of load which may be considered viable obviously rises as the investment in the plant increases. The low load shown for such operations as deburr, fit and hand paint can, therefore be considered acceptable. There appeared to be two instances of plant being grossly under-utilised, these being the external grinder and the horizontal mill. The external grinder was included because such a machine was surplus to the

Machine Type	Machine Code	Process Time Actual Hrs/Yr	Set Time Actual Hrs/Yr	Total Actual Hrs/Yr	Number of Machines
Auto - chuck	AC1P			3799	2.2
Capstan - bar	CB4	1533	952	2485	1.4
Capstan - chuck	CC5	1821	704	2525	1.4
Horizontal Mill	MH	56	84	140	0.08
Drill	DS4	303	116	419	0.24
External Grind	GRE	45	32	77	0.04
Deburr	DEB	513	-	513	0.3
Degrease	DEGA	8	-	8	-
Fit	FIT	8	-	8	-
Hand Paint	HP	9	-	9	-
	OPERATIONS OUTSIDE THE UNIT				
Harden	HDN	501	-	501	-
Oxide Black	OB	4	-	4	-

Note. The loads were calculated in actual hours/year on the basis of current factory efficiencies. The equivelent number of machines that the load represented were derived assuming 1760 available hours/year.

TABLE 7.3 First Approximation of Machine Loads requirements of the existing production facility and, therefore, represented a very small investment.

Although only 10% of the capacity of the horizontal mill would be utilized by this component range, the machine was retained due to the following considerations:

i) To achieve the maximum flexibility within the unit in order to allow the manufacture of one off batches of parts to alleviate shortage situations.

ii) A significant proportion of turning load was generated by parts requiring milling.

iii) The purchase of a second-hand machine could reduce the investment and, therefore, the acceptable level of utilisation.

In addition it was considered that more work could be generated for the milling machine by transferring components from existing sources to the new unit.

7.3.6. Revision of Code Filters

In this instance, the need to repeat the cycle did not arise, since the filters proved efficient in extracting the relevant component groups.

7.3.7. Review of Process Data

The reduction of the potential range to 73 parts allowed more detailed evaluation of the assumptions which were used to establish the first estimate of machine loads. The conversion factors were checked for all transfers between automatic and capstan turning machines.

In a similar manner, setting times were also checked and realistic batch frequency calculated for each part The method of analysis is shown in Appendix 7, and the results given for each part in Appendix 8. The revised machine loads are shown in Table 7.4. Comparison, of these loads with the original estimates in Table 7.3, show that large reductions are evident, particularly with respect to setting times. This is a reflection of the level of error which resulted from the original assumptions concerning batch frequency and length of setting times, both of which were too large.

7.3.8. Machine Requirements

The machine loads given in Table 7.4 implied a requirement for the classes and types of machines described in Table 7.5. The assumption that the two automatic lathes would become available from the existing production facility was based on the fact that the non-current spares load on this type of machine exceeded two machine years at that time.

The machines selected are types which are considered to be standard for the task within CompAir Industrial. Lack of resources did not allow a proper investigation of machines offered by alternative manufacturers, or of the suitability of different types of machine.

An investigation was made, however, into the distribution of batch size and frequency throughout the group.

Figure 7.2 shows the yearly batch frequency plotted against batch size. It also indicates the type of lathe which was called for by the existing operation layouts.

Machine Type	Machine Code	Process Time Actual Hrs/Yr	Set Time Actual Hrs/Yr	Total Actual Hrs/Yr	Number of Machines
Auto - chuck	AC1P	2576	344	2920	1.95
Capstan - bar	CB4	1025	129	1154	0.8
Capstan - chuck	CC5	1419	164	1583	1.1
Horizontal Mill	MH	58	16	74	0.05
Drill	DS4	321	20	341	0.2
External Grind	GRE	71	9	80	0.05
Deburr	DEB	376	6	382	0.3
Degrease	DEGA	8	-	8	-
Fit	- T	3		8	-
Hand Paint	HP	10	-	10	-
	OPERATIONS OUTSIDE THE UNIT				
Harden	HDN	148	-	148	-
Oxide Black	OB	1	-	4	-
Shot Blast	SB	3	-	3	-
Deburr	VF	30	-	30	-
Deburr	RF	8	-	8	-

Note. The loads were calculated in actual hours/year on the basis of current factory efficiencies. The equivelent number of machines that the load represented were derived assuming 1760 available hours/year.

TABLE 7.4 Refined Machine Loads

Machine Description	CompAir M/c Code	Cost £'s S/hand	Cost £'s New	Number Required	Source
Chucking Automatic	AClP	-	-	2	Existing Production
Herbert No.5 Chucking Capstan	CC5	6,000	18,500	1	Purchase
Herbert No.4/5 Bar Capstan	CB4	6,000	17,500	1	Purchase
Four Spindle Drill	DS4	3,000	6,000	1	Purchase
Medium Size Horizontal Mill	MH	4,500	6,600	1	Purchase
External Grinder	GRE	-	-	1	Surplus to production requirements

All prices at 1978 levels.

Average of Quotes from several suppliers of secondhand Machine Tools.

Table 7.5 Machine Tool Requirements

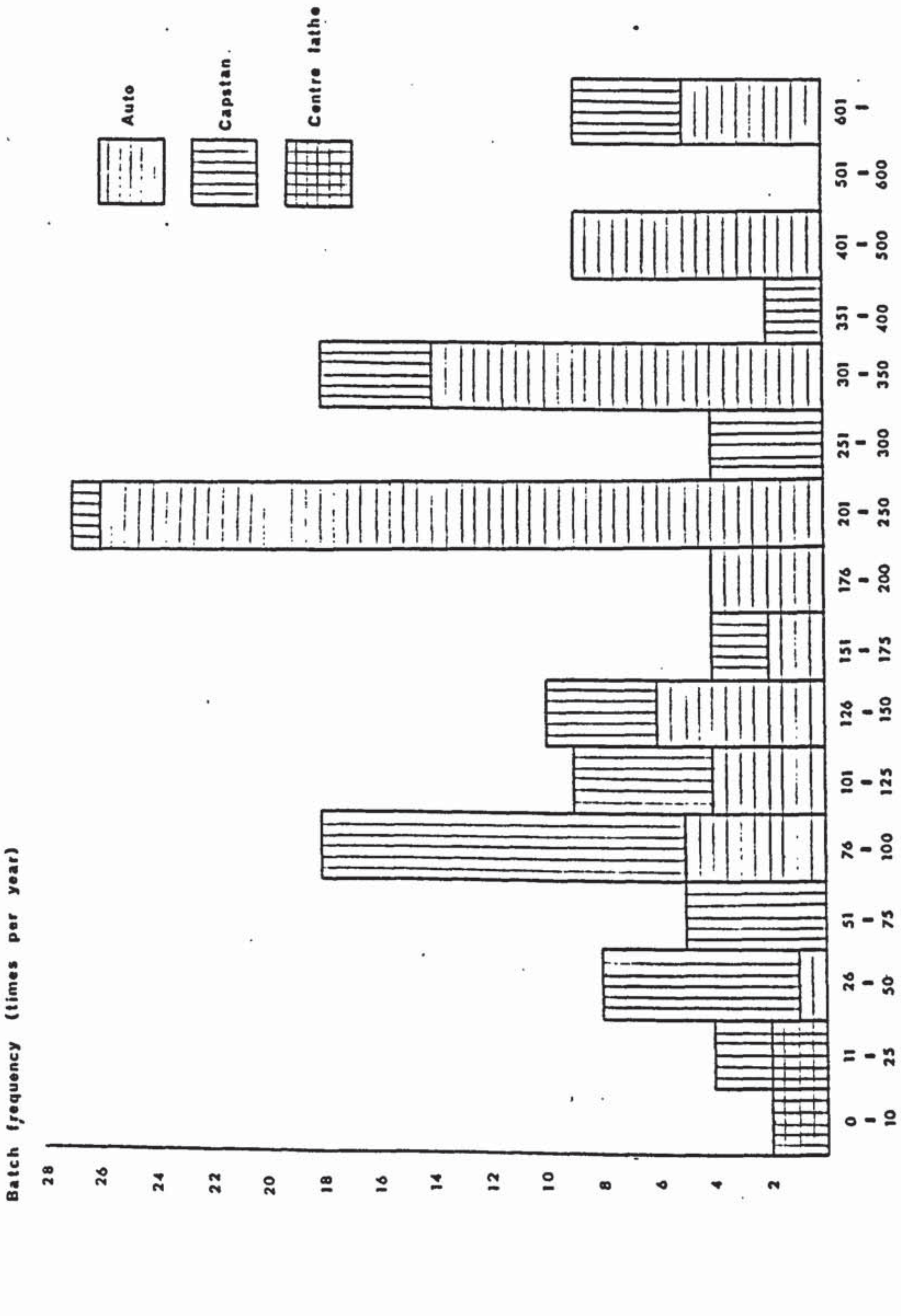

FIGURE 7.2 BATCH FREQUENCY V. BATCH SIZE

The following points should be noted:

i) The original method called for the use of an automatic lathe for 30% of batches whose normal size was less than 150.

ii) The original method called for the use of a capstan lathe for 60% of the batches made where the calculated batch size was greater than 600;

iii) 40% of the batches made and 54% of the part numbers had calculated batch sizes in the range 15-150.

The new method does not call for an automatic lathe for any components which have batch sizes less than 250. Production of batches smaller than this is confined to capstan machines. It should be noted, however, that NC turning machines are commonly considered economic, for simple components, for batch sizes in the range 15-150 (see Rathmill & Littlefield, 1978). The fact that a large proportion of the work load generated by this group of components fell into this range indicated that further investigation into the suitability of NC for this application could be justified.

7.3.9 Tooling and Layout Requirements

Where the method of manufacture was modified by transferring operations from one machine type to another, the need arose to investigate any additional tooling which might be required.

All the affected components were examined but in every case either tooling already existed for the revised method or standard tooling could be utilised. The tooling costs associated with manufacturing these components on the unit were therefore considered to be negligible.

The layout of the machine shop was considered only in the broadest context as a potential site had not been identified. The floor area requirements for the machines, material storage and offices were estimated at 2400 sq. ft.

7.3.10 Manning Requirements

Manning levels and organisation are likely to be substantially affected by the results of the dynamic response design exercise but an example of one of the many combinations of skill patterns and manning levels is included in Table 7.6.

7.3.11. Characteristics of the Selected Parts Range

In Table 7.7 the significance of the selected range in terms of number of parts, monthly usage, monthly usage value and shop load are compared with:

i) The non current parts indentified by the initial computer analysis as having potential for manufacture.

ii) The total non current spares range

It should be noted that the selected range represents:

- 12.5% of the production sourced non-current spares range by part number.

Function	Number	Skill	Direct/ Indirect.
Loader-auto	1	semi-skilled	Direct
Semi-Auto and Inspection	1	skilled	indirect
Setter/op - Capstan	2	skilled	direct
Setter/op - Capstan Mill, Drill, Grind	1	skilled	direct
Labourer/Hand Ops.	1	semi-skilled	direct
Foreman/Clerk	1	-	staff

Table 7.6 Manning Levels and Skills

	Range Selected For Pilot Unit		Range Identified by Computer Analysis		Total Spares Range*	
	Absolute	% Total	M.U.V $\geqslant$ £5	Total	M.U.V $\geqslant$ £5	Total
No. Parts						
Source 1	72	12.5	106	321	342	578
Source 1&2	73	6.8	114	356	633	1066
Monthly Usage						
Source 1	2830	35.0	4320	4442	7300	8070
Source 1&2	2830	12.0	4860	5029	21400	24500
Monthly Usage Value	5000		6485	6784		
Source 1	5000	27.0	6485	6784	18300	18500
Source 1&2	5000	13.0	7027	7197	37600	37900
Shop Load (hrs/yr)						
Allowed	3370	2.6				129630
Cycle	5680	40.0				14240

* Excludes Assemblies

Source 1 Manufactured

Source 2 Bought Out

M.U.V Monthly Usage Value

Table 7.7 Characteristics of Selected Range of Non-Current Parts.

- 35% of the production sourced non-current spares range by monthly usage.

- 27% of the production sourced non-current spares range by monthly value

- The monthly usage value of the selected range represents 2.5% of that for all the spares (including current parts) and 7.5% of all spares manufactured on the existing production facility.

A full description of the parts range is given in Appendix 8.

The above figures relate to the 73 non-current parts selected for detailed analysis. The potential range of parts which could be manufactured is, however, much larger. It was estimated that a further;

- 150 non current parts with monthly usage value less than £5.

- 145 current parts with monthly usage value greater or equal to £5.

- 500 current parts with a monthly usage value less than £5.

would have suitable physical characteristics to enable them to be manufactured in the pilot unit.

The manufacture of two-thirds of the part range is sub-contracted.

The whole production process was performed by a sub-contractor for 34 of the parts whilst the remaining 14 had only selected operations performed outside. The high incidence of sub-contracting may be explained by the competitive nature of sub-contract prices for this class of component. (That is, medium size turned components of a fairly simple nature).

The company cost accountant performed a production cost analysis on the basis of the outline form of the design described above. A copy of the analysis previously presented in a report to the company (Appendix 4, Love and Peckett, 1978) is given in Appendix 9, the machine tool purchase costs in Appendix 10 (originally Appendix 5, Love and Peckett, 1978) and the calculation of stock and work in progress savings in Appendix 11 (originally Appendix 6, Love and Peckett, 1978). It is evident that the reduction in holding costs (estimated at £3,300 p.a 1977/78 prices) would not be sufficient to completely offset the increase in unit production costs which are given in Appendix 8. The increase in costs and the necessary plant investment, the latter offset by a stock saving of £16,600, must be considered in the context of a significant improvement in service which would result from a reduction in lead times.

7.4 Conclusions

The main conclusions to stem from the outline design exercise were:

i) The range of non-current parts described above could be considered adequate to form the basis of a viable spares manufacturing unit.

ii) The modified Opitz code was successfully applied to the CompAir parts range.

iii) The manual analysis of machine loads proved the most tedious and time consuming stage of the exercise.

iv) Although the cost analysis indicated that unit production costs would rise (in comparison to existing methods), this could be offset by the effects of a large reduction in lead times and work in progress.

The potential for the use of the code in a broader context was investigated. In addition to its use in production system design exercises analagous to that described here, the company production and design engineers agreed that applications related to the reduction of component and tooling variety would also be viable. The production engineers also identified the potential inherent in the code for the standardisation of process methods. The company data processing department arranged for the code to be entered and viewed on the main production stock file of the production control system. In addition the extension of the company computerised sort/search procedures to include the calculation of provisional machine loads was explored and found to be feasible.

A development programme was therefore prepared and presented to the company which incorporated all the facilities described above.

Chapter 8 Factors in Manufacturing System Design

8.1 Introduction

The majority of production system design exercises carried out in industry would typically stop at the point reached at the end of the last chapter; that is once the number and type of machine tools, manning levels and production costs have been estimated. Innovation in design is normally concentrated on the process technology or, more rarely, on the organisation of the system. The performance of the system is frequently perceived purely in terms of unit production costs. Reductions in lead times and work in progress costs are mentioned in papers dealing with the installation of N.C. machines or Group Technology (e.g Williamson,1972; Hawkins,1973,1974; Rathmill and Littlefield,1978; Craven,1974; Connolly,1970; Mikton,1964) but these have normally been measured after commissioning rather than specifically defined during the design phase.

A survey of the use of more advanced computer and analytical techniques in British manufacturing industry (Kochhar,1978) in 1978 showed the limited extent that relevant O.R. methods are utilised in practise. The survey of 500 companies showed that only 3% used assembly line balancing, 23% job-machine sequencing, 17% general purpose simulation, and a mere 9% had facilities to simulate the day-to-day operation of their production system. The latter facility can be considered essential to the evaluation of broader performance criterea in new system design.

Kochhar comments:

> "The overall impression is that the vast majority of manufacturing companies do not make use of Operations Research techniques.......... More sophisticated a particular O.R. technique, less use is made of it"

That interest exists within industry in improvement of lead time performance is clear from the response to ideas such as Group Technology which claim to make significant advances in this area. It is in the prediction of such performance factors that activity is less evident perhaps because the analytical techniques required are considered unduly sophisticated by practising production engineers. Those companies in Kochhar's survey which did use simulation were all large and manufactured high technology products.

The design approach developed here demands prior consideration of the manner in which the organisation of the manufacturing system can be expected to influence it's performance. The analysis of historical demand data indicated that the conditions under which a spares production unit would operate cannot be considered to approximate steady state demand. The assumption of steady state demand conditions is implicit in most conventional design exercises and is also to be found in many simulation studies of machine shop behaviour. The industrial dynamics analysis highlighted the importance of the source lead time characteristics in influencing the behaviour of the complete system under conditions of fluctuating demand. The assumption of steady state conditions and the assessment of various design options against such criterea would therefore be questionable in this application (and probably many others).

Short term fluctuation in demand for components is a phenomena well recognised by management scientists. The introduction of stocks as a buffer between sales and production is normally justified as a decoupling device aimed at smoothing demand on the production facility and improving service levels to customers. Much of the development of stock control techniques has been aimed at improving the efficiency with which this task can be achieved. The success with which the stock is able to decouple the production system was shown by Forrester's work (1961) to be limited to the noise, rather than long term trend, element of the demand pattern. The production/distribution model developed here and examples by other workers (eg. Fey,1962; Coyle,1977) all show that the presence of stocks in the customer-manufacturer chain amplifies low frequency fluctuation in demand trends.

The usefulness of the more advanced forecasting techniques, which can detect the presence of such trends more quickly and accurately lies in their ability to provide an early indication to the stock control system that the ordering pattern should be modified. The assumption frequently present in this approach is that the source of supply can respond with little change in the delivery lead time. If the source fails to respond, or does so with a significant deterioration in service, then the advantages offered by an improved forecasting system are lost.

Low variability in batch lead times is a desirable performance feature even when supplying to stock or under steady state demand conditions. Part of the safety stock generated by the more sophisticated stock control systems (Peckett,1979) exists to offset variability in supply lead times. The size of the remainder of the safety stock, which covers short term demand fluctuation, is also dependant on the length of the lead time since this will largely determine the period of uncertainty which has to be planned for. These more conventional considerations reinforce the conclusions from the dynamics study that short lead times are an essential feature of the new design specification. In addition a requirement for minimal lead time variability is seen to be desirable to limit the size of finished stocks.

Whilst lead times are recognised as a conventional measure of production system performance the concepts of capacity response and lead time - work in progress characteristic are more novel. The industrial dynamics exercise concentrated on exploration of the manner in which capacity was modified to suit demand in the longer term, that is by adjustment of machine or labour capacity. The flexibility of the manufacturing system in relation to changes in patterns of demand without major modification to the configuration is also important, that is, what range of demand levels or product mixes can be accommodated without a serious deterioration in performance.

The concepts of a lead time - work in progress characteristic and short term capacity response are interlinked. A 'good' capacity response will tend to reduce the rise in work in progress whilst a 'flat' lead time - work in progress characteristic would minimise lead times for a given level of work in progress.

The majority of production systems can be perceived as a network of inter-related queues. The complexity of this network being dependant on the class of system ie job, batch, flow. The nature of flow line systems is such as to place the queueing stage prior to issue and to ensure near optional balance of machine or more frequently labour capacity. This results in the simple queueing structure seen in Figure 8.1. Comparison of this situation with that postulated in the industrial dynamics model is instructive. The form of the lead time function in the model is shown schematically in Figure 8.2. The size of the variable element of the lead time is dependant on the degree to which the system is under or over loaded and on the value of DOIF. Adjustment to the value of DOIF tends to increase or decrease the gradient of the line.

The delay relationships implied by the flow line form of layout can be expected to lead to dominance of the variable element in the total lead time. The queueing structure for this class of system can also be expected to yield an approximately linear relationship between lead time and work in progress.

The situation for batch manufacturing is, however, more complex. The simplified view of batch manufacture shown in Figure 8.3 suggests that as work in progress rises lead times do not increase until all the spare labour or machine capacity available has been utilised. Restricted labour or machine capacity will result in interference between queues and lead times will then rise with load.

A complete batch manufacturing workshop consists of a number of such machine groups each interacting to produce a complicated overall response. This situation is shown in Figure 8.4.

Factors which could be expected to improve the potential for a shallow lead time - work in progress response are those which seek to improve the flexibility of the manufacturing unit. These factors would also tend to improve the capacity realiseable from the unit under conditions of varying demand or product mix. They could be seen to improve the performance in two ways - by limiting the size of the backlog built up during periods when issue rate exceeds

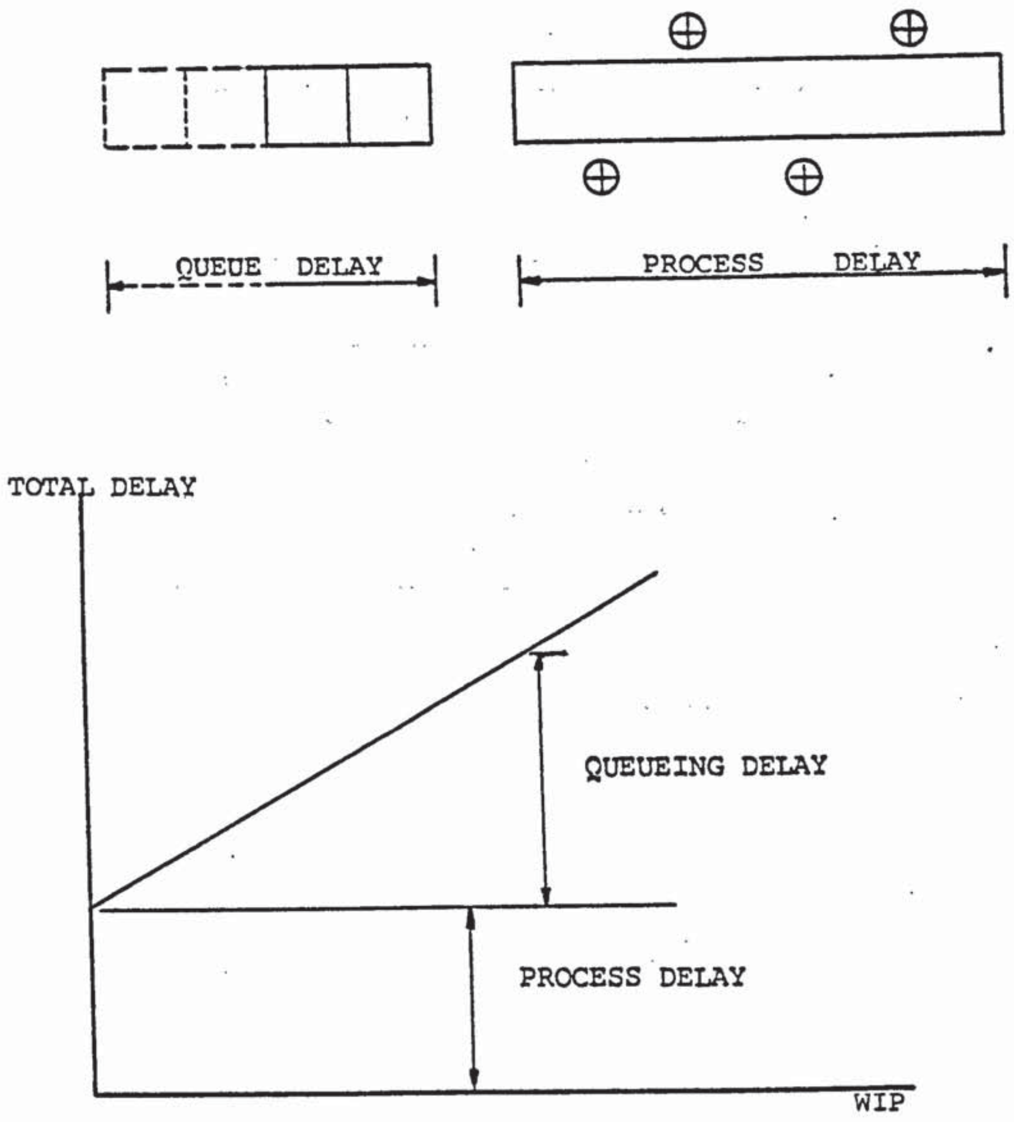

Figure 8.1 Queueing in Flow Line Manufacturing Systems

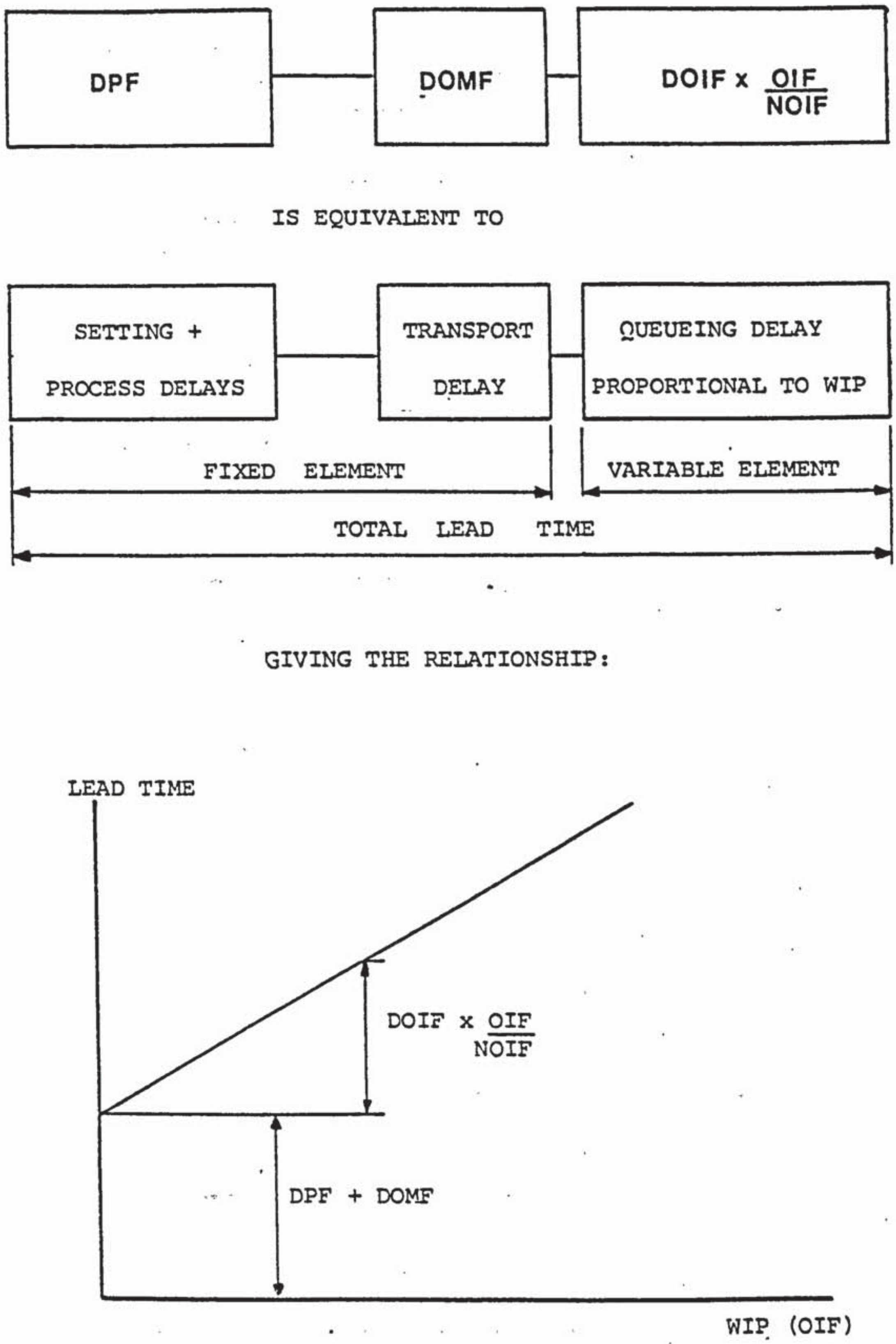

Figure 8.2 Industrial Dynamics Lead Time Relationship

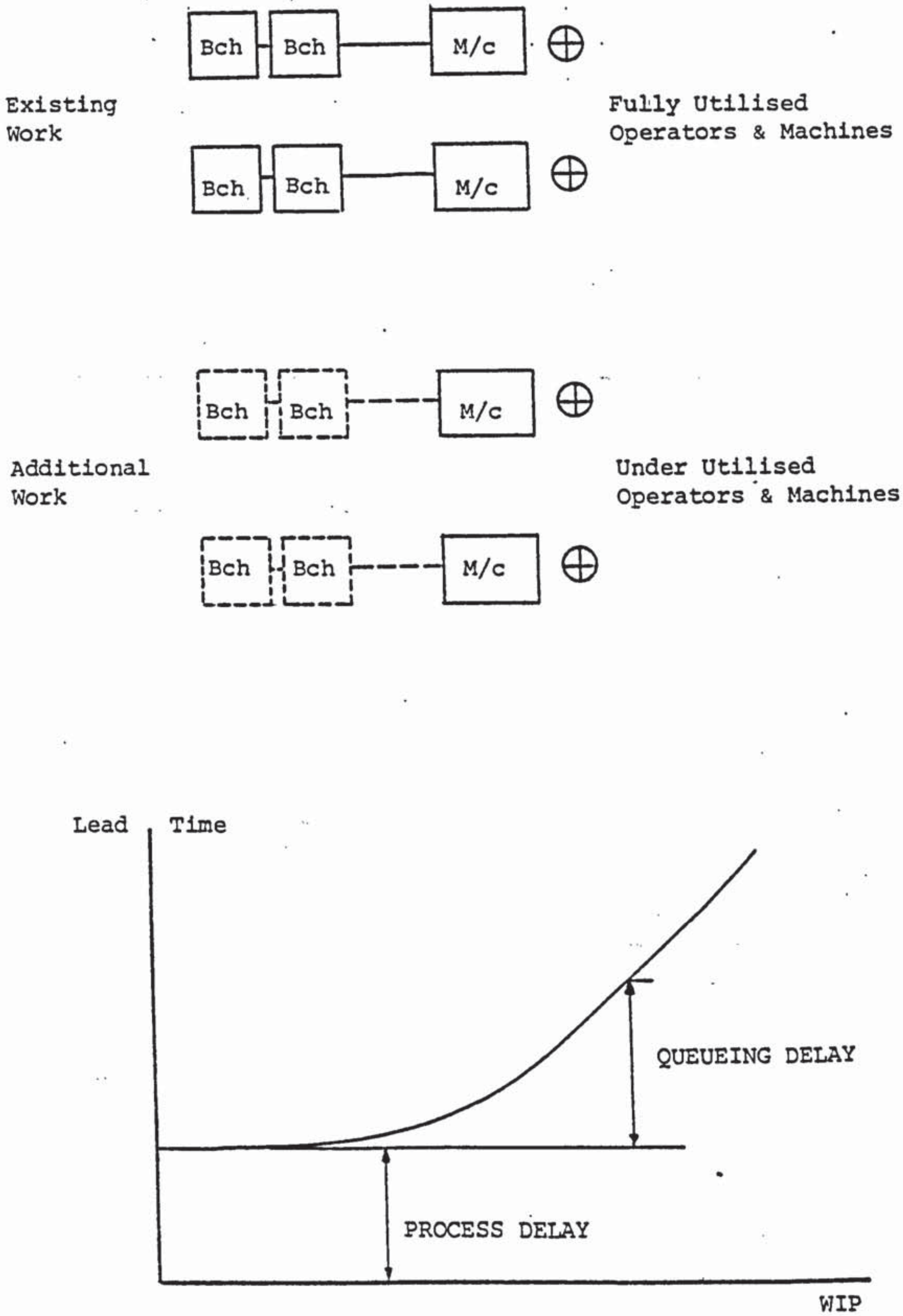

Figure 8.3 Batch Manufacture Queueing Structure at a Single Machine Group

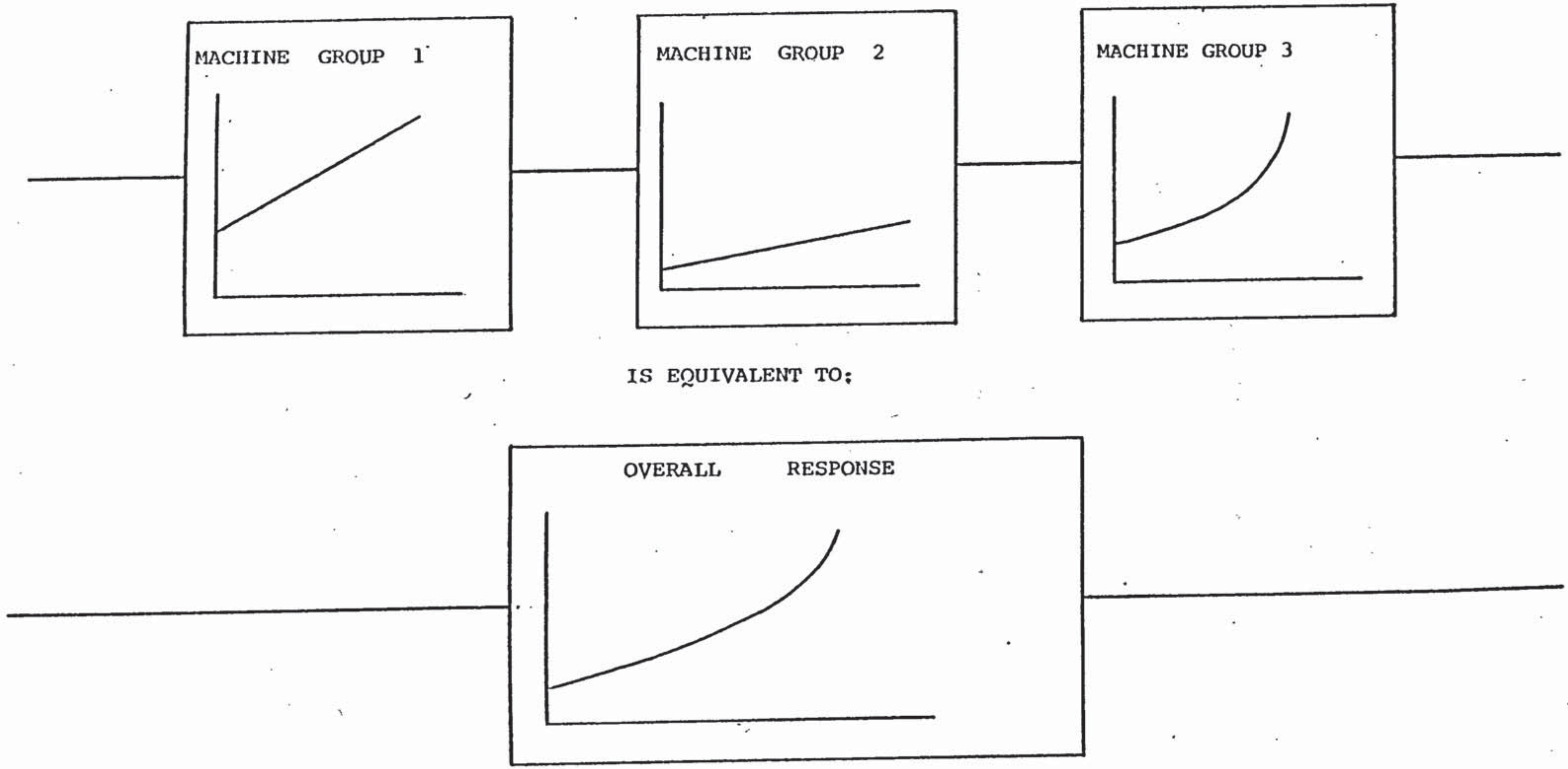

Figure 8.4 Interaction of Characteristics in Batch Manufacture

capacity and by reducing lead times at given levels of work in progress.

The need is therefore to explore the influence of organisational factors which might be expected to :-

- Yield short consistant lead times
- Improve the utilisation of potential machine and labour capacity
- Maximise the flexibility with which the unit may respond to changes in the demand structure of the product mix.

The following section reviews factors which could be expected to influence the above objectives and considers the literature in each area.

8.2 Literature Survey

8.2.1 Introduction

The most obvious place to expect to find work relevant to this area is within the industrial or systems dynamics literature. However, as was shown in the previous review of industrial dynamics literature in section 4.1.3 above, the extensions of Forrester's basic production/distribution model were generally aimed at increasing the breadth of coverage of the models to include areas such as employment policies (Schlager,1964) or the operation of complete industries (Yurow,1967). The majority of the reports of applications become somewhat superficial when discussing the manner in which their conclusions were applied in practice. J.A.Yurow

(1967) comments at the end of his paper that:

> "......a continuous representation is useful for obtaining qualitative managerial guidelines. If more precise measurements are needed, the author recommends simulating the production - distribution system by means of a discrete rather than a continous model."

The literature in this area yielded no guidance relevant to the detail design of the manufacturing unit.

The use of industrial dynamics concepts does not seem to have been extended or checked by any workers using discrete simulation techniques. No references have been uncovered which specifically attack the problem of production system design from this point of view. Where material does have some relevance it appears almost incidental to the main thrust of the work. This finding is consistant with that of D.I.Peckett in his analagous review of the application and theory of stock control (Peckett,1979).

A number of relevant areas were reviewed with special attention being paid to work which could be considered to relate, even marginally, to the performance objectives outlined at the end of the previous section. The areas considered are described in the following sub-sections.

8.2.2 Operational Policies

The heading used here can be considered to cover such factors as capacity, batch sizes and scheduling rules.

A large body of literature exists which is devoted to the problem of resource planning (eg. Riggs,1976). The problem is normally formulated in terms of a number of production - stock policies to be compared with demand patterns of varying complexity (both in terms of the number of product lines handled and the form of the demand call). The policies to be considered may include normal working, overtime working, sub-contracting, make v buy, and stock building, each policy incorporating appropriate cost penalties. The objective of the approach is to minimise an appropriate production or overall cost parameter for an existing range of production options. Essentially it has application <u>after</u> the design stage and considers lead time or service criteria only indirectly via the stockholding or back order costs implied by such factors. This material can therefore be seen to be largely irrelevant to the determination of suitable detail design criteria.

The size of the batches to be processed by the manufacturing system can be expected to influence lead times directly via changes in ratio of setting to process times (and therefore adjusting the level of realised capacity) and by determining the size of the machining delay (equivalent to DPF). In addition the possibility exists that as the level of demand rises or falls the batch size will influence the manner in which that change is translated into activity within the manufacturing unit.

Conventional Economic Batch Quantity (EBQ) analysis ,rather like resource planning, is concerned with minimising the cost of production. Hagan and Leonards (1973) paper provides a typical example of the approach where costs are assumed to essentially divide into two components, one varying directly with batch size and the other being fixed per batch. The complexity of the analysis varies depending on the detail of the treatment but the same basic assumptions and objectives are common to all. The influence of batch size on other aspects of system performance are not considered.

Burbidge (1971) tackles the validity of many of the assumptions used in EBQ approach and correctly draws the distinction between the various 'batch' sizes actually utilised in industry. He shows, for example, that the influence on costs of changes in the order quantity is quite different to that yielded by modification of the 'run' quantity. Burbidge also points out that the batch size can effectively determine the degree of control that can be exercised on the system and the length of the response time of it to changed circumstances, he says (p130-132,1971):

> 'Sensitivity,the first of these indices of efficiency, is a measure of the capacity of the system to respond to changes in the "input"

and

> 'If batch quantities are small production control will be much more sensitive than if batch quantities are large'.

The second indice proposed by Burbidge is 'flexibility' which is expressed as the time which elapses before a change in policy or product can be effected, obsolescence is used as an example of this process.

Both these comments are relevant to the problem at hand since it is precisely this response to 'changes in input' in which we are interested. A simulation analysis of the influence of batch sizes on a number of performance factors was presented by J.R. Crookall and

L.C.Lee (1977). The paper also examined the effect of inherited work in progress levels, tool setting, transport times, manning levels and priority rules. The findings in these latter areas are discussed below.

The variation in batch size was tied to the shop job issue rate in two ways, firstly such that the total processing load (set plus run time) remained constant and secondly such that the run load also remained constant. The simulation showed that for the former case improvements in most measures of the system performance, such as facilities utilisation, jobs completed, lateness, throughput time, queueing and work in progress levels were attendant on decreases in batch size.

The connection between issue rate and batch size would clearly be present in a real system but it is unlikely that the maintenance of a constant total processing load would represent a practical policy. In the long term the demand must be satisfied, whatever batch size is chosen, and since on average;

Demand = Issue Rate x Batch Size

the issue rate could be expected to vary inversely in proportion to the batch size. The second case proposed by Crookall and Lee therefore approaches reality more closely than the first since the run time (rather than set plus run) will be directly proportional to the number of components in the batch. The results for this case were not so consistently in favour of smaller batches, most measures remaining insensitive or actually deteriorating.

Although the conclusions derived from this work may not be generally true for all manufacturing systems since the simulation was based on an abstract cell structured shop, the evidence is sufficient to suggest that batch size does have a significant influence on the non-economic measures of performance relevant to this study.

The paper does not, however, explore the influence of batch size on system performance under conditions of varying load. These conditions would be necessary in order to explore the effect on the 'sensitivity' and 'flexibility' measures suggested by Burbidge.

A major area of research, utilising both mathematical and simulation techniques, concerns the operation of scheduling rules. The scheduling problem tackled here is that of determining the basis upon which jobs should be selected from a queue waiting at a machine, in order to optimise on a parameter such as lateness, average lead time or utilisation of the service facility. The mathematical approach tends to break down for cases where several machines/queues exist or inter-arrival and service times fail to exhibit simple distributions. In such circumstances the use of discrete simulation models allows analysis of more complex (and relevant) classes of manufacturing systems to be undertaken.

The early work by R.W.Conway and A.J.Rowe in the period 1958 - 1965 set a precedent for this form of investigation. Although Conway's early work (1960) was limited by the speed and capacity of the computers then available, the conclusions he reached have remained in many respects unchallenged by later work. It is also interesting to note that at this early stage recognition existed of the potential influence of load on the operation of the various rules. Conway, Johnson and Maxwell, (1960) say;

> 'A rule that was superior under conditions of heavy load might not be advantageous when the shop was lightly loaded. To investigate this possibility the rules were compared at three different levels of shop load, designated as Heavy, Medium and Light.'

and the paper presents utilisation and approximate processing data for each of the load conditions. The relationships implied for the relative performance of the rules do not appear to be consistent for all loads. Unfortunately Conway does not quantify what was meant by the level of loading in relation to the capacity of the production unit, he merely indicates the number of jobs held constant in the shop at 10, 25 and 45 (light, medium, heavy respectively) and also fails to indicate why these particular values were chosen.

The paper by A.J.Rowe (1960) also discusses the influence of load on the performance of various rules. In this case, however, an actual machine shop was modelled and real process data utilised. The load considerations applied to that generated at particular machine groups within the shop by a single order issue rate equivalent to approximately 80% of total capacity. The conclusions for example that 'the difference amongst distributors (of lateness for each rule) appears most significant at heavier loads' are based on examination of mean waiting times at each of the different machine groups within the shop. The gross level of work in progress or issue rate was not varied in the experiment and neither were any of the simulation runs replicated.

A later paper by Conway (1965a) is addressed specifically at the relationship between scheduling rules and work in progress. Improvements in the computing facilities available allowed the length of the simulation runs to be considerably increased although the shop size remained limited at nine machines and process data were generated from appropriate distributions within the program. A large number of different rules were considered. Some quite complex amalgums of process time and delivery factors, and the resultant levels of work in progress measured. The work showed that;

> 'There does not appear to be any reasonable measure of performance in this abstract model of a job shop that is invariant under the choice of priority rule'
>
> 'Even the work content measure, which is known to be constant for a one-machine shop, can be varied in a larger shop'
>
> 'The priority rule under which the job with the shortest processing time is selected clearly dominated all the other rules tested..... It surely should be considered the "standard" in scheduling research.'

In addition, Conway showed that errors of up to ± 100% in estimating process times had minimal effect on the efficiency of the shortest processing time rule.

It should be noted, however, that this study was based on a small, abstract model using artificial data. The processing data distributions were chosen to yield potentially high plant utilisation (90%) and to evenly distribute the work load amongst all the machines in the shop.

Ashour and Vaswani (1972) explore the influence of the form of the process time distribution on the conclusions reached by Conway. They also use a small shop, identical in structure to Conways, with high plant utilisation (93%) and state that;

> '.....empirical evidence has indicated that the size of the shop has not been a major variable. Consequently it is sufficient to experiment with relatively small shops and extend, as generalisations, the resulting conclusions'

Their results indicated that, particularly for the slack per operation (or 'float' based) rule, the performance is influenced by the form of the processing times distribution. The implication is that the validity of the application of conclusions from such simulations to real machine shops may well depend on the relevance of the actual component characteristics to the theoretical distributions assumed in the models. Further, that when engaged in the design of a specific manufacturing unit the use of real component data could be expected to yield more reliable conclusions.

A study by Hitomi et al (1977) examined the performance of the common rules under flow and part-flow conditions, such as might arise in a Group Technology cell, as well as under pure job shop conditions. Analysis of variance was used to determine the influence of several factors on performance including shop load (actually ratio of issue rate against shop processing capacity), set-run ratios, and shop flow patterns.

The results showed that the shortest processing time rule yielded superior mean througput time performance irrespective of the component flow pattern considered. Although not statistically significant, it was also suggested that the disparity between rules increased when the number of operations per component was not identical for all parts. In addition it was found that the load factor was responsible for between 50% and 97% of the mean flow time variance (depending on which rule was considered). The influence of the load factor was therefore considerably greater than either the set-run ratio or set up time variance. These latter conclusions were also found to hold for maximum throughput time but no significant differences were found between any of the rules for this measure of performance.

The paper referred to above by Crookall and Lee (1977) also studied the performance of a limited range of scheduling rules. It was found that the rules which combined elements of Shortest Processing and Minimum Slack times yielded superior performance to that offered by First Come First Served. A third rule which added consideration of setting times was particularly effective for small batches.

The relationship between scheduling rules and work in progress or load can be considered from two aspects:

i) For a constant issue rate the rules will influence the level of work in progress generated in the shop.

ii) The level of work in progress or load will be a major influence on the performance of a rule against parameters such as mean or maximum throughput time

The sensitivity of the rule performance conclusions to the process data distributions suggests that the use of actual component data would provide more reliable results for a specific design exercise. Alternatively close matching between theoretical and actual process data would be a necessary prerequisite.

However, it should be noted that all the studies mentioned utilised steady state conditions, ie the issue rate was invariable and normally less than the throughput capacity of the machine shop. The performance of the various rules under conditions of varying demand were not studied.

Generally the shortest processing time rule tended to produce superior performance both in terms of work in progress levels and average throughput time. More surprisingly Conway (1965b) showed that this rule also yielded good performance against lead time variance, although the minimum 'slack per operation' rule was slightly superior.

Thus whilst the literature indicates potential candidates which might be expected to minimise the build up of work in progress during periods when the issue rate exceeds shop capacity, no specific studies covering this circumstance was found. A similar conclusion applies to lead time performance. Minimum processing time or minimum slack/operation rules might be expected to give good results but their influence on lead times under conditions of varying demand has not been explored.

8.2.3. Layout and Work Organisation

The organisational aspects of the design exercise such as plant layout, materials handling, and job design are largely constrained by the 'class' of the production system. If the volume and product variety permit adoption of mass production techniques then such a choice implies the application of sophisticated materials handling, flow plant layout, and division of work elements. Spares manufacture clearly falls within the batch manufacturing sphere. This class of system allows a broader range of options which may, in general, be categorised under two headings - functional layout and Group Technology.

The traditional approach to batch manufacture utilises functional plant layout; that is where all the machines of a similar type are grouped together in the shop. Batches normally exhibit a complex flow pattern and operational balance is achieved through the presence of large queues of work before each machine group. Operators are frequently single skilled and often continuously work on an individual machine type. The lead time performance is typically poor, both in terms of length and variability, due to the high level of work in progress and the control problems which that generates. The problems of control are linked to the high level of work in progress and the complexity of the component flow paths. This latter factor prevents effective detailed forward scheduling of specific batches throughout their operation sequence, since arrival times at particular machine groups cannot be predicted with any degree of accuracy. In such circumstances, adequate levels of utilisation of facilities, especially with the use of single-skilled operators, can only be achieved with large buffers of work in progress at each machine group. Maintaining queue discipline, essential for the application of scheduling rules, can also be difficult, particularly under incentive payment conditions.

Those companies who have achieved good control performance using functional layout have generally utilised a very detailed (and expensive) computer based production control system, often with real-time feedback of progress information from the shop floor, (see Malcolm,1976; Norton and Fogg,1977; Leonard and Rathmill,1977) Thus functional layout batch manufacture can be considered to be an inherently poor system, although the performance can be improved by the application of rigid sequence discipline and sophisticated management control systems.

An alternative approach to functional layout , Group Technology was developed during the 1950's and 1960's as a means of bringing some of the benefits displayed by mass production to batch manufacture. Whilst Group Technology,as presented by Burbidge (1975), Thornley (1971) etc, represents a complete manufacturing philosophy, the central theme rests on the manufacture of 'families' of components, grouped on the basis of process similarities, within self-contained cells of dissimilar machines. The small size of each unit and the much simplified flow patterns that follow from this approach ease the problems of control and, particularly for flow line class of G.T. systems, allow detailed forward scheduling to take place. Most G.T. systems are also characterised by some element of labour flexibility. This factor allows the cell to be balanced by movement of operatives, thus dispensing with the need for high, within cell, levels of work in progress.

The majority of the reports of practical applications of the technique indicate large reductions in the level of work in progress and lead times (eg Connolly et al,1970; Williamson,1972; Hawkins,1974). In addition a reduction in the variability of lead times is also normally achieved. Some applications also report that the opportunity was taken to sequence production so as to reduce set up times and effectively increase batch sizes, (eg. Hawkins,1973), an activity made easier by the component similarity inherent in the family structure.

The evidence for the superiority of Group Technology over functional layout is primarily empirical. The performance of such systems under fluctuating demand or conditions of varying product mix are not normally considered in this literature.

The characteristics of the technique can be considered in two classes - those which are unique prerequisites to its application, and other features which are normally found in G.T. systems (and may prove essential for sucess) but which could be incorporated in a functional production system. It is clear that the division of the component range into families and the physical grouping of the plant into cells or flow lines are essential features of the approach, and must therefore be considered in the former category. The benefits which flow from such features can also be considered to be unique to the approach. These would include, for the examples quoted, reduced transport time/costs, easier operational control and improved management accountability.

The second set of features may be more commonly found in G.T. systems because such an approach focusses the designer's mind on the potential for their use or because the basic plant or component structure enables easier implementation. It is certainly possible to improve the degree of sequence planning in any form of production system but the family and cell/flow line structure of G.T. systems offers inherently less opportunity for deviation from the plan and thus a better chance of success. The reduction of batch sizes coupled with an associated reduction of setting from careful scheduling of job characteristics is an obvious opportunity given the family grouping basic to G.T.

The small size of most cells and the clear definition of the component load for each cell, again basic to G.T. installation, inevitably leads to consideration of the use of labour flexibility as a balancing device. Implementation of such a mechanism is clearly going to be easier in the tightly structured environment offered by G.T. but it could also be considered theoretically feasible for a functional system.

Reports of analytical studies of Group Technology systems occur less frequently in the literature and are, in general, less effusive in their support of the technique. Notable in this respect is the later work by Rathmill and Leonard (1977). Their cost analysis, initially based on queueing models of the two systems, showed that, with the exception of two machine group/cell configurations, functional layout yielded superior performance. The parameter used for comparison included the costs of work in progress and machine idle time. The analysis is especially interesting in that the influence of scheduling efficiency was quantified in both models in terms of the inter-arrival distributions. The conclusions hold for equivalent degrees of scheduling effectiveness between the systems but the authors fail to consider the costs associated with achieving the respective degrees of control in each case.

The analysis is based, in each case, on elements of the total production system - a single machine group for functional layout and an individual cell for G.T.The comparison assumes that the results for each element can be directly carried over to that for the equivalent complete system. This certainly appears reasonable in the case of G.T. systems where generally the elements would operate in parallel but validity is less clear when elements are arranged in series, as in functional layout.

The authors also report, giving little detail, on the results of a simulation exercise which indicated that uncontrolled G.T. was inferior to uncontrolled functional layout in terms of work in progress and waiting time. They conclude that sound scheduling is therefore necessary for G.T. but concede that the complexity of the task is much reduced in such circumstances. They do not report on comparisons of well controlled examples of both systems.

They also investigated the influence of G.T. on batch size utilising practical survey data and an E.B.Q. formula developed by Hagan and Leonard (1973) to determine not only the effect on optimum batch size but also on the sensitivity of production costs to deviation from it. It was found that results varied depending on circumstances.

In general the authors indicate that the G.T. flowline offers undoubted advantages, but only when product mix and demand are stable in contrast to G.T. cells which they believe may result in a deterioration in performance in comparison with well disciplined Functional Layout.

Unfortunately they do not explicitly consider lead times as a performance factor and neither does the work specifically evaluate comparative performance under dynamic load conditions.

Rathmill and Leonard's conclusions are in some instances consistant with those of a simulation study reported by Athersmith and Crookall (1974). A number of different configurations were simulated ranging from one cell of 28 machines of 4 types to an 11 cell system with cell content arranged to perfectly match the component mix. The single cell system yielded the shortest throughput time, and the lowest work in progress (in terms of number of batches).

The stability of the various systems was explored by altering the issue rate to the shop, the authors comment:

> 'A critical value of inter-arrival time must therefore occur, below which the system is unstable and above which equilibrium conditions can be sought. .....It is salutory to note how sensitive are the measures to inter-arrival time and hence the importance of this factor in system performance evaluation (cellular or otherwise). Furthermore input rate affects the response rate to change.'

In addition the results also imply that the 'response rate to change' is affected by the cell configuration. The conclusions from this paper support the view expressed above (section 8.1) that the organisation of the production system could be expected to influence its performance under dynamic load conditions.

Later work by Crookall and Lee (1977), already referred to in section 8.2.1. above, also has clear relevance for the study of dynamic performance. Amongst the many factors studied they examined the influence of 'inherited' work in progress levels on throughput time length and variability. The results are expressed in terms of the issue rate used during the initial 'build up' period of the simulation run. Since neither the length of the build-up period nor the 'normal' input rate for the shop floor are given it is not possible to interpret the results in normal work in progress terms. However the results are important since the relationship shown for job lateness against initial input rate is analagous to the lead time - load concept developed during the industrial dynamics analysis (Chapter 6 above). The authors give plots of the lateness -

initial issue rate for each of the three scheduling rules tested. These results indicate that each of the rules produce quite different relationships both for the mean and standard deviation of job lateness. The authors recognise but do not expand on this aspect of the results, merely stating:

> 'The effect (of higher work in progress) is inevitably adverse on mean job lateness and variability of lateness, according to the priority rule adopted.'

The same paper also includes a study of the influence of manning levels and skill patterns on system performance. The skill pattern investigation concentrates on the proportion of setter-operators required rather than multi-machine operational abilities.

An optimum balance of setting skills/manning levels was derived for normal operating conditions. Although the manning combinations were tested for two scheduling rules the experiment was not extended to incorporate the influence of work in progress on the results.

The relevance of both the Crookall papers is clear since the results reported therein support the view that the organisation of the manufacturing unit could have considerable influence on its performance under conditions of fluctuating demand.

A review (see Bibliography) of other papers concerned with the influence of design factors on performance failed to yield any further evidence relevant to this study .

8.3 Conclusions

The review of the factors affecting the relevant measures of performance of manufacturing systems has identified the following points:

i) Whilst the influence of factors such as scheduling rules or flexibility of labour on system performance has been studied, mainly utilising simulation techniques, the effect of these features has not been explicitly explored under conditions of dynamic demand trends.

ii) The industrial dynamics literature can offer no guidance in the specification of the detail design features.

iii) There is some indication in the literature that the conditions likely to arise under fluctuating demand, eg variation in work in progress levels, could influence the relative performance of scheduling rules.

iv) The organisational factors which could be expected to influence performance are;

a) Scheduling rules

b) Batch Sizes

c) Flexibility of Labour

d) Layout (ie cell structure)

although the potential of the last factor 'd' is limited by the restriced size of the pilot unit.

It is also evident from the discussion and review of the literature that the complexity of batch manufacture precludes comprehensive analysis of the influence of the factors outlined above using mathematical techniques such as queueing theory. Discrete simulation is clearly a better alternative, offering a ready mechanism for the manipulation of the configuration of the manufacturing unit, and flexibility in the measurement of its performance. The development of a comprehensive batch manufacturing simulation package is described in the next chapter.

Chapter 9 Development of the Batch Manufacture Simulation Package

9.1 Simulation Package Design Philosophy

In order to assess the influence of factors such as scheduling rules or flexibility of labour on the operation of the manufacturing unit it was clearly necessary for the simulation to represent the detailed activities of the men, machines and batches which make up the production system. The type of abstract models used by Crookall (1977) and Conway (1965) were felt to be inappropriate since detailed design recommendations were required of direct relevance to the pilot spares manufacturing unit. The conclusion by Ashour and Vaswani (1972) that the form of the distribution of process times could influence the relative performance of various scheduling rules also supported the decision to utilise real process data in the simulation. In addition it was felt that a more direct relationship between the form of the simulation and that of the real machines/parts range would greatly assist acceptance of the technique by the company.

The structure of the model should also, ideally, be easy to modify, especially in relation to the factors to be studied. Thus it was desirable that the operating or setting skills of the men should be easily modified, as should the numbers and types of machines and the constitution of the component range.

There also existed the broader requirement of the Teaching Company Scheme that any techniques developed under its aegis should have potential application in other companies or industries. This latter requirement supported the development of a package that included more comprehensive facilities than were strictly necessary for the design of the spares unit.

The development phase of a simulation exercise can follow basically two alternative paths; an existing package having all the necessary features can be used, or a tailor-made program can be developed in either a special (ie simulation) or general purpose language.

A number of complete simulation packages do exist which are centred on manufacturing applications including 'GEMS' (Phillips and Handwerker,1979),'PROSIM' (Taylor and Turner,1972; Mize,1971; Kroll,1974), 'MAFLOS' (Mitome et al,1973), 'PASS' (Blumberg,1978; Tabata et al,1977) and untitled systems described by Roggenbuck and Hopwood (1977) and Patel et al (1973).

An examination of GEMS (Phillips 1979) shows it to be more related to a sophisticated high level simulation language orientated toward production modelling,than a job shop type of package.

A number of versions of 'PROSIM' have been developed (Taylor 1972 , Mize 1971 and Kroll 1974). The earliest version was designed to complement the development of a production control information system. The program was used to provide input data (ie it simulated events in a machine shop) to test the performance of the latter system. The program allowed flexible specification of the size of the machine shop and component range but did not include operators in the simulation and the level of operational monitoring was very limited. The input of data utilised cards and the results were analysed by a post-processor using a tape produced by the main program.

PROSIM W, a later version, described by Kroll (1974) includes facilities to accommodate assemblies, purchased parts and orders, tooling, rejects and breakdowns but remains card input orientated and the package was designed as a teaching rather than design aid.

Roggenbuck and Hopwood (1977) describe a system developed at Ford (USA) which automatically assembles a simulation program from pre-written GPSS segments in response to a system specification constructed using layman's (ie production engineering) terminology. The package is card driven and limited in application to assembly and transfer lines, but the concept and motivation are analagous to the situation faced here.

The paper by Mitome et al (1973) provides only limited information about the manner in which MAFLOS is operated, but the implication is that it is not an interactive system. The features of the package are also poorly described but the example quoted implies concentration on the movement of material through flow, rather than batch, production systems.

The PASS system described by Blumberg (1978), incorporates both the stock control and manufacturing functions and has comprehensive cost monitoring facilities. The package is written in SIMSCRIPT II.5 and is available only on a consultancy or leasing basis from the company who developed the system. The paper lacks information about the size or efficiency of the programs, but implies that the manufacturing system can be modelled to include the detailed activities of men (including the effects of skill patterns), machines and orders. The report implies that the main purpose of the system is to evaluate the effects of modifying stock control rules, forecasting systems and production policies. The specification of the manufacturing system is normally translated into PASS programming by the consulting company, thus implying that some skill is necessary to successfully operate the system.

Another system called 'PASS', although quite different to that discussed above, is described by Tabata et al (1977) of Hitachi Ltd, Japan. The system is designed to assist the evaluation of alternative forward planning strategies. An approach based on the PERT technique is used to model the operation of a complete factory, containing several workshops, at a microscopic level. The communication with the user is V.D.U based and the operation of the package is truly interactive in that it allows an iterative search for optimal solutions. Whilst the approach is interesting, the level of detail modelled is inadeqate for production system design purposes.

A particularly comprehensive batch manufacturing package is reported by Patel et al of I.B.M. The program is written in GPSS-V and allows specification of complex process routing (including reject re-working), manning skills and multi-man or multi-machine operation, machine breakdown and repair times, and complex work period patterns. No facilities are available for the use of different scheduling rules (FIFO is normally used) nor does the paper indicate the manner in which the issue of batches to the shop is defined or generated. The form of the input required to specify the workshop configuration is not specified.

A practical problem surrounds the use of all simulation packages - that of availability. The majority of packages reported upon in the literature were developed in the United States or Japan and consequently are designed for use on American computers, most frequently IBM machines. Since access to such a machine was not possible at either the company or the University their use, even if suitable, was not practicable.

Specialist simulation languages, such as GPSS or CSL, offer the user many advantages over conventional general purpose languages particularly in relation to the rapid translation of simulation concepts into code. A clear relationship between the program code and simulation logic aids debugging and the power of these languages can be expected to yield shorter (and therefore less error prone) programs. Providing the suitability of the language to the task is assured, the development phase of the project can be expected to be much reduced in comparison to that required when programming in FORTRAN or ALGOL. However, the operation of a program written in such a language still requires the user to possess considerable computing skills.: thus it would not be feasible to expect a 'typical' production engineer to be able to utilise such a tool without considerable training in computing and simulation techniques. Whilst the latter requirement will always be present it was felt that the possiblility existed that the computing aspects of a program's operation could be made transparent to the user.

The package described below allows the user to sit at a computer and, using simple terminology, to describe the esential features of a batch manufacturing workshop. The computer prompts the user to define the number, type and attributes of the machines, men, components, and orders that make up the simulation model. Checks are built in to ensure that all the data entered are mutually consistant. Once the model has been constructed, further modifications can be accommodated rapidly without the need to re-enter all the basic data. The addition of more machines or a change in the operating skills of a man can be achieved in a few minutes at the terminal.

Extensive sampling routines are incorporated in the package to allow simple definition of events such as machine break-downs, absenteeism and sickness. Comprehensive monitoring facilities exist which allow study of work in progress, lead times and facility utilisation. The amount of information produced by the monitoring system can be tailored to meet the needs of the user.

The programs currently run on the University ICL 1904S computer but transfer to the DEC20 machine located at Birmingham University (but accessible from Aston) is expected to be achieved during 1980.

The following sections briefly describe the facilities offered by the package and outline the principles of its operation.

9.2 Description of the Simulation Program.

9.2.1 Model 'Class' and Selection of Simulation Language.

Computer simulation models may be classified in a number of ways, Mize (1979) suggests the following:

i) Deterministic vs Stochastic

ii) Continuous vs Discrete vs Combined

iii) Static vs Dynamic

iv) Equal vs Nonequal Time Increments.

The classification of the model effectively determines the range of simulation languages which will be suitably structured for the task.

The vast majority of jobshop models contain some stochastic elements, process times, operator performance, or the order issue rate can all be described by probability distributions.

Unlike the industrial dynamics models a job shop model requires its constituent variables to change their value or state instantaniously at specific points in time - they do not vary continuously with time.

The operation of a machine shop is dynamic, the number of entities in the model and their relationships change frequently throughout the simulation run.

Two methods of advancing simulated time in discrete models are available. The system variables may be updated at fixed points through time using either constant time increment (in a manner analagous to that used in the industrial dynamics models) or a program 'clock' mechanism can be arranged to advance by a variable increment dependant on the occurance of the next prospective change of state of the system. The special purpose discrete simulation languages generally incorporate the latter time advance mechanism in their structure and its operation is arranged to be virtually transparent to the user.

Discrete models can be futher sub-divided in relation to their conception of how the various aspects of the system behave. In particular the causal mechanism which controls the occurance of events in the model can be orientated towards events, activities or the complete process.

Event orientated models operate by generating a list of future event times, proceeding to the next event, evaluating the state of the system, creating new events and adding to the event list, and repeating this cycle until the end of the simulated period is reached. In such models it is necessary to schedule the future <u>time</u> at which an event will occur at the point at which it is generated. Whilst it may be possible to define the clock time at which processing may be completed on a machine (the event being 'finish processing') since all the relevant factors are probably known when the job started (eg machining time), other circumstances can arise where an event can be expected to occur only when a series of specified conditions are satisfied. Testing for such conditions, (eg availability of an operator having the correct skill) may be impossible or at least difficult at the 'event generation' stage.

Activity orientated models consist of a series of descriptions of the activities which can expect to occur during the operation of the simulation. The conditions which must be satisfied to initiate or stop an activity are embedded in these descriptions. In addition activities extend over a period of time whilst, by definition events occur at instantaneous points of time.

Process or transaction models are developed by describing the sequences of events which each class of entity in the model can be expected to be subjected to. This approach is partially useful where a fixed structure of sequences exists since the language (eg GPSS) can provide 'shorthand' functions to describe common transaction sequences such as queueing /server systems.

In practise all these approaches may be capable of simulating a particular system and languages are now available which incorporate all of these concepts.

Shannon (Chapter 3, 1975) presents a decision flow diagram to assist in the selection of an appropriate simulation language. The evaluation of the simulation design requirements via this chart indicated that an activity based language would be the most suitable. The University computing facility offered only two such languages - C.S.L (ICL 1900 version) and E.C.S.L (operational on the ICL 1904S but not ICL supported). The two languages are inter-related since E.C.S.L is an extended version of C.S.L. The differences between them are, however, very significant and may be summarised as:

i) E.C.S.L operates in a similar way to BASIC ie. a resident interpreter/translator executes the program line by line and does not produce a compiled object code. C.S.L translates the source text into a FORTRAN program which is then compiled and an object code produced. Although the E.C.S.L approach carries a penalty in terms of higher execution time, it does eliminate the problems associated with error tracing. An execution error which appeared in a test job shop model written in C.S.L was not traceable to the source text and probably stemmed from a fault in the C.S.L translator. E.C.S.L errors normally relate directly to the source text easing development problems.

ii) The syntax requirements of E.C.S.L are much simpler. The form of the language allows a self documenting, almost English, style of text. In particular, the handling of entity attributes and chains of test conditions simplifies program writing and logic. For example, the description of an attribute associated with the Xth man which holds his performance would be in C.S.L :-

MAN.X(2)

and in E.C.S.L :-

PERF OF MAN X

iii) The activity structure allows an entity to be 'withdrawn' from the simulation for an appropriate duration rather than merely being instantaneously moved between two sets. In C.S.L two activities are required to simulate the 'start' and 'finish' of an activity - E.C.S.L requires only one.

iv) The program development aids are extensive including switchable levels of monitoring of the state of program variables during execution, and complete a dump of all variable names and their associated values when an execution error occurs.

v) The range of built in functions allowing ready sampling of a large number of probability distributions, eg negative exponential, normal etc.

vi) Histogram recording mechanisms to allow accumulation of entity performance data throughout a simulation run.

vii) The ability to define entity attributes of several types other than numeric, including strings (eg NAME of MAN A) , histograms (eg RECORD of MAN A), and, most important, sets (eg ROUTE of JOB B).

It is also interesting to note that the author of the language (Clementson) claims that an E.C.S.L program would take 1/10th of the number of lines of the equivalent FORTRAN and that it could be written in 1/20th of the time.

The current version of E.C.S.L used in this application occupies 80K of core, an alternative smaller version (32K) is also available at Aston. The size of the program determines the storage capacity available to the simulation for holding information about the state of the various entity attributes and sets. It is difficult to accurately assess the storage requirements of a particular program but the machine shop program reaches the limit with a total of approximately 700 entities (ie. number of machines, men, orders, batches, parts etc.) and extensive histogram based recording of results. A complete listing of the E.C.S.L code for the simulation program is given in Appendix 12.

9.2.2. General Background

The activity stucture of the language conceives the machine shop as consisting of a number of different entities (men, machines, batches, etc.) which progress, with time, through a series of queues and activities. For example, a batch (entity) waits in a queue called 'wait' (set) until other entities (men and machines) are in the correct state for processing (activity) to start.

The program is written in three sections:-

- Initialisation, which sets up the starting conditions and values of all key variables.

- Activities, one activity for each type of state that is to be considered by the simulation

- Finalisation, which prints all the results histograms and other monitoring data.

The program, having completed the actions contained in the initialisation section, cycles round the activities section, testing for entry to each activity on each pass. The simulated time is advanced before each cycle by a period equal to the time to the next prospective change of state of any of the entities. The state of all the entities is checked and, where necessary, modified before the cycle starts. In this way the inefficiency attendant on the use of fixed interval time increments is avoided.

Each activity in the program consists of a series of heading tests, each of which must be satisfied if entry is to be made, followed by a description of the effect the activity is to have on the entities involved. The normal effect is to move the entities from one queue to another often after a specified delay. For example, if a batch were to be processed for 121 minutes the PROCESS activity would:-

- Select a batch from the queue of WAITing jobs

- Select a machine from the queue of STOPped machines (providing the machine which had previously been set up for this batch was available).

- Select a man from the queue of IDLE men providing the man has the appropriate skill to run the machine.

The selected entities would be removed from their respective queues and returned after a delay of 121 minutes.

The activity cycling continues until the specified simulation run time is reached when the finalisation section is entered and the results printed.

9.2.3 Description of Activities

The following real entities are considered - men, machines, jobs, parts and orders. An order may be for a quantity equivalent to several batches. The 'part' entity is not active in the simulation but serves to record all the fixed data about a component - setting and process times, batch quantity, etc.

All the entities follow a closed loop through the simulation to queue 1 - activity - queue 2 - activity - queue 1. Parts, orders and cycle back into 'pool' queues which hold entities not engaged in the simulation at that time.

The path through the key activities in the program is described below.

ORDER PROCESSING

SETUP

A special activity called SETUP is used to prepare the initial conditions that obtain at the start of the simulation run. The activity reads in order data and, providing the order's day of issue equals zero, also reads the state of each batch associated with the order in terms of the number of operations already completed. The appropriate number of JOBS are selected from the POOL, their routes assigned and adjusted, and passed to the shopfloor queue WAIT. These batches therefore represent the work in progress used to 'fill' the machine shop at the start of the run.

ORDERGEN

Where a series of specific orders have been defined this activity is used to read in the data and assign the key attributes - issue date, completion data, part number and order quantity to the order entities. The activity operates only when the clock time equals the day of issue of the next order. The orders are assigned to a queue AWPLAN where they await the availability of a planning clerk.

AUTOGEN

If the user does not wish to specify a series of orders this activity can be utilised to automatically generate orders during the simulation run. Using the batch size and demand data for the parts range a distribution of batch frequencies is derived. This distribution is then sampled each time the activity is entered. The order stream produced will therefore reflect the batch frequency for each member of the parts range.

The interval between orders being generated can either be fixed at a used defined value or made to vary sinusoidally during the run.

As with the ORDERGEN activity orders are passed to the queue AWPLAN to await planning and issue.

PLAN

When a planning clerk becomes available, the activity PLAN is entered. This activity selects the first order and finds the appropriate 'part' entity. The part attributes hold all the fixed data about that component such as process route, setting and process times and batch quantity. The batch quantity is compared with the order quantity and an appropriate number of jobs (batches) are selected from the job pool. All the relevant data is now transferred to the job's attributes - due date, batch quantity, part number, route, setting and process times and the priority set equal to the due data. The jobs are then moved to the AWISSUE queue after an appropriate planning delay. The order and part entities are returned to their respective pools.

OPERATIONAL ACTIVITIES

Three vital queues exist on the shop floor:-

WAIT - Which holds all jobs not engaged in any activity. There is therefore only one queue holding all jobs waiting at all the machines.

IDLE - which holds all the men not engaged in an activity.

STOP - Which holds all the machines not engaged in an activity.

All the shopfloor activities move men, machines and jobs from and back into these queues after varying periods of time. The relevant activities are:-

<u>SETTING</u>

Selects a new job/man/machine combination, and returns them to the waiting state either when the set up is complete or when another activity is due to start which will affect the state of the man or machine, e.g. breakdown.

<u>PROCESS</u>

Selects a job/man/machine combination providing the set up of the job on the machine is complete and the man has the appropriate processing skills. The entities are released either when processing is complete or when another activity is due to start which affects the state of the man or machine.

<u>AUTOLOAD</u>

The process activity operates on a one man/one machine basis. Automatic machines are frequently run by one operator supervising several machines. This activity (and AUTOPROCESS) are designed to cover this situation. A man/job/machine combination is selected providing the set up of the job is complete on the machine and the man has the appropriate operating skill. The entities are released after the material loading time.

AUTOPROCESS

This activity corresponds to the cycle part of the automatic machines operation. Whilst a man is required to start the machine, he is not needed for the remainder of the machine cycle. A job/machine combination is therefore selected and released after the cycle time of the machine whilst the man is selected and released immediately (i.e. his presence in IDLE tested for).

All the above activities can be interrupted by any of three activities which effect the state of the men or the machines. These are:-

FINWORK

At the end of each work period, normally of 240 minutes (4 hours), the men are all withdrawn for a period equal to 60 minutes (lunch break) or 900 minutes (overnight). This activity also allows a man to be withdrawn for a complete day to cover for sickness. A histogram is sampled which describes the probability of a man being sick. This probability is input as data via the interactive program described below.

If the entrance to this activity interupts the setting of a machine (for example), the setting activity will restart after the appropriate delay.

ABSENT

This activity represents the absence of a man from his machine, for a tea break or smoke etc. The period of absence and the time between absences are sampled from two normal distributions which are common for all the men. The characteristics of these distributions are input as data via the interactive program. Whilst the FINWORK activity withdraws only the man, this activity withdraws the complete man/machine/job combination.

BREAK

Machine breakdown is simulated by this activity. The length of the breakdown and the time between breakdowns is sampled from two normal distributions (as with ABSENT). In this case, each machine has its own pair of distributions. The mean and standard deviations are again input by the interactive program as data. This activity can have three possible end results. The length of the breakdown is first tested against a fixed limit time (at present 60 minutes) and the man is released after whichever time is the shorter. Next the breakdown time is tested against a factor, times the setting time of the job on that operation. The job is released, to be set up on another machine, if the breakdown time is the greater. The job is then held for a time equal to the setting time to correspond with the breaking down of the job on the machine. An example of the operation of this activity is given in Table 9.1.

SCHEDULER

A special activity called SCHEDULER allows shopfloor re- scheduling to take place. Before each activity cycle starts, all the jobs in the shopfloor queue WAIT are re-ordered into ascending priority sequence. The SCHEDULER activity recalculates the priority of each batch on the basis of a rule which can be selected from a number of alternatives. The rule number is input as data via the interactive program. The options include:-

- minimum due date

- minimum setting, machining or processing times

- minimum float

- random selection

Breakdown Duration Mins	Machine Released after mins	Man Released after mins	Job Released after mins
50	50	50	50
80	80	60	80
3000	200	60	200

Note:

Man Release Limit = 60 Mins

Job Setting Time = 200 Mins

Factor = 10

Table 9.1 Operation of the BREAKDOWN Activity

INSP

Finally, when a job has completed all the required operations a dummy activity called INSP is entered which records data about the lead time of the job and removes it from the active part of the simulation by placing it in the dummy queue pool.

9.2.4 Description of System Monitoring

The output from the program can be adjusted to suit the particular needs of the experiment. Aside from certain fixed data all the main monitoring features are switchable (via the interactive program).

The following data is always output:-

Basic Shop Data

This includes:

- Basic machine data, breakdown times, etc.
- Group machine content
- Parts Range Data, route, process times etc.
- Men's operating and setting skills
- Men's absence, sickness and work period data
- Runlength and the period for which result recording had taken place.

Machine Activity Record

This record gives the number of minutes each machine has spent in key activities such as setting, processing, autoprocess etc, and in the idle state. The results are presented in tabular and pictorial histogram form.

Man Activity Record

This record repeats the information given for machines, as described above.

Allowed/Cycle Minutes produced

For each man, the record gives the allowed and cycle minutes produced in setting, processing, auto loading and auto processing. The attendance minutes are also given as is the effective performance percentage for each man.

In addition the following are switchable:-

Job Track Monitoring

This facility provides a record of all the movements of batches, men and machines throughout the length of the simulation run. Each time an activity is entered a line of data is printed giving the clock time, entity identity and the duration of the activity.

Queue Monitoring

At the beginning or end (or both) of each activity cycle, the state of all the important queues is printed out. These include the machines in STOP, men in IDLE, jobs in AWPLAN and WAIT. The WAIT job queue listing also gives the priority of each batch (in brackets) and is further sub-divided into the batches waiting at each group of machines.

Work in Progress Monitoring

The program monitors the level of work in progress;

(a) at each machine group, and

(b) for each machine group

(c) total for all groups

at predetermined time intervals. This interval (in working days) is input as data using the interactive program. The total work in progress figure is further split into work awaiting issue, work on the shopfloor and the combined total. It is expressed as allowed or cycle hours. The output is in tabular and pictorial histogram form.

Lead Time Monitoring

The lead time of each batch is recorded in two ways:-

(a) in the job track record described above

(b) in a variety of histograms

The histogram recording provides the following

(a) the distribution of batch lead times

(b) the average batch lead time during each monitoring time interval.

(c) the distribution of batch queueing times

(d) the average batch queueing time during each monitoring time interval.

In all cases the lead time is expressed in hours. The lead time can be recorded either, from the planning of the batch, or from the issue of the batch.

The work in progress, lead time and machine/man activity monitors can be switched to print the state at the end of each monitor period during the run in addition to the normal print during finalisation.

The model also prints details of all the batches which are active both at the end of each monitor period and at the end of the simulation.

Examples of output from the model including most of the above monitors are given in Appendix 13.

9.3 Interactive Program Description

9.3.1. General

This program was developed to complement the Batch Simulation program for three main purposes, which were:-

i) To allow definition/modification of the configuration of a workshop to be made easily and quickly.

ii) To remove the need for a user to have more than a minimal understanding of computer programming or operating systems.

iii) To reduce the possibliity of errors occurring in the manipulation of large amounts of data, especially those associated with formatting and correspondence between entity classes (for example, specifying a mans setting skill to include a non-existant machine group).

The program therefore allows the user to refer to machines, parts etc. using normal company terminology. Likewise, the output from the simulation program is presented in the same form, thus the user does not need to know that operator 'Fred' is regarded as Man 15 within the programs.

Once all the data has been entered, the interactive program rewrites the salient parts of the simulation program and outputs the data to a file in a form acceptable to the simulation program. Macros are used on the ICL 1900 system to control the loading and running of both programs so that this process is not apparent to the user.

9.3.2. Brief Description

Two modes of data entry are allowed:-

i) Description of a completely new workshop configuration.

ii) Modification of part of the data base from a previous simulation run.

As (i) above proceeds the refined data is written to a disk file in such a form that it can be read back for subsequent modification in mode (ii). The order and type of data entry is as follows:-

Machine Data

- name, type, breakdown data

Group Data

- name,machine content (by name)

Man Data

- name, work period, absence data, sickness data, setting skills. (by group name), running skills (also by group name)

Part Data

- name, batch quantity, demand, process route (by group name), process data, (setting, process, load, cycle times)

Order Data

EITHER;

- order quantity, part name, issue date, due date.

OR

- automatic order generator switch, seed, start date.

Monitoring and Runtime specification

- Controls for all the Activity, Work in Progress, and Lead Time monitors. Runlength and Runin period specification.

As data is entered it is checked for consistency with that already specified and various levels of re-entry allowed.

In the modification mode skipping of each major entry section is allowed. An example of dialogue during the entry of data for a new configuration (mode (i)) is given in Appendix 15.

9.3.3. Operational Considerations

The program is written in ICL 1900 Extended Fortran and the current version runs in 28K of core on a 1904S under the control of a GEORGE 3 operating system.

The size of the program is controlled mainly by the maximum number of entities which need to be described. The current capacity (which can be readily modified) is:-

20 men

40 groups

75 parts

17 ops/part

51 orders

2 batches/order

20 machines

3 machines/group

40 skills/man

In addition, names of men, machines and groups may not exceed 8 characters and those of part numbers 16 characters. Both of these constraints are a function of the type of computer used but could be adjusted to suit a users requirement.

Execution times are, of course, small - 15 seconds of mill time on the 1904S are rarely exceeded. Complete listings of the interactive program and control macros are given in Appendix 14.

9.4 Summary of Features of the Simulation Package

The main features of the complete package can be summarised as follows:

i) The use of the package does not require the user to possess extensive computing skills.

ii) The configuration of the machine shop and the specification of the component range can be accomplished interactively using normal company terminology.

iii) Within the limitations imposed by the range of activities available and the job-shop format of the model, modification of the features of the machine shop organisation can be rapidly and easily achieved.

iv) Multi-machine operation by a single operator is allowed.

v) Automatic machines which do not require constant attendance during the machining cycle can be specified.

vi) Activities to describe machine breakdowns, operator absenteeism and sickness are available.

vii) The order intake stream can be automatically generated or explicitly specified by the user.

viii) A variety of scheduling rules can be specified including minimum due date, float, processing time, or random selection criterea.

ix) Especially extensive and flexible monitoring of the activity of men, machines and batches is available.

x) Gross measures of performance, such as work in progress levels and average lead times are also extensive both for recording the state during and at the end of a simulation run

xi) The structure of the programs provides facilities for the ready addition of new activities to the model.

Chapter 10 Batch Manufacture Simulation Experiments

10.1 Configuration of the Model

The interactive program was used to set up the basic form of the model, in terms of the number of men and machines, established by the conventional design procedure described in Chapter 7. Details of the component range identified by that exercise, (see appendix 8), were also entered into the model and, initially, factors such as skill pattern, batch size etc. were defined at their 'normal' or expected values.

The early test runs of the model, carried out for verification purposes, identified two minor operational problems. Specifically these were:

i) The operation of the AUTOLOAD and AUTOPROCESS activities which simulate the operation of automatic machines proved to generate a considerable (and unacceptable) increase in exectution times. This arose because of the chucking nature of the machines being simulated. Entry to the activities was being made for every component produced. Given the large batch sizes and short machining cycles (2 minutes typically) the program was being forced to scan all the activities at very small simulated time intervals. An approximation was therefore introduced to allow entry to AUTOLOAD to occur only once at the start of a batch by putting the machine cycle time equal to the sum of the loading and machining times for the whole batch. Comparative runs of the model showed that the effect of the approximation was minimal.

ii) The operations, such as heat treatment, which were clearly going to be performed outside the machine cell were included in the model but nominal process times (2 days) were defined for them. In order to avoid the possibility that these processes could prove a constraining influence during the simulation, a number of dummy men were introduced whose skills were arranged to exclusively cover these operations. The results presented in later sections exclude consideration of the 'dummy' men and ex-cell operations.

It should also be noted that although provision was made in the program for simulation of absence, sickness and machine breakdowns these factors were not studied in the experiments described here and zero probabilities were assigned to all of them.

The performance of the men was set at 230%(the CompAir factory average) for those running manually controlled machines and 100% for operator(s) of the automatic lathes.

10.2 Form of the Experiments

The discussion in Chapter 8 indicated the need to explore the influence of the following factors on system performance:

i) Batch Size.

ii) Scheduling Rules.

iii) Flexibility of Operators.

The conditions under which these factors were to be tested clearly had to approximate those suggested by the industrial dynamics analysis. One series of runs were therefore performed with the machine shop subjected to a varying level of demand over a period of 230 weeks. The level of demand was adjusted by causing the total yearly batch frequency to follow a sinusoidal path having an amplitude of 40% of the mean level and a period of 220 weeks. These figures were consistant with those shown for a similar period by the multi-source model for the bought out desired manufacturing rate (the pilot unit is equivalent to another bought out source of supply) when it was subjected to a 20% fluctuation in end customer demand. The machine shop model determines the part number (and therefore all the route and process data) for each issued batch by sampling a histogram which is structured to reflect the normal yearly batch frequency expected for each component. The interval between samples effectively determines the batch issue rate to the shop and is calculated from the reciprocal of the total batch frequency for all components, mentioned above. The component mix or sequence of part numbers issued, is controlled by the random stream used in the histogram sampling process. The component mix can therefore be changed by altering the value of the seed used by the associated random number generator. This value is entered as part of the run specification data using the interactive program.

The runlength for this series of experiments would ideally be sufficiently long to incorporate many complete demand cycles. Unfortunately the computer time required to simulate a single cycle was so large as to prohibit longer runs on economic and practical grounds.

A second series of runs were also performed over much shorter run lengths in order to establish the necessity for each model configuration used in the longer cyclic run series and to extend the data available for study of the lead-load characteristic. In this case the total yearly batch frequency was fixed at twice the normal level. Thus the load generated on the shop would greatly exceed its capacity and work in progress could be expected to rise throughout the simulated period. The simulated time period was set initially at 7 months but later extended to 12 months for the scheduling rule runs. The decision to extend the runlength arose from the need to ensure the completion of a sufficiently large sample of consecutive batches in order to limit bias in the lead time-work in progress characteristics (see Section 10.5 below).

The number of levels of each of the factors which could be studied was limited by the economics of the computer usage. Accordingly, since identification of trends was the essential point of the exercise, the batch size investigation was limited to comparing a 'normal' run with runs having batch sizes of half, three quarters and twice the normal figure respectively. For the reasons quoted in section 8.2.2 this simple approach was taken to ensure that the quantity of components ordered (or issued) would remain constant for each case.

The surprisingly good performance reported in the literature for the minimum setting time rule led to an expansion of this class of rule to also include minimum machining time and minimum process time (setting plus batch machining time) alternatives. In each case the rule was evaluated from data for the next operation.

The common minimum duedate rule was complemented by an alternative of the same class - minimum remaining float per operation which was calculated from:

$$\text{Float/Operation} = \frac{\text{Completion Due Day - Current Day}}{\text{Number of Remaining Operations}}$$

Although more complex rules exist these were considered representative of the main classes orientated either toward improved capacity utilisation (minimum setting etc) or delivery performance (minimum duedate and float).

The number of permutations possible in defining the number and skill patterns of the operators was obviously very large. Selection of the range to be tested was therefore limited by decisions to keep the number of men constant,at five,for all runs and to regard them all as setter operators. In this way the experiment could concentrate on the effect of broadening the range of skills.

The number of men chosen (five) and the variety of machine types in the shop (ten) dictated the minimum of two skills per man. However, examination of the machine types listed in Table 10.1 shows that some of the processes, such as 'hand paint', had limited skill content. The allocation of skills to individual men was governed by the following procedure:

i) Allocate a 'main' skill type for which high utilisation could be expected.

Skill Type	Operator Number				
	1	2	3	4	5
Bar Capstan	*		@	+	
Chucking Capstan		*	+		@
Chucking Auto		@	*		+
4 Spindle Drill	@	+		*	
Horizontal Mill	+			@	*
External Grinder	x				*
Deburr		x		*	
Degrease			*	x	
Hand Paint		*	x		
Fit	*				x

Key:

2 skills/man Run - *

3 skills/man Run - * & +

4 skills/man Run - * & + & x

5 skills/man Run - * & + & x & @

All men are setter operators

Table 10.1 Skill Patterns used for the Labour Flexibility Run Series.

ii) Allocate a secondary skill, priority being given to processes actually having limited skill content.

iii) If all limited skill processes have been allocated assign the skill for low utilisation machine type.

iv) For runs requiring more than two skills per man continue to allocate following the procedure described in i to iii above.

A series of four runs were set up covering 2,3,4 and 5 skills per man, the detailed allocation of skills are shown in Table 10.1. The results of these runs were compared with those from the 'standard' configuration. The skill pattern used as 'standard' is shown in Table 10.2.

Constant issue rate runs were performed for all the factors mentioned above but the scheduling rules based on minimum machining and minimum setting times were deleted from the longer fluctuating demand series. The results from the shorter run series indicated only limited performance differences between all three process time orientated scheduling rules. It was felt that under these circumstances the additional computer time required for a complete long run series could not be justified.

10.3 Experimental Conditions

A factor of major importance in the design of simulation experiments concerns the manner in which the system behaves as simulated time progresses. The majority of studies are concerned with establishing the limits of the operational performance of a system under 'normal' or 'steady state' conditions. In such

Process	Operator									
	1		2		3		4		5	
Bar Capstan	s	o	-	-	-	-	s	o	-	-
Chucking Capstan	s	o	-	-	-	-	s	o	-	-
Chucking Auto	-	-	s	-	-	o	-	-	-	-
4 Spindle Drill	-	-	-	-	-	-	s	o	-	-
Horizontal Mill	-	-	-	-	-	-	s	o	-	-
External Grinder	-	-	-	-	-	-	s	o	-	-
Deburr	-	-	-	-	-	-	-	-	s	o
Degrease	-	-	-	-	-	-	-	-	s	o
Hand Paint	-	-	-	-	-	-	-	-	s	o
Fit	-	-	-	-	-	-	s	o	-	-

Note:
's' - Setting Capability

'o' - Operating Capability

Table 10.2 Skill Pattern used for the 'Standard' Run.

circumstances measurements are taken when the system has settled down and any variation that exists can be considered to be equally distributed (in the long term) about a single state. Kleijnen (page 69 ,1975) defines steady state as occuring when:

> "....the probability of being in one of its states is governed by a fixed probability function"

and Emshoff and Sisson (page 190 ,1970) take a slightly broader view saying:

> "....that a system has reached stable or steady-state conditions when successive observations of the system's performance are statistically indistinguishable"

These conditions would be satisfied by a job shop model where the issued load is always less than the shop capacity, as was the case in the study reported by Hitomi (1977).

The objective detection of steady-state conditions is more difficult than their definition, Shannon (page 183-4,1975), mentions six methods proposed by various workers. Considerations of the two forms of order intake patterns proposed in these experiments immediately indicates that steady-state performance is not likely to be achieved. The constant order intake run series will, by definition, subject the shop to a load which will be constantly greater than its capacity and thus stablilisation of conditions cannot be expected (particularly in relation to work in progress levels). The fluctuating order intake trend utilised in the second run series will not allow conditions to stabilise in the machine shop although gross measures of performance over each complete cycle might be expected to do so if the run length were large enough to incorporate many cycles.

The state of the system at the begining of the simulation is particularly important in the study of models which exhibit transient response characteristics. Measurements of the performance of steady state models, by definition, exclude the effects of starting conditions but this approach is clearly impossible where stable performance is never attained. This problem is further complicated when comparing alternative policies or model configurations, particularly when the 'normal' or expected initial conditions are different for each policy. Conway (1963) suggests three choices:

i) Test each system starting empty and idle

ii) Test each system with a common set of starting conditions which represent a reasonable compromise between those expected for each policy.

iii) Test each system with its own most reasonable set of initial conditions.

The third option implies some pre-judgement of the results of the study and must therefore be treated with some suspicion.

The first option is 'safe' but, for steady-state systems, expensive in computer time because the model must be run for a long time before stable conditions are achieved and measurement can begin. This option was chosen for the constant order intake run series since the steady-state criteria clearly did not apply.

The second option probably represents the most efficient compromise of the three alternatives and was chosen with slight modification for the fluctuating demand run series. In a similar manner to that used by Crookall and Lee (1977), each of the model configurations were subjected to a constant issue rate (which approximated twice the capacity of the shop) for a fixed period before the issue rate was brought under the control of the cyclic function in the program.

The behaviour of the system also has a considerable influence on the form of the statistical analysis of the results.

A problem common to many simulation studies, particularly of queueing systems, concerns the presence of autocorrelation in the results. This occurs when the result of a particular observation is influenced by a previous one, for example successive measurements of work in progress at a machine will all be inter-related. Two methods are commonly described for overcoming this problem:

i) Replication of the complete run normally using a different random number stream in each case.

ii) Batch sampling of the results from a single run.

In both cases the aim is to achieve a series of independent measures of the mean value of some performance index. The batch method divides the observations from a run into a series of samples, each have its own estimate of the true mean. The central limit theorem is normally involved to allow confidence limits to be established on the basis of the variance of these sample means. Conway (1963) demonstrated that, in practise, the insertion of intervals between batches, during which no measurements are taken (to strengthen the assumption of independence) may actually increase the variance for a given run length. This finding is consistent with Shannon's comment (page 189,1975) that in the use of the central limit theorem:

> "the condition of independence of many contributing random variables is not necessary, and they need not arise from a common probability density function."

However, as Gordon states (page 280,1969):

> " Another problem that must be faced is that distributions may not be stationary. In particular a simulation run is started with the system in some initial state, frequently idle......... The early arrivals then have more than normal probability of obtaining service quickly, so a sample mean that includes the early arrivals will be biased."

Thus, although many of the measures in the model, such as average lead time or work in progress, which are taken through or at the end of successive periods of simulated time can be equated to batch sampling, the requirements for stationary distributions cannot be satisfied for either run series.

The alternative approach of replication is mentioned by Emshoff and Sisson (page 193,1970) specifically in relation to transients:

> "In studying transients with a stochastic model,the run must be replicated by restarting to obtain a distribution of results"

This approach, however, results in a single observation for each run, its direct application is therefore limited to gross measures of performance which can be summed over the whole period of the simulation. The use of traditional methods of deriving confidence limits still rests on the assumption of the central limit theorem, in this regard Kleijnen (page 87,1975) states:

> "The 'stationary r-dependant central limit theorem' ....implies that the average of each run is (approximately) normally distributed (unless periodicities exist)"

Unfortunately periodicities do exist, indeed they dominate the response of the system when subjected to fluctuating demand patterns. Thus replication is likely only to be useful in relation to the constant issue rate runs and then only to evaluate single measures of the system's performance over the complete run.

Spectral Analysis would, initially at least, appear to offer the possibility of more comprehensive analysis of system performance but, as Kleijnen (page 89,1975), Shannon (page 228,1975) and Van Horn (1971) all point out, this technique can only be applied to steady-state conditions.

A more practical problem also arises in relation to the replication of runs - that of the cost associated with the extra computer time obviously required. This cost must be set against the consequent improvement in the level of confidence one has in the results. The economic aspect may also be supplemented by limitations imposed by the capacity of the computer installation. The C.P.U time required to execute one of the constant issue rate runs varied between one and twelve hours and approximately twice these figures were required for the longer fluctuating demand series. These factors combined to prevent the replication of any of the experimental runs.

However these problems do not prevent the adoption of policies which tend to reduce variance for a given sample size (or runlength). Correlated sampling is of particular relevance when the problem can be resolved into the comparison of two alternative policies, and where it is the difference between them which is of especial interest. Shannon (page 203 and pages 222-227, 1975) describes this technique and points out that the necessary sampling method can be achieved by using identical random number streams for both runs. Paired observations are taken, one from each run (eg values taken at the end of successive time periods), and the hypothesis tested that the mean of the population of differences is zero. Depending on the number of pairs tested either the 't' or normal statistics can be used for the test. In either case the test depends on the assumption of normality in the underlying populations, where such an assumption is suspect Shannon suggests the use of the nonparametric Mann-Whitney ranking technique.

The latter approach, therefore, offered the possibility of establishing some measure of confidence in the relative system performance of the various operational policies to be tested. In fact both tests were used but the results for the 't' difference procedure should be viewed with some reservations, since the required normality assumption is of questionable validity.

10.4 Measures of Performance

Although the simulation package provides extensive monitoring facilities only a sub-set of these were required in the experiments reported here. In addition some modifications were necessary to the data produced by the model to improve the clarity of presentation of results.

In general it was felt desirable to establish consistent units of measurement for performance factors which could be considered to be inter-related, for example, work in progress levels and load (or order issue rate) are related in this way. Whilst measurement of both the above examples could be expressed in terms of hours of work content, this form of presentation tends to restrict the interpretation of results to the specific machine cell/component range being studied. For this reason, where possible, conversion to a more general form of presentation has been achieved by expressing work in progress levels in weeks of average demand and instantaneous issue rates as a percentage of the 'normal' level. The average demand level which equated to the 'normal' issue rate was calculated from:

$$\frac{\text{Sum((Work Content / Batch) x (Batch Freq/Year))for all parts}}{\text{Number of Periods / Year}}$$

This figure can be considered to be the basic 'design' load for the machine shop. The batch size directly influences the size of the load figure, for example smaller batches will generate a higher work load than standard. However, the standard figure of 7557 Hrs/Year was used throughout the presentation of results and corresponds to the 'normal' batch sizes given in Appendix 8.

The options available for measurement of issue and completion rates are limited to those based on work content (load) or a count of individual batches. Whilst the control of the issue rate is exercised essentially in terms of the latter measure, the former approach allows more comprehensive interpretation of the system performance. The results for both issue and completion rates are given in terms of the percentage of the 'design' or 'normal' load, calculated from:

$$\frac{100 \times \text{Work Content Issued (or completed) during Monitor Period}}{\text{Design Load / Period}}$$

A broader range of alternatives are available for the recording of work in progress levels, Conway (1965b) suggests four possibilities:

"1) Work Remaining - the sum of the processing times of all operations not yet completed or in process for all the jobs in the shop.

2) Total Work Content - the sum of the processing times of all operations of all jobs in the shop.

3) Work Completed - the sum of the processing times of all the completed operations of all jobs in the shop.

4) Imminent Operation Work Content - the sum of the processing times of the particular operations for which jobs are waiting in queue."

The above are all in addition to a simple batch count which provides a fifth alternative. Every measure can be considered valid but 'Work Remaining' can be expected to have most relevance as an indication of the backlog or congestion in the shop. This measure has therefore been used throughout the study and the results expressed as a function of the design load. The work in progress level in weeks was calculated from:

$$\frac{\text{Sum (Work Content Remaining in hours) for all batches}}{\text{Design Load (hours/week)}}$$

It should be noted that the simulation package can also report the imminent operation work content (4) and that the total work content (2) can be derived by comparison of the cumulative issued and completed load figures.

The measurement of lead times is also more complex than is initially apparent. Whilst it is straightforward to measure the throughput or queueing time of an individual batch the extension of this data to provide gross or average figures raises special problems associated with the selection of the batch sample. A sample which includes all issued batches will be biased by the lack of data for those uncompleted jobs remaining in the system when the run terminates. Even if the runlength is extended (and issues to the shop stopped) until all jobs are completed the conditions which apply during the run-out period could not be considered typical and some element of bias will be introduced into the results. The bias introduced by terminating the run without a run-out period may be considered acceptable (providing the sample is large enough) when set against the additional computer time required by the latter approach.

When studying the performance of the machine shop under varying conditions of load and work in progress the overall average lead time (or variance) for the complete run is of less interest than the way the 'average' moves throughout the simulated period. For this reason, although overall figures were obtained, average lead times were also calculated for batches completed during successive periods throughout the run. These figures give a useful impression of the service offered by the machine shop as perceived by a customer or, as in this case, the stock control system. In addition if a plot of this statistic against simulated time is compared with the movement of work in progress levels, information about the dynamic performance of the system can be derived.

The use of these statistics to derive a lead time - work in progress characteristic was found to be inappropriate since the lag between movements of work in progress and average lead times introduced severe distortion of the results. Such an approach would tacitly assume that the level of work in progress at the moment at which the batch was completed can be taken to properly represent the influence of this factor on the lead time of the batch. The lead time is more directly influenced by the level of work in progress throughout the life of the batch, that is the period between issue and completion. An additional feature was therefore added to the model to allow calculation of the average level of work in progress throughout the life of each batch.

When average load was plotted against lead time using data for each individual batch completed during a run, the result exhibited such wide dispersion that a trend characteristic was difficult to identify. This was particularly true of the minimum processing time scheduling run which tended to produce high lead time variance. In order to clarify any trends that might be present the data for individual batches were grouped into cells, each cell having an interval of 500 hours. Thus all batches having average work in progress levels between 0 and 500 hours were placed in the first cell, all having levels between 501 and 1000 hours in the second cell and so on. The mean and standard deviation of the lead times of the batches were then calculated for each cell. A plot of the cell means then allowed a lead time-work in progress characteristic to be produced for each run and a similar plot of cell standard deviations gave a measure of lead time variability at particular levels of work in progress.

This procedure raised the problem, mentioned earlier, of selection of an appropriate sample of batches. When all the batches completed during a constant issue rate run were included in the analysis the characteristic showed a marked reduction in cell mean lead times at high levels of work in progress. It should be noted that this series of runs were set up to generate a continued build up of work in progress which reached a maximum when the run terminated. In such circumstances a large number of batches remained incomplete at the end of the simulation and could not, therefore, be included in the lead time analysis. The completion pattern was therefore examined for each run and a common sample of consecutively issued (and completed) batches extracted for analysis. The results for the constant issue rate runs discussed in later sections are based on this form of analysis. This problem was much less significant in the analysis of the longer fluctuating demand runs since relatively few batches remained incomplete when the simulation terminated.

In addition to measuring the lead time, the simulation program also accumulated the total queueing time and calculated the average queueing time per operation for each batch. The latter measure can be considered particularly interesting since it eliminates any variability introduced by differences in the length of component process routes.

The utilisation of the men and machines was measured during each monitoring period throughout the run and expressed as a percentage of the available working time. In examining these results it should be noted that the average operator performance data provided by the company included the effects of absence, breakdowns, waiting material etc.

10.5 Results

10.5.1 Constant Batch Issue Rate Run Series

For this series of runs the batch issue rate remained fixed at a level which approximated to twice the design load (as defined in section 10.4). The runlength varied between 12 months, with a bi-monthly monitoring period, (scheduling rule runs), and 7 months with results taken monthly (batch size and labour flexibility runs).

10.5.1.1 Scheduling Rules

The work in progress and completion data for the scheduling rule series of runs are shown in Table 10.3. The completion results are presented in terms of the work content of;

i) all the batches completed during the run.

ii) those batches completed during the last 6 months of simulated time.

The latter measure is included to indicate the capacity that would be realised when an adequate supply of work is available throughout the machine shop. In addition the work content of all the

Scheduling Rule	Work Content of Completed Batches			Work in Progress at Run Termination (Wks at Design Load)	
	% Total Issued	% Design Load			
		Complete Run	Last 6 Months	Remaining	Total
Random	36.2	79.4	90.5	40.2	55.9
Minimum:					
Duedate	53.5	117.0	123.7	38.1	40.8
Float	51.4	112.7	117.8	38.7	42.6
Setting Time	49.5	108.4	117.7	37.5	44.3
Machining Time	49.7	109.0	116.5	36.7	44.1
Process Time	48.7	106.7	118.0	36.6	45.0

Note:

Remaining W.I.P. Work content of the (Remaining) Operations for all batches present

Total W.I.P Work content of (all) operations for all batches present

Average Issued Load 219% of the Design Load.

12 Months of Operation Simulated.

Table 10.3 Work in Progress and Completion Results for Scheduling Rule Series of Constant Issue Rate Runs.

completed batches is expressed as a percentage of the total work content issued to the shop during the run. It should be noted that, in this instance, the work content issued averaged 219% of the design load over the whole run.

The 'remaining' measure of work in progress gives an indication of the amount of work (rather than batches) completed during the simulation period whilst the 'total' figure provides an assessment of the amount of work left in the system.

The most significant differences in performance occur between the results for the random rule and those for all the others. The capacity realised during the last six months of the run is approximately 30% less than that achieved by the other configurations. This poor performance is also reflected in the work in progress figures which are the highest for all the runs.

The results for the three process orientated rules (minimum setting, machining, and process times respectively) are all very similar. Work in progress figures differ by less than one week and the capacity realised equalled approximately 117% of the design load for all these runs. The remaining work in progress levels were slightly lower than those for the due date and float rules, reflecting the improved facility utilisation offered by process orientated scheduling rules. The poorer completion performance, when compared to the duedate rule, is reflected in the higher total work in progress levels exhibited by these runs.

The minimum duedate run achieved the highest realised capacity (123.7%) and the lowest level of total work in progress. Surprisingly, the performance of the minimum float rule was markedly inferior to that shown by the minimum duedate run. Whilst the total work content over the whole run was higher (112.7%) than that achieved by the process rules (best 109%) the capacity realised in the last six months (117.8%) was virtually identical to that shown by the minimum setting and process rule configurations.

The lead time-work in progress characteristics for those runs are given in Figures 10.1 and 10.2 and plots of the within- cell lead time standard deviation against work in progress in Figures 10.3 and 10.4.

The process rules exhibit broadly similar responses for both the mean and standard deviation plots. These rules show a slower increase in mean lead times, when compared to the minimum duedate,float and random runs, until work in progress levels reach approximately 24 weeks, when a rapid increase in lead times occurs, reaching similar levels to those shown by the other rules.

The minimum duedate and float rules show an almost linear response, a quality not matched by either the random or process rule runs. The duedate, float and random rules follow a very similar response up to approximately 20 weeks work in progress when some divergence is evident. In comparison to the duedate run, the float rule returns slightly lower mean values and the random rule fluctuates more widely about a broadly similar trend.

The mimimum duedate and float rules show lower standard deviations than any other run. The highest value is reached by the random rule which follows a similar trend to that shown by the process runs. Thus, although the process rules yield superior mean lead time responses, particularly at modest levels of work in progress, this performance is offset by higher standard deviations and inconsistency in the form of the response characteristic. Although the duedate and float rules offer no advantages over even random selection in terms of mean lead times, they do offer a more

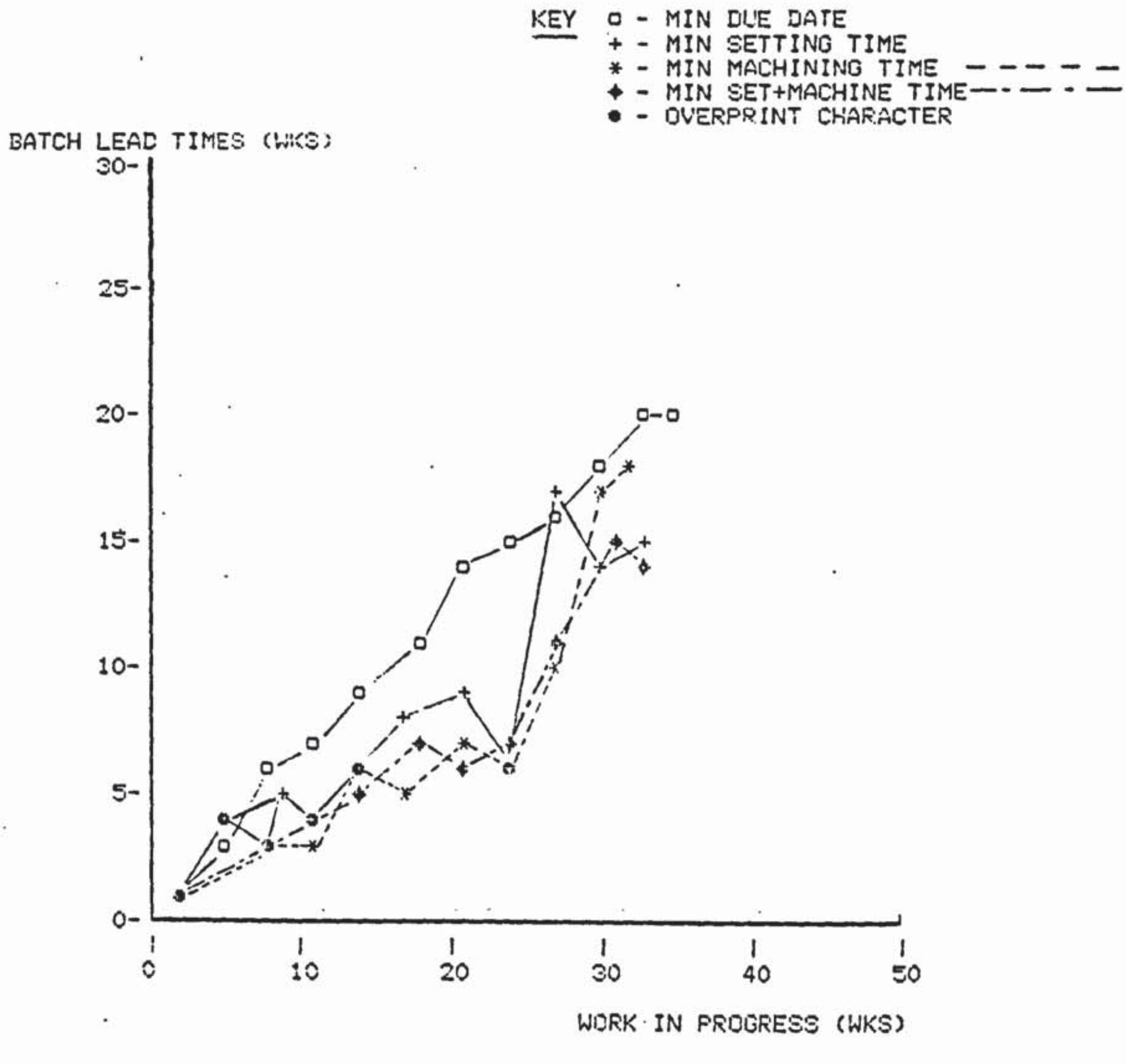

Figure 10.1 LEAD TIME - WORK IN PROGRESS RELATIONSHIP DUE DATE AND PROCESS TIME ORIENTATED SCHEDULING RULES

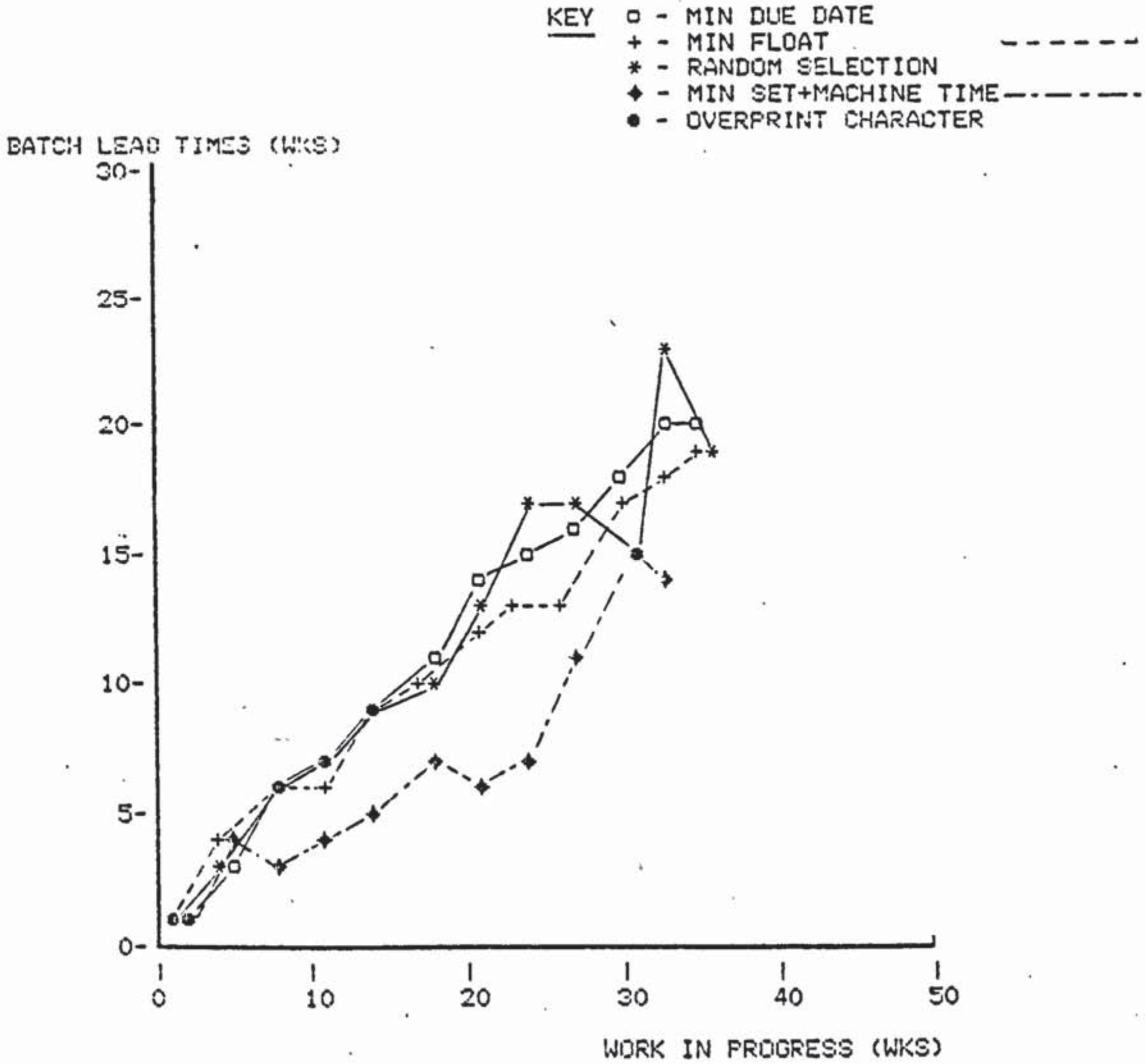

Figure 10.2 LEAD TIME - WORK IN PROGRESS RELATIONSHIP DUE DATE, FLOAT, RANDOM AND PROCESS TIME SCHEDULING RULES

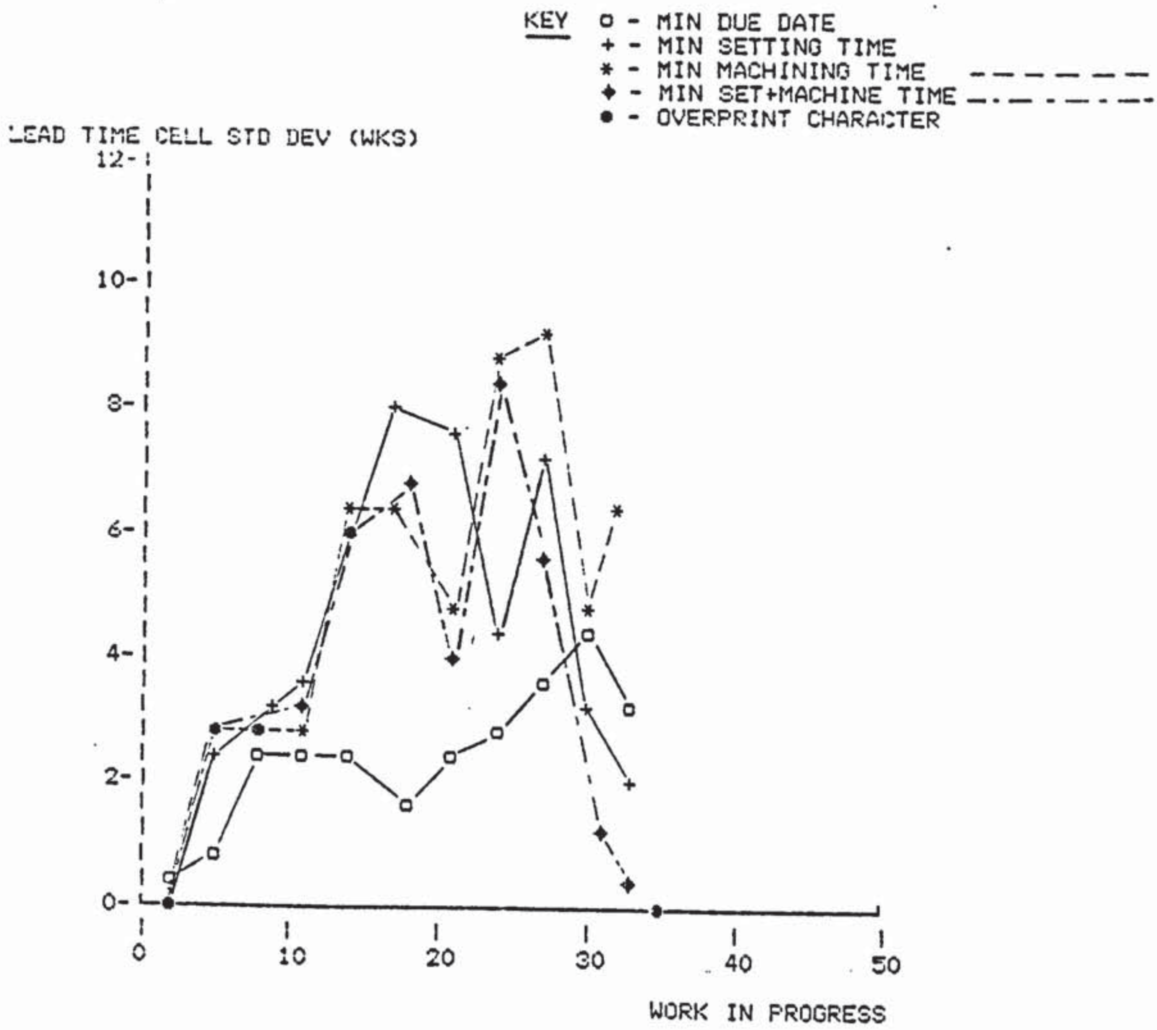

Figure 10.3 <u>LEAD TIME VARIABILITY - WORK IN PROGRESS RELATIONSHIP</u>

<u>DUE DATE AND PROCESS TIME ORIENTATED SCHEDULING RULES</u>

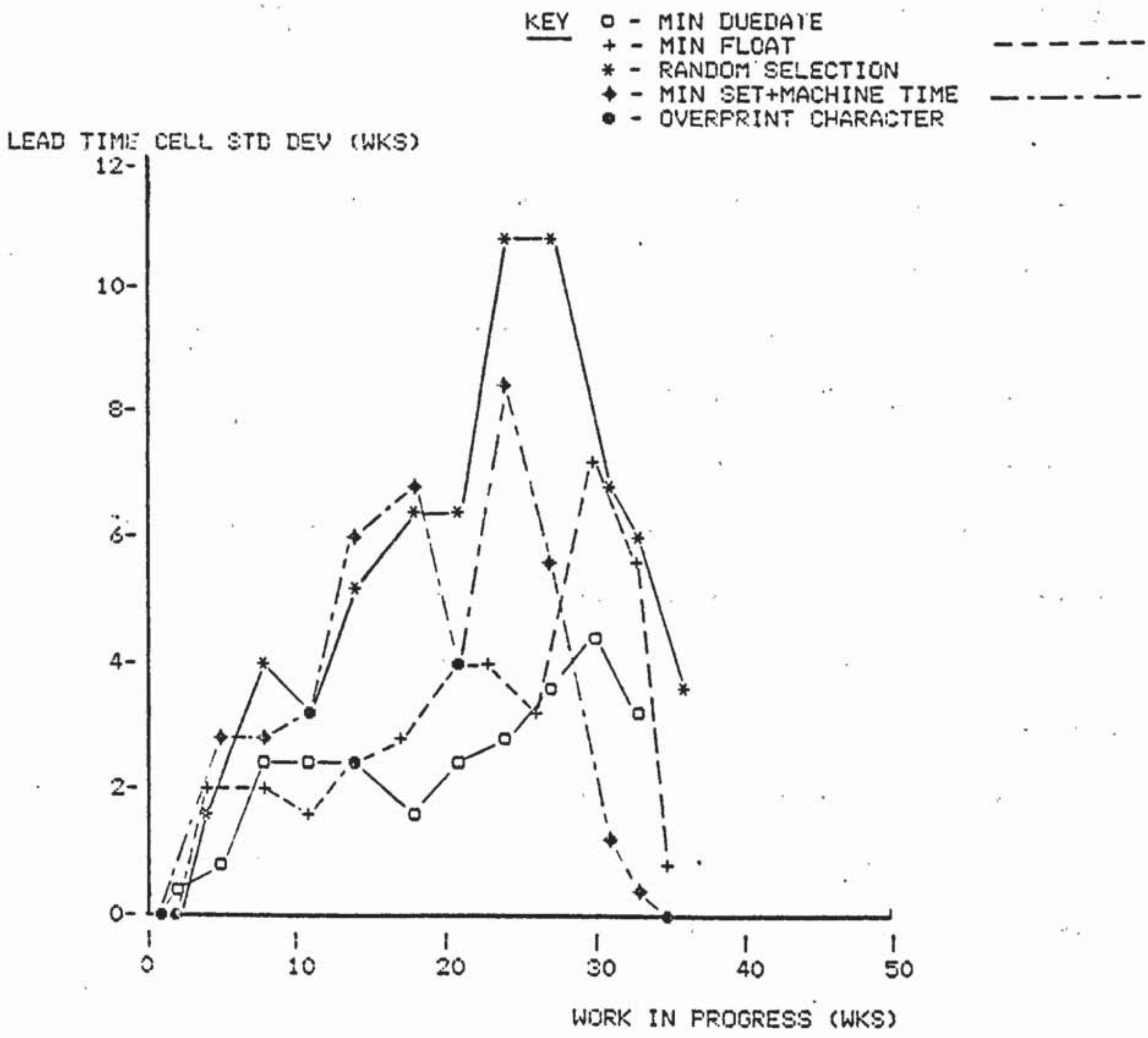

Figure 10.4 LEAD TIME VARIABILITY - WORK IN PROGRESS DUE DATE, FLOAT, RANDOM AND PROCESS TIME SCHEDULING RULES

linear response and significantly lower standard deviations. The within-cell standard deviation reflects the range of lead times of batches completed at a particular level of work in progress. This measure can therefore be considered to reflect the reliability or consistency of lead times offered by the scheduling rule. This aspect of performance can also be examined by comparing the pattern of batch completions for the various rules. The model assigns each batch a unique number upon issue to the machine shop. Since the numbers are issued in sequence, the presence of lead time variability will be reflected by a wide range of incomplete batch numbers. Figure 10.5 shows the number of batches from each range of ten batch numbers, that remained unfinished at the end of the simulation. The figure compares the performance of the minimum process, duedate and random selection runs. The poor performance of the random and minimum process time rules is reflected by the presence of many low numbered (and therefore early issued) batches.

The convergence of the mean lead time characteristics at high levels of work in progress and the attendant reduction in standard deviation for all the runs is an interesting phenomena. Whilst the evidence cannot be considered conclusive, this does suggest that the superior performance of the process rules at low levels of work in progress is achieved primarily by the 'stalling' of larger batches which, when eventually completed (toward the end of the run when the work in progress levels are high), result in a sharp increase in average lead times.

the Mann-Whitney ranking and 't' difference tests were applied to the lead time means and standard deviations calculated for each work in progress cell and plotted in Figures 10.1-10.4. The results

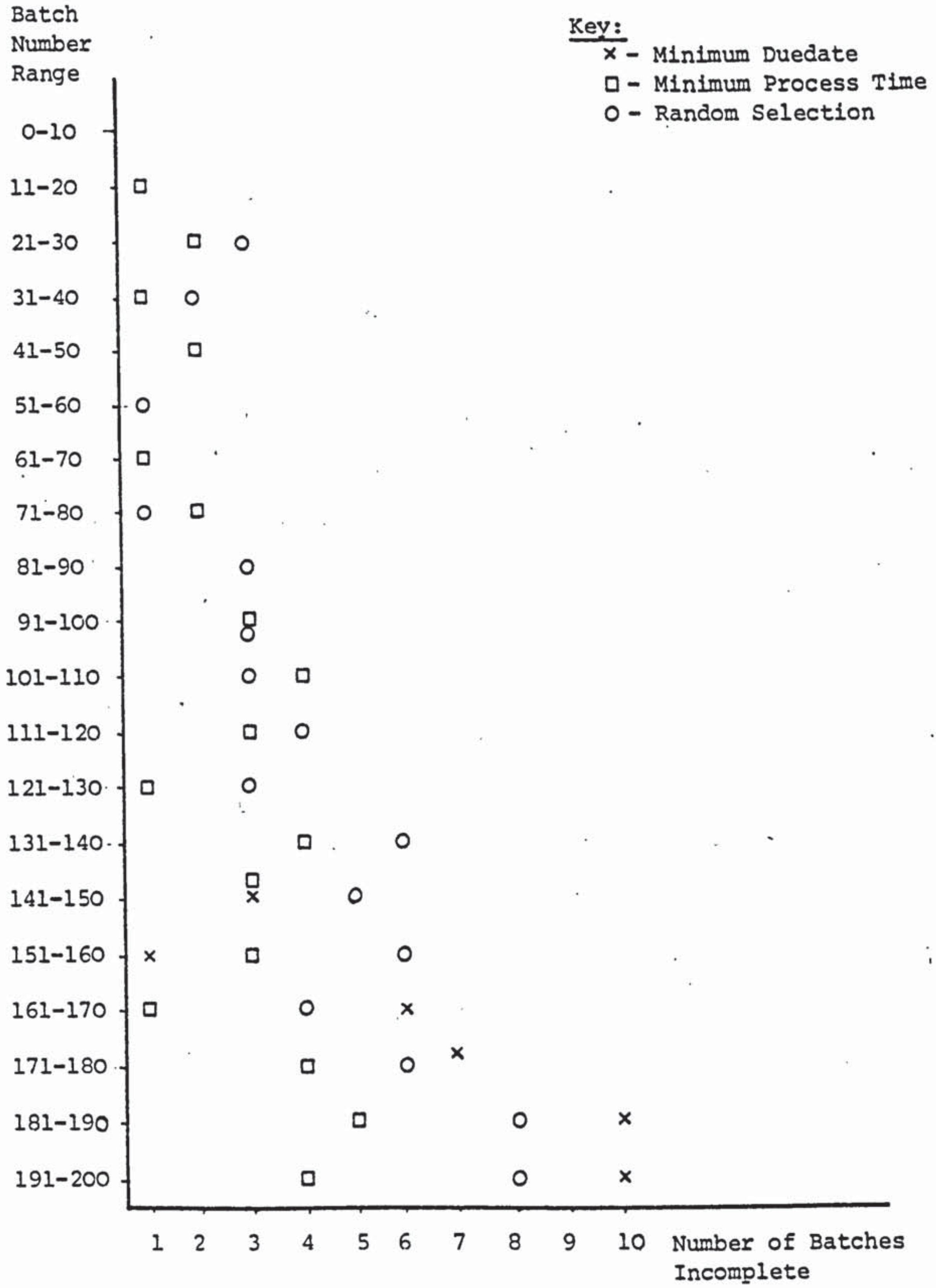

Figure 10.5 Distribution of Batches Incomplete at the Termination of the Runs.

are given in terms of the values of 'u' and 't' calculated for each pair comparison in Tables 10.4 and 10.5. In addition the tables indicate the significance of the calculated statistic for each comparison.

Table 10.4 shows the results for the three process time orientated rules and confirms their similarity of performance. The due date, float, process time and random rules are compared in Table 10.5, and again the results generally confirm the differences in performance mentioned above, particularly in relation to the random rule.

10.5.1.2 Operator Flexibility

This series of runs was carried out over a simulated period of 8 months in contrast to the 12 months used for scheduling rule experiments. The shorter runlength accounts for the slight difference of 8% in the average issued load figures (211% for the former and 219% for the latter).

The work in progress and completion results are given in Table 10.6. The double skilled configuration returns a much poorer performance than all the other runs, achieving less than 100% of the design completion rate and showing a very rapid build up of work in progress, which reached almost 30 weeks (remaining) by the end of the run. The performance of the 3, 4 and 5 skilled runs was very similar, particularly in relation to final work in progress values which differed by less than one week (remaining) and 1.5 weeks (total). The five skilled run did achieve the highest realised capacity but the improvement over the three skilled run was marginal.

First Sample		Second Sample			
		Minimum Machining		Minimum Process	
		Value	p	Value	p
Lead Time Means (of each W.I.P. cell)					
Min set	u t	55 1.04	- -	52 2.03	- *
Min machining	u t			58 0.77	- -
Lead Time Standard Deviations (of each W.I.P. cell)					
Min set	u t	52 1.00	- -	54 0.95	- -
Min machining	u t			47 1.836	- *

Note:

'p' is the probability associated with the Null hypothesis

key;

- \- p greater than 0.1
- * p less than 0.1
- ** p less than 0.05
- *** p less than 0.005

Table 10.4 Mann-Whitney (u) and 't' Difference Test Values for the Process Time Orientated Scheduling Rules Results (Constant Batch Issue Rate Series)

First Sample		Second Sample					
		Minimum Process		Minimum Float		Random Selection	
		Value	p	Value	p	Value	p
Lead Time Means (of each W.I.P. cell)							
Minimum Duedate	u	37	-	53	-	60	-
	t	4.74	***	3.02	**	0.25	-
Minimum Process	u			40	-	38	-
	t			4.8	***	3.69	**
Minimum Float	u					55	-
	t					1.83	*
Lead Time Standard Deviations (of each W.I.P. cell)							
Minimum Duedate	u	41	-	51	-	24	**
	t	1.53	-	1.96	*	3.82	**
Minimum Process	u			52	-	42	-
	t			0.58	-	2.22	**
Minimum Float	u					34	-
	t					2.89	**

Note: 'p' is the probability associated with the null hypothesis.

Key:
- \- $p > 0.1$
- * $p < 0.1$
- ** $p < 0.05$
- *** $p < 0.005$

Table 10.5 Mann-Whitney (u) and 't' Difference Test Values for the Duedate, Float, Process and Random Scheduling Rule Results. (Constant Batch issue rate series)

Skill Pattern	Work Content of Completed Batches			Work in Progress at Run Termination (Wks at Design Load)	
	% Total Issued	% Design Load Complete	Last 4 Months	Remaining	Total
Standard Manning	51.3	108.5	113.8	25.2	28.8
2 skills/man	44.9	94.8	97.2	29.6	32.6
3 skills/man	53.8	113.7	124.6	23.2	27.4
4 skills/man	53.3	112.6	116.5	23.7	27.7
5 skills/man	55.74	117.8	124.2	23.7	26.2

Note:

Remaining W.I.P.	Work content of the (Remaining) operations for all batches present
Total W.I.P	Work content of (all) operations for all batches present
Average Issued Load	211% of the Design Load.

8 Months of Operation Simulated.

Table 10.6 Work in Progress and Completion Results for the Labour Flexibility Series of Constant Issue Rate Runs.

The markedly inferior performance of the double skilled arrangement was mainly due to a reduction in the capacity realised from the automatic lathes. Since only one man could operate and set these two machines, interference between these activities reduced the plant utilisation.

The superiority of the 3 to 5 skill runs in comparison to the 'standard' arrangement is partially due to an increase in the performance of the automatic lathe setter. This arose as a consequence of the need to specify both setting and operating skills for each man. (rather than having seperate operators and setters) for these runs. This point is discussed more fully in section 10.5.2.2 below.

The lead time-work in progress characteristics, shown in Figure 10.6, are virtually identical for all the 3 to 5 skilled runs. The slightly lower lead times returned by the double skilled run at levels of work in progress above 12 weeks are the result of the restriction in capacity realised from the automatics. The build up of work at these machines raises the level of the average work in progress monitored for the completed batches. The sample of consecutively issued batches used for the lead time analysis of this run contained a significant number of jobs which remained incomplete at the end of the run. Thus the results were biased by the predominance of non-automatic jobs, which had avoided the queueing delay at the restricted operation.

Examination of the standard deviations plotted in Figure 10.7 shows that the lead time variability is similar for all the 3 to 5 skilled runs.

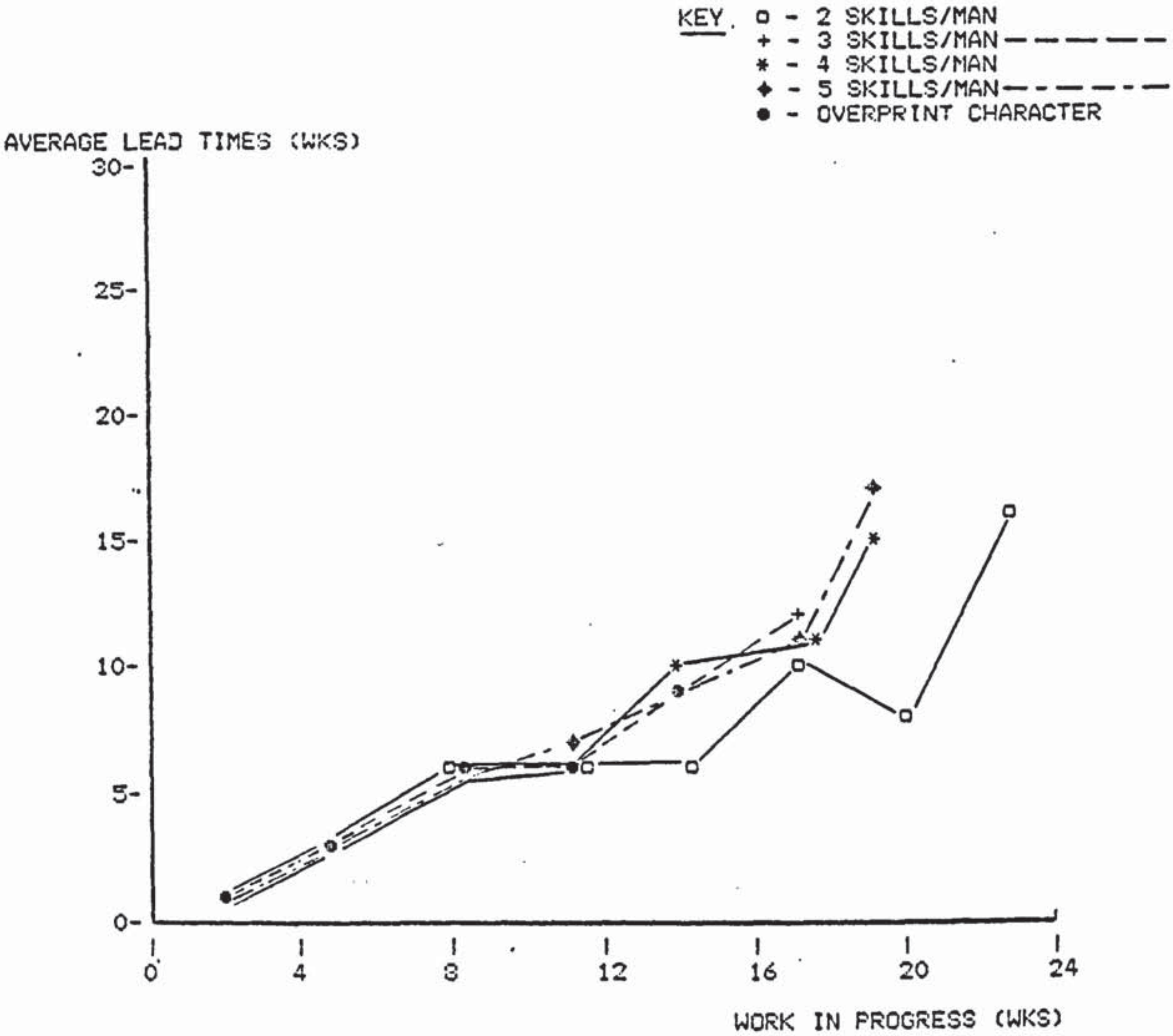

Figure 10.6 <u>LEAD TIME - WORK IN PROGRESS RELATIONSHIP</u>
<u>LABOUR FLEXIBILITY SERIES</u>

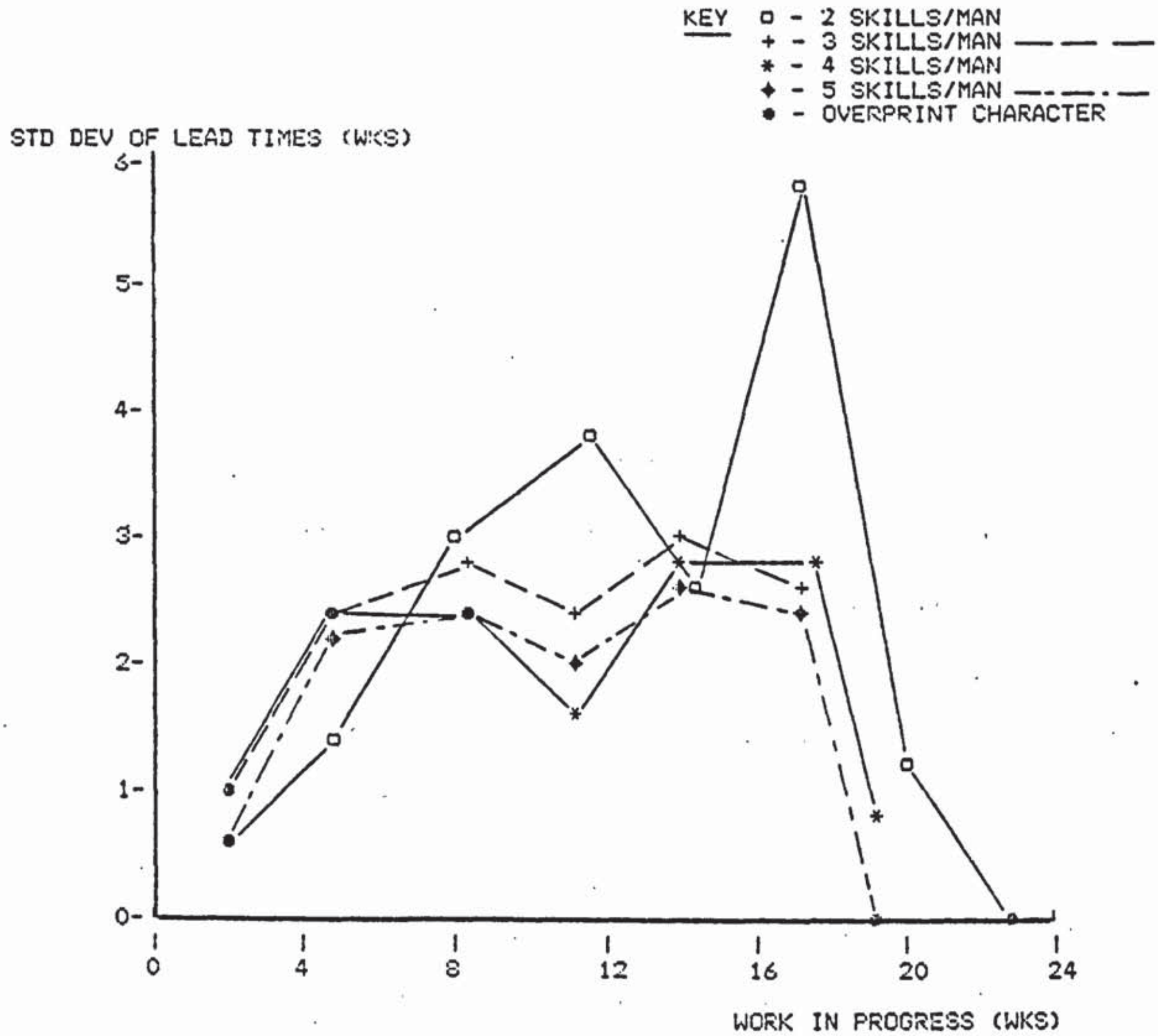

Figure 10.7 <u>LEAD TIME VARIABILITY - WORK IN PROGRESS RELATIONSHIP</u>

<u>LABOUR FLEXIBILITY SERIES</u>

The higher degree of variability implied by the results for the two skilled arrangement is consistent with operating conditions described above.

The similarity of the lead time performance of the multi-skilled configurations is confirmed by the results of the statistical analysis given in Table 10.7.

10.5.1.3 Batch Size

Table 10.8 summarises the work in progress and completion performance for batch sizes ranging between twice and half the normal or 'standard' figure. The modification of batch size led to a corresponding change in the order issue rate and thus in the load issued to the shop for each run. The effect of halving the batch size, for example, was to increase the load issued by 37% (of the design level), in comparison to the standard run. The adjustment of the order issue rate also meant that the distribution of components selected for manufacture varied from one run to another. The component selection sequence was the same, since identical random number seeds were used for all runs, but the quantity of jobs selected varied in proportion to the appropriate batch issue rate.These factors complicate performance comparisons between the various runs.

In general one would expect the load and final levels of work in progress to rise as the batch size is decreased. A corresponding deterioration in completion performance could be expected as the setting load increased with a reduction in batch sizes. The results broadly support these expectations particularly in relation to work in progress and the completion rate achieved during the last 4 months of the simulation.

First Sample		Second Sample					
		3 Skills/man		4 Skills/man		5 Skills/man	
		Value	p	Value	p	Value	p
Lead Time Means (of each W.I.P. cell)							
2 Skills /man	U	15	-	20	-	20	-
	t	1.66	-	1.82	-	1.75	-
3 Skills /man	U			17	-	18	-
	t			0.17	-	0.12	-
4 Skills /man	U					23	-
	t					0.92	-
Lead Time Standard Deviation (of each W.I.P. cell)							
2 Skills /man	U	14	-	19	-	17	-
	t	0.82	-	1.15	-	1.56	-
3 Skills /man	U			16	-	12	-
	t			1.18	-	4.78	**
4 Skills /man	U					19	-
	t					1.32	-

Note:

'p' is the probability associated with the Null hypothesis

key;

-	p greater than	0.1
*	p less than	0.1
**	p less than	0.05
***	p less than	0.005

Table 10.7 Mann-Whitney (u) and 't' Difference Test Values for the Operator Flexibility Lead Time Results (Constant Batch Issue Rate Series)

Batch Size	Work Content of Completed Batches			Work in Progress at Run Termination (Wks at Design Load)	
	% Total	% Design Load.			
	Issue	Complete Run	Last 4 Months	Remaining	Total
2xStandard	50.1	106.7	124.9	27.8	29.7
Standard	51.3	108.5	113.8	25.2	28.8
0.75Standard	47.5	113.7	113.1	31.2	35.2
0.5Standard	44.5	110.3	110.0	34.2	38.5

Note:

Remaining W.I.P — Work content of the (Remaining) operations for all batches present

Total W.I.P — Work content of (all) operations for all batches present

Average Issued Load
= 211% (Design Load) Standard.
= 213% (Design Load) 2 x Standard
= 239% (Design Load) 0.75 x Standard
= 248% (Design Load) 0.5 x Standard.

8 Months of operation Simulated.

Table 10.8 Work in Progress and Completion Results for the Batch Size Series of Constant Issue Rate Runs.

The 'standard' batch size run shows a surprisingly good performance in comparison to the results for the maximum (twice standard) batch size tested. This performance is due to similarity of the run's respective issued loads, in fact the load for the standard run (211%) was actually marginally lower than that for the other run (213%). The completion rates achieved in the last part of the run (113.8% and 124.9% respectively) are probably a better indication of the affect attendant on an increase in batch sizes.

The lead time performance is shown in Figures 10.8 and 10.9 and proved to be very similar for all the runs, although the smallest batch sizes run (half the standard value) did show greater variability at high levels of work in progress. The statistical analysis (see Table 10.9) confirmed the similarity of the lead time responses.

10.5.2 Fluctuating Batch Issue Rate Run Series

These runs were used to more closely approximate the kind of operational conditions to which the manufacturing unit could be expected to be subjected to. The batch issue rate followed a sinusoidal path having an amplitude of 40% of the design load and completing a full cycle of 220 weeks within the simulated time period. Whilst it would have been desirable to simulate several complete demand cycles, this option could not be followed due to the excessive computer time required for its execution.

The results of the constant issue rate series of runs demonstrated that all three process orientated scheduling rules returned very similar performance characteristics. In order to conserve computer time it was therefore decided to retain only the minimum process time (ie setting plus machining time) rule for this

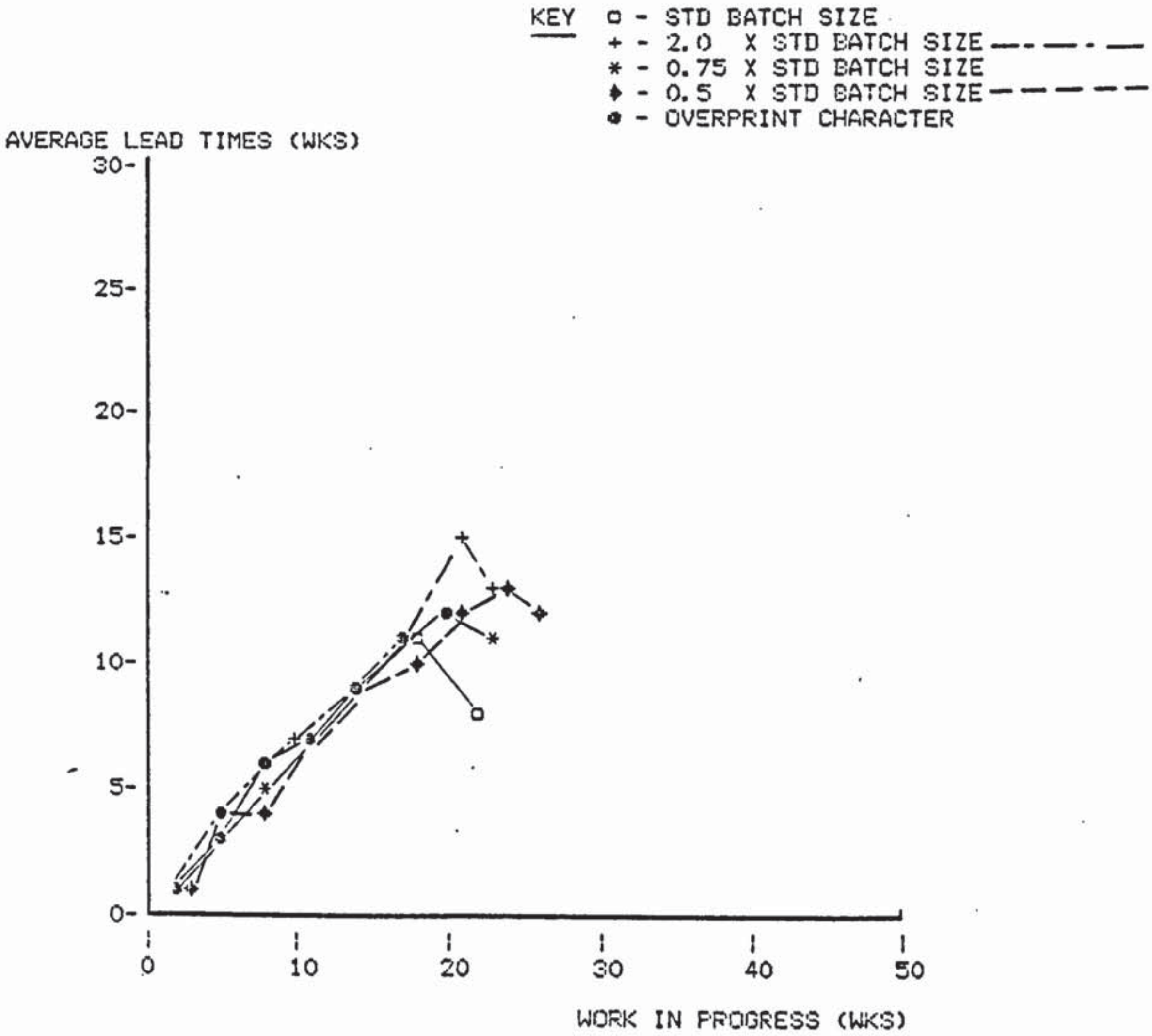

Figure 10.8 LEAD TIME - WORK IN PROGRESS RELATIONSHIP
BATCH SIZE SERIES

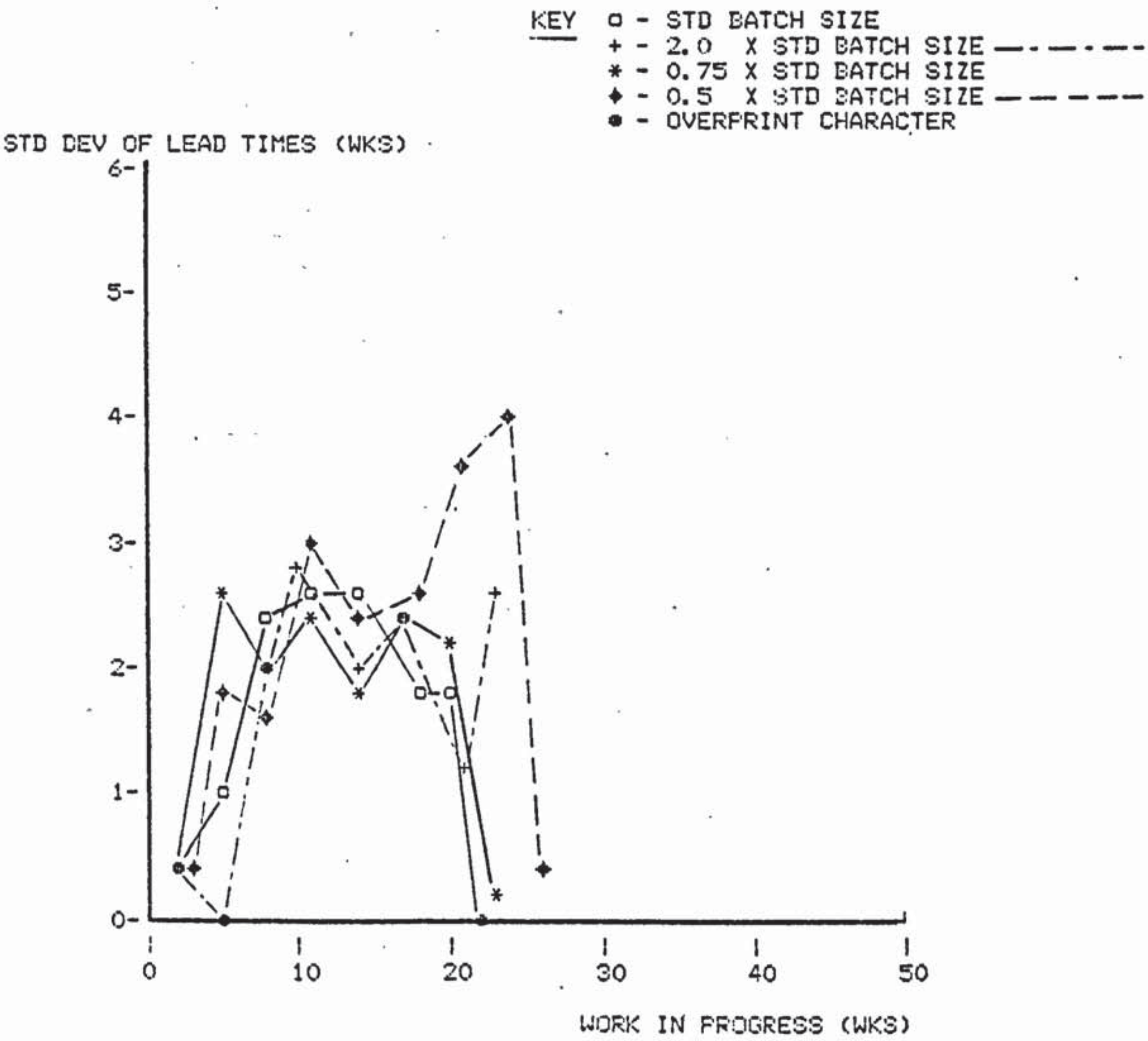

Figure 10.9 LEAD TIME VARIABILITY - WORK IN PROGRESS RELATIONSHIP BATCH SIZE SERIES

First Sample		Second Sample					
		2 x Std Batch Size		0.75 x Std Batch Size		0.5 x Std Batch Size	
		Value	p	Value	p	Value	p
Lead Time Means (of each W.I.P. cell)							
Std Batch S	U	19	-	29	-	31	-
	t	1.85	-	0.99	-	0.21	-
2 x Std	U			20	-	20	-
	t			2.34	*	3.14	**
0.75 x Std	U					31	-
	t					0.81	-
Lead Time Standard Deviations (of each W.I.P. cell)							
Std Batch S	U	22	-	27	-	18	-
	t	0.355	-	0.64	-	1.72	-
2 x Std	U			23		13	**
	t			0.10		2.18	*
0.75 x Std	U					19	-
	t					1.43	-

Note:

'p' is the probability associated with the Null hypothesis

key;

-	p greater than	0.1
*	p less than	0.1
**	p less than	0.05
***	p less than	0.005

Table 10.9 Mann-Whitney (u) and 't' Difference Test Values for the Batch Size Lead Time Results (Constant Batch Issue Rate Series)

longer series of runs.

The work in progress and completion results are presented in a different manner to that used for the constant issue rate run series. Since the state of the system at the end of the complete run is of less interest than its performance during it, detailed plots of the work in progress, issues, completions and average lead times are given, for all this experimental series, in Figures 10.10 to 10.39. In addition the performance of the machine shop during the period of the simulation in which the planned load exceeded the design level is summarised in Table 10.10 (issues, completions, lead times and work in progress) and Tables 10.11 to 10.13 (plant and operator utilisation).

The lead time - work in progress characteristics are given in Figures 10.18,19,28-31,38 and 39. In addition the results of the Mann-Whitney and 't' difference tests are given for paired comparisons of work in progress, completion rates, average lead times, and lead time-work in progress characteristic performance for all runs in Tables 10.14 to 10.19. For convenience all these figures and tables are gathered together at the end of this sub-section.

As before, the results will be discussed for the scheduling rules, labour flexibility, and batch size experiments in turn.

10.5.2.1. Scheduling Rules

The summary of work in progress and completion performance given in Table 10.10 shows that, for the scheduling series, random selection of batches results in the highest levels of work in progress although the average level of completion is broadly the same as that achieved by the other rules. The average and peak levels of work in progress follow the same pattern which, although the differences are small, is consistent with that shown by the constant issue rate experiment (see Table 10.3). The process time rule returns the lowest level of remaining work in progress but the marginal improvement that this offers implies only a small increase in effective utilisation of resources. This view is confirmed by the detailed utilisation figures given in Tables 10.11 to 10.13.

The peak level of completions achieved during any six month period was approximately 20% less than the peak issue rate for all these runs. The higher peak value shown by the random rule (137%) was sustained only for a single period whilst the peak values (131 - 133%) achieved by the other rules were maintained over several periods. The equivalent average figures show a shortfall of between 4 and 6%, the best performance being achieved by the float and random rules and the worst by the process rule. The latter result is consistent with the tendancy of the process rule to give priority to batches having smaller work content.

The form of the completion response is similar for all the rules (see Figures 10.10 to 10.13) but the work in progress levels show a more peaked characteristic for the random rule.

Comparisons of the average lead and queueing/operation times for batches completed during successive two month periods with work in progress levels are given in Figures 10.14 to 10.17. The minimum processing rule run (Figure 10.17) shows a much slower initial rise in mean lead and queueing/operation times when compared to the other runs. Whilst the movement of lead times follows that of work in progress relatively smoothly for the duedate, float and random runs, the process time response fluctuates wildly during the peak demand period. The former runs exhibit a lag of approximately six months between work in progress and lead time responses. The form of the process time response makes determination of the lag for this run an impossible task. The queueing statistic follows that for lead times closely for all the rules indicating that, as expected, most of the throughput time is spent queueing for facilities and that distortion introduced by route and process data variation is limited. These comments are confirmed by the results of the 't' difference test given in Table 10.14, but no significant differences were identified by the Mann-Whitney ranking procedure.

The lead time - work in progress characteristics are plotted for all the scheduling runs in Figure 10.18. The relative performance of the rules is consistent with that produced by the constant issue rate series up to the same maximum level of work in progress. The process rule returns lower, and the random rule higher, mean lead times than those offered by the duedate and float rules. The duedate and float characteristics move closely together and follow a more linear response than the other rules. The random rule shows greater divergence in these runs than was evident in the constant issue rate series. It is interesting to note that the gradient of the random response approximates to unity. In steady state conditions the following relationship can be expected to hold:

Work in Progress = Lead Time x Issue (or Completion) Rate

If consistent units are used throughout this equation and the work in progress is expressed in terms of the issue rate, the relationship simplifies to:

Work in Progress = Lead Time

Thus a gradient of unity is representative of average or steady state conditions. The random rule results are therefore consistent with these conditions whereas the other rules all offer improvements over this 'average' concept.

The lead time variability implied by the within-cell standard deviations, given in Figure 10.19, also follow the same pattern established by the constant issue rate results. The duedate and float runs show a minimal increase in variability with increased work in progress and return consistently lower values than the other runs. Both the random and process time rules exhibit much higher standard deviations than those of the duedate and float runs, the process rule being markedly superior to the random rule at high levels of work in progress. These conclusions are again supported by the results of the statistical analysis shown in Table 10.15.

Whilst the choice of scheduling rule appears to have had only a limited influence on the levels of work in progress or completion rates, it does have a substantial effect on the form of the lead time - work in progress characteristic, and on the lead time variability.

10.5.2.2. Operator Flexibility

The work in progress and completion performances of the operator flexibility runs are shown graphically in Figures 10.19 to 10.23 and summarised in Table 10.10. Comparison with the performance achieved by the scheduling rule series of runs shows the marked superiority of the manning configurations used in the 3-5 skill flexibility runs. Much lower values of peak (16 to 21 weeks) and average (12 to 15.5 weeks) levels of work in progress were recorded and an increase of approximately 5% was shown in the capacity realised by the machine shop. The redistribution of skills necessary to set up the flexibility runs also necessitated some modification of the operator performance levels. Two operators were exclusively associated with the automatic machines in the 'standard' configuration, both being assigned performances of 100%. The flexibility configuration required men to operate and set both automatic and manually controlled machines and a performance figure of 230% was therefore assigned to reflect the factory average for manually controlled operations. The manner of the model's operation of automatic machines meant that the machining part of the process would still be carried out at the equivalent of 100% performance, (even when the man's performance was nominally 230%). The setting of the machines was, however, directly affected by the new performance levels, as can be confirmed by reference to the setting utilisations given in Table 10.11. Comparison of the figures for the scheduling and flexibility runs for the automatics shows the reduction in setting times consequent on the performance increase. However, examination of the machining utilisation figures for the three-skilled run shows that only marginal increases in output (0.4 and 1.5%) were achieved (compared with the reference run) in spite of the extra time made available for production as a result of the reduced setting times. The most significant improvement in utilisation occurs for the two capstan lathes being 1.4% and 3.8% for the bar and chucking machines respectively.

The double skilled configuration shows much poorer performance than the other runs, achieving lower peak (117%) and average (98.5%)completion rates along with much higher remaining work in progress levels (see Table 10.10). The availability of only one operator capable of setting or running the two automatics led to a severe reduction in their utilisation. (Tables 10.11 to 10.13 refer) and a consequent reduction in the capacity realised by the machine shop.

The increase in the number of skills from three to five led to a slight increase in the average completion rate from 129.1% to 131.5% and a corresponding reduction in the average level of remaining work in progress from 12.3 to 11.5 weeks. A reduction of 1.7 weeks also occurred in the peak work in progress values. The improvements in the response of the system are also evident from graphs plotted in Figures 10.20 to 10.23. Examination of the average lead and queueing/operation times of completed batches plotted for successive bi-monthly periods in Figures 10.24 to 10.27 shows the response of the three, four and five skilled runs to be very similar. The summary data in Table 10.10 shows that the average lead time for the peak demand period (months 3 to 30) varies by less than 0.5 weeks. The average lead times achieved are better than those shown by any other run excepting the process scheduling rule which exhibits a much higher peak lead time value. The five skilled configuration returns the lowest combination of peak and average lead time values. The results of both the Mann-Whitney and 't' difference tests, presented in Table 10.16, detect significant differences between the response of the double skilled and other flexibility runs in relation to all the gross measures of performance. The comparisons with the standard manning arrangement are also significant for the work in progress and lead time responses.

The lead time-work in progress characteristics are shown for the two, three, four and five skilled runs in Figure 10.28. All the runs follow virtually identical paths up to approximately 8 weeks work in progress when the double skilled run diverges from the others. The within-cell standard deviations for these runs are plotted in Figure 10.29 and all show virtually identical responses up to 10 weeks work in progress, after which the double skilled run shows much higher values.

The response for the double skilled run is compared with the 'standard' and five skilled results in Figures 10.30 and 10.31. The most notable feature is the much higher variability shown by this run in comparison with the standard arrangement at high levels of work in progress (see Figure 10.31).

Thus, whilst the skill configuration was seen to exert a considerable influence on completion rates, work in progress levels and average lead times during the period of peak demand, only minimal differences were identified in the form of the lead time - work in progress characteristics for all but the double-skilled run. This view is supported by the results of the statistical analysis shown in Table 10.17.

10.5.2.3 Batch Size.

The smaller batch size runs (0.5 and 0.75 of the standard value) proved to be so inefficient in execution that they had to be truncated when only 24 months operation had been simulated. An increase in the number of jobs present in the machine shop naturally followed adjustment of the batch issue rate to compensate for the reduction in batch sizes. The computation time required by the program's activity entry routines increased dramatically with the number of jobs active in the model. The half standard batch size run had consumed over 35 hours of c.p.u. time before being abandoned.

Consequently the results for the smaller batch size runs are presented for a runlength of just under half that used for the other experiments. The comparative data presented in Table 10.10 for all the batch size runs applies only to the period between months 3 and 24 inclusive.

The decision to adjust the issue rate to correspond with variation in batch size so as to maintain the quantity of components produced resulted in large changes in the level of the average load on the shop. Reference to Table 10.10 and Figures 10.32 to 10.34 shows the magnitude of the load variation attendant on this policy.

Doubling the batch size led to a reduction of the average load, during the peak demand period, to 112.5% from 137.2% of the standard run. The fact that the peak and average completion rates exceed the corresponding issue figures is a direct consequence of the high issue rate used during the first four months to 'fill' the system. This policy is also reflected by the early (and untypical) peak in work in progress levels. The low level of work in progress and short lead times evident in Figure 10.35 and summarised in Table 10.10 are an obvious corollary to the reduction in shop load. The utilisation figures given in Tables 10.11 and 10.12 confirm the reduction in the ratio of setting to machining times for all operations.

The trends associated with the reduction of batch sizes is the converse of that shown by the larger batch size run. The work in progress and lead times all increase substantially, the smallest batch size run reaching peak levels between 40% and 50% higher than the standard version. The load on the shop also increases from an average figure of 137% for the standard run to 146.6% and 150% for the three- quarter and half standard batch size runs respectively. The capacity realised from the shop by the smallest run deteriorates by 6.8% in comparison to the standard version. It should be realised that this figure underestimates the drop in useful output since it includes setting hours in the completed load statistic. The setting time per component produced will be higher for smaller run quantities and thus distort the significance of relative completion rates.

The statistical tests identify differences between the performance of the batch size runs and the others for the work in progress and average lead time measures. Surprisingly, with the exception of the standard and twice normal runs, the completion patterns were not identified as being significantly different (see Table 10.18).

The lead time-work in progress characteristics, shown in Figure 10.38, are very similar for all the runs. Some differences are evident in the standard deviation plots shown in Figure 10.39; the smaller batch size runs show lower levels of variability at up to 12 weeks work in progress. Thereafter the standard deviation of the half standard run climbs to values comparable to those of the larger runs. The trend is not consistent since the three quarter standard run maintains lower values throughout the complete range of work in progress levels. The variability of the latter run is identified as being significantly different to the remainder by the results of the statistical analysis. given in Table 10.19.

In general, the conventional view that larger batch sizes will increase manufacturing efficiency by a reduction in set to run ratios appears to be supported by the results of these experiments. The validity of this conclusion is limited to cases where manufacturing practise is analagous to that presented in the model, that is where the setting, run, and transport quantities are all identical.

Simulation Run	Issued Load % Design Level		Completed Load % Design Level		Remaining W.I.P. Wks of Design Load		Lead Time Weeks	
	Peak	Average	Peak	Average	Peak	Average	Peak	Average
Scheduling Rule Series - months 3 to 30 inclusive								
Random	153	130.3	137	126.7	22.2	16.3	19.8	13.2
Duedate	153	130.3	132	125.2	21.4	15.7	16.2	11.6
Float	153	130.3	131	126.2	21.3	15.6	15.6	11.0
Process Time	153	130.3	133	123.9	20.6	15.1	18.3	8.1
Labour Flexibility Series - months 3 to 30 inclusive								
2 Skills/man	153	130.3	117	98.5	45.0	30.1	15.6*	10.2
3 Skills/man	153	130.3	140	129.1	16.5	12.3	13.0	8.2
4 Skills/man	153	130.3	136	129.3	15.9	12.5	15.2	8.7
5 Skills/man	153	130.3	139	131.3	14.8	11.5	11.0	8.2
Batch Size Series - months 3 to 24 inclusive only								
2 x Standard	123	112.5	124	115.8	15.8	12.8	14.1	10.8
Standard	153	137.2	132	126.8	21.1	14.7	14.7	10.6
0.75 x Standard	162	146.6	134	121.6	29.3	18.7	17.4	11.8
0.5 x Standard	169	150	129	120	33.4	23.8	22.5	14.5

* Lead time peaked at 41.5 wks later in the run

Note:-

Peak load figures are the maximum of calculated 6 month moving averages

Table 10.10 Summary of Performance during the Period of Peak Demand

Machine/ Operator	Simulation Run										
	Standard Run	Scheduling			Batch Size			Operator Flexibilty			
		min float	min process	random	2 x standard	0.75 x+ standard	0.5 x+ standard	2 Skills	3 Skills	4 Skills	5 Skills
Machines											
Cap bar	8.6	8.7	8.7	8.9	3.7	9.8	15.1	5.9	9.0	9.0	9.0
Cap chuck	9.1	9.0	9.0	8.9	4.7	13.2	18.4	9.1	9.4	9.4	9.5
Auto 1	10.6	10.9	11.2	10.9	5.9	13.7	19.2	3.1	4.9	4.7	5.0
Auto 2	11.4	11.4	11.1	10.9	6.1	13.6	17.1	2.0	4.7	5.0	4.9
4 Sp drill	1.03	1.04	1.08	1.03	0.56	1.26	1.8	1.04	1.05	1.06	1.06
Hor mill	1.07	1.04	1.10	1.10	0.33	1.00	1.7	1.06	1.07	1.06	1.05
Ext grind	0.67	0.67	0.70	0.70	0.16	0.54	0.77	0.6	0.66	0.67	0.67
Fit	-	-	-	-	-	-	-	-	-	-	-
Deburr	0.34	0.35	0.35	0.33	0.17	0.44	0.59	0.26	0.35	0.35	0.36
Degrease	0.02	0.02	0.01	0.02	0.02	0.04	0.03	0.004	0.02	0.02	0.02
H/paint	-	-	-	-	-	-	-	-	-	-	-
Operators											
Man 1	10.9	10.6	10.2	10.6	5.2	14.3	19.8	8.9	7.4	7.4	6.6
Man 2	23.8	24.1	24.3	23.6	13.2	29.4	33.9	9.1	9.2	9.0	6.4
Man 3	0.1	0.05	0.05	0.05	-	0.15	0.40	5.1	5.6	5.3	6.9
Man 4	9.6	9.8	10.3	10.0	4.2	11.37	17.8	1.5	4.03	4.6	5.1
Man 5	0.75	0.82	0.78	0.83	0.36	1.02	1.41	2.1	5.8	5.8	7.4

+ These runs averaged over months 3 - 24 inclusive only

Table 10.11 Average setting Performance (%) during the period of peak demand (months 3 - 30 inclusive)

Machine/ Operator	Simulation Run										
	Standard Run	Scheduling Rules			Batch Size			Operator Flexibility			
		min float	min process	random	2 x standard	0.75 x[+] standard	0.5 x[+] standard	2 skills	3 skills	4 skills	5 skills
Machnies											
Cap bar	76.7	77.1	76.1	73.0	71.5	68.3	65.8	77.3	78.1	77.8	78.0
Cap chuck	73.8	73.6	72.9	73.3	79.7	80.6	74.0	71.9	77.6	76.7	78.2
Auto 1	88.1	88.4	88.1	88.5	93.8	86.0	80.3	60.7	88.5	90.6	92.1
Auto 2	88.0	88.0	88.4	88.4	93.7	84.5	79.3	37.4	89.5	89.9	91.6
4 Sp drill	17.6	17.7	17.3	17.0	19.1	19.1	16.0	17.8	17.8	18.0	18.0
Hor mill	3.8	3.7	4.2	4.1	2.6	2.9	2.9	3.7	3.75	3.7	3.7
Ext grind	5.9	5.9	6.3	6.35	2.7	3.0	3.4	5.4	5.8	5.9	5.9
Fit	0.08	0.08	0.08	0.08	0.4	0.17	0.12	0.08	0.08	0.08	0.08
Deburr	27.6	28.4	28.0	26.6	29.3	26.0	23.4	19.4	28.5	28.7	29.2
Degrease	0.27	0.27	0.23	0.27	0.6	0.43	0.24	0.08	0.27	0.27	0.27
H/paint	1.8	1.8	1.8	1.8	1.95	2.3	1.3	0.57	1.8	1.8	1.8
Operators											
Man 1	88.4	38.8	88.5	89.0	88.3	85.64	80.1	77.3	56.1	57.5	61.1
Man 2	-	-	-	-	-	-	-	72.3	80.9	82.3	93.6
Man 3	176.1*	176.4*	176.6*	176.9*	187.6*	170.5*	159.5*	98.0	94.4	94.7	91.8
Man 4	89.4	89.1	88.4	89.7	87.8	88.5	81.9	37.1	63.0	62.3	59.7
Man 5	29.6	30.4	30.0	28.6	31.8	28.7	24.9	9.2	94.2	94.2	92.3

* Operator runs two automatic machines
\+ Average for months 3 - 24 inclusive only

Table 10.12 Average Machining Performance (%) during the period of peak demand (months 3 - 30 inclusive)

Machine/ Operator	Simulation Run										
	Standard run	Scheduling Rules			Batch Size			Operator Flexibility			
		min float	min process	random	2 x standard	0.75 x^{+} standard	0.5 x^{+} standard	2 skills	3 skills	4 skills	5 skills
Machines											
Cap bar	85.3	85.7	84.8	86.9	75.3	78.1	80.9	86.2	87.1	86.8	86.9
Cap chuck	82.9	82.6	81.8	82.1	84.4	93.7	92.4	81.0	87.1	86.1	87.7
Auto 1	98.7	99.3	99.4	99.4	99.7	99.7	99.5	63.8	93.4	95.3	97
Auto 2	99.4	99.4	99.5	99.4	99.8	98.1	96.4	39.3	94.2	94.9	96.6
4 Sp drill	18.6	18.7	18.4	18.0	19.7	20.4	17.8	18.8	18.8	19.1	19.1
Hor mill	4.9	4.7	5.3	5.2	2.9	3.9	4.6	4.8	4.8	4.8	4.8
Ext grind	6.6	6.6	7.1	7.1	2.9	3.6	4.2	6.0	6.5	6.6	6.6
Fit	0.08	0.08	0.08	0.08	0.4	0.17	0.12	0.08	0.08	0.08	0.08
Deburr	27.9	28.7	28.4	27.0	29.4	26.5	24.0	19.7	28.8	29.0	29.5
Degrease	0.29	0.28	0.25	0.28	0.6	0.47	0.27	0.08	0.29	0.28	0.28
H/paint	1.8	1.8	1.8	1.8	1.95	2.3	1.30	0.57	1.8	1.8	1.8
Operators											
Man 1	99.3	99.5	98.7	99.6	93.5	99.9	99.9	86.2	63.5	64.9	67.6
Man 2	23.8	24.1	24.3	23.6	13.2	29.4	38.9	81.5	90.0	91.2	100
Man 3	176.2*	176.4*	176.7*	177.0*	187.6*	170.7*	159.9*	103.2	100	100	98.7
Man 4	99.0	98.9	98.7	99.7	92.0	99.8	99.7	38.6	67.0	66.9	64.8
Man 5	30.3	31.2	30.8	29.5	32.2	29.8	26.3	11.3	100	100	99.7

* Operator runs two automatic machines
\+ Results averaged over months 3 - 24 inclusive only

Table 10.13 Average total Performance (%) during the period of peak demand (months 3 - 30 inclusive)

First Sample		Second Sample					
		Min Proc Time		Min Float		Random Sel	
		Value	p	Value	p	Value	p
Work in Progress Levels							
Min Duedate	U	83	-	95	-	83	-
	t	5.48	***	1.43	-	5.29	***
Min Proc	U			87	-	77	-
	t			4.46	***	6.69	***
Min Float	U					83	-
	t					5.68	***
Completion Rates							
Min Duedate	U	89	-	97	-	77	-
	t	0.26	**	0.17	-	0.78	-
Min Proc	U			88	-	86	-
	t			0.58	-	0.86	-
Min Float	U					78	-
	t					1.24	-
Average Lead Times of Completed Batches							
Min Duedate	U	45	**	81	-	75	-
	t	3.66	**	2.98	**	2.62	**
Min Proc	U			46	**	35	**
	t			3.31	**	5.33	***
Min Float	U					70	-
	t					3.45	**

Note:

'p' is the probability associated with the Null hypothesis

key;

- \- p greater than 0.1
- * p less than 0.1
- ** p less than 0.05
- *** p less than 0.005

Table 10.14 Mann-Whitney (u) and 't' Difference Test Values for the Duedate, Float, Process, and Random Scheduling Rule Results (Fluctuating Demand Series)

First Sample		Second Sample					
		Min Process		Min Float		Random Selection	
		Value	p	Value	p	Value	p
Lead Time Means (of each W.I.P. cell)							
Minimum Due date	u	15	-	23	-	19	-
	t	2.20	*	1.79	-	2.34	*
Minimum Proc time	u			15	-	15	-
	t			2.10	*	2.67	**
Minimum Float	u					20	-
	t					2.39	*
Random Selection	u						
	t						
Lead Time Standard Deviation (of each W.I.P. cell)							
Due date	u	10	*	24	-	11	*
	t	2.4	*	0.85	-	2.85	**
Proc time	u			11	*	21	-
	t			2.40	*	0.69	-
Float	u					12	-
	t					2.98	**
Random	u						
	t						

Note: 'p' is the probability associated with the Null hypothesis

key:
- \- p greater than 0.1
- * p less than 0.1
- ** p less than 0.05
- *** p less than 0.005

<u>Table 10.15 Mann-Whitney (u) and 't' Difference Values for Lead Time - Work in Progress Analysis of the Scheduling Rule Series of Runs</u>

FIRST SAMPLE		SECOND SAMPLE							
		2 Skills/man		3 Skills/man		4 Skills/man		5 Skills/man	
		Value	p	Value	p	Value	p	Value	p
Work in Progress Levels									
Standard Manning	u t	27 6.9	*** ***	51 7.18	* ***	48 6.46	* ***	44 6.49	** ***
2 Skills/man	u t			13 7.25	*** ***	14 7.02	*** ***	9 6.98	*** ***
3 Skills/man	u t					92 1.78	- *	74 5.24	- ***
4 Skills/man	u t							74 5.24	- ***
Completion Rates									
Standard Manning	u t	23 4.94	*** ***	87 0.87	- -	76 0.94	- -	73 1.08	- -
2 Skills/man	u t			17 8.13	*** ***	15 6.39	*** ***	19 4.43	*** ***
3 Skills/man	u t					93 0.08	- -	82 0.45	- -
4 Skills/man	u t							87 0.56	- -
Average Lead Times of Completed Batches									
Standard Manning	u t	90 0.27	- -	36 5.68	** ***	47 4.96	** ***	39 5.74	** ***
2 Skills/man	u t			56 2.66	- **	63 2.16	- **	53 2.76	- **
3 Skills/man	u t					80 2.61	- **	91 0.04	- -
4 Skills/man	u t							90 1.69	- -

Note:-

'p' is the probability associated with the null hypothesis.

Key:
- \- $p > 0.1$
- * $p < 0.1$
- ** $p < 0.05$
- *** $p < 0.005$

Table 10.16 Mann-Whitney ('u') and 't' Difference Values for the Labour Flexibility W.I.P., Completion Rate and Average Lead Time Results

		2 Skills/ man		3 Skills/ man		4 Skills/ man		5 Skills/ man	
		Value	p	Value	p	Value	p	Value	p
Lead Time Means (of W.I.P. cells)									
Standard Manning	u	19	-	15	-	16	-	12	-
	t	2.541	**	1.193	-	1.226	-	0.841	-
2 Skills/ man	u			17	-	17	-	11	-
	t			0.337	-	0.14	-	0.75	-
3 Skills/ man	u					17	-	12	-
	t					1.02	-	2.01	-
4 Skills/ man	u							12	-
	t							1.104	-
Standard Deviation of Lead Times (of W.I.P. cells)									
Standard Manning	u	15	-	14	-	13	-	9	-
	t	2.49	**	1.79	-	2.09	*	2.06	-
2 Skills/ man	u			16	-	16	-	10	-
	t			1.28	-	1.47	-	2.13	*
3 Skills/ man	u					17	-	10	-
	t					0.85	-	2.13	*
4 Skills/ man	u							11	-
	t							0.90	-

Note: 'p' is the probability associated with the Null hypothesis
key:

- \- p greater than 0.1
- * p less than 0.1
- ** p less than 0.05
- *** p less than 0.005

Table 10.17 Mann-Whitney (u) and 't' Difference Values for the Lead Time - Work in Progress Analysis of the Labour Flexibility Series of Runs

First Sample		Second Sample					
		Standard		0.75 x Std		0.5 x Std	
		Value	p	Value	p	Value	p
Work in Progress Levels							
2 x Std	U t	73 1.09	- -	56 -2.29	- **	27 3.88	** **
Std	U t			65 3.58	- **	40 6.58	* ***
0.75 x Std	U t					56 6.16	- ***
Completion Rates							
2 x Std	U t	62 2.8	- **	67 1.47	- -	68 1.26	- -
Std	U t			68 0.39	- -	69 0.42	- -
0.75 x Std	U t					81 0.13	- -
Average Lead Times of Completed Batches							
2 x Std	U t	78 0.41	- -	77 0.90	- -	54 2.4	- **
Std	U t			73 2.68	- **	54 4.93	- ***
0.75 x Std	U t					63 4.1	- **

Note:

'p' is the probability associated with the Null hypothesis

key;

-	p greater than	0.1
*	p less than	0.1
**	p less than	0.05
***	p less than	0.005

Table 10.18 Mann-Whitney (u) and 't' Difference Test Values for the Batch Size W.I.P., Completion Rates and Average Lead Time Results

First Sample		Second Sample					
		2 x Std		0.75 x Std		0.5 x Std	
		Value	p	Value	p	Value	p
Lead Time Means (of W.I.P. cells)							
Std B/S	U	11	-	22	-	21	-
	t	1.57	-	3.12	**	2.07	*
2 x	U			8	-	9	-
	t			3.8	**	2.38	*
0.75 x	U					38	-
	t					0.99	-
Standard Deviation of Lead Times (of W.I.P. cell)							
Normal	U	12	-	10	*	21	-
	t	0.22	-	4.53	**	0.47	-
2 x	U			2	**	7	-
	t			5.93	**	2.22	*
0.75	U					29	-
	t					2.74	**

Note:
'p' is the probability associated with the Null hypothesis

key;

- `-` p greater than 0.1
- `*` p less than 0.1
- `**` p less than 0.05
- `***` p less than 0.005

Table 10.19 Mann-Whitney (u) and 't' Difference Test Values for the Lead Time - Work in Progress Analysis of the Batch Size Series of Runs

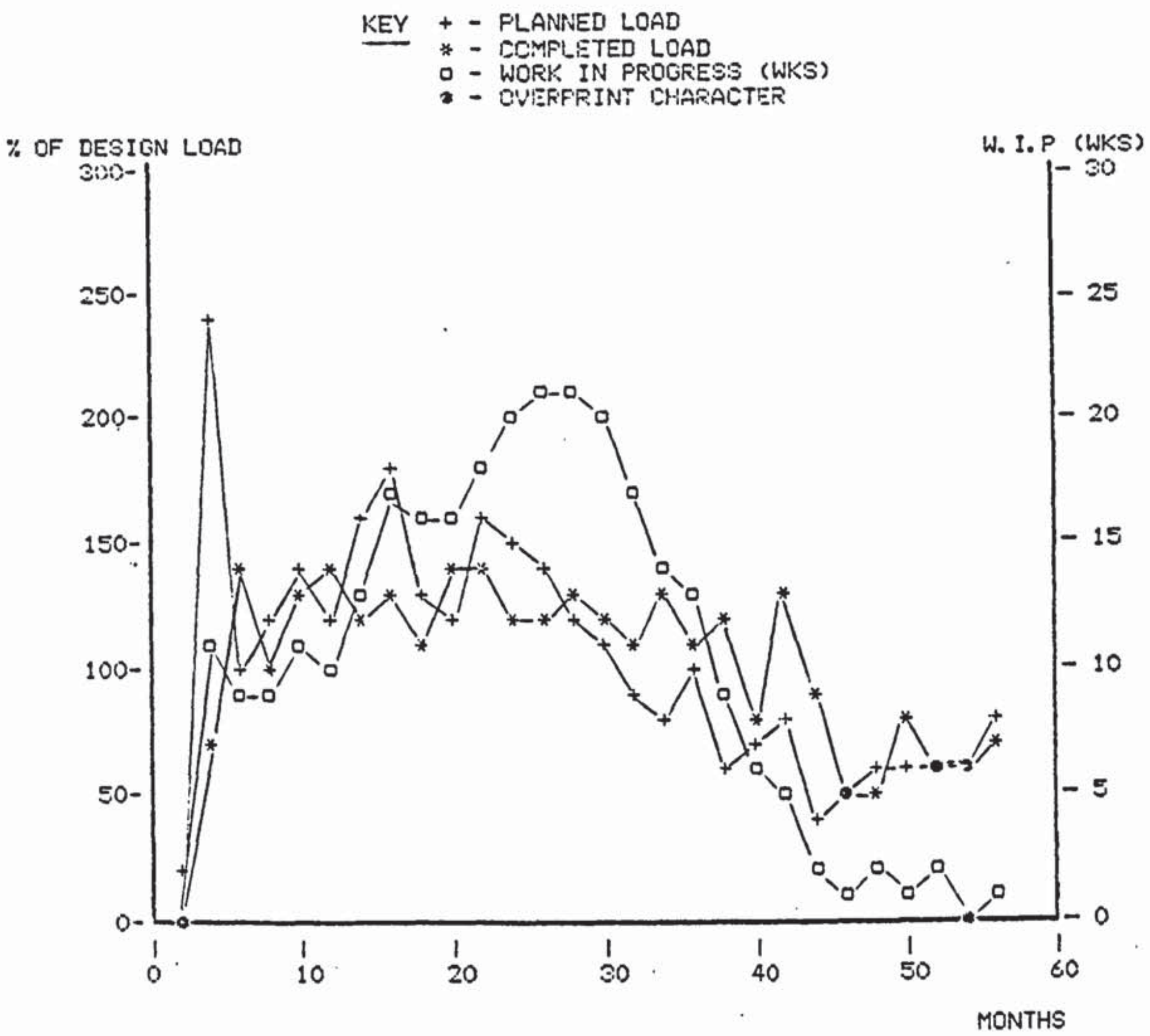

Figure 10.10 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES SCHEDULING RULE SERIES - MINIMUM DUE DATE

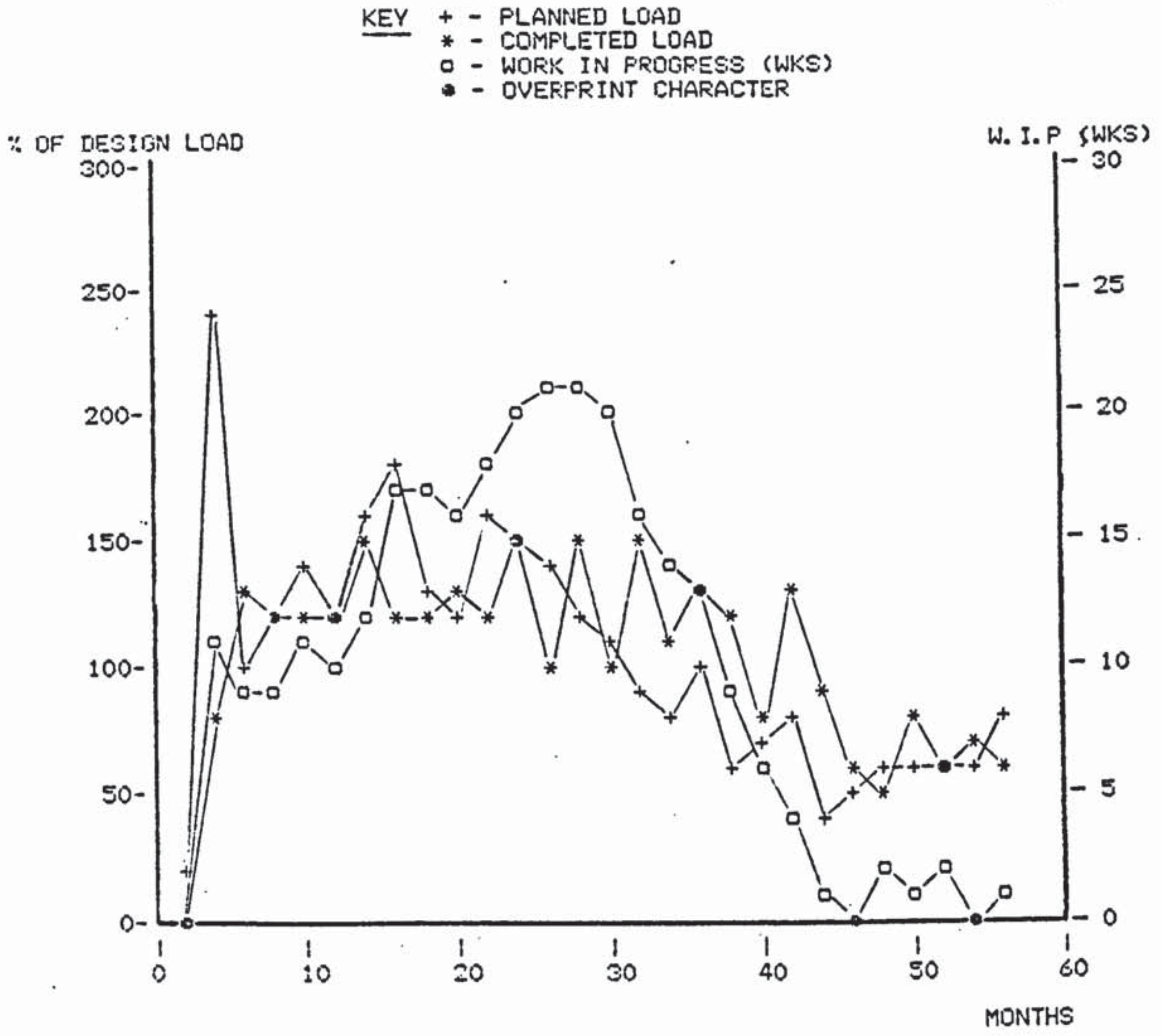

Figure 10.11 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES SCHEDULING RULE SERIES - MINIMUM FLOAT

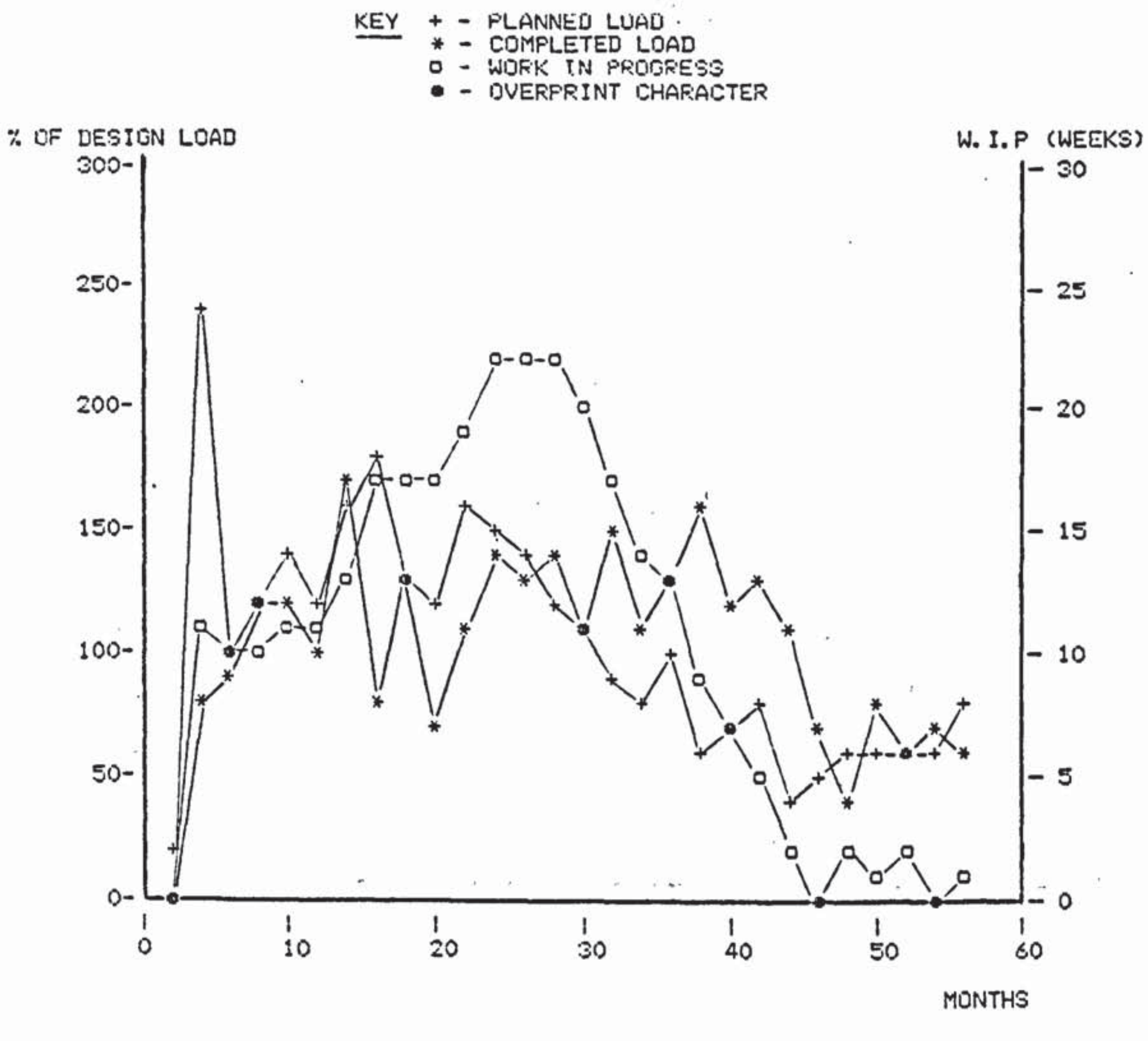

Figure 10.12 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES SCHEDULING RULE SERIES - RANDOM SELECTION

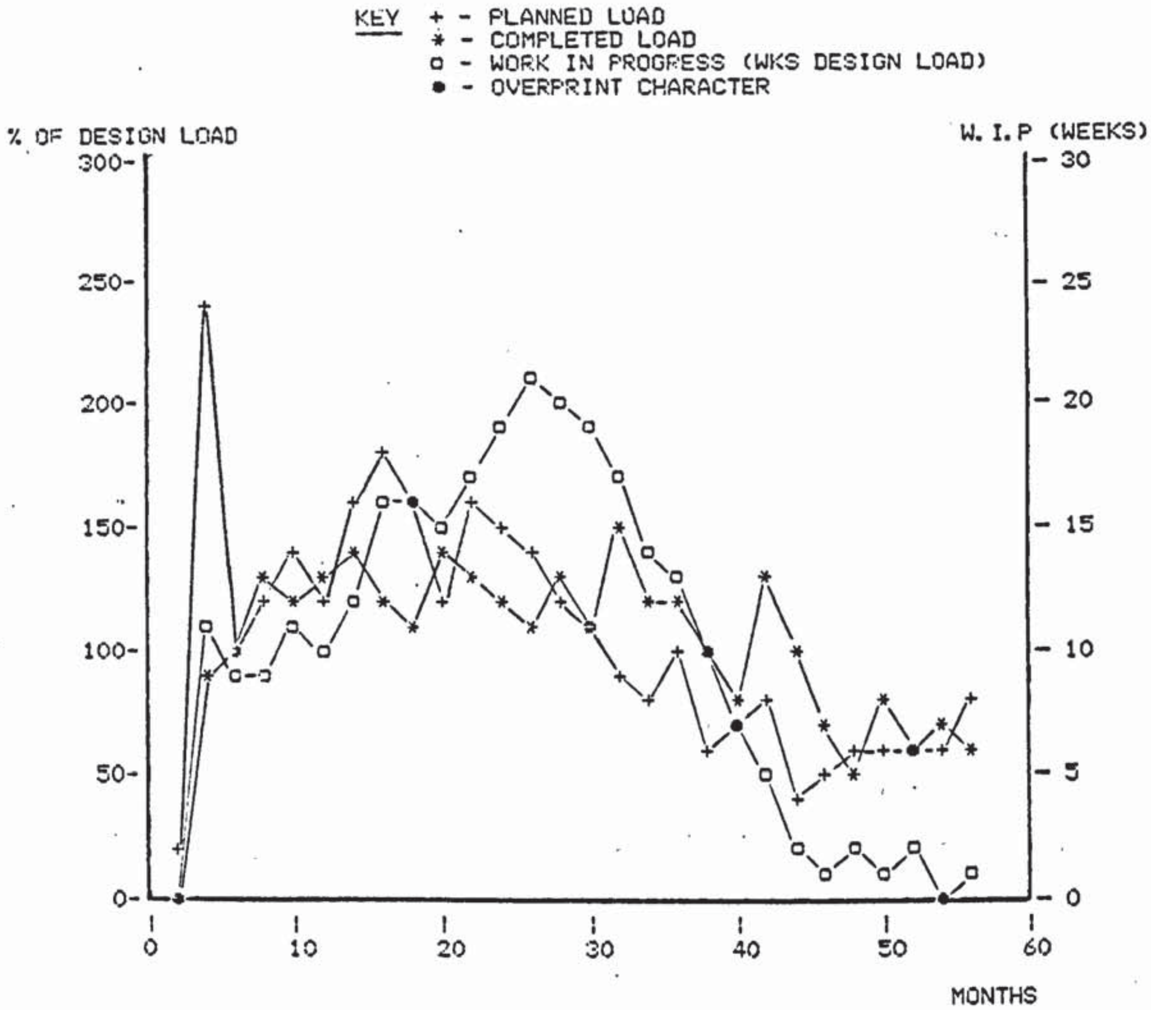

Figure 10.13 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES SCHEDULING RULE SERIES - MINIMUM PROCESS TIME

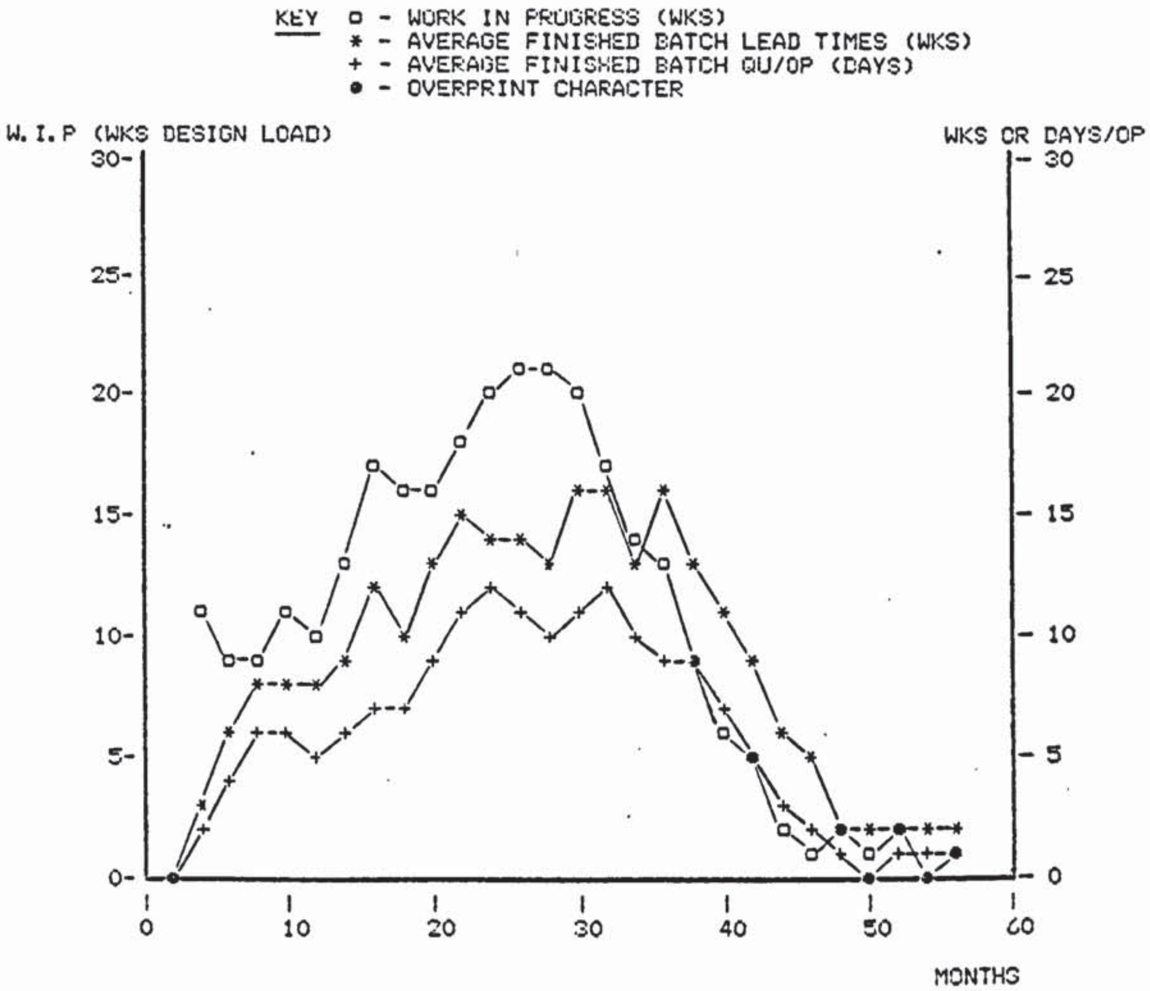

Figure 10.14 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION

SCHEDULING RULE SERIES - MINIMUM DUE DATE

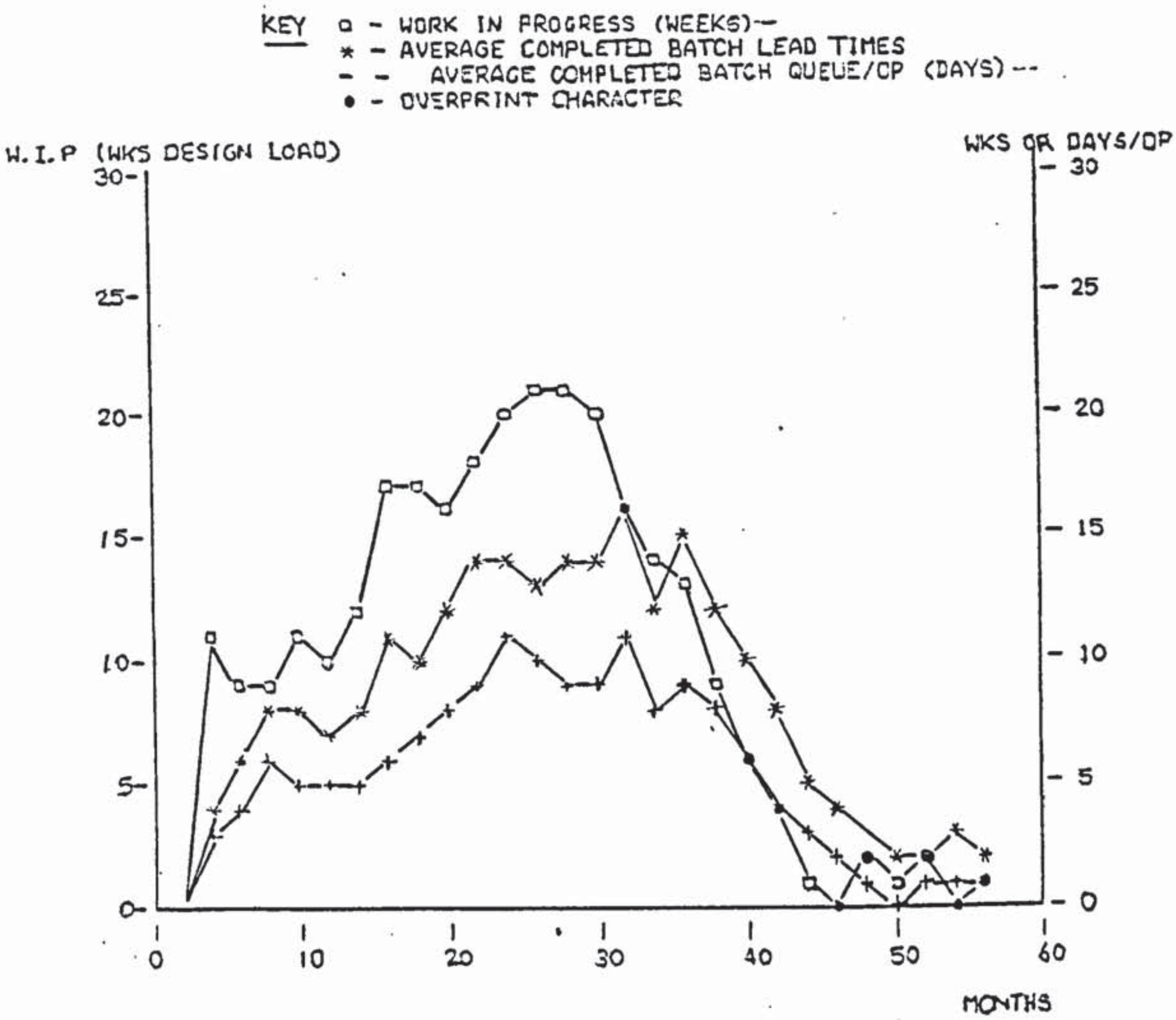

Figure 10.15 Workshop Performance:-
Work in Progress, Average Lead Times and
Queueing Time per Operation
Scheduling Rule Series - Minimum Float

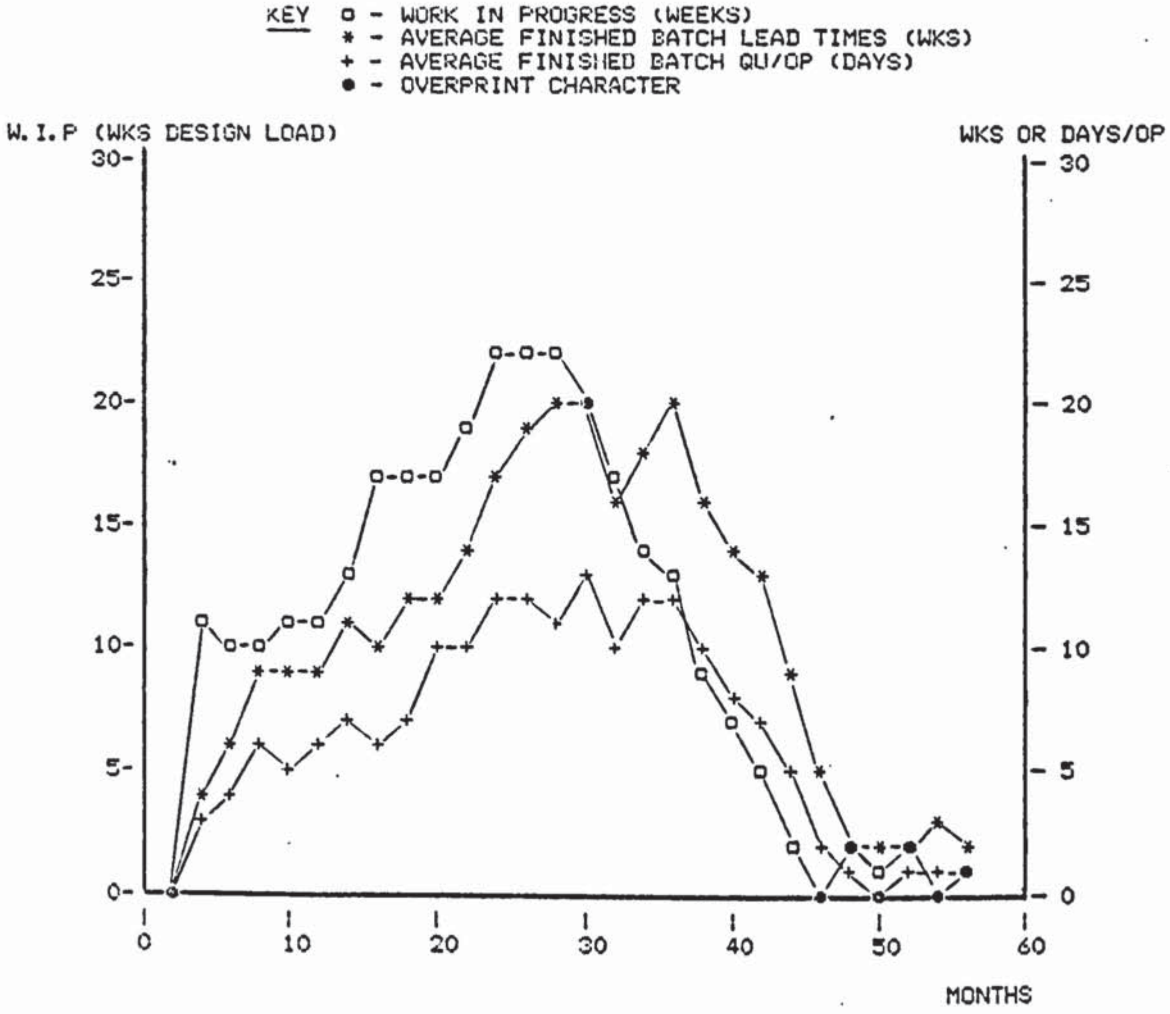

Figure 10.16 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION

SCHEDULING RULE SERIES - RANDOM SELECTION

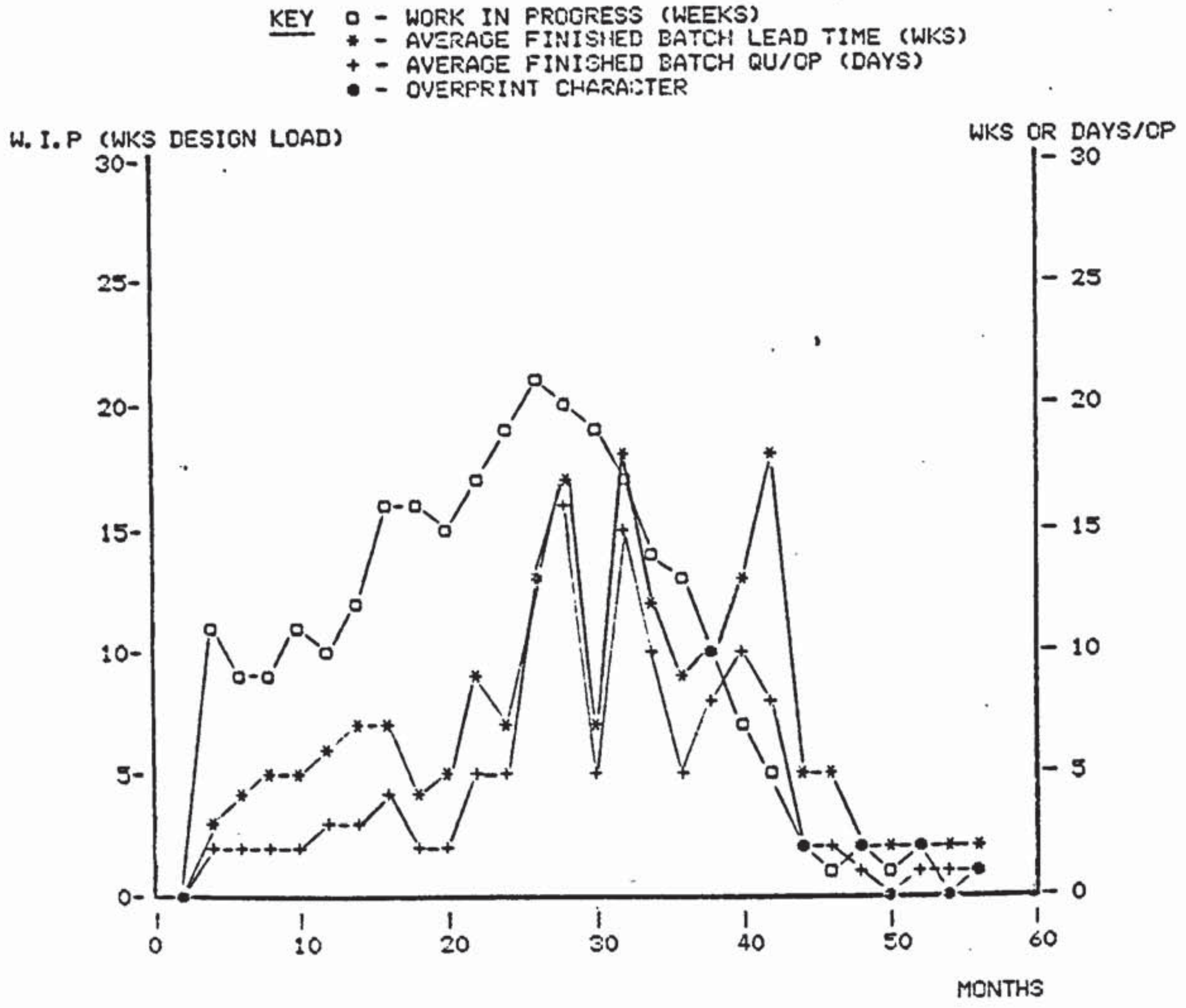

Figure 10.17 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION SCHEDULING RULE SERIES - MINIMUM PROCESS TIME

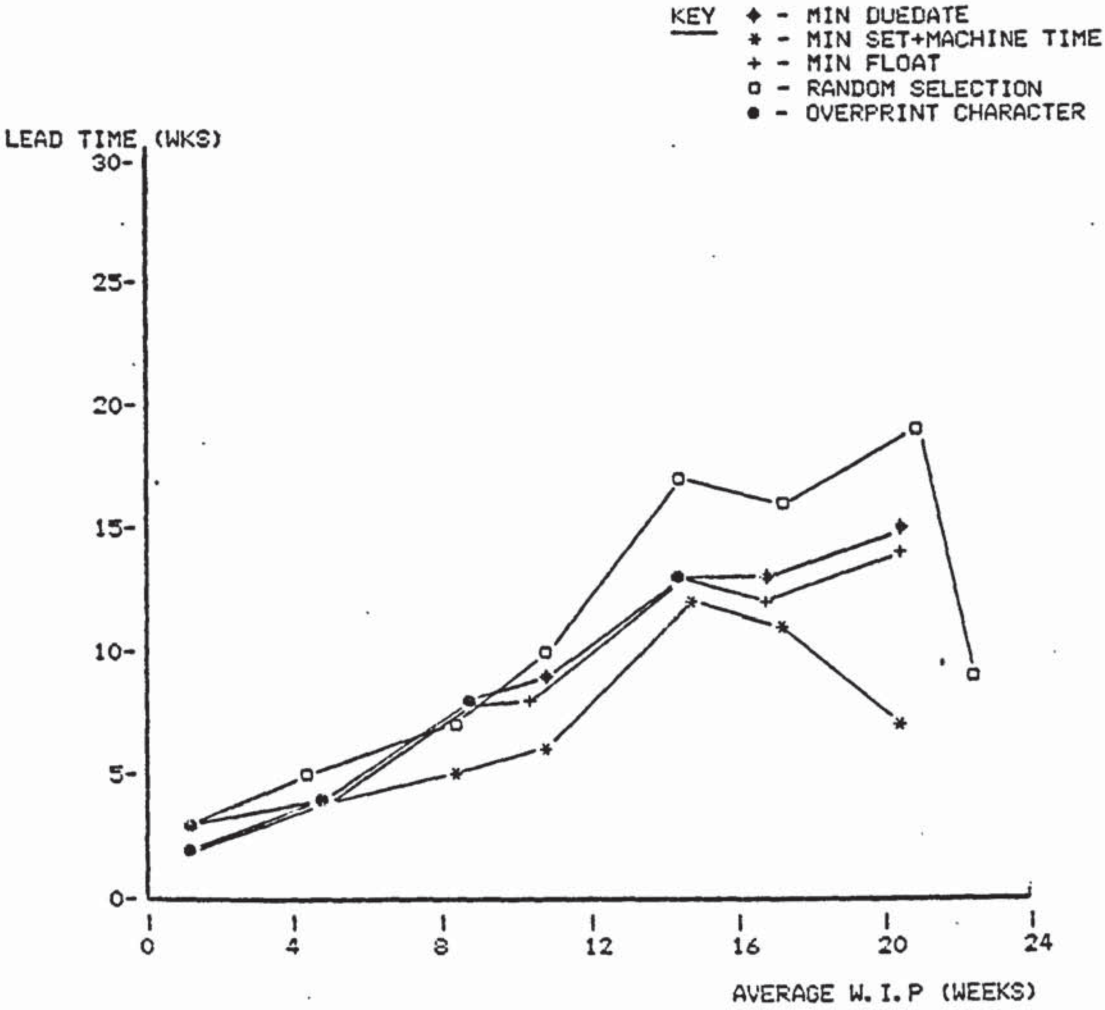

Figure 10.18 <u>LEAD TIME - WORK IN PROGRESS RELATIONSHIP</u>

<u>SCHEDULING RULE SERIES</u>

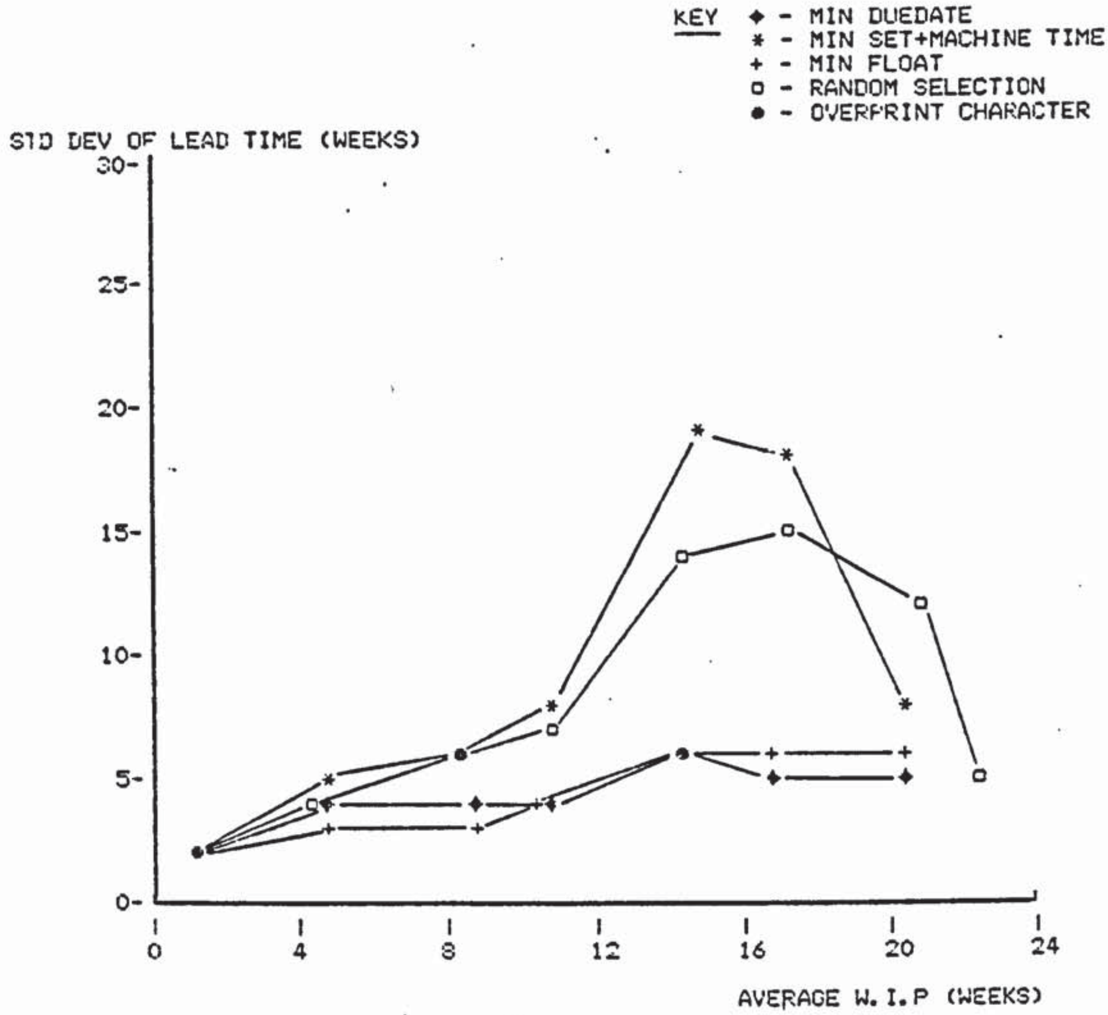

Figure 10.19 LEAD TIME VARIABILITY - WORK IN PROGRESS RELATIONSHIP

SCHEDULING RULE SERIES

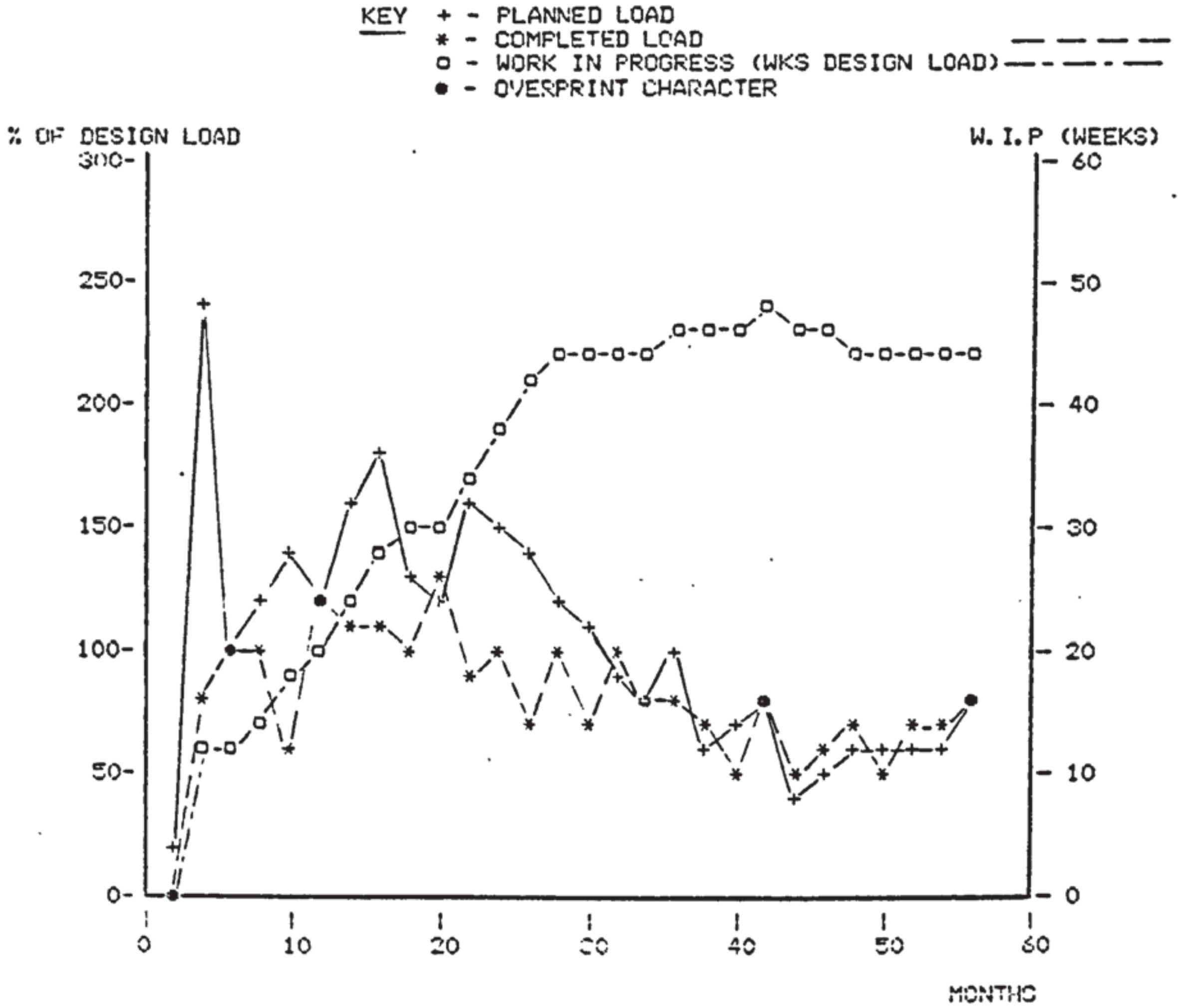

Figure 10.20 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES LABOUR FLEXIBILITY SERIES - 2 SKILLS PER MAN

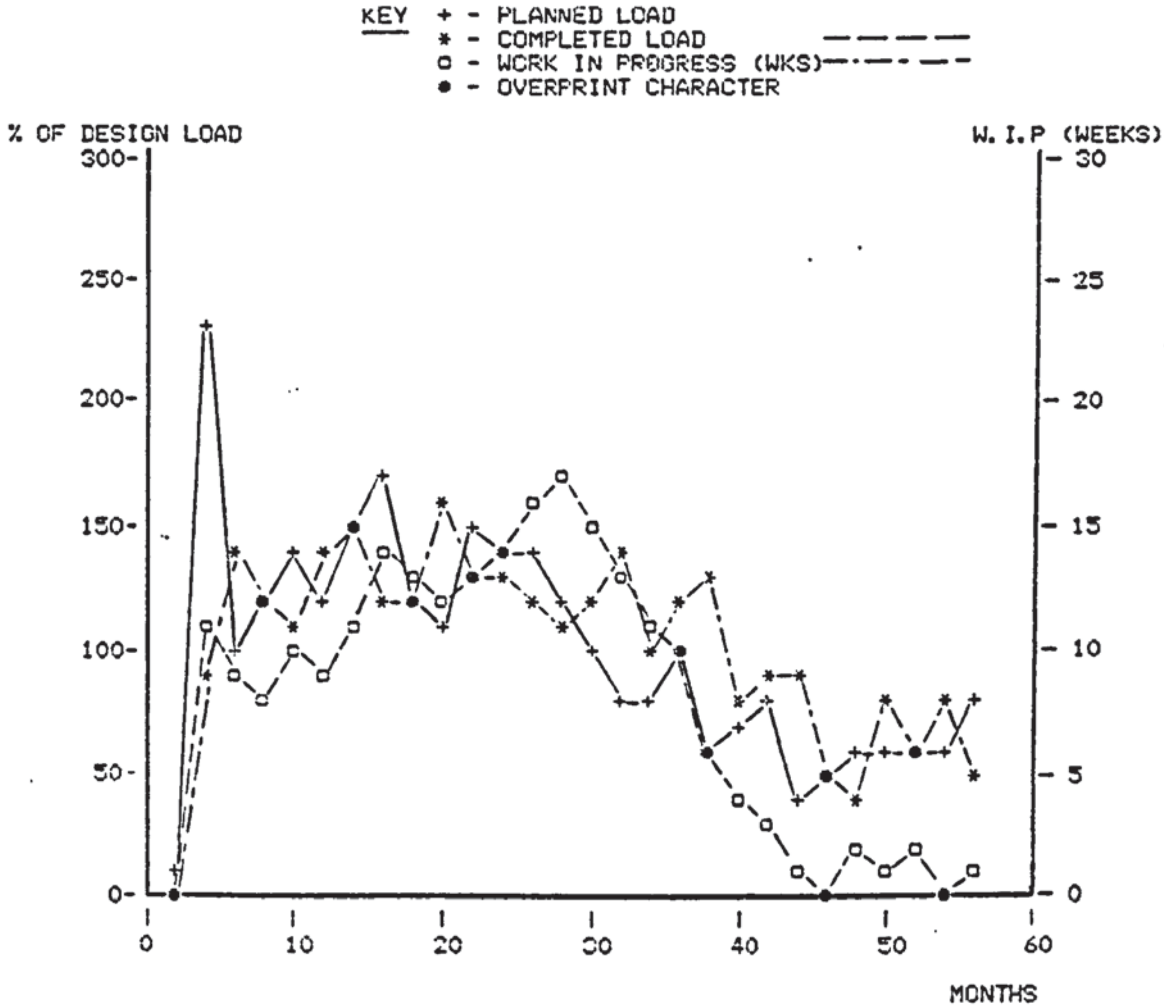

Figure 10.21. WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES LABOUR FLEXIBILITY SERIES - 3 SKILLS PER MAN

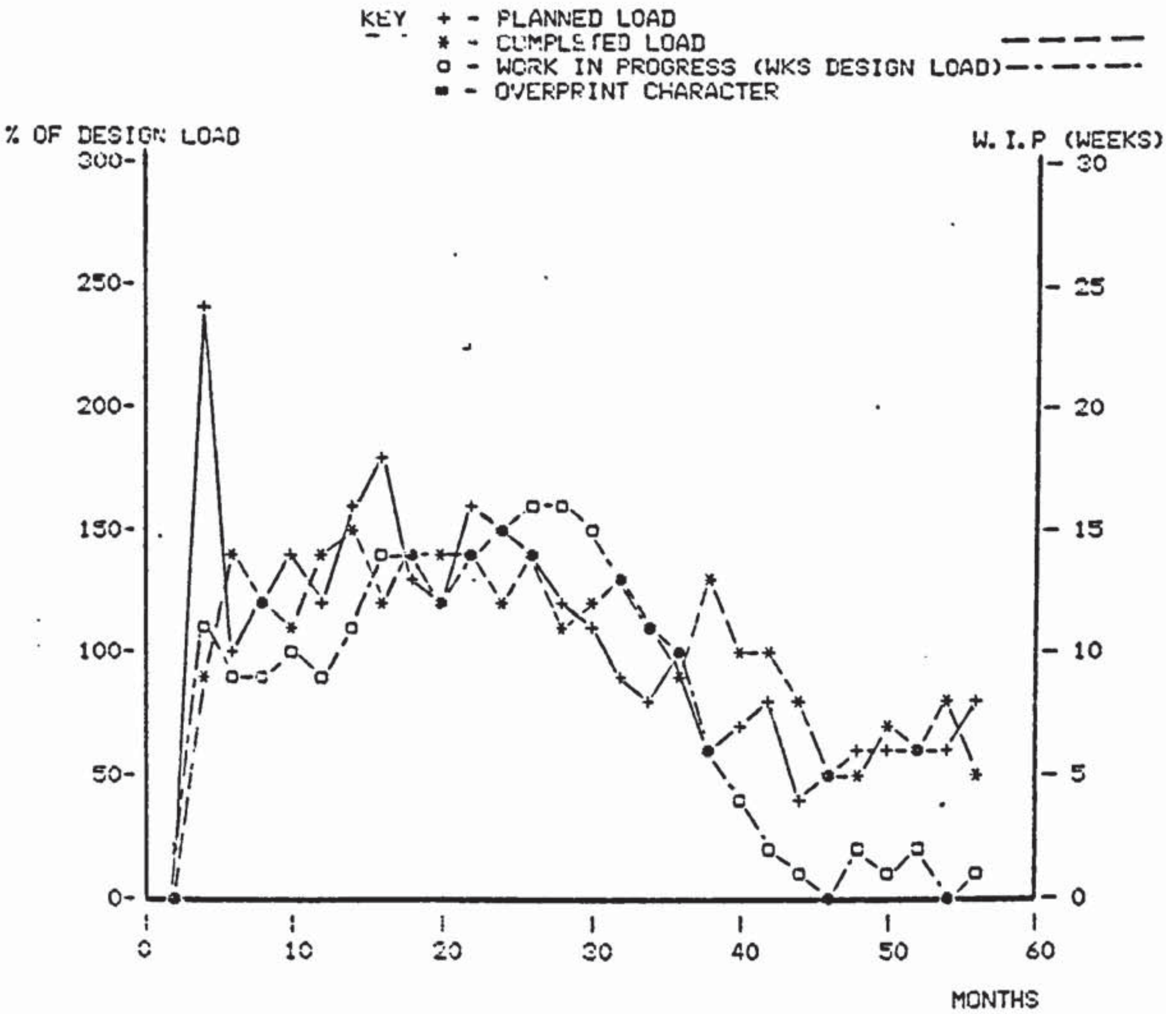

Figure 10.22 <u>WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES</u>

<u>LABOUR FLEXIBILITY SERIES - 4 SKILLS PER MAN</u>

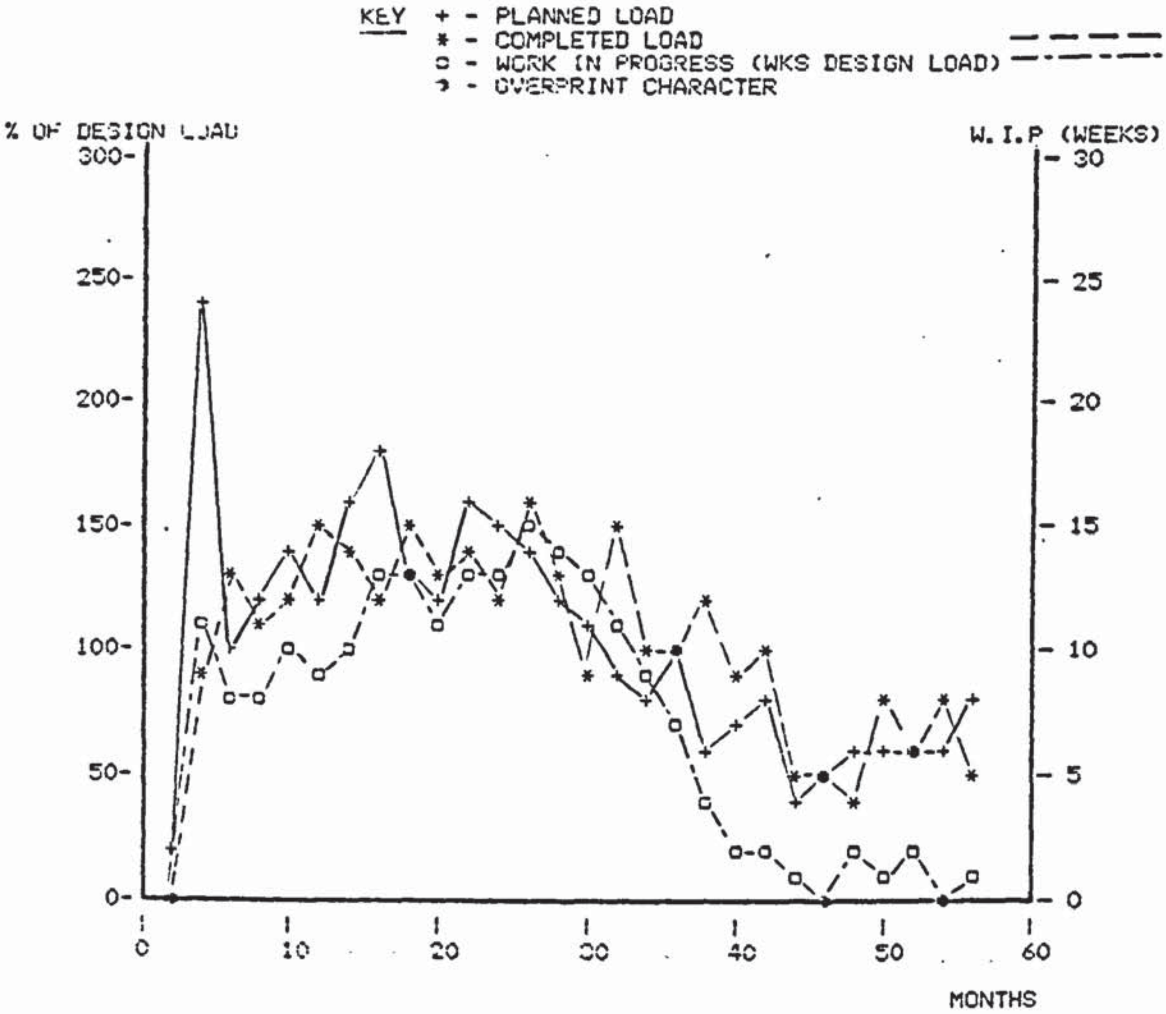

Figure 10.23 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES LABOUR FLEXIBILITY SERIES - 5 SKILLS PER MAN

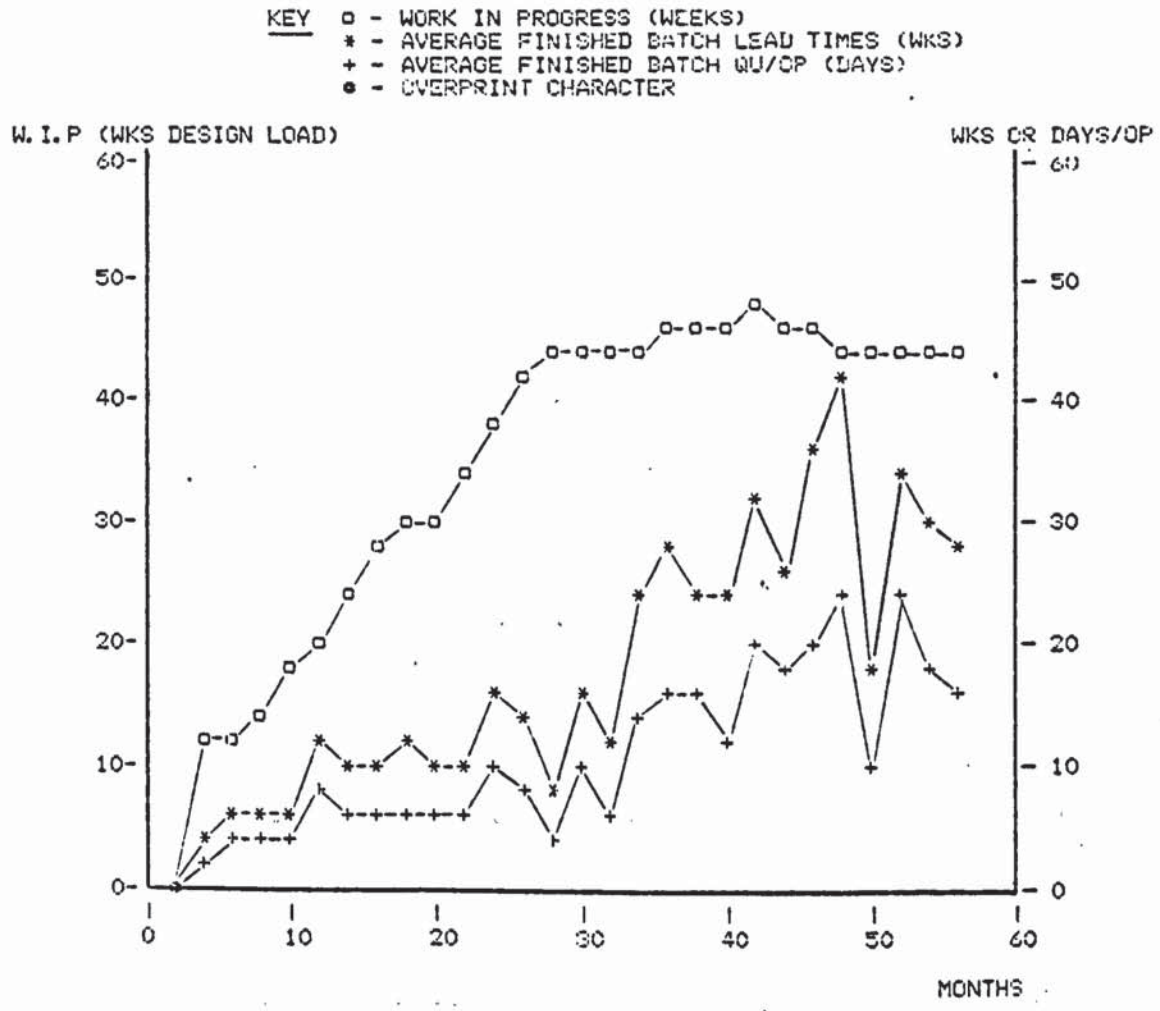

Figure 10.24 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION LABOUR FLEXIBILITY SERIES - 2 SKILLS PER MAN

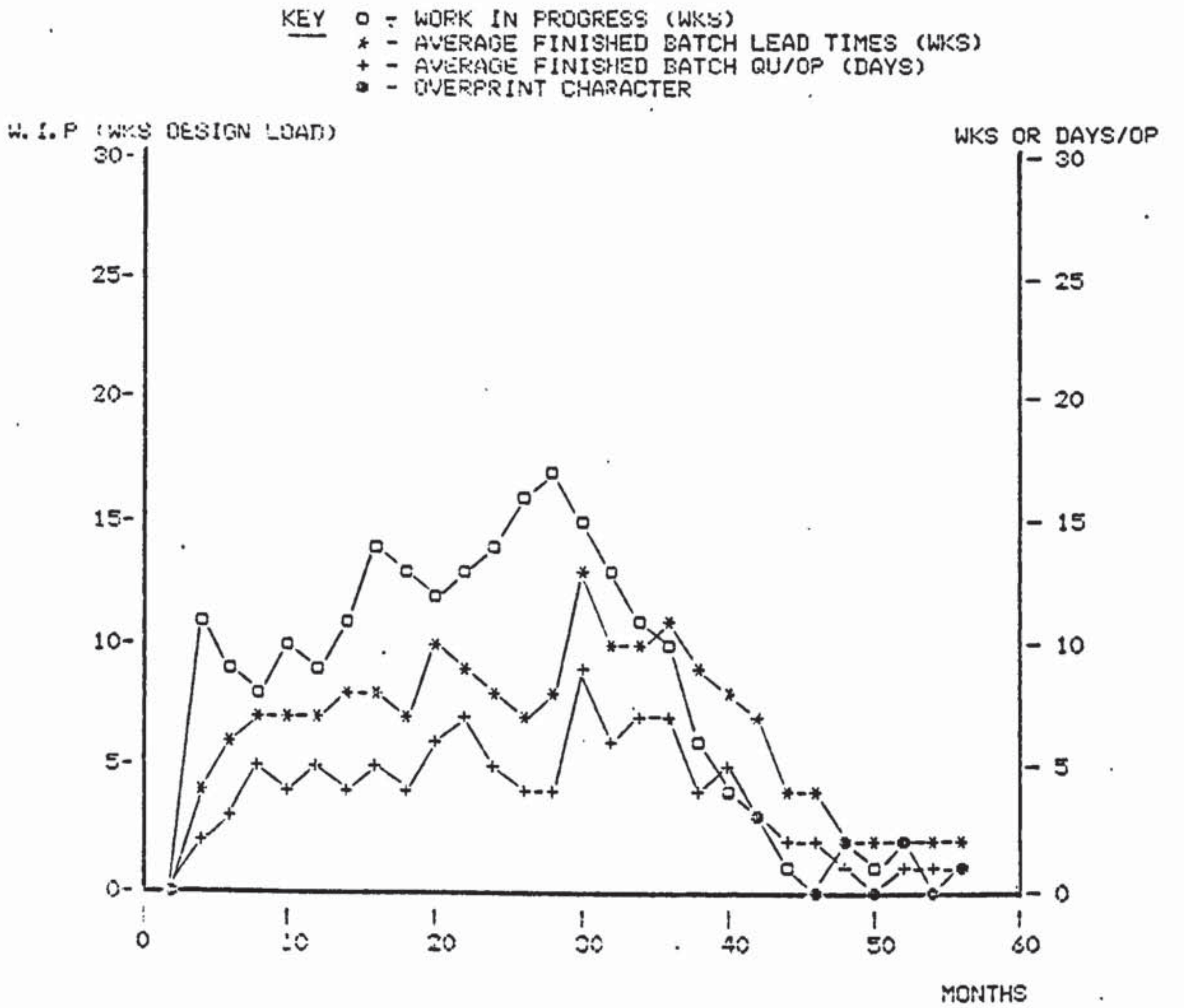

Figure 10.25 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION LABOUR FLEXIBILITY SERIES - 3 SKILLS PER MAN

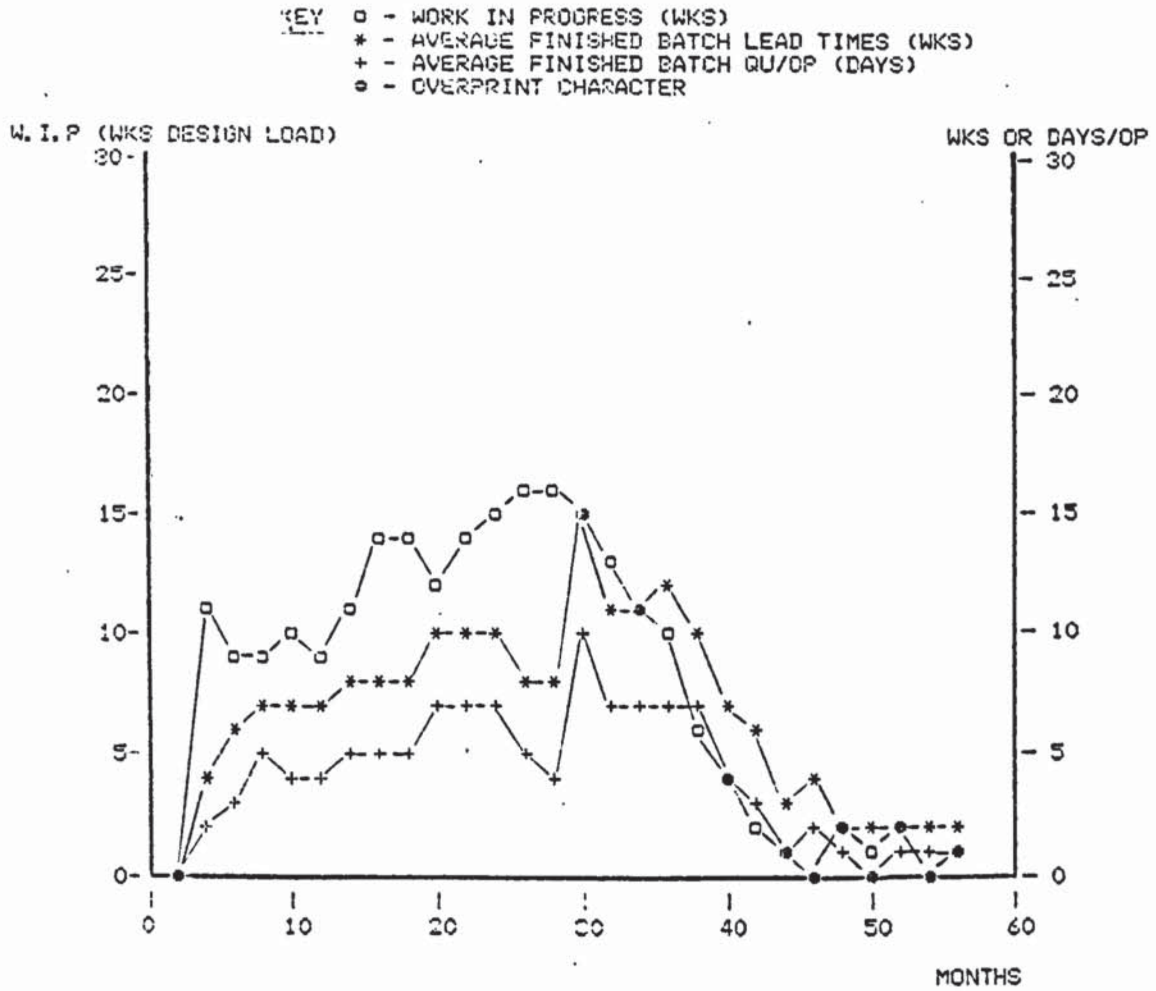

Figure 10.26 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION LABOUR FLEXIBILITY SERIES - 4 SKILLS PER MAN

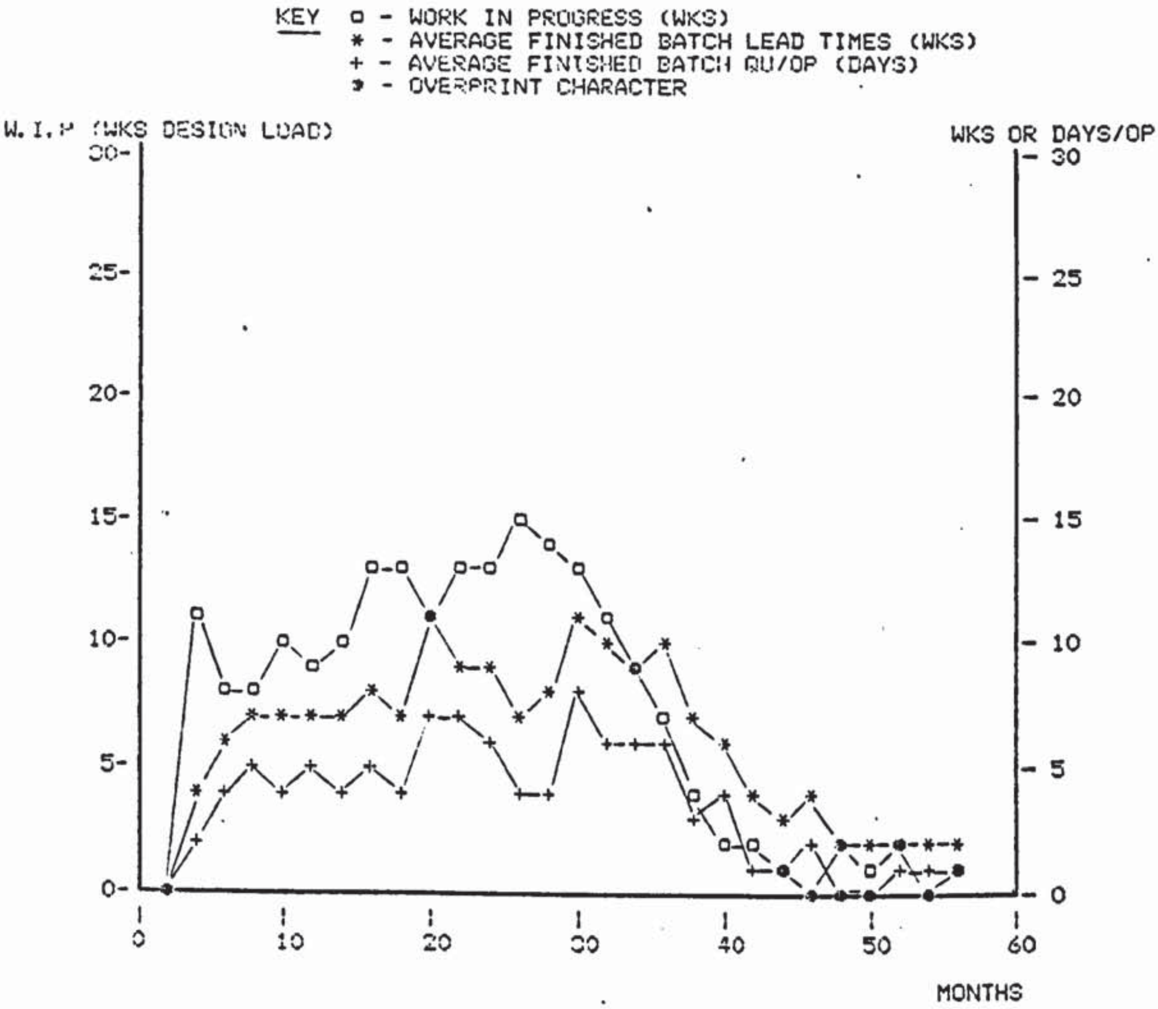

Figure 10.27 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION LABOUR FLEXIBILITY - 5 SKILLS PER MAN

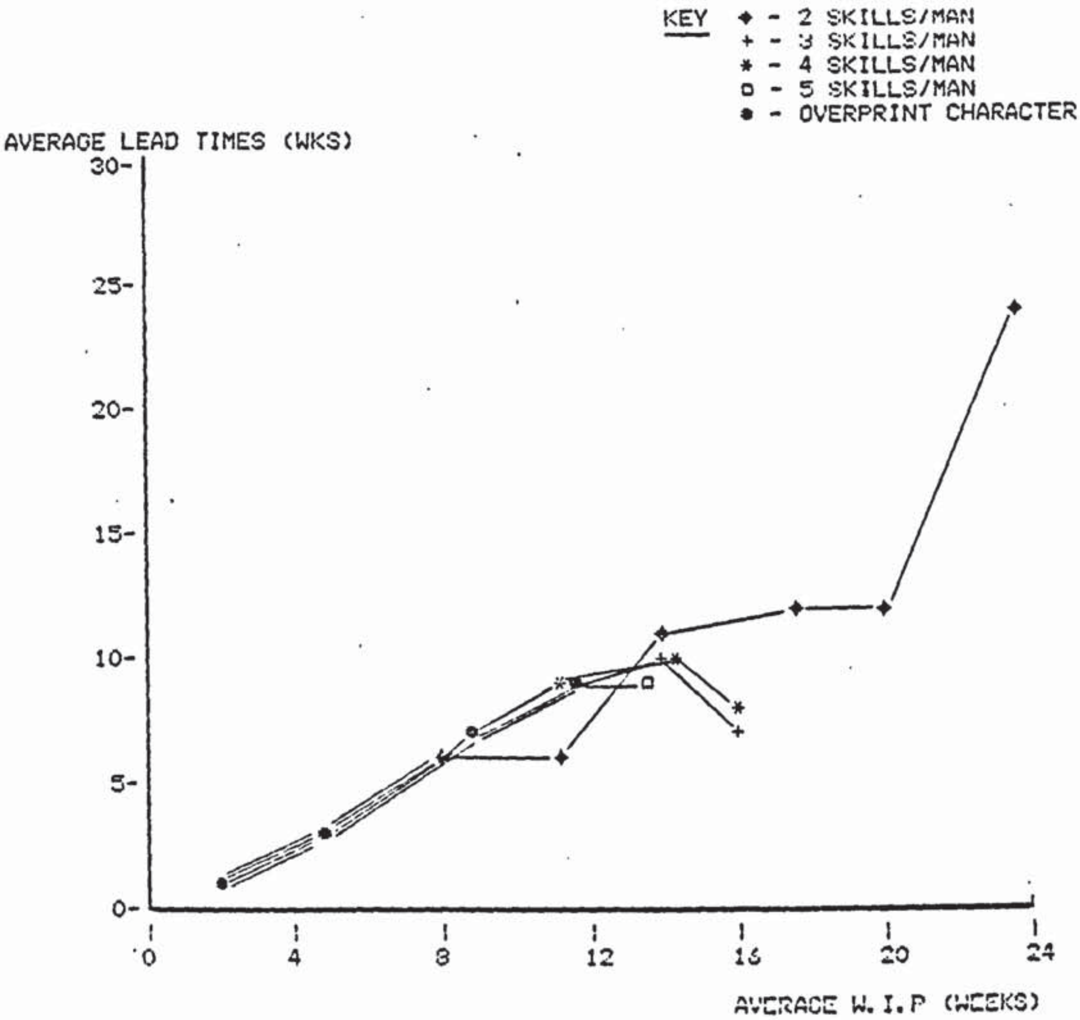

Figure 10.28 LEAD TIME - WORK IN PROGRESS RELATIONSHIP
LABOUR FLEXIBILITY SERIES

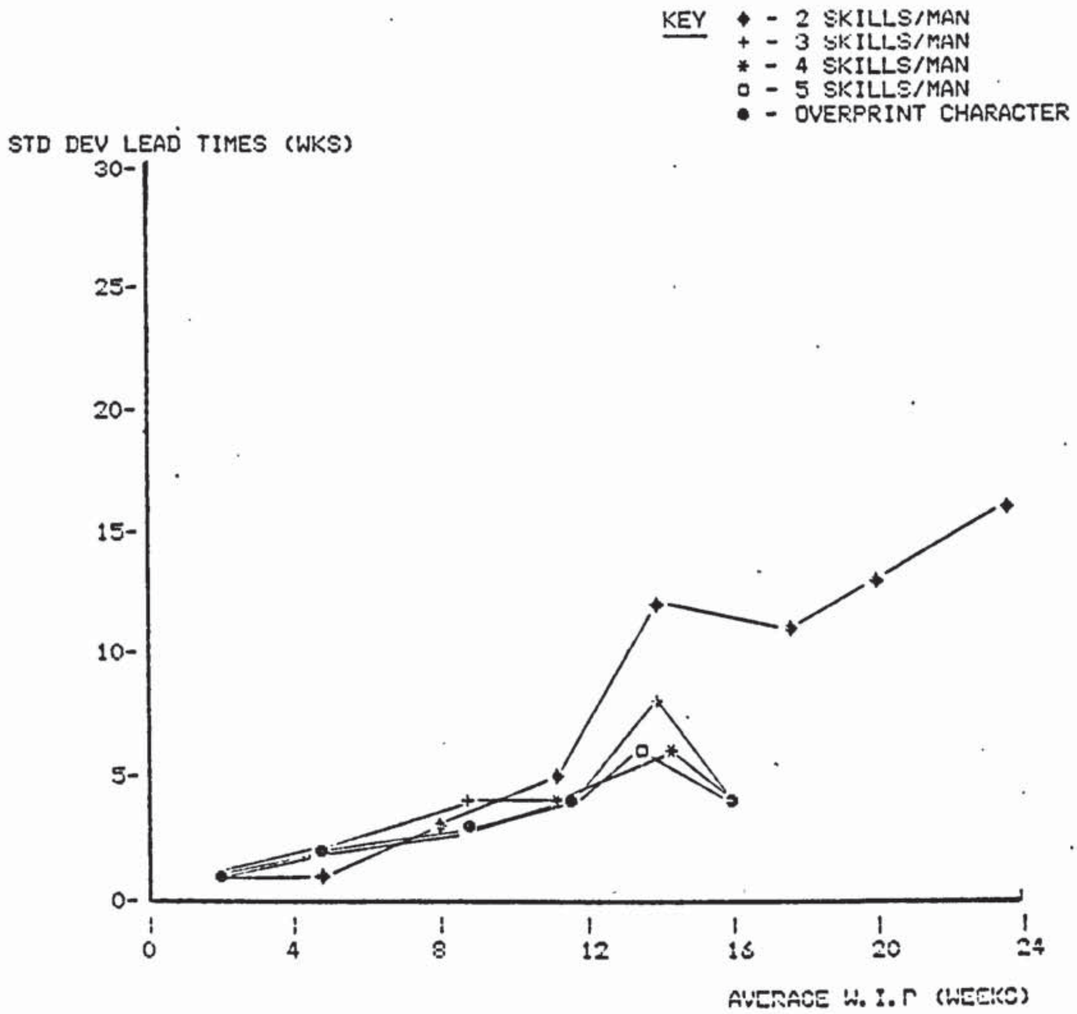

Figure 10.29 LEAD TIME VARIABILITY - WORK IN PROGRESS RELATIONSHIP

LABOUR FLEXIBILITY SERIES

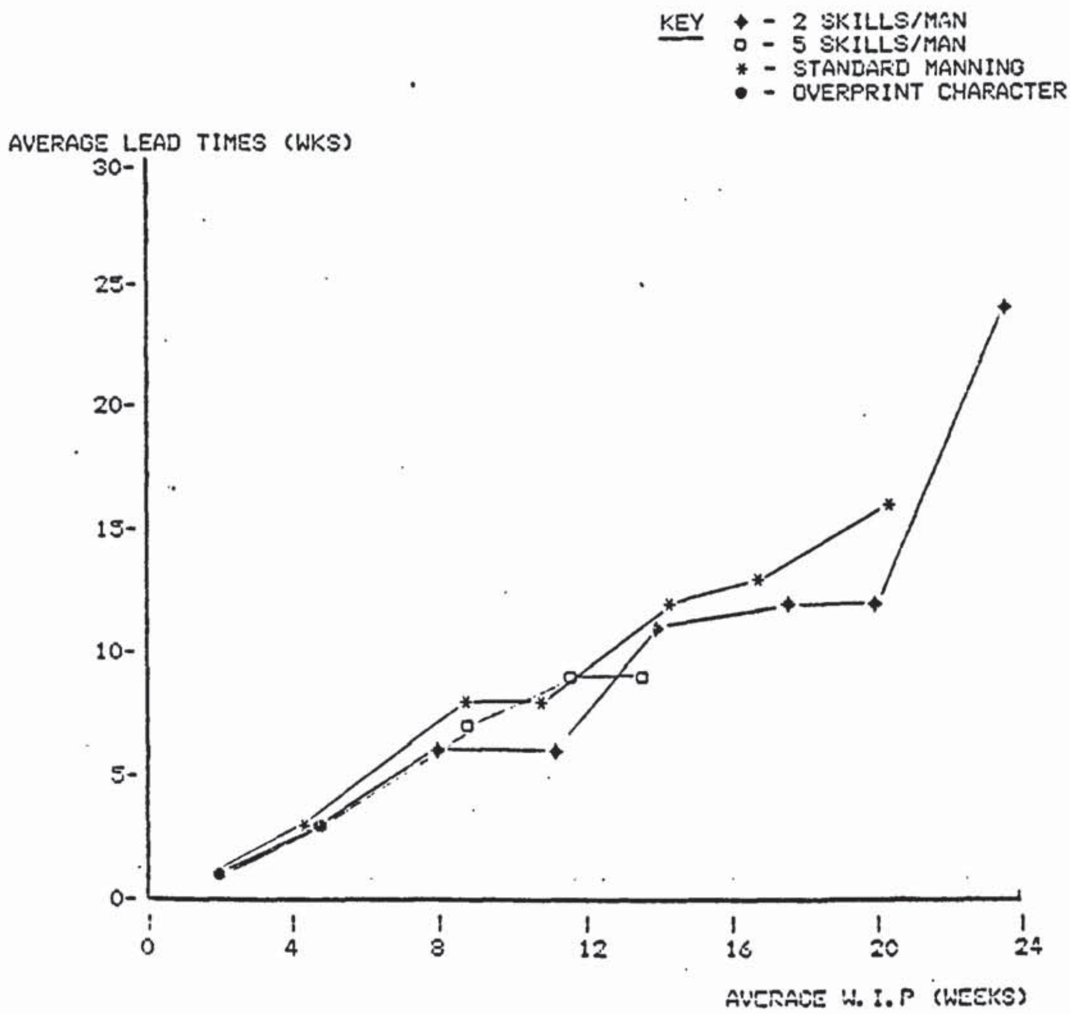

Figure 10.30 LEAD TIME - WORK IN PROGRESS RELATIONSHIP
COMPARISON WITH 'STANDARD' MANNING ARRANGEMENT

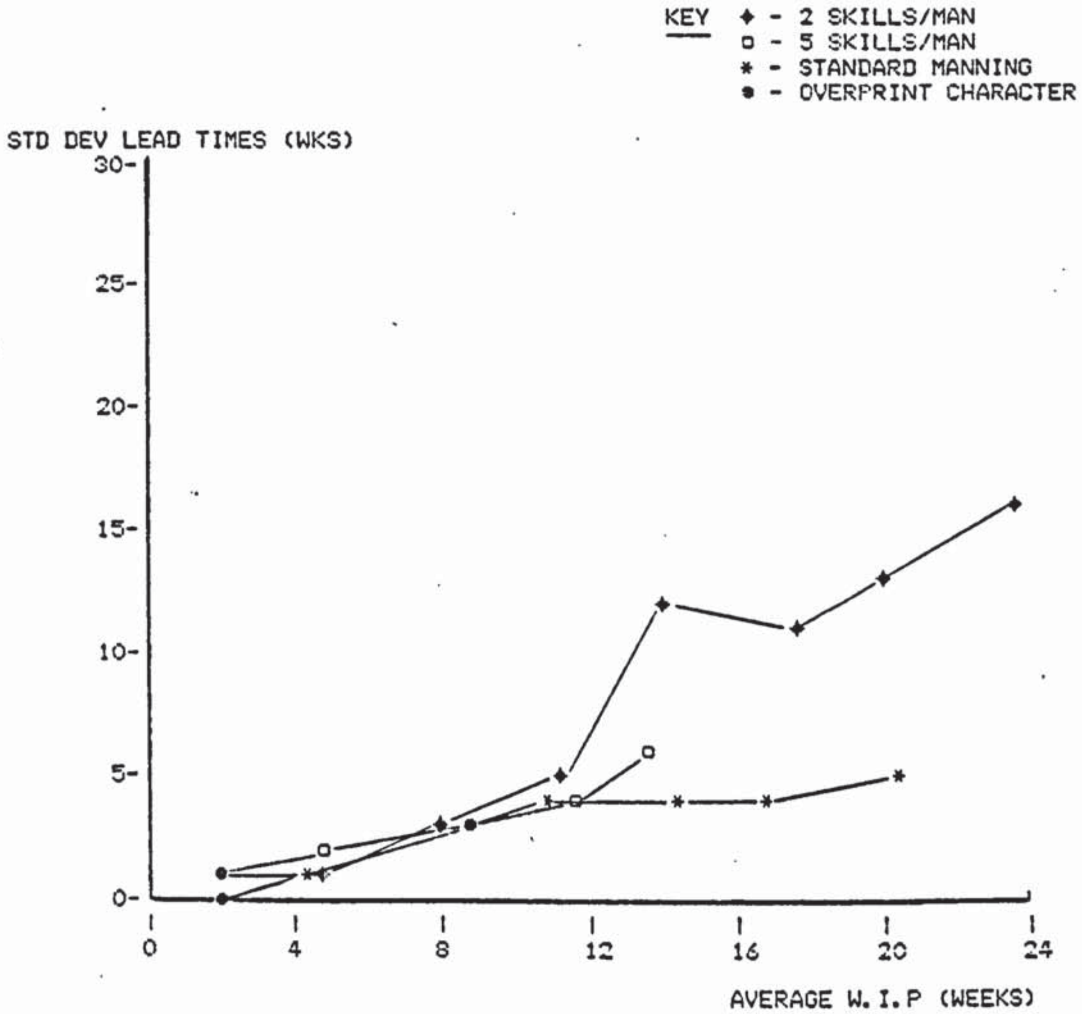

Figure 10.31 LEAD TIME VARIABILITY - WORK IN PROGRESS RELATIONSHIP

COMPARISON WITH 'STANDARD' MANNING ARRANGEMENT

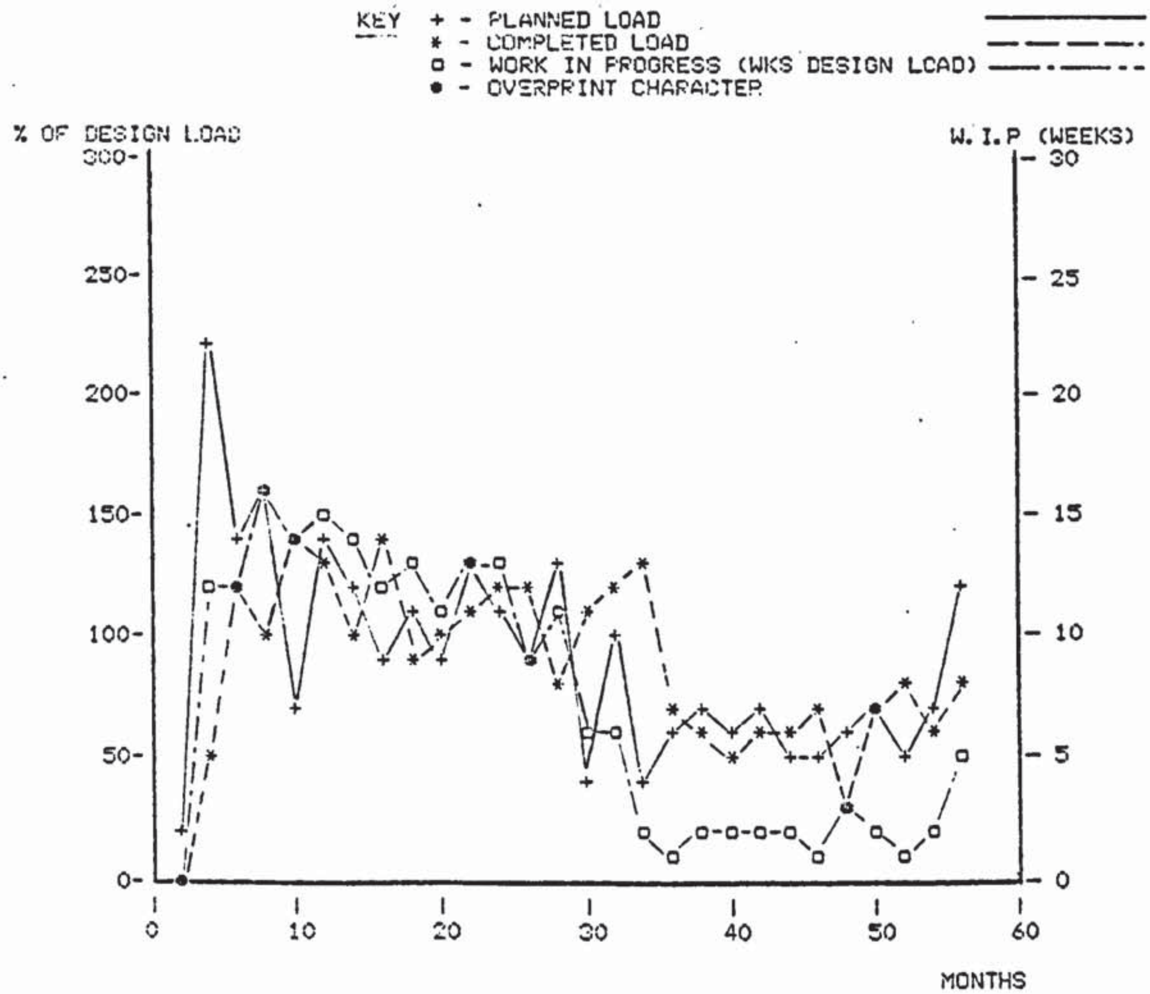

Figure 10.32 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES BATCH SIZE SERIES - 2 X STANDARD

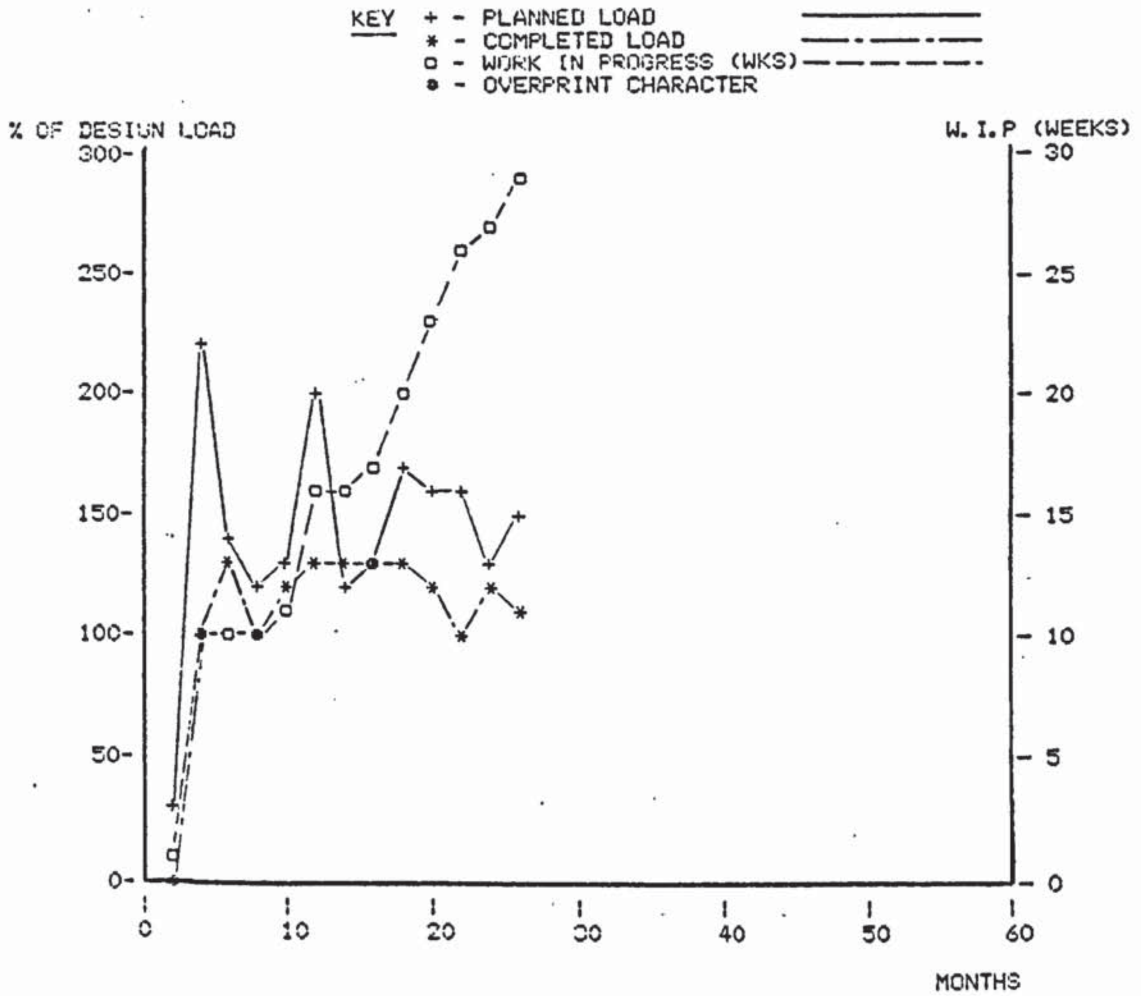

Figure 10.33 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES

BATCH SIZE SERIES - 0.75 X STANDARD

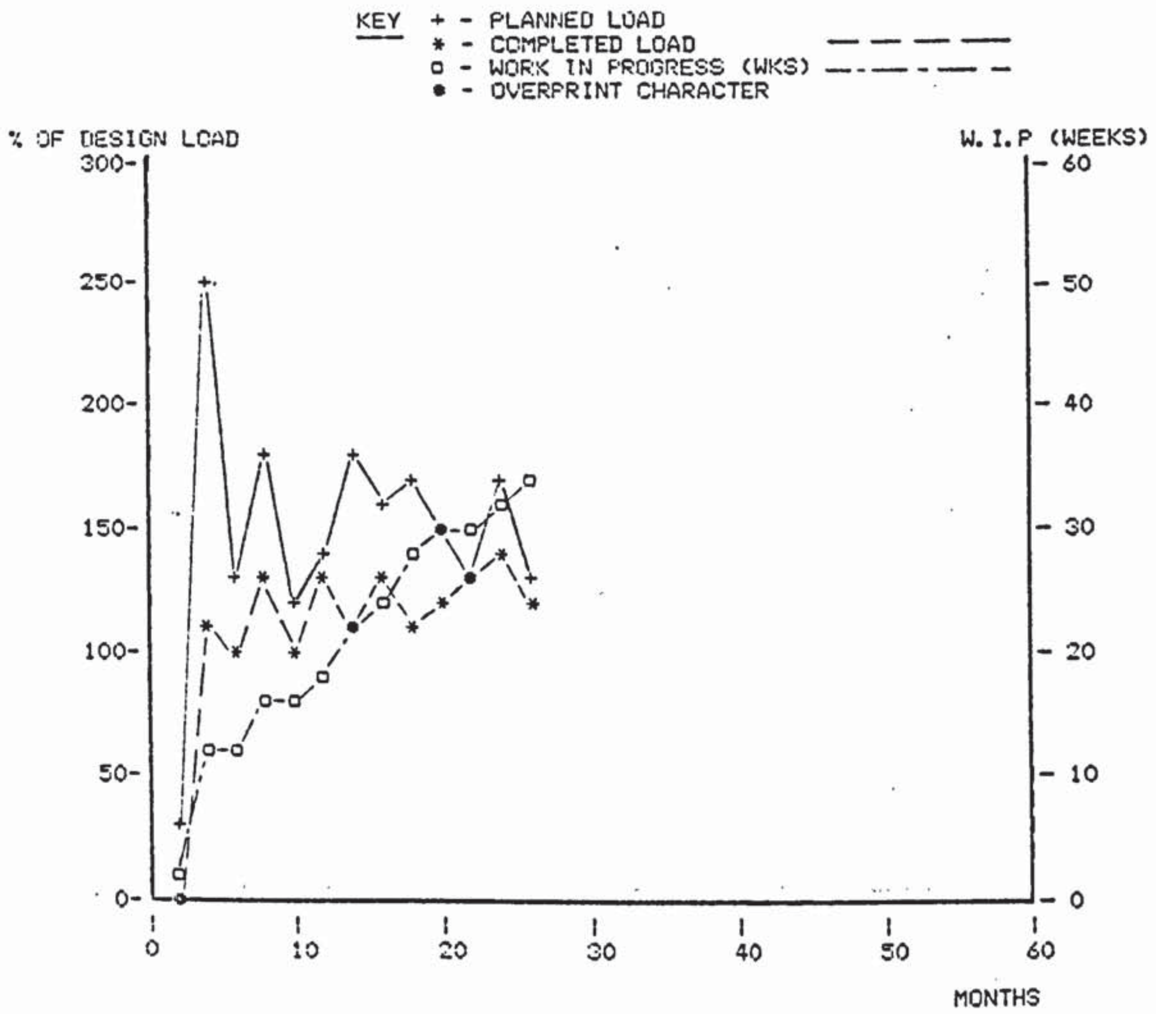

Figure 10.34 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, PLANNED LOAD AND COMPLETION RATES
BATCH SIZE SERIES - 0.5 X STANDARD

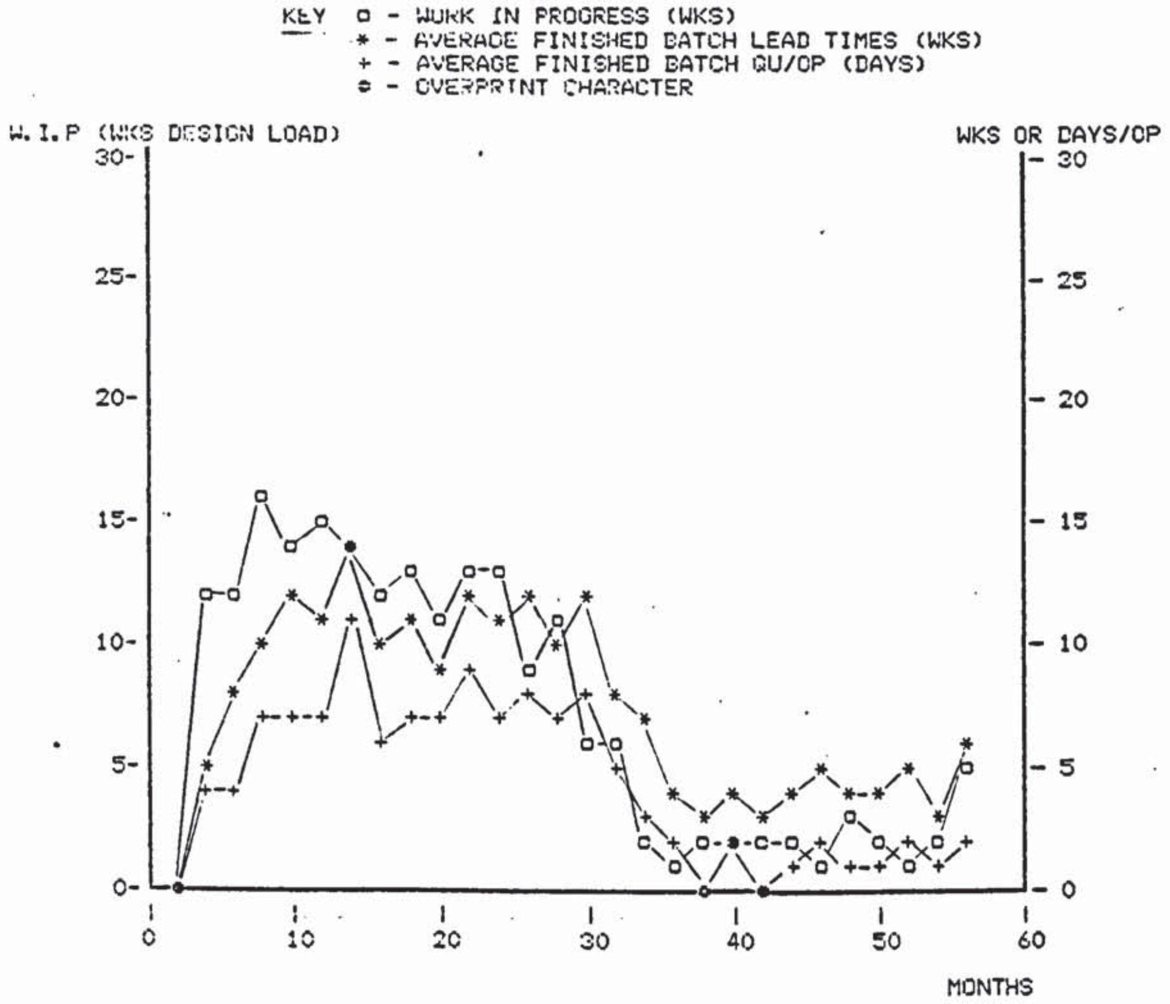

Figure 10.35 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE TIMES AND QUEUEING TIME PER OPERATION BATCH SIZE SERIES - 2 X STANDARD

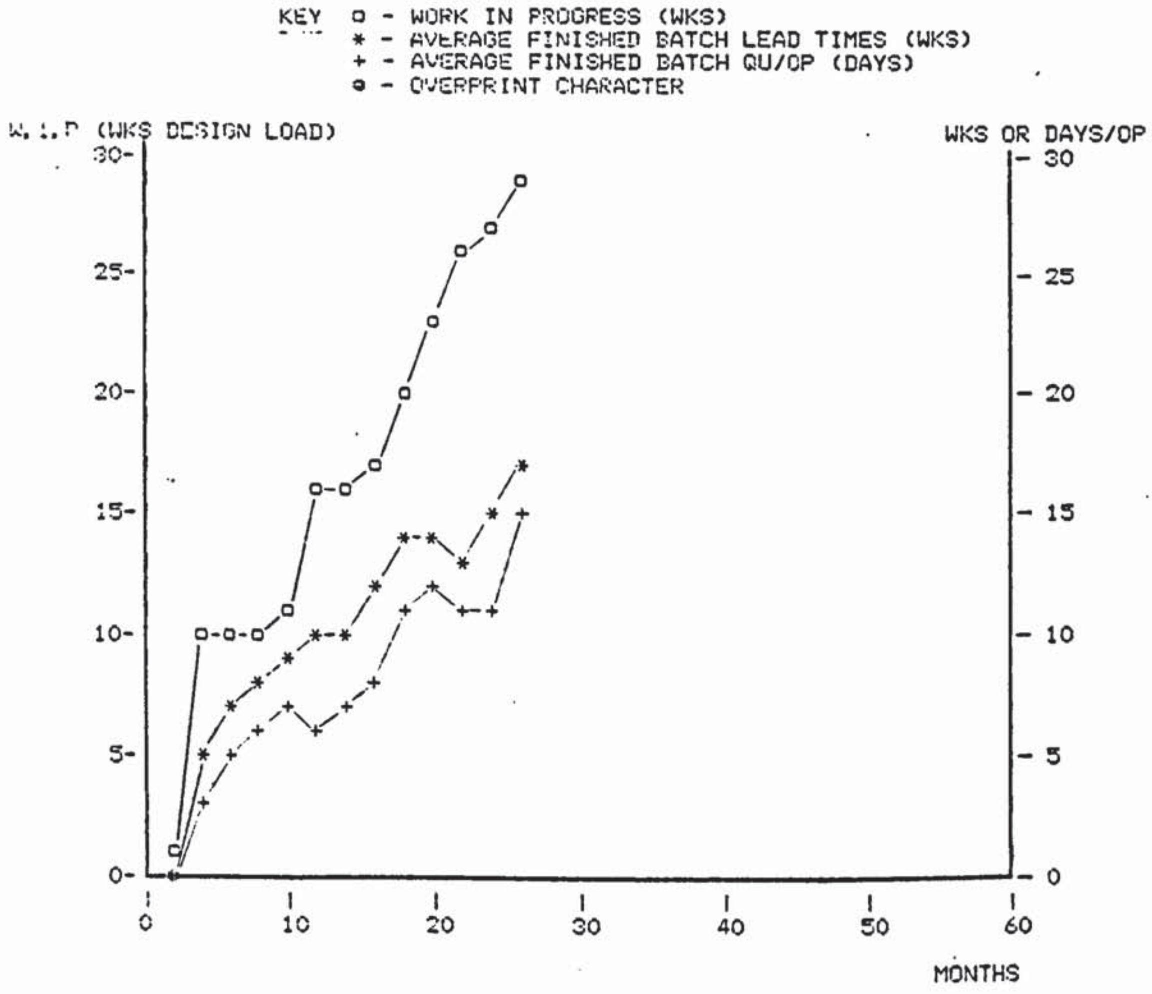

Figure 10.36 WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION BATCH SIZE SERIES - 0.75 X STANDARD

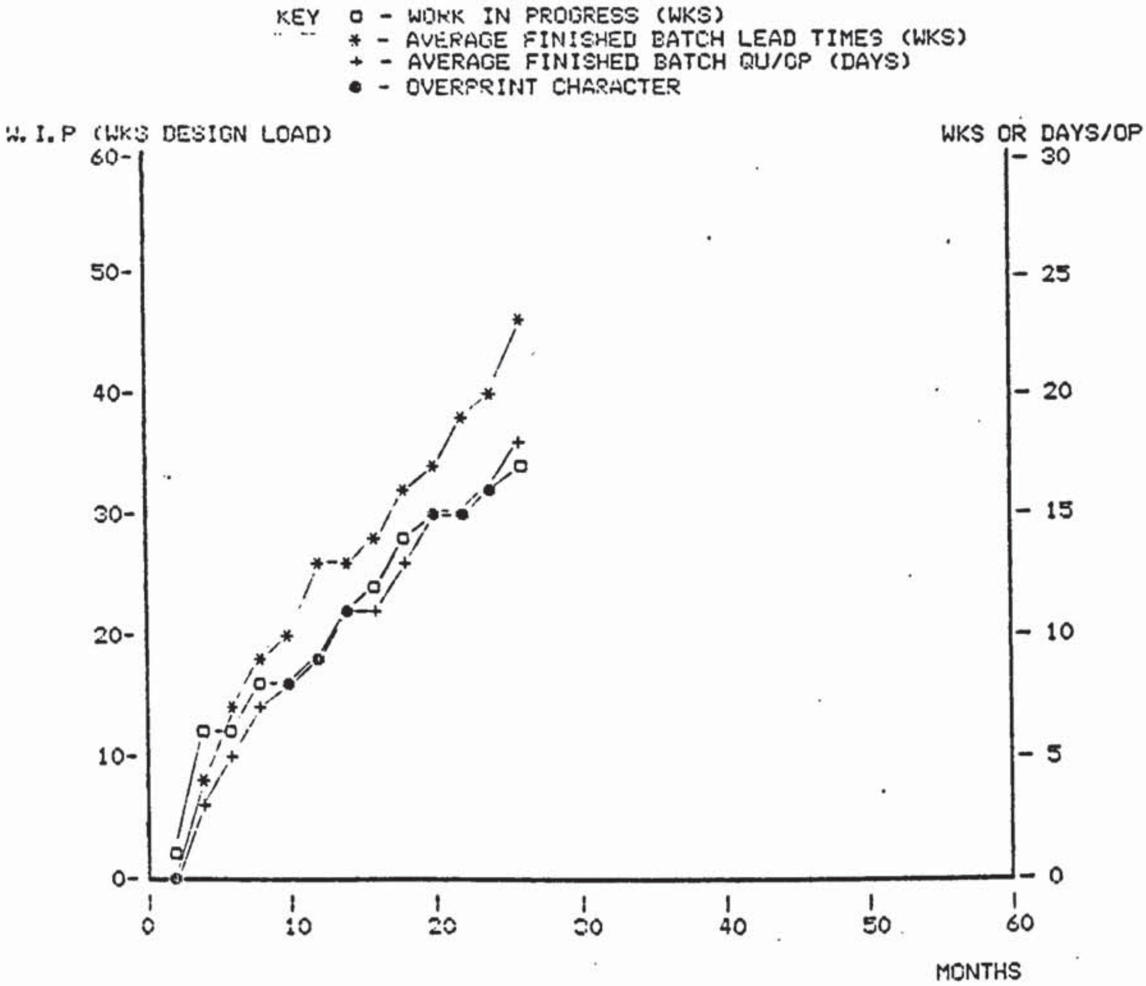

Figure 10.37 <u>WORKSHOP PERFORMANCE: - WORK IN PROGRESS, AVERAGE LEAD TIMES AND QUEUEING TIME PER OPERATION BATCH SIZE SERIES - 0.5 X STANDARD</u>

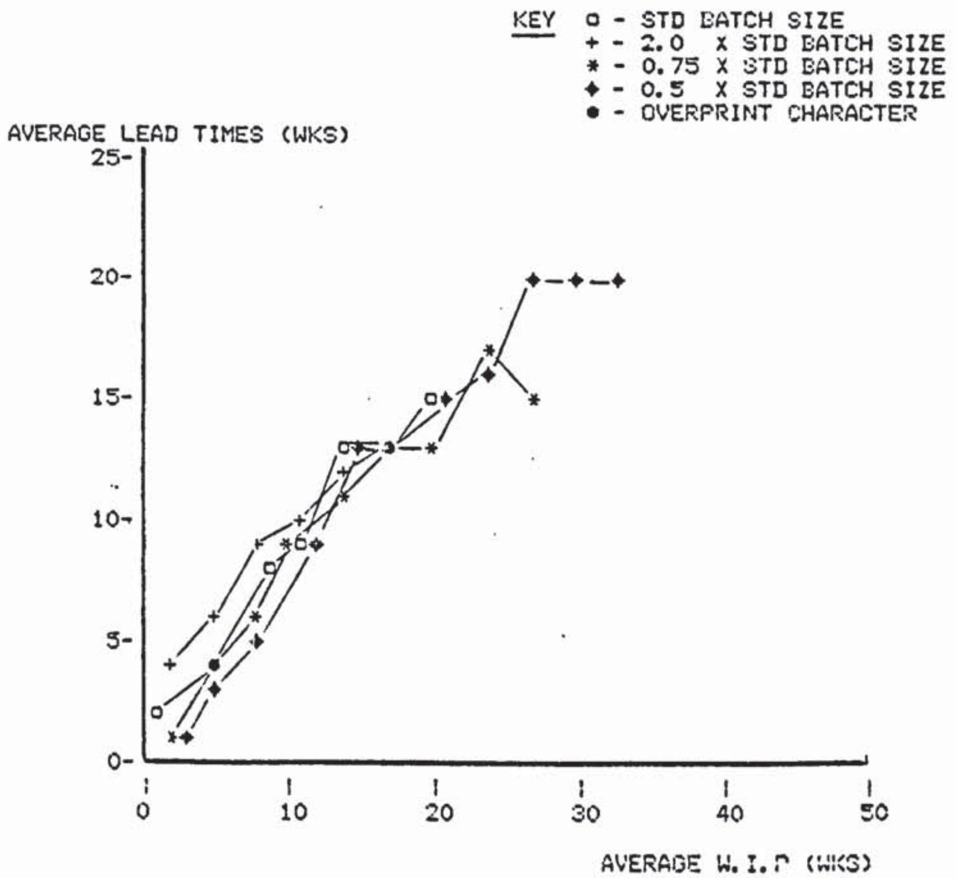

Figure 10.38 LEAD TIME - WORK IN PROGRESS RELATIONSHIP BATCH SIZE SERIES

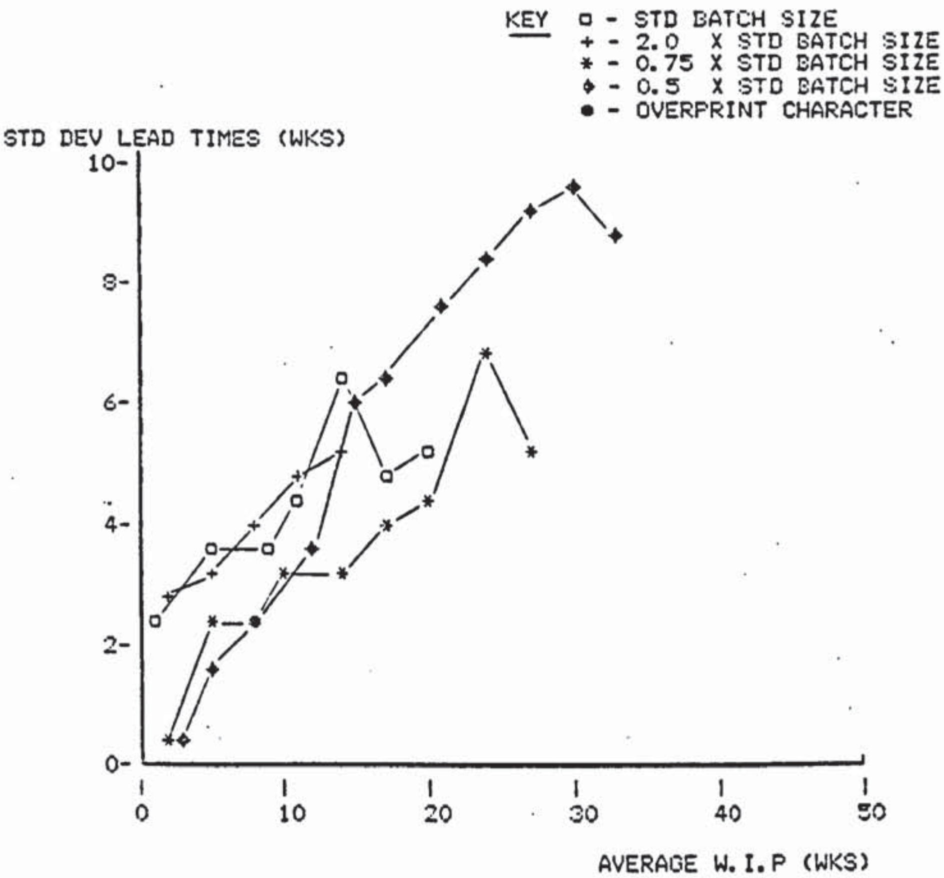

Figure 10.39 LEAD TIME VARIABILITY - WORK IN PROGRESS BATCH SIZE SERIES

10.6 Summary of Results

The results from this series of experiments showed that all the factors examined; scheduling rules, operator flexibility and batch size had a significant influence on some aspects of the machine shop's performance. The conclusions are summarised for each of these factors below.

10.6.1 Scheduling Rules

The choice of scheduling rule was found to mainly influence the various measures of lead time performance. The capacity realised by the machine shop and the levels of work in progress generated varied by only a limited extent between the various rules; specifically:

i) Random selection of batches produced the worst lead time performance in terms of average levels and variability.

ii) The duedate and float rules showed very similar performances in all respects.

iii) The improved facilities utilisation to be expected from the process orientated rules was barely confirmed by the results. They did, however, achieve a significant reduction in average lead times but also displayed high levels of lead time variability.

iv) The best (or 'flattest') lead time - work in progress characteristic was shown by the process rules, followed by the minimum duedate/float runs. The random rule gave the steepest characteristic and the highest within - cell standard deviation.

v) There was some suggestion that the efficiency with which the process rules tend to produce lower average lead times might prove to be merely a 'temporary' phenomena, since only marginal increases in facilities utilisation were achieved in these runs.

10.6.2. Operator Flexibility

Those runs in which the operator possessed more than two skills returned the best overall performance of the whole experimental series. They showed the lowest levels of work in progress and lead times and the highest realised capacity of any model configuration. Specific points to note include:

i) As operator flexibility increased the capacity realised from the machine shop rose and the level of work in progress and average lead times fell accordingly.

ii) The magnitude of the improvement was greatest from two to three skills/operator and became less significant for subsequent increases in flexibility.

iii) The form of the lead time - work in progress characteristic was virtually identical for the three, four and five skilled runs and showed close correlation with the 'standard' configuration at lower levels of work in progress.

10.6.3. Batch Size

The reduction in the set : run ratio attendant on an increase in batch sizes led directly to lighter loading of the shop. In spite of the lighter load the large batch size run failed to improve on the work in progress and lead time performance shown by the best (5 skills/operator) of the flexibility series of runs.

The lead time - load characteristic deteriorated slightly with increased batch size when compared to the 'standard' version of the model.

The smaller batch size runs produced a marked reduction in performance as a direct consequence of the increase in shop load which followed from the increased set:run ratios.

Some differences in the lead time variability were evident for the batch size runs although no consistent trend could be identified. The lead time-work in progress characteristics were identical for all the batch size runs.

10.6.4 General Conclusions

The modelling of the machine shop under dynamic load conditions allowed a more comprehensive study of its performance characteristics. The various configurations of the model were seen to show significant differences in their response to the fluctuating demand cycle. The measures related to the dynamic behaviour, such as peak work in progress and lead time levels, allowed improved assessment of the robustness of each machine shop design configuration.

The assumption of a linear lead time - work in progress characteristic proposed in the industrial dynamics models was validated by the results of these experiments.

It is also interesting to note that the trends evident from the more economical constant issue rate experiments were generally confirmed by the results of the fluctuating demand series of runs.

Chapter 11. Conclusions related to the Provisioning of Spares

11.1 Total System

The initial industrial dynamics study of the spares system demonstrated the extent of the interaction of it's component parts. The sensitivity analysis (see Chapter 4) established the key areas as being the operation of the stock control systems at the warehouse and distributors, and the characteristics of the source of supply. The former areas are examined in considerable detail by D.I.Peckett (1979) and G.M.Evans (1978).

The fluctuations evident in the historical spares system performance data were recognised as being of considerable significance since they represented the boundaries within which the new system would have to operate. It was clearly important to establish if the variation in demand seen at the source of supply was externally driven or the result of internal interactions. The 'multi-source' industrial dynamics model was developed to more faithfully represent the operation of the various sources of supply and allowed study of the influence of the original equipment (OE) demand on the behaviour of the spares system. The analysis indicated that, whilst the demand for spares and O.E rose in unison with the level of economic activity, and therefore competition for resources did exist, the interaction was insufficient to cause the degree of fluctuation demonstrated by the real system. The introduction of a small fluctuation in end customer demand (± 20% at distributors) was found to be sufficient to create behaviour in the model typical of the real system.

The conclusion that the fluctuation was externally driven implied that the provisioning system would have to be designed so as to maximise it's performance under such operating conditions.

The use of the industrial dynamics models was extended to determine the most pertinent source performance criteria and to gain some indication of the direction that the future development should take. The results of these experiments (see Chapter 6) indicated that the service offered by the warehouse to the distributors was significantly affected by the rate at which manufacturing capacity is brought into line with demand and by the length and manner in which the lead time varies with load. At this stage it was possible to draw some overall conclusions which related particularly to the bought - out and sub - contract sources of supply (see Sections 6.4.2. and 6.4.4). These were essentially that:

i) The responsibility for the setting and execution of procurement policies should be placed under the direct control of the Parts Division.

ii) Procurement decisions should pay particular attention to the lead time and prospective/historical peak demand delivery performance of potential or exisiting suppliers.

iii) The purchasing system should be modified to allow independent sourcing of current parts at the discretion of the Parts Division.

iv) The company should consider production of components which are at present bought out, providing the manufacturing unit could substantially better the lead times (and unit costs) offered by existing suppliers.

v) The useful nature of the sub - contract provisioning option was clearly established and it was suggested that the retention of suppliers during periods of low demand could prove cost - effective if this would guarantee capacity when the next upturn in business occurred.

The decision to proceed with the design of a pilot spares manufacturing unit (see section 6.4.3) was made on the basis of the following factors:

i) The performance of the existing manufacturing facility was inadequate and its operation and design was orientated toward production of compressors.

ii) The prospective growth in the number and proportion of non - current spares implied a divergenge of the type of production facilities needed to meet the process requirements of the O.E. and spares component ranges.

iii) The quantity of spares manufactured separately could be phased with the reciprocating compressor obsolesence programme.

iv) The design of a pilot unit would allow the development of appropriate techniques and design principles to be established for use in the expanded facility.

Whilst the industrial dynamics models established the desirability of certain operational characteristics, such as short lead times and rapid capacity response, they did not indicate how this performance could be achieved in practise. In order to explore the performance of various design options under the relevant operational conditions it was necessary to establish a more detailed model of the manufacturing unit. The conclusions from this exercise are discussed in the following section.

11.2 Pilot Spares Manufacturing Unit

The machine shop simulation experiments clearly indicated that the conventional procedure (described in Chapter 7) did not yield the best design and that the former technique was necessary to establish the appropriate operational policies.

The simulation results indicated that significant reductions in the levels of work in progress and average lead times could follow from relatively small increases in the capacity realised from the machine shop. The flexibility runs (except for the double skilled one) achieved a 5% increase in realised capacity in comparison with the 'standard' model configuration. The corresponding reduction in the values of peak work in progress and lead times were much greater reaching 30% and 25% respectively. Thus, where demand can be expected to fluctuate significantly, it is clear that the production facility should be designed to maximise the capacity which could be realised from the unit. Accurate design for the 'average' level of demand would result in unacceptable performance during busy periods. Obviously the installation of excessive levels of plant capacity or deliberate overmanning would not make economic sense. However, within the plant and manning constraints imposed by economic considerations it is possible to organise the system to achieve the maximum potential capacity and flexibility. It is worth noting, however, that in relation to spares, the company's declared policy sets customer service as the first priority.

It is also useful to distinguish between attributes of the design which can be considered to be permanent features, such as the plant and physical layout, and those which can be modified during the life of the unit. Manning levels and skill patterns can be considered to be amenable to change although the delays involved are so significant to render these aspects of the design essentially permanent features. Operational policies, such as the setting of batch sizes, can be modified against a relatively short time scale.

The batch size experiments clearly demonstrated the dramatic reduction in machine shop load which followed an increase in batch sizes. This suggests a mechanism by which the load on the shop could be adjusted to minimise the effects of an increase or decrease in demand. Whilst conventional EBQ theory would suggest that an increase in batch size above the optimum level would result in a corresponding rise in total costs, this view remains valid only in steady state conditions. A rising demand would, in any case, lead to an increase in the optimum batch size. During a period of rising demand stocks would tend to be depleted ahead of the arrival of additional supplies, implying that stockholding costs would actually fall during this period. The critical facet of such a policy would not relate to the period of increasing demand but to the behaviour of the system as demand begins to die away. The expected build up of stock at this point would be exacerbated by the legacy of large batches generated during the peak demand period but remaining in the production system. Clearly the magnitude of this problem would be dependant on the lags in the system. Short lead times would be beneficial in this respect and the use of a sophisticated forcasting system to drive the batch size mechanism would also clearly be required. The behaviour of such a system is not amenable to simplistic analysis and requires further detailed study to achieve proper understanding. The use of an extended version of the batch manufacture simulation package would be suitable for this task but it is, unfortunately, beyond the scope of this thesis.

The operator flexibility experiments clearly showed that benefits would accrue from operators possessing more than one main skill. All the multi - skilled runs returned performances much superior to the 'standard' configuration. The need to have at least two men capable of operating the automatic lathes was also clearly demonstrated.

The increase in the number of skills/operator from three to five did show some improvement in shop performance but this could not be considered sufficient to justify the problems and costs associated with the maximum level of multi - skilling. The practical implications, in terms of training and recruitment difficulties, are such as to eliminate this option. It is pertinent to note that, in spite of the current high level of unemployment, CompAir are experiencing problems in recruiting men possessing conventional skill patterns.

The use of operators possessing two main skills (eg turn/mill) and one subsiduary (eg deburr) therefore represents a reasonable compromise between improved machine shop performance and the practical recruitment and training problems.

The implications of the results of the scheduling rule experiments are less clear. The 'flattest' lead time - work in progress response and lowest average batch lead time were shown by the minimum imminent process time rule but this performance was offset by a high degree of lead variability (exceeded only by the random selection procedure). Whilst this latter feature is undesirable it is of less importance when supplying to stock rather than direct to end customers. Theoretically, at least, an increase in the level (and cost) of the appropriate element of the safety stock should ensure retention of adequate customer service.

However, the manner in which this rule operates bears closer examination. In contrast to some other worker's findings, for example Conway (1960,1965b), this class of rule resulted in only marginal increases in facilities utilisation. The fact that completion rates were actually lower for this class of rules implies that the improved average lead times were achieved largely by batch manipulation rather than a general increase in throughput efficiency. These rules will tend to 'stall' larger batches, holding them back for completion until late in the simulation run. The rise in the lead time - work in progress characteristic at high levels of work in progress shown for these rules in the constant issue rate experiments is consistent with this view. It is not the level of work in progress which is pertinent here but the length of the simulated time period that has elapsed from issue since for these runs the two are directly related. This view is supported by the failure of the process rule to achieve a higher completion rate during the period of peak demand in the second series of experiments.

In such circumstances the equivalence of the average batch lead time and the throughput delays used in the industrial dynamics models is less clear. The latter relate to the gross flow of components rather than batches. Comparison of average levels of work in progress for the different rules might therefore be considered to prove a more reliable and significant indicator since this measure is more directly related to the gross component flow. The levels of remaining work in progress attained by the process rules are only marginally less than those achieved in the minimum duedate and float runs, suggesting that only a minimal improvement is offered by the former in relation to the industrial dynamics criteria.

Both the duedate and float rules showed significantly superior performance than that achieved by random selection of batches. This superiority extended across all the measures of performance including; peak and average work in progress levels, capacity realised, average lead times, the lead time - work in progress response and lead time variability. The random rule can be considered to represent 'uncontrolled' planning of batch flow through the shop and the results therefore demonstrate the undoubted value of instituting an effective shop floor control system.

The closeness of the performance returned by the duedate and float rules implies that the extra computational effort (and the consequences for the control system organisation) attendant on the use of the float rule is not justified by improved system performance. It should be noted that this conclusion applies only where the circumstances surrounding the allocation of duedates are similar to those used in the model.

The organisational conclusions for the pilot spares manufacturing unit can be summarised as:

i) The nominal batch size for a component should be adjusted to reflect demand trends, since larger batch sizes result in a significant reduction in the shop load for a given demand level.

ii) Operators should generally possess at least two main skills and one subsidiary one.

iii) Tight control of batch sequencing through the shop is essential.

iv) The lead time improvements offered by the minimum processing time rules are superficial.

v) The use of a minimum duedate scheduling rule will represent the best compromise between performance and computational efficiency.

11.3 General Conclusions

The purpose of this project was not merely to make specific recommendations to the company concerning the form and organisation of the pilot manufacturing unit, but also to consider the broader implications for an expanded spares production facility.

The majority of the desirable features incorporated in the pilot unit can be extended to an expanded facility, these being:

i) Adjustment of set: run ratios by modification of the batch size to alter the machine shop load in parallel with demand trends.

ii) Use of multi - skilled operators to increase the flexibility of the unit.

iii) Application of rigid control of batch sequencing utilising the minimum duedate scheduling rule.

At this point it is worth considering whether these design features are encompassed by any particular manufacturing philosophy. The conclusions reached in the discussion were that:

i) Group Technology can, through appropriate cell scheduling techniques, allow realisation of reduced set: run ratios. Whilst this facility does not directly correspond with the requirements of (i) above the greater degree of control offered by GT systems would facilitate the process of batch size adjustment. The short lead times normally associated with GT installations would also tend to minimise the problem of lag in the batch size adjustment mechanism.

ii) The use of multi - skilled operators is common in GT systems but much rarer in plants using Functional Layout.

iii) Even the critics of Group Technology admit that good progress control is easier to achieve under this system The random selection of batches can be considered to be equivalent to the situation that arises in poorly controlled functional layouts. The poor performance attendant on the random selection of batches underlines the importance of this attribute of GT systems.

Thus it is possible to envisage the expansion of spares manufacture being achieved by extending the range of parts made on an enlarged pilot unit and by identifying new families to be made in additional manufacturing cells.

The use of the design aids developed during this project would clearly be invaluable in the process of evaluating the strategy to be employed in later phases of the exercise. The ability to access the component data base using the coding system is essential for the initial identification and analysis of potential component families. The simulation package provides the best method of evaluating the performance of alternative design options, particularly in relation to the kind of dynamic operating conditions which can be expected to apply for the forseeable future.

The design philosophy proposed by this thesis does not simply apply to the provisioning of spare parts at CompAir Industrial Ltd. The principle that the basis of a design exercise should not rest on the assumption of average or steady state conditions can be considered to have universal application to manufacturing industry. The suggestion that the worth of a design solution should be explicitly measured in terms of lead time and work in progress performance, as well as by a conventional assessment of unit processing costs, also has broad application. Whilst these aspects of manufacturing system design are not of themselves new, they are not generally applied in industry in the manner proposed here. It is relevant to note that not one report was found during the literature survey of a design exercise which included comprehensive assessment of performance under conditions of dynamic demand.

The problems attendant on such an approach are clear from the experience gained during this project. The ability to access the component data base in an efficient and flexible manner should be considered a prerequisite of sound manufacturing system design. The coding system used in this exercise provides the essental features for such a task. The computerisation of the process of building and modifying an appropriate base component range would clearly aid this stage of the design exercise.

The most important problem, however, involves the evaluation of the performance of the prospective design solution. Recourse to simulation techniques provides the obvious solution, but it's application normally requires the user to possess considerable computing skills, and commits the company to a long (and expensive) development period.

The simulation package developed here aims to overcome these problems by minimising the user's interaction with the operating system of the computer and eliminating programming entirely from its application. In addition the use of interactive techniques to input the system specification and the ability to accept the user's own terminology throughout the exercise reduces the potential for logic and data format errors, and encourages ready acceptance of the system.

Thus not only has a particular approach to the design of manufacturing systems has been postulated and demonstrated in this thesis but the necessary tools have also been developed to allow the broader application of the principles established here.

Chapter 12. Validity of the Simulation Models

12.1. General Discussion

The term 'validation' is normally applied to the process of establishing confidence in a simulation model's ability to emulate the real system. This discussion will include consideration of all the models developed during the project, including the two based on industrial dynamics techniques as well as the discrete machine shop model.

The process of establishing confidence in a models utility for a particular task is a gradual one which continues throughout the model building as well as final testing phases. Errors can arise in the basic assumptions which underly the form of the model, in the detailed logic of its structure or in the process of converting the logic into a computer program. Much philosophical discussion attends the concept of what constitutes 'validity' in a simulation model (Chapter 6, p208-218, Shannon, 1975)..

The concept of validity applies to all forms of model whether solved by mathematical or simulation techniques. It is important to realise that what constitutes validity is dependant on the purpose for which the model was constructed.

Many simulation models are built to achieve greater understanding of the mechanisms which underly the real system as well as to evaluate the performance of alternative policies or system structures. Validity in this context has a quite different meaning than that for models which exist only for predictive purposes. For example, stock control systems contain mathematical forcasting models that exist to predict forward demand levels, but need say nothing about the structure or mechanisms at work in the market place. Such models may be considered valid for their purpose and are judged only by their ability to minimise error between predicted and actual demand histories. In the former case, however, validity must include consideration of the correspondence between the structure of the model and that of the real system. Thus a simulation model which achieves perfect agreement with real system data histories is not necessarily valid unless structural correspondence can also be demonstrated.

Two extreme views may be advanced in relation to the philosophy which underlies the analyst's approach to validation. There are those 'Rationalists', such as Forrester, who assert that the validity of the model may rest only on the acceptance of those assumptions which underly the model as being obvious basic truths, proven by mere statement. Alternatively the 'Empiricists' contend that all assumptions must be verified exclusively by experimental means, ie. by comparison of model and system data streams.

The suspicion exists that the view of the management scientist may be biased by the conditions under which he is forced to work. The pure empiricist would reject all the industrial or system dynamics modelling as being of no value since all such models contain relationships which cannot be verified against real system data. To take such a view would clearly not be sensible given the undoubted contribution these techniques have made to the understanding of complex systems whose size is well beyond the capacity of other, more conventional, simulation methods. As Forrester (p144,1961) says:

> "Much of the behaviour of systems rests on relationships and interactions that are believed, and probably correctly so, to be important but that for a long time will evade quantitative measure. Unless we take our best estimates of these relationships and include them in a system model, we are in effect saying that they make no difference and can be omitted. It is far more serious to omit a relationship that is believed to be important than to include it at a low level accuracy that fits the plausible range of uncertainty."

Clearly acceptance of the rationalist view, when applied to a specific model, is dependant on just how 'obvious' the truth of the basic assumptions is felt to be. The more abstract and intangible the model components the more difficult acceptance becomes. The earlier industrial dynamics models (eg Fey,1962) which are of a similar class to the ones used in this exercise, tended to contain less contentious relationships than those proposed in later work (eg Forrester,1971). The spares system models do not contain variables such as 'pressure for expansion' (Roberts,1964)

Similar considerations also apply to the comparison of the model behaviour with that of the real system. Much of the literature (eg Kleijnen,1975; Shannon,1975; Fishman and Kiviat,1968 etc.) is devoted to the identification of statistical tests which can be applied to the model and system data histories to establish agreement. Shannon (Chapter 6,1975) suggests that, whilst the process of model building is essentially a subjective one, the validation exercise must utilise objective criteria. This view ignores the value of the experienced observer whose 'feel' for the real system can be exploited in an assessment of the reality of the model output. The subjective or 'face' validity of the model is also likely to be the determining factor in management's acceptance of the model's results (eg. see Schlager,1963).

Clearly where comparison with real system data is possible, and agreement is demonstrated, the analyst's confidence in the model will, necessarily, be higher than where it rests simply on examination of the model's basic assumptions and logical relationships. This approach carries an implicit assumption that the appropriate actual system data exists or can be gathered. Much of the literature, particularly that which concentrates on the statistical aspects of the problem, ignores the possibility that the data or the system being modelled does not exist. In the latter case there is clearly no way in which the validity of the model can be demonstrated to an empiricist. Even where the model parameters, exogenous input and structure can be adjusted to correspond to the real system (at some point or state in time), and agreement between the two can be demonstrated, subsequent modification of the model destroys the basis for comparison and any validity implied by the exercise. Whilst such a procedure would, of course, increase confidence, absolute proof of validity could only follow after the real system had been modified and shown to perform in a similar manner to that predicted by the model. Thus, absolute proof of validity is available only long after the conclusion of the modelling exercise. These circumstances are, unfortunately, especially relevant to the spares manufacturing simulation exercise since no correspondence exists between the proposed pilot unit and the present production facility. In many cases members of the base component range are either sub-contracted or manufactured on different machine tools to those incorporated in the pilot unit. However, as Hermann (1967) pointed out, validity needs to be established against a number of criteria and not simply by direct comparison between model and system data histories.

Hermann proposed five validity criteria:

i) Internal validity - using model replication, and holding model inputs constant, one determines whether the variance of the response is too large;

ii) Face validity - using subjective opinions regarding the surface, or initial, impression of the model's realism;

iii) Variable parameter validity primarily 'sensitivity testing' in order to ascertain whether the effects of changes in the model's variables are compatible with comparable alterations in the modelled system;

iv) Event validity - comparison of 'predictions' (responses) of the model with past (recorded) history of the actual system;

v) Hypothesis validity - examination of connections between system elements, so as to determine whether the model reproduces these relationships.

It should be noted that these criteria contain subjective and objective elements and are aimed at consideration of the model structure as well as comparison of real system data with the model output.

Fishman and Kiviat (1968) draw a distinction between 'verification' and 'validation':

i) Verification - the process of ensuring that the model behaves as intended by the model builder

ii) Validation - the comparison of the behaviour of the verified model with that of the real system.

This classification would lead to Herman's 'internal validity' being regarded as part of the 'verification' rather than 'validation' stage of the exercise.

The following sections discuss the application of these criteria, where possible, to the various models of the spares system.

12.2 Validity of the Industrial Dynamics Models

The verification of both the industrial dynamics models was straightforward, consisting of two stages. Firstly, as part of the debugging of the programs, the value of all the variables was manually calculated over two time increments. Given the same initial conditions, correspondence between the calculated end values and those of the model indicated the absence of 'bugs' in the program. The second stage involved holding all the exogenous inputs to the model constant and observing the form of the model output. Any instability evident in the latter would indicate faults in the model, since the logical relationships, as conceived, should result in a stable output under such conditions. After some program debugging (rather than structural modification) both models fulfilled these requirements and thus met the first of Hermann's test criteria.

Throughout the development of the models, close contact was maintained with spares and production personnel who, on the basis of their experience of the real system, were able to check and comment on the 'reality' of the models' behaviour. Agreement was reached that the models did show responses typical of the real system. (ie face validity achieved)

The sensitivity analysis using the basic model and the experiments with the multi-source model (which concentrated on these sectors added to the basic version) provided data to test Hermann's 'variable parameter validity'. The model responses remained stable over extreme ranges of parameter values (see Chapters 4,5 and 6) enhancing confidence in the robustness of the models. In general the responses to parameter changes were consistent with those one would expect from the real system.

The comparison of the models' performance with that of the real system highlighted the problems of data scarcity and reliability. Both the length of the time periods simulated and the concept of gross flows inherent in most industrial dynamics models create difficulties in identifying suitable real system data sources. Whilst the warehouse performance was fairly well documented (stocks, order intake, first pick etc. see section 3.3), a complete set of data for all the relevant measures was available for only a single 'cycle' in demand. The situation at distributors and in the factory was even worse. Generally, in these areas, records were maintained for only limited periods of time and discarded when of no further use. The lead time data presented in section 3.3 was actually derived from the spares control system records rather than those of the factory. Many of the distributors destroyed their record of stock movements 'when the card was full' or shortly afterwards. Some indication of the pattern of demand at distributors was established by analysis of the monthly turnover of four UK distributors who, between them, accounted for 28% of the home market. The sample nature of this data and the extent of the processing required must decrease confidence in the reliability of any conclusions which may be drawn from it. The distributor demand data is of critical importance not only because it provides the basis of a check on the amplification inherent in the distributors stock control system, but because it provides the only indication of the form of the exogenous input to the model.

The paucity of data for the complete system dictated the use of the key warehouse measures of performance as the basis of the 'event validity' comparison. It is frequently possible to adjust the values of the model parameters so as to yield superior matching of the model and system performance. However, such an approach would invalidate the logic used to derive the parameter values initially. The model configuration used for the validity tests therefore retained the standard parameter values previously discussed in Chapters 4 and 5. A common range of distributor demand levels was used to drive both the basic and multi-source models. A sinusoidal form of input was used with a period of 220 weeks and amplitudes of 7%, 10%, 20% and 25% of the mean demand level.

A summary of the comparative performance of the two models and the real system, in relation to stocks, shortages and order intake levels, is given in Table 12.1. Inspection of the table shows that the multi-source results come closest to those of the real system, particularly for the 20% and 25% runs. The 25% run with this model gives the best fit for maximum and minimum shortage levels but the

Variable	Historical Values	Basic Model**				Multi-Source Model**			
		Amp (% mean) Dist Demand				Amp (% mean) Dist Demand			
		7	10	20	25	7	10	20	25
Stocks (weeks)									
Max	29/27.5	24.1	25.9	31.1	34.3	24	23.8	29	32
Min	12.5/15	15.8	14.2	9.9	8.3	18.5	17.7	15	14
Mean	app 21	19.7	19.6	19.1	19.0	20.8	20.8	20.4	20.1
Period	3.5/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5
Shortages (mths)									
Max	1.2/1.3	0.93	1.05	1.54	1.85	0.80	0.88	1.05	1.25
Min	0.1	0.54	0.48	0.33	0.26	0.55	0.55	0.35	0.28
Mean	0.66	0.72	0.75	0.86	0.94	0.68	0.68	0.7	0.73
Period	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5
Smoothed Order Intake (Warehouse) (% mean)									
Max	116/110+	107.5	110.5	120	124.2	107.5	110	120	126
Min	87/94	92.4	88.5	78	72.2	92.4	88.5	78	73
Mean	100	100	100	100	101	100	100	100	100
Period	4/5.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5	4/4.5

\+ Historical order intake, monthly items, smoothed 6 month delay, mean calc years 1969-1978
** Values taken after the first completed cycle over the following three cycles.

Table 12.1 Comparison between Historical and the Industrial Dynamics Models Performances

20% run is superior in relation to all the stock measures, the average shortage level, and order intake figures. Comparison of the movement of stocks and shortages for the real system and the latter run have clearly been presented in graphical form in Chapter 5 (see Figures 5.3 and 5.4).

The basic model shows a greater amplitude of fluctuation in stocks and shortages for a given level of order intake than that shown by the multi-source model. The minimum level of shortages attained by both models over all the runs failed to reach the 0.1 months shown by the real system, although maximum and mean levels are comparable. The degree of variation in the warehouse order intake necessary for the models to show similar stock and shortage movements is also higher than that measured in the real system.

Direct comparison of these model and system outputs are not strictly valid since the respective inputs (ie customer demand) were not identical. The non-availability of suitable reliable customer demand (rather than sales) figures prevented such a test. The only information available applied to the sales (by value) of a sample of the U.K distributors. This data suggests a much smaller variation in customer demand ($\pm$ 7%) than that required by the models to produce performance typical of the real system. Whilst it should be noted that sales will normally represent a smoothed version of demand, this discrepancy does imply that the amplification shown by the model's distribution sectors is too low. The necessity for higher variability in the models' warehouse order intake also suggests the presence of greater amplification in the stock control routines of the real system.

However, without the ability to test the models using real system input data, these comments can only be viewed as conjectural. The tests do establish that the models are capable of producing performance broadly comparable with that of the real system.

The basic model was also subjected to additional comparisons which tested the lag between order and stock receipts at the warehouse and the relationship between the warehouse and distributors' shipment rates. These comparisons are fully described in D.I.Peckett's PhD thesis (Section 6.5, 1979) with whom the basic model was jointly developed.

The validity of the basic hypothesis contained in the models is dependant on acceptance of the relationships as described in Chapters 4 and 5.

Any assessment of the validity of these models should consider the purpose for which they were built. The application of these models strove to identify:

i) The source of the fluctuation evident in the real system data histories;

ii) Those parts of the system which had critical influence on its performance.

iii) The performance trends attendant on modification of the critical parameter values.

In this context the deficiencies which arose in the validation exercise were not considered to be of sufficient magnitude to undermine the validity of the conclusions reached in relation to the purpose of the various experiments.

12.3. Validity of the Spares Manufacturing Model

The complexity of this model generated a need for a more extended verification phase than that required by the industrial dynamics model. The facilities available in the simulation language (E.C.S.L) to aid this process are extensive. The following special functions were utilised to allow manual checking of the execution of the program:

i) Variable Dump - on each ocassion the time advance mechanism is activated, and prior to the start of the corresponding activity scan, the names and values of all the program variables are dumped to the output file.

ii) Activity Scan Record - the number of the last statement executed in each activity, during each activity scan, is printed to the output file.

iii) 'Check' print statements - these can be inserted at critical points in the program and can be activated by the programmer to output the values of appropriate variables (or the contents of sets) for preset periods of the simulation.

These facilities were used most frequently to check that the program was faithfully representing the logic of the model.

The 'internal validity' of the model was assessed by the use of the more detailed performance monitors built into the package (rather than the language). The 'Job Track' and 'Queue' monitors (see section 9.2.4) allowed the activities of individual men, machines and batches to be followed through each change of state. The use of a small, predetermined, sequence of orders produced a deterministic model response which was checked by a parallel manual simulation exercise.

In addition to these tests the behaviour of the model during the various experimental runs also contributes to confidence in the models internal validity The points to note are:

i) The load generated on the various machines is consistent with that calculated from average demand data during the conventional design exercise described in Chapter 7.

ii) Whenever the issued load fell below the machine shop capacity the completion and issue rates converged (after the elimination of surplus work in progress). This phenomenon may be seen especially clearly in the labour flexibility runs (Figures 10.20 to 10.23)

iii) The movement of work in progress levels is consistent with the relative difference between issue and completion rates for all the experimental runs.

iv) The movement in average batch lead times (and queueing /operation) is consistent with changes in the level of work in progress.

The levels of work in progress and lead times attained during the fluctuating demand series of experiments were felt to be typical of the industry. A small sample of throughput times taken for components manufactured in part of the medium/ heavy compressor machine shop showed that queueing/operation times of one to two weeks were typical. The sample was limited in duration (2 months) and the range of batches monitored were destined primarily for compressor build requirements. This coupled with the non-alignment of the sample and model component ranges, makes the use of this data unsuitable for proof of the model's 'event validity'. The fact that the lead times presented by the model did fall within the range shown by the sample does, however, contribute towards confidence in its face validity.

Since the system being modelled did not exist, it was clearly impossible to establish 'event validity' for the model. The possibility of modelling an existing part of the factory was investigated, but the mis-match between the spares unit and any of the existing departments, coupled with the scarity of relevant long term performance data for the factory prevented the success of such an exercise.

The experiments performed with the model did allow a limited form of 'variable - parameter validity' testing. Whilst the equivalent changes in parameter values could not be made to the real system (even if it had existed, it would not have been economically viable or practicable to do so), the response of the model was, in general, consistent with the result expected from experience or analysis. The scheduling rule results generally agree, or at least show comparable trends to the work reviewed in section 8.2.2. However, comparison with the findings of other workers is complicated by the need to ensure comparable operating conditions. As Panwalkar and Iskander (1977) point out in their survey of scheduling rule research, the extraction of general conclusions from the literature is difficult (page 59):

"One of the main reasons for obtaining conflicting results in various simulation experiments involving a given rule is the difference in operating conditions"

It was not possible to identify any experiments which utilised comparable operating conditions to those applied in this exercise. This problem applies equally to the modification of batch sizes and operator skill patterns.

It may be said that the art of simulation lies in deciding what should not be included in the model. The closer the model structure reflects that of the real system the more complex and inefficient it becomes. In this instance the exclusions included:

i) Overtime working

ii) Operator absenteeism and sickness (although facilities are available in the package).

iii) Multi-shift operation.

iv) Variability in operator performance.

v) Machine breakdowns (although facilities are available in the package).

vi) Re-working of rejects.

vii) Detailed emulation of the operation of the automatic lathes (although facilities are available in the package).

The majority of the above ommissions were not felt to be especially relevant to the identification of the basic configuration and operational policies of the manufacturing unit. The length of the periods to be simulated and the consequent importance of the execution times required by the model also created pressure to eliminate facilities felt to be of marginal relevance to the experimental task. The fact that allowances for breakdowns and other unplanned stoppages were built into the company's operator performance data was felt to justify the removal of the absence and breakdown activities from the model. CompAir Industrial work a single 8 hour day shift system throughout the production facility and no modification of this policy was anticipated for the spares unit. The inclusion of operator performance variability and re-working of rejects would have added considerable execution time to the model and it was realised that no relevant data existed for this particular component range/machine grouping configuration.

The inclusion of overtime working, whilst offering an alternative area for further investigation of appropriate policies, was not felt properly to be considered as a basic element of the system since overtime is not an obligatory requirement of the workforce.

Whilst the absence of proof of 'event-validity' was recognised as a serious shortcoming, the general behaviour of the model in relation to the other criteria was felt to such as to justify confidence in its application.

12.4. Evaluation of the Modelling Techniques Used.

The industrial dynamics models were sucessful in meeting their primary purpose of identifying the sensitive or critical parts of the system and indicating the direction in which development should proceed to ensure improvements in the system performance. These models were less succesful in assisting the redesign of the stock control system (Peckett,1979) or the design of the spares manufacturing unit. Such design exercises, necessarily, require decisions to be made at a detailed, component level. The aggregation of the system entities inherent in industrial or system dynamics models and the corresponding problems of parameter identification prevent a direct contribution to this process.

This difficulty seems common to other industrial dynamics models of comparable systems (Yurow,1967) but, in general, the authors of industrial dynamics models appear so committed to the technique that no attempt was reported of combining the merits of the approach with those of discrete simulation methods. The method described here, and also follwed by D.I.Peckett (1979) for the spares stock control system, seeks to combine the strengths of both techniques. D.I.Peckett was able to insert his detailed stock control model into the industrial dynamics program to achieve parallel operation and thus allow retention of the interaction between the various total system elements. This approach is naturally to be preferred but is practicable only if the discrete model is very efficient. The stock control model achieved greater efficiency through a relatively simple structure and a degree of agregation which would not have been acceptable in the job shop model.

The loss of the effects of the total system interaction in the job shop experiments was minimised by seeking to establish performance in line with criteria previously defined by the industrial dynamics models. The similarity between the linear lead time - work in progress relationship assumed in the industrial dynamics models and that demonstrated by the discrete model increases confidence in this approach. However, it is clear there will exist some dynamic interactions between the system elements which could degrade the validity of the conditions under which the job shop model was tested. For example, the action of the distributor and warehouse stock control systems in adjusting the level of order cover, and the rate at which these adjustments are made, is dependant on the response of the supplier. Whilst the demand trends used in the discrete model experiments were consistent at a gross level with those shown by the industrial dynamics models, investigation of the effects of such action at a detail component level (eg on product mix) could not be evaluated by this approach.

The limited efficiency (and power) of the computer available, prevented the use of replication to establish greater confidence in the discrete model results. The ability to perform a greater number of runs with different seeds for the order generator would also allow evaluation of the robustness of the machine shop design to variations in component mix, since this factor is controlled by the order generator seed. Ideally one would like to simulate several complete demand cycles, an option which is not practicable given the present efficiency of the machine shop model. Whilst the experiments were aimed primarily at the performance differences which existed between alternative configurations of the machine shop it would have been very useful to also be able to utilise the model as a predictive tool. Given the nature of the demand conditions under which the model operated, replication would offer the only way of establishing confidence limits on absolute predictions of performance. Clearly the low efficiency of the machine shop model limited both the breadth and application of the experimental results especially in relation to their use to predict, in absolute, rather than relative terms, the performance of a particular design configuration.

In conclusion it is important to realise that, as Shannon (1979, page 262) says:

> "....validation should be considered one of degree and not an either-or notion; it is not a binary decision variable where the model is valid or invalid. There are no one or two tests which will serve to validate a simulation model, rather, confidence in the usefulness of a model must gradually accumulate ...."

and that as Rivett (1980 page143) concludes:

> "At its heart it is fair to say that the application of simulation models involves an act of faith. In saying this, however, we have to realise that the application of most operational research models involves acts of faith"

Chapter 13 Further Work

13.1 System Interaction

The analysis of the operation of the total spares system at CompAir Industrial, presented here and in D.I.Peckett's PhD Thesis (1979) has demonstrated the significance of the interaction between the various elements of the system and the importance of assessing performance across a wide range of operating conditions. Whilst the early industrial dynamics work amply demonstrated the critical nature of these factors, the extension of this approach at a detailed level has not been attempted. The mainstream of industrial (or system) dynamics has moved on to greater things and the majority of discrete modelling exercises have concentrated on sub-system simulation. Many of the most important system design problems can only be resolved at a level where discrete modelling is essential or at least where the aggregation of entities has been carefully contrived. The modification of the industrial dynamics models to allow representation of the movement of the orders and materials as a number of distinct flows, aggregated by value category at the warehouse, and by component type or production department of the factory, would allow a more realistic assessment to be made of broad policy alternatives for the spares system. The expansion of the multi-source model to more faithfully represent the interaction between the compressor build and spares requirements would also require more detailed representation of the relevant flows.

It would appear that the development of more detailed industrial dynamics models, or hybrids containing some discrete elements, could be established to allow the evaluation of broad policy decisions within the company and to control and guide sub-system development. Ultimately such a model (or models) could be expected to include elements describing O.E., marketing and distribution sectors as well as cash flows within the organisation.

The application of such models to detail design problems will, however, remain limited. Whilst some sub - system development can be carried out in isolation, there are many areas where the effects of interaction between system elements cannot be ignored at a detailed, component level. For example, the full economic evaluation of the modification of batch size with demand trends requires consideration of the influence of such a policy on stocks as well as the production system. The form of the stock control rules, the value category structure and the characteristics of the forcasting system are all of significance in this regard. The addition of a stock control section to the machine shop model would be required to allow such an investigation to proceed on a sound footing.

An extended discrete model would also allow checks to be performed on the performance and structure of the industrial dynamics models; in particular on the presence or otherwise of amplification in the system.

The evaluation of the machine shop performance under dynamic load conditions made the basic assumption that the shop configuration (ie manning levels etc.) would not change during the simulation period. This assumption was valid in relation to the need to investigate the most appropriate <u>basic</u> configuration of the unit, but clearly one could not expect management to remain inactive in the face of some of the circumstances predicted by both kinds of model. The industrial dynamics models did allow a mechanism by which the capacity of the production unit could be modified to match demand trends. There exist some policies, notably the use of overtime and adjustment of labour capacity, whose execution lies within the timescale simulated by the machine shop model. The addition of routines to add facilities to simulate these factors would allow further investigation of the appropriate policy rules in relation to different kinds of demand trend.

These suggested developments, combined with the need to replicate runs and thus establish confidence limits for predictions of absolute performance levels, demand the enhancement of the efficiency of the discrete model. Several alternatives exist which offer the possibility of faster execution times:

i) Re-examination of the existing model program to determine if structural modification would result in faster execution.

ii) Rewrite the program in an alternative language that produces a compiled object code. The possibilities here include other simulation languages, such as GPSS or SIMSCRIPT, and high level general purpose languages of which the most promising is PASCAL due to its flexible data structure.

iii) The movement of the complete package to a totally dedicated mini-computer, thus avoiding the limitations on job time imposed by the time sharing, multi - user systems inherent in large computer installations. The loss of execution speed attendant on the use of a mini - computer would be offset by the ability to run the program continuously, for several days if necessary.

The re-examination of the existing program structure represents possible short term action, whilst the other possibilities will be explored as part of the enhancement of the complete Batch Manufacturing Simulation Package described below in Section 13.2.

13.2 Development of the Design Package

The application of the complete batch manufacturing simulation package to other problems is clearly desirable in order to evaluate both the suitability of the structure from a user's point of view, and to determine what new activities need to be added to maximise the potential range of systems that it can be used to simulate. This process has already started with its use in a theoretical study of the operational economics of a GT cell but the need obviously also exists to gain further experience with industrial applications.

The constraints and requirements of the project at CompAir dictated the form that the package should take. In particular the interactive program was designed essentially as a mechanism by which the specification of a machine shop could be readily translated into a form acceptable to the simulation program. At present, the use of the package demands that the user has already determined the outline specification of the production system in terms of the number of machines, men, and form of the component range required etc. In it's present form the package is essentially an evaluation tool to be applied after the initial design exercise is complete. The classification and coding system, on the other hand, aids the initial stages of the design exercise by helping to identify the potential component range. The experience at CompAir showed that the process of refining the potential component range and establishing the broad outline specification was especially tedious and time consuming. A complete design evaluation package should therefore incorporate the existing elements, but also include facilites to:

i) Interrogate the companies component/product data base by size, features, material, product etc.

ii) Match the production features of the component range with a suitable selection of machine tools.

iii) Calculate approximate machine/labour loading on the basis of existing and forecast demand levels.

iv) Allow extensive user manipulation of the component/machine range to assist the emergence of a suitable outline design.

v) Provide an estimate of likely performance of the design, without recourse to simulation, to ease preliminary evaluation of alternative designs.

vi) Assist in the economic evaluation of the design after the performance data has been refined by the simulation.

Stages (i) and (ii) imply an extension of the coding facility to include the ability to describe machines in a manner consistent with that used for components. The remaining facilities (and the execution of the first two) would naturally be computer based. The machine capacity required to perform such tasks is well within the capability of the current generation of micro-computers.

Communication between computers of different types and sizes is commonplace and therefore the concept of placing the interactive parts of the package on a small, local, micro-computer does not present any special technical problems. Thus, the expanded package would consist of the simulation program and the process data base resident on a powerful central computer (or dedicated mini-computer), whilst the peripheral programs would be executed on micro-computers sited in a user company's production engineering department.

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COMPARISON WITH OTHER SPARES OPERATIONS

The tables overleaf show how the Company's Parts Division compares with those of Ford, Aveling Barford, J.C. Bamford, Leyland and CompAir C & M.

TABLE A - GENERAL

		BROOMWADE	HOLMAN	FORD	LEYLAND	J.C.B.	AVELING BARFORD
TURNOVER (net)	£M	4.96	5.4	100	70	7.3	6.0
NO. OF LINES	UNITS	12,000	15,000	80,000	60,000	34,000	73,000
LINES HANDLED PER WEEK	x1000 UNITS	3.0-3.5	3.5-4.0	160	120	5-6	3.0
WAREHOUSE AREA	x1000 SQ.FT	20*	30	1600	820	80	100
OFFICE AREA	x1000 SQ.FT	2.4	1.5	86	est. 50	12.5	15
WAREHOUSE STAFF		31+8(x)	28	700	1050	30	60
OFFICE STAFF		25+5(y)	26	600	400	40	90
ESTIMATED STOCK TURN (net sales price)		2.2	2.8	about 4	2.8	1.8	1.3
TURNOVER/WAREHOUSE AREA	£/SQ.FT	248	200	62.5	87.5	91.25	60.0
TURNOVER/TOTAL SPARES EMPLOYEES	£/PERSON	72,000	96,000	77,000	48,000	104,000	40,000
PRIORITY ORDERS / TOTAL ORDERS	%	26	15	20	20	25	20

* Including allowance for Packing, Despatch, Shipping, Holding and Loading

(x) Allocated from Distribution (by J.B.S.)

(y) Allocated from Provisioning and Publications (by J.B.S.)

TABLE B - NATURE OF BUSINESS

	BROOMWADE	HOLMAN	FORD	LEYLAND	J.C.B.	AVELING BARFORD
TURNOVER £M	4.96	5.4	100	70	7.3	6.0
SUPPLY % U.K.	60	40	60	50	35	20-25
NO. OF OUTLETS						
a) TOTAL	140*	210	2000	600		
b) U.K.	30	21***	1500	450	{12 DISTRIBUTORS {52 DEPOTS	{7 DEPOTS {+ 3500** CUSTOMERS
c) EXPORT TERRITORIES	110	OVER 120.	128	N/A	106	N/A
d) EXPORT OUTLETS	110	189	EST. 500	150	106(?)	150
SPARES COVER GIVEN AFTER PRODUCT WITHDRAWN FROM PRODUCTION (YEARS)	5 TOOLS 10 LIGHT COMPRESSORS 15 HEAVY & MEDIUM COMPRESSORS	5 OCCASIONALLY 7	10	NOT SET BUT 10+	NO CUT OFF	10 GRADERS AND TRUCKS 18 ROAD ROLLERS
SOURCING % IN COMPANY	30	90 TOOLS 25 PORTABLE COMPRESSORS 50 RIGS	50	50	40	30%

* Also 2,700 tool and spray finishing customers

** At 10,000 addresses

*** Also 1,600 individual accounts at 6,000 addresses

TABLE C - SERVICE TO CUSTOMERS

	BROOMWADE	HOLMAN	FORD	LEYLAND	J.C.B.	AVELING BARFORD
SERVICE						
- levels						
Number	3	3	2	2	3	7
Priority	YES	YES	YES	YES	YES	YES (3)
Routine	YES	YES			YES	YES (2)
Stock	YES	YES	YES	YES	YES	YES (2)
- targets						
Priority (hours)	48	12-36	24	24	24	24
Routine (days)	12-15	7	-	-	7	-
Stock (days)	20	28	7	7	14	14
- aim/achievement (%)	(1)					
Priority	90/80	96/90	95/90	97.5/96(?)	99/99	95/95+
Routine	90/85	{92.5/75	-	-	95/94	{95/93
Stock	85/85	{-90	95/90	96/90(?)	90/90	
- availability	Ansaphone outside office hrs	Telex only outside office hrs	Ansaphone outside office hrs	Ansaphone outside office hrs	24 hour	Ansaphone outside office hrs
- take back scheme	NO	YES	YES	NO	YES	NO
- unit exchange scheme	NO (air ends soon)	YES (air ends only)	YES	YES	?	YES

(1) The 85/90% objectives have since been modified, whilst the 80/85% achievement is an estimated average, covering the years 1973 to 1977.

APPENDIX I (cont'd)

TABLE D - WAREHOUSE

	BROOMWADE	HOLMAN	FORD	LEYLAND	J.C.B.	AVELING BARFORD
AREA sq.ft. x 1000	20	30	1600	820	80	100
HOW DIVIDED	BY PRODUCT	BY PRODUCT NUMBERICALLY	BY PART CHARACTERISTICS	BY PART CHARACTERISTICS	BY PART CHARACTERISTICS	BY PART CHARACTERISTICS
RACKING a) MAIN (heavy and large pallet held	13' HIGH RACKING	15' HIGH RACKING	21' HIGH RACKING	30' HIGH RACKING	30' HIGH RACKING	VARIOUS RACKING
b) SMALL PARTS (shelved or container	FIXED BINS	SMALL MOVEABLE BINS	FIXED BINS	SUPERMARKET TYPE AREA	SUPERMARKET TYPE AREA	FIXED BINS
PART PLACING	(FORK LIFT (TRUCK AND (MANUAL	(FORK LIFT (TRUCK OR (ORDER (PICKER	PALLET PLACERS	HIGH LIFT PALLET PLACERS	HIGH LIFT PALLET PLACERS	(CRANE, FORK (LIFT AND (MANUAL
PART PICKING			STACATRUCK	STACATRUCK	STACATRUCK	
MECHANISATION LEVEL	LOW	HIGH	MEDIUM/HIGH	VERY HIGH	HIGH	LOW
CORROSION PROTECTION						
WHEN:	AT DESPATCH	AT DESPATCH	ON RECEIPT	BEFORE RECEIPT	ON RECEIPT	ON RECEIPT
a) CRITICAL ITEMS	RUSTILLO OIL	ENSIS OIL	ENSIS OIL AND PLASTIC MESH SLEEVES	ENSIS OIL OR EQUIVALENT	CROCELL HOT DIP	CROCELL HOT DIP
b) BRIGHT ITEMS	RUSTILLO OIL	ENSIS OIL	ENSIS OIL	ENSIS OIL OR EQUIVALENT	ENSIS OIL	CRODA PENTAGEL 3/15
PACKING						
WHEN:	AT DESPATCH	ON PICKING	ON RECEIPT	BEFORE RECEIPT	ON RECEIPT	AT DESPATCH
METHOD FOR:						
a) VERY SMALL ITEMS	PLASTIC BAGS	PLASTIC AND JIFFY BAGS	PLASTIC BAGS	ENCAPSULATION	PLASTIC BAGS	PLASTIC BAGS OR PLASTIC MESH
b) SMALL/MEDIUM ITEMS	NONE	PLASTIC AND MOULD WRAP	WAXED CARDBOARD BOXES	CARDBOARD BOXES	CARDBOARD BOXES	CARDBOARD BOXES
c) LARGE ITEMS (prior to crating)	NONE	POLYTHENE	NONE	NONE	NONE	NONE

TABLE E - INFORMATION AND ASSISTANCE TO DISTRIBUTORS

	BROOMWADE	HOLMAN	FORD	LEYLAND	J.C.B.	AVELING BARFORD
PUBLICATIONS						
PROCEDURES MANUAL	NO	YES	YES	YES	YES	NO
PARTS BOOKS	BOOKS	BOOKS	MICROFICHE	MAINLY BOOKS BUT MICROFICHE FOR UNIPARTS	BOOKS - WANTING TO CHANGE TO MICROFICHE	MICROFICHE AND BOOKS
COURSES						
SPARES	NO	NO	YES	YES	YES	NO
SERVICE	YES	YES	YES	YES	YES	YES
SPARES MANAGEMENT ADVICE	NO	YES	YES	YES	YES	PLANNED
ASSISTANCE IN PROMOTION OF :						
a) SPARES	NO	NO	YES	YES	?	NO
b) ACCESSORIES	NO	NO	YES*	YES*	YES*	NO

* Recent activity has been intensive

Appendix 2 Long Term Demand

Several approaches to the problem of forecasting the rate of decline in demand for a non current spare part were investigated.

1. Part Population

The suggestion that a correlation might exist between the decline of the field population of a machine type and the demand for the corresponding spare parts was thought to be worthy of further investigation.

Estimates of field population were not available in the company and it was, therefore, decided to investigate sales histories of particular machine types, in the belief that this information coupled with estimates of machine life would yield approximately the same results.

Several sources of sales histories were identified but each had one or more deficiencies, either in the manner in which the information was organised, its reliability or the length of time for which the records were available. The latter point was especially important as many of the key machine types had been in production for over 30 years. Virtually all the information was contained on manual records kept before the introduction of the computer.

In order to test the validity of the hypothesis, sales records for the last twelve years were manually analysed and a machine selected which had been introduced during this period - the V-Compact medium sized reciprocating compressor. Selection of this machine minimised the problem of assessing the effects of obsolesence on population and the development history of the machine was readily available.

Whilst the discussion had tended to centre on machine population, the identification of the population of individual parts was the real requirement. Different machines, within the same product range, tend to use different quantities of the same part in their assembly. This is particularly true of high wearing items such as valves.

The individual components of the V-Compact range were, therefore, analysed and a selection of suitable part populations built up.

The change in these populations was tested against corresponding spares demand patterns. No correlation was found.

The exercise was repeated for a small compressor and a similar result obtained.

2. Decay Curves

An analysis of all the available demand data for non-current spares was performed using the Aston computer, in an attempt to find whether a pattern exists which is common to all non-current spares. The first attempt was based on calculating the demand in a given year after obsolescence compared with the demand of the part in the last full year that it was current. Not only were the results inconclusive, but the number of parts for which the necessary information was available were too few for confidence. The second attempt was to calculate the relationship of the demand figures in any given year of obsolescence to the demand in the previous year.

Once again, no suggestion of a pattern emerged.

Manual analyses were carried out for two of the most significant product families (valve and valve parts, and pistons). As before, there was no discernable trend over the seven years for which data are available. This is true whether the period for which data are available occurs immediately after the part became non current or several years later.

3 Financial

The Spares Division produced figures indicating how much revenue was generated in 1975-76 for groups of spare parts relating to machines made obsolete a number of years previously.

A search for common trends in the data failed, and the only conclusions to emerge from this part of the investigation were:-

i) The decline for spare parts when a machine is made obsolete is difficult to forecast.

ii) There is substantial demand for spare parts for at least seven years of obsolescence.

It was decided that unless continuous data could be made available, for a much longer period (15 years) further investigation of long term demand trends at CompAir is likely to prove too expensive of time and effort to justify the uncertainty of the results likely to be obtained.

The Company therefore agreed to suspend further investigation of this area.

APPENDIX 3 BASIC INDUSTRIAL DYNAMICS MODEL EQUATIONS

DISTRIBUTOR EQUATIONS

Retail unfilled order level
$$UOR.K = UOR.J + (DT)\ (RRR.JK - SSR.JK) \qquad 1\ L$$

Retail inventory level
$$IAR.K = IAR.J + (DT)\ (SRR.JK - SSR.JK) \qquad 2\ L$$

Shipping to be tried
$$STR.K = \frac{UOR.K}{DFR.K} \qquad 3\ A$$

Limit to shipping
$$NIR.K = \frac{IAR.K}{DT} \qquad 4\ A$$

Shipping = n/
$$SSR.KL = \begin{cases} STR.K \text{ if } NIR.K \not> STR.K \\ NIR.K \text{ if } NIR.K < STR.K \end{cases} \qquad 5\ R$$

Shipping delay
$$DFR.K = DHR + DUR \left(\frac{IDRD.K}{IAR.K}\right) \qquad 6\ A$$

Desired inventory
$$IDR.K = (AIR)\ (RSR.K) \qquad 1 \qquad 7\ A$$

Avg Sales at retail
$$RSR.K = RSR.J + \frac{DT}{DRR}\ (RRR.JK - RSR.J) \qquad 2 \qquad 8\ L$$

Ideal delay inventory
$$IDRD.K = AIRD\ (RSRD.K) \qquad 9\ A$$

Avg Sales at retail for delay calc
$$RSRD.K = RSRD.J + \frac{DT}{DRRD}\ (RRR.JK - RSRD.J) \qquad 10\ L$$

Purchase decision rate
$$PDR.KL = RRRC.JK + \frac{1}{DIRI} \left\langle (IDR.K - IAR.K) + (UOR.K - UNR.k) \right\rangle$$
$$+ \frac{1}{DIRP}\ (LDR.K - LAR.K) \qquad 11\ R$$

$$RRRC.JK = RCO\ (RRR.JK) \qquad 12\ A$$

Desired level in pipeline
$$LDR.K = (RSR.K)\ (DCR + DMR + DFF.K + DTR) \qquad 13\ A$$

Actual level in pipeline
LAR.K = CPR.K + PMR.K + UOF.K + MTR.K. 14 A

Unfilled normal requisitions at retail
UNR.K = (RSR.K) (DHR + DUR) 15 A

Clerical order delay from retail

CPR.K = CPR.J + (DT) (PDR.JK - PSR.JK) 16 L
PSR.KL = DELAY 3 (PDR.JK, DCR) 17 R

Mail order retail
PMR.K = PMR.J + (DT) (PSR.JK - RRF.JK) 18 L
RRF.KL = DELAY 3 (PSR.JK, DMR) 19 R

Material in transit to retail
MTR.K = MTR.J + DT (SSF.JK - SRR.JK) 20 L
SRR.KL = DELAY 3 (SSF.JK, DTR) 21 R

Actual level in pipeline
LAR.K = CPR.K + PMR.K + UOF.K + MTR.K. 14 A

Unfilled normal requisitions at retail
UNR.K = (RSR.K) (DHR + DUR) 15 A

Clerical order delay from retail

CPR.K = CPR.J + (DT) (PDR.JK - PSR.JK) 16 L
PSR.KL = DELAY 3 (PDR.JK, DCR) 17 R

Mail order retail
PMR.K = PMR.J + (DT) (PSR.JK - RRF.JK) 18 L
RRF.KL = DELAY 3 (PSR.JK, DMR) 19 R

Material in transit to retail
MTR.K = MTR.J + DT (SSF.JK - SRR.JK) 20 L
SRR.KL = DELAY 3 (SSF.JK, DTR) 21 R

FACTORY WAREHOUSE EQUATIONS

Unfilled orders at factory
UOF.K = UOF.J + DT (RRF.JK - SSF.JK) 22 L

Requisitions smoothed at factory
RSF.K = RSF.J + (DT/DRF) (RRF.JK - RSF.J) 23 L

Unfilled orders normal at factory
UNF.K = RSF.K (DHF + DUF) 24 A

Actual inventory at factory
IAF.K = IAF.J + DT (SRF.JK - SSF.JK) 25 L

Ideal inventory at factory
IDF.K = AIF (RSF.K) 26 A

Delay in filling orders at factory
DFF.K = DHF + DUF (IDF.K/IAF.K) 27 A

Shipping rate to be tried at factory
STF.KL = UOF.K/DFF.K 28 A

Negative inventory limit at factory
NIF.KL = IAF.K/DT 29 A

Shipping rate sent from factory
SSF.KL = STF.KL if NIF.KL ≥ STF.KL 30 R
NIF.KL if NIF.KL < STF.KL

Pipeline orders desired at factory
LDF.K = RSF.K (DCF + DPF + DSF.K) 31 A

Pipeline orders actual at the factory

LAF.K = CPF.K + OPF.K + OIF.K 32 A

Manufacturing rate wanted at the factory
MWF.KL = RRF.JK + 1/DIF⟨(IDF.K - IAF.K) + (LDF.K - LAF.K)
+ (UOF.K - UNF.K)⟩ 33 A

FACTORY SOURCE EQUATIONS

Ideal manufacturing rate at the factory
IMWF.KL = IMWF.JK + DT/DIMF (MWF.KL - IMWF.JK) 34 A

Manufacturing rate decision at factory
MDF.KL = MWF.KL 35 R

Manufacturing ordered rate at factory
MOF.KL = DELAY 3 (MDF.KL, DCF) 36 R

Clerical orders in process at factory
CPF.K = CPF.J + DT (MDF.JK - MOF.JK) 37 L

Orders awaiting issue at the factory
OIF.K = OIF.J + DT (MOF.JK - MIF.JK) 38 L

Normal level of orders awaiting issue at the factory
NOIF.K = (DOIF + DOMF) IMWF.K. 39 A

Delay in issuing orders to the factory
DOF.K = DOMF + DOIF (OIF.K/NOIF.K) 40 A

Material issues to be tried at factory
MTF.KL = OIF.K/DOF.K. 41 A

Material issue rate to the factory
MIF.KL = MTF.KL if MTF.KL $\leq$ OVT (IMWF.KL) 42 R
OVT (IMWF.KL) if MTF.KL $>$ OVT (IMWF.KL)

Shipments received from the factory
SRF.KL = DELAY 3 (MIF.JK. DPF) 43 R

Orders in progress at the factory
OPF.K = OPF.J + DT (MIF.JK - SRF.JK) 44 L

Smoothed delay in issue of material
DSF.K = DSF.J + DT/DSPF (DOF.J - DSF.J) 45 A

Appendix 4 Listing of Basic Industrial Dynamics Model Program

```
LIST(LP)
PROGRAM (FXXX)
INPUT   1= CR0
INPUT   3= TR0
INPUT   5= CR1
OUTPUT  2= LP0
OUTPUT  6= LP1
CREATE  4= ED1
COMPRESS INTEGER AND LOGICAL
EXTENDED DATA
TRACE 0
END
SUBROUTINE DP(VAR,S,SS)
S=S+VAR
SS=SS+(VAR*VAR)
RETURN
END
SUBROUTINE RANDOM(RAND)
RAND=(RAND+3.141592664)**5.0
RAND=RAND-IFIX(RAND)
RETURN
END
SUBROUTINE LEVEL(DT,LEV,RAIN,RAOT)
REAL LEV
LEV=LEV+DT*(RAIN-RAOT)
RETURN
END
SUBROUTINE AVG(DT,AG,VNEW,DLY)
AG=AG+(DT/DLY)*(VNEW-AG)
RETURN
END
SUBROUTINE SERV(ERD,RSRD,RRR,SMERD,DT,DED,AIRD,SAFD,STOBD)
ERD=RSRD-RRR
ER=ERD-SMERD
2 SMERD=SQRT((SMERD**2)+((DT/DED)*ER)*(ERD+SMERD))
AIRD=SAFD*SMERD/RSRD+STOBD/2
RETURN
END
SUBROUTINE DELAY3(R1,R2,AIN,OUT,DT,DEL)
R11=R1
R21=R2
R1=R1+3.0*(DT/DEL)*(AIN-R1)
R2=R2+3.0*(DT/DEL)*(R11-R2)
OUT=OUT+3.0*(DT/DEL)*(R21-OUT)
RETURN
END
C MAIN PROGRAM
```

```
      MASTER SPARMODA
CDECLARE REAL & INTEGER
      INTEGER TIM
      INTEGER T(15)
      REAL MWF,LDF,LAF,MDF,IMWF,MOF,LDR,LAR,MTR,IAF,NIF,IDF,IAR
      REAL IDR,IDRD,NIR,M1,M2,NIRK(50),LINE(100),MIF,NOIF,MTF,IDFD
       REAL LEAD,INIT(50)
C DIMENSION MODEL VARIABLES
       DIMENSION AB(50),P(60)
      EQUIVALENCE(AB(1),UOF),(AB(2),IAF),(AB(3),SRF),(AB(4),MWF),
     &(AB(5),SSF),(AB(6),DOF),(AB(7),OPF),(AB(8),RRF),(AB(9),RSF),
     &(AB(10),CPF),(AB(11),NIF),(AB(12),MIF),(AB(13),OIF),(AB(14),IDF),
     &(AB(15),LDF),(AB(16),LAF),(AB(17),UNF),(AB(18),DFF),(AB(19),STF),
     &(AB(20),IMWF),(AB(21),MOF),(AB(22),MDF),(AB(23),DSF),
     &(AB(25),MTF),(AB(26),LEAD),(AB(27),IAR),(AB(28),UOR),(AB(29),SSR),
     &(AB(30),RSR),(AB(31),RSRD),(AB(32),CPR),(AB(33),PMR),
     &(AB(35),RRR),(AB(36),NIR),(AB(37),IDR),(AB(38),IDRD),
     &(AB(24),NOIF),(AB(39),RRRC),
     &(AB(34),MTR)
      EQUIVALENCE(AB(40),LAR),(AB(41),UNR),(AB(42),DFR),(AB(43),STR),
     &(AB(44),LDR),(AB(45),PSR),(AB(46),SRR),(AB(47),PDR),
     &(AB(48),AIRD),(AB(49),AIFD)
C SET-UP PLOTTING FACILITIES
      DIMENSION IP(12),NOP(12),V(50),S(12)
C SET-UP MEAN & SD. FACILITIES
      DIMENSION AMEAN(18),SD(18)
C SET-UP  AGE FACILITIES
      DIMENSION PERC(50)
      DATA V(1)/'  UOF'/,V(2)/'  IAF'/,V(3)/'  SRF'/,V(4)/'  MWF'/,
     &V(5)/'  SSF'/,V(6)/'  DOF'/,V(7)/'  OPF'/,V(8)/'  RRF'/,
     &V(9)/'  RSF'/,V(10)/'  CPF'/,V(11)/'  NIF'/,V(12)/'  MIF'/,
     &V(13)/'  OIF'/,V(14)/'  IDF'/,V(15)/'  LDF'/,V(16)/'  LAF'/,
     &V(17)/'  UNF'/,V(18)/'  DFF'/,V(19)/'  STF'/,V(20)/'  IMWF'/,
     &V(21)/'  MOF'/,V(22)/'  MDF'/,V(23)/'  DSF'/,V(24)/'  NOIF'/,
     &V(25)/'  MTF'/,V(26)/' LEAD'/,V(27)/'  IAR'/,V(28)/'  UOR'/,
     &V(29)/'  SSR'/,V(30)/'  RSR'/,V(31)/' RSRD'/,V(32)/'  CPR'/,
     &V(33)/'  PMR'/,V(34)/'  MTR'/,V(35)/'  RRR'/,V(36)/'  NIR'/,
     &V(37)/'  IDR'/,V(38)/' IDRD'/,V(39)/' RRRC'/,V(40)/'  LAR'/,
     &V(41)/'  UNR'/,V(42)/'  DFR'/,V(43)/'  STR'/,V(44)/'  LDR'/,
     &V(45)/'  PSR'/,V(46)/'  SRR'/,V(47)/'  PDR'/,V(48)/' AIRD'/,
     &V(49)/' AIFD'/
          DATA T(1)/1/,T(2)/2/,T(3)/3/,T(4)/4/,T(5)/5/,T(6)/6/,
     &T(7)/7/,T(8)/8/,T(9)/27/,T(10)/28/,T(11)/29/,T(12)/30/,T(13)/31/,
     &T(14)/35/,T(15)/9/
C READ IN VARIABLE DATA
      DO 80 I=1,45
      READ(1,107)P(I)
   80 CONTINUE
      READ(1,107)P(55)
      WRITE(6,431)(P(I),I=1,45),P(55)
C READ IN PLOTTING SYMBOLS & PLOTTING DATA
      READ(1,400)DOT,STAR,A,B,C,D,E,F,G,H,R,Q,X,Z,BLANK
      P(49)=0.0
```

```
C READ NO OF GRAPHS REQUIRED
      READ(5,410)MAX
C READ WHICH VARIABLES REQUIRE PLOTTING
      IF(MAX.EQ.0)GOTO 407
      DO 405 K=1,MAX
  405 READ(5,415)NOP(K)
  407 S(1)=A
      S(2)=B
      S(3)=C
      S(4)=D
      S(5)=E
      S(6)=F
      S(7)=G
      S(8)=H
      S(9)=R
      S(10)=Q
      S(11)=X
      S(12)=Z
C READ IN INPUT DATA
   81 READ(3,802)IN,VAL
      WRITE(6,432)IN,VAL
      IF(IN.EQ.60)GOTO 83
      IF(IN.EQ.50)GOTO 82
      P(IN)=VAL
      GOTO 81
   82 CONTINUE
      RRI=P(1)
      DT=P(2)
      OI=P(3)
      RI=P(4)
      AIR=P(5)
      AIRD=P(6)
      RRCO=P(7)
       DRR=P(8)
      DRRD=P(9)
      DHR=P(10)
      DUR=P(11)
      DIRI=P(12)
      DIRP=P(13)
      DCR=P(14)
      DTR=P(15)
      DMR=P(16)
      DRF=P(17)
      AIF=P(18)
      DUF=P(19)
      DHF=P(20)
      DIF=P(21)
      ALF=P(22)
      DCF=P(23)
      DIMF=P(24)
      DPF=P(25)
      DOMF=P(26)
      DOIF=P(27)
```

```
      DSPF=P(28)
      DEV=P(29)
      STPT=P(30)
      STPH=P(31)
      RMPST=P(32)
      RMPFT=P(33)
      RMPH=P(34)
      SNEST=P(35)
      PER=P(36)
      SNEH=P(37)
      OVT=P(38)
      STOBD=P(39)
      STOBF=P(40)
      DED=P(41)
      DEF=P(42)
      SAFD=P(43)
      SAFF=P(44)
      DRFD=P(45)
      PROB=P(55)
       WRITE(2,710)
      WRITE(2,9999)
      WRITE(2,711)STOBD,STOBF,DED,DEF,SAFD,SAFF,DRFD
      WRITE(2,715)RRI,DT,OI,RI
      WRITE(2,760)
      WRITE(2,770)DEV,STPT,STPH,RMPST,RMPFT,RMPH,SNEST,PER,SNEH
      WRITE(2,720)
      WRITE(2,730)AIR,AIRD,RRCO,DRR,DRRD,DHR,DUR,DIRI,DIRP,DCR,DTR,DMR
      WRITE(2,740)
      WRITE(2,750)DRF,AIF,DUF,DHF,DIF,ALF,DCF,DIMF,DPF,DOMF,DOIF,DSPF
      WRITE(2,780)PROB
C INITIAL CONDITIONS
C STEADY STATE DEFINED TERMS (L2 A1 R1)
      NUM=0
      DO 200 K=1,18
      AMEAN(K)=0.0
  200 SD(K)=0
      RRR=RRI
      RSR=RRR
      RSRD=RRR
      RRF=RRR
      CPR=RRR*DCR
      PMR=RRR*DMR
      MTR=RRR*DTR
      PDR=RRR*RRCO
      SSF=RRR
      IAR=RSR*AIR
      RSF=RRF
      RSFD=RRF
      CPF=RRF*DCF
      OPF=RRF*DPF
      IMWF=RRF
      PSR=PDR
      IAF=RSF*AIF
```

```
      IDF=IAF
      IDRD=RSRD*AIRD
      UOR=RSR*(DHR+DUR*IDRD/IAR)
      UOF=RSF*(DHF+DUF*IDF/IAF)
      SRR=SSF
      MDF=RRF
      MOF=MDF
      MIF=MOF
      SRF=MIF
      P1=PSR
      P2=PSR
      R1=RRF
      R2=RRF
      S1=SRR
      S2=SRR
      M1=MOF
      M2=MOF
      SF1=SRF
      SF2=SRF
      DOF=DOMF+DOIF
      DSF=DOF
      OIF=RRF*DOF
C INITIAL AUX EQUNS
      NIR=IAR/DT
      IDR=RSR*AIR
      IDRD=RSRD*AIRD
      RRRC=RRR*RRCO
      LAR=CPR+PMR+UOF+MTR
      UNR=RSR*(DHR+DUR)
      NIF=IAF/DT
      IDF=RSF*AIF
      CALL AVG(DT,DSF,DOF,DSPF)
      LDF=RSF*(DCF+DPF+DSF)
      LAF=CPF+OPF+OIF
      UNF=RSF*(DHF+DUF)
      DFR=DHR+DUR*(IDRD/IAR)
      DFF=DHF+DUF*(IDF/IAF)
      MWF=RRF+( (IDF-IAF)+(LDF-LAF)+(UOF-UNF))/DIF
      STR=UOR/DFR
      LDR=RSR*(DCR+DMR+DFF+DTR)
      STF=UOF/DFF
      CALL AVG(DT,IMWF,MWF,DIMF)
      NOIF=(DOIF+DOMF)*IMWF
      DOF=DOMF+(OIF/NOIF)*DOIF
      MTF=OIF/DOF
      LEAD=DCF+DPF+DOF
C INITIAL RATE EQUNS
      CALL DELAY3(R1,R2,PSR,RRF,DT,DMR)
      CALL DELAY3(P1,P2,PDR,PSR,DT,DCR)
      CALL DELAY3(S1,S2,SSF,SRR,DT,DTR)
      CALL DELAY3(M1,M2,MDF,MOF,DT,DCF)
      CALL DELAY3(SF1,SF2,MIF,SRF,DT,DPF)
        OVL=OVT*IMWF
```

```
      IF(MTF.LE.OVL)GOTO 16
      MIF=OVL
      GOTO 17
   16 MIF=MTF
   17 MDF=MWF
      IF(NIF.GE.STF)GOTO 12
      SSF=NIF
      GOTO 13
   12 SSF=STF
   13 IF(NIR.GE.STR)GOTO 14
      SSR=NIR
       GOTO 15
   14 SSR=STR
   15 PDR=RRRC+((IDR-IAR)+(UOR-UNR))/DIRI+(LDR-LAR)/DIRP
      WRITE(4)(AB(K),K=1,13)
      WRITE(4)(AB(K),K=14,26)
      WRITE(4)(AB(K),K=27,37)
      WRITE(4)(AB(K),K=38,49)
      M=NINT(OI/DT)
      OI=DT*FLOAT(M)
      N=NINT(RI/OI)
      RI=OI*FLOAT(N)
C INPUT GENERATOR
      ISPT=NINT(STPT/DT)
      IRPST=NINT(RMPST/DT)
      IRPFT=NINT(RMPFT/DT)
      ISNST=NINT(SNEST/DT)
      IPER=NINT(PER/DT)
C START OF MAIN CALCULATIONS
      L=1
      TIM=1
      DO 21 I=1,N
      DO 20 J=1,M
C NOISE GENERATOR
      CALL RANDOM(PROB)
      IPROB=IFIX(PROB*10.0)
      IF(IPROB.EQ.0)RND=-1.6449
      IF(IPROB.EQ.1)RND=-1. 364
      IF(IPROB.EQ.2)RND=-0.6745
      IF(IPROB.EQ.3)RND=-0.3853
      IF(IPROB.EQ.4)RND=-0.1257
      IF(IPROB.EQ.5)RND=0.1257
      IF(IPROB.EQ.6)RND=0.3853
      IF(IPROB.EQ.7)RND=0.6745
      IF(IPROB.EQ.8)RND=1.0364
      IF(IPROB.EQ.9)RND=1.6449
      RND=RND*DEV
      IF(RND.LT.-1.0)RND=-1.0
C STEP CALCULATION
      IF(TIM.GE.ISPT)GOTO 30
      STP=0.0
      GOTO 31
   30 STP=STPH
```

```
C SLOPE CALCULATION
   31 IF(TIM.GE.IRPST.AND.TIM.LT.IRPFT)GOTO 32
      IF(TIM.GE.IRPFT)GOTO 33
      RMP=0.0
      GOTO 34
   32 RMP=(FLOAT(TIM-IRPST)/FLOAT(IRPFT-IRPST))*RMPH
      GOTO 34
   33 RMP=RMPH
C SINE CALCULATION
   34 IF(TIM.GE.ISNST)GOTO 35
      SNE=0.0
      GOTO 36
   35 SNE=SNEH*SIN(2.0*3.1415927*(FLOAT(TIM-ISNST)/FLOAT(IPER)))
   36 CONTINUE
      RII=(1.0+RND)*(RRI+STP+RMP+SNE)
      TIM=TIM+1
      RRR=RII
C     START OF LEVEL CALCS
      CALL LEVEL(DT,UOR,RRR,SSR)
      CALL LEVEL(DT,IAR,SRR,SSR)
      CALL AVG(DT,RSR,RRR,DRR)
      CALL AVG(DT,RSRD,RRR,DRRD)
      CALL LEVEL(DT,CPR,PDR,PSR)
      CALL LEVEL(DT,PMR,PSR,RRF)
      CALL LEVEL(DT,MTR,SSF,SRR)
      CALL LEVEL(DT,UOF,RRF,SSF)
      CALL LEVEL(DT,IAF,SRF,SSF)
      CALL AVG(DT,RSF,RRF,DRF)
      CALL AVG(DT,RSFD,RRF,DRFD)
      CALL LEVEL(DT,CPF,MDF,MOF)
      CALL LEVEL(DT,OPF,MIF,SRF)
      CALL LEVEL(DT,OIF,MOF,MIF)
C           START OF AUX EQUATION CALC
      NIR=IAR/DT
      IDR=RSR*AIR
      IDRD=RSRD*AIRD
      RRRC=RRR*RRCO
      LAR=CPR+PMR+UOF+MTR
      UNR=RSR*(DHR+DUR)
      IDF=RSF*AIF
      NIF=IAF/DT
      CALL AVG(DT,DSF,DOF,DSPF)
      LDF=RSF*(DCF+DPF+DSF)
      LAF=CPF+OPF+OIF
      UNF=RSF*(DHF+DUF)
      DFR=DHR+DUR*(IDRD/IAR)
      DFF=DHF+DUF*(IDF/IAF)
      MWF=RRF+( (IDF-IAF)+(LDF-LAF)+(UOF-UNF))/DIF
      STR=UOR/DFR
      LDR=RSR*(DCR+DMR+DFF+DTR)
      STF=UOF/DFF
      CALL AVG(DT,IMWF,MWF,DIMF)
      NOIF=(DOIF+DOMF)*IMWF
```

```
      DOF=DOMF+(OIF/NOIF)*DOIF
      MTF=OIF/DOF
      LEAD=DCF+DPF+DOF
C     START  OF  RATE  EQUATION  CALC.
      CALL DELAY3(R1,R2,PSR,RRF,DT,DMR)
      CALL DELAY3(P1,P2,PDR,PSR,DT,DCR)
      CALL DELAY3(S1,S2,SSF,SRR,DT,DTR)
      CALL DELAY3(M1,M2,MDF,MOF,DT,DCF)
      CALL DELAY3(SF1,SF2,MIF,SRF,DT,DPF)
        OVL=OVT*IMWF
       IF(MTF.LE.OVL)GOTO 46
       MIF=OVL
      GOTO 47
   46 MIF=MTF
   47 MDF=MWF
      IF(NIF.GE.STF)GOTO 42
      SSF=NIF
      GOTO 43
   42 SSF=STF
   43 IF(NIR.GE.STR)GOTO 44
       SSR=NIR
      GOTO 45
   44 SSR=STR
   45 PDR=RRRC+((IDR-IAR)+(UOR-UNR))/DIRI+(LDR-LAR)/DIRP
      KB=1
      DO 205 K=1,15
      KA=T(KB)
      CALL DP(AB(KA),AMEAN(K),SD(K))
       KB=KB+1
  205 CONTINUE
      NUM=NUM+1
   20 CONTINUE
      L=L+1
      WRITE(4)(AB(K),K=1,13)
      WRITE(4)(AB(K),K=14,26)
      WRITE(4)(AB(K),K=27,37)
      WRITE(4)(AB(K),K=38,49)
   21 CONTINUE
      REWIND4
      DO 210 K=1,15
      AMEAN(K)=AMEAN(K)/FLOAT(NUM)
      SD(K)=(SD(K)/FLOAT(NUM)-(AMEAN(K)**2))
      IF(SD(K).GE.0.0)GOTO 210
      WRITE(2,8000)SD(K),AMEAN(K),NUM,K
      SD(K)=0.0
  210 SD(K)=SQRT(SD(K))
      WRITE(2,420)
      WRITE(2,430)(AMEAN(L),L=1,15)
      WRITE(6,433)(AMEAN(L),L=1,15)
      WRITE(2,440)(SD(L),L=1,15)
      WRITE(6,433)(SD(L),L=1,15)
      IF(P(49).NE.0.0)GOTO 890
      WRITE(2,800)
```

```
      DO 90 L=1,N+1
      READ(4)(AB(K),K=1,13)
      READ(4)
      READ(4)
      READ(4)
      LI=L-1
   90 WRITE(2,810)(AB(I),I=1,13),LI
      REWIND4
      WRITE(2,820)
      DO 91 L=1,N+1
      READ(4)
      READ(4)(AB(K),K=14,26)
      READ(4)
      READ(4)
      LI=L-1
   91 WRITE(2,830)(AB(I),I=14,26),LI
      REWIND4
      WRITE(2,850)
      DO 92 L=1,N+1
      READ(4)
      READ(4)
      READ(4)(AB(K),K=27,37)
      READ(4)
      LI=L-1
   92 WRITE(2,860)(AB(I),I=27,37),LI
      REWIND4
      WRITE(2,870)
      WRITE(2,875)
      DO 93 L=1,N+1
      READ(4)
      READ(4)
      READ(4)
      READ(4)(AB(K),K=38,49)
      LI=L-1
      WRITE(2,880)(AB(I),I=38,47),LI
   93 WRITE(2,885)(AB(I),I=48,49)
      REWIND4
  890 CONTINUE
C  PICK UP WHICH OUTPUTS ARE REQUIRED
      WRITE(2,505)
      WRITE(2,9999)
      IF(MAX.EQ.0)GOTO 280
      DO 600 M=1,MAX
  600 WRITE(2,510)V(NOP(M)),S(M)
C PRINT Y AXIS & SHOW SCALE
      WRITE(2,450)
      DO 230 M=1,100
  230 LINE(M)=DOT
      WRITE(2,460)(LINE(M),M=1,100)
      READ(4)(AB(K),K=1,13)
      READ(4)(AB(K),K=14,26)
      READ(4)(AB(K),K=27,37)
      READ(4)(AB(K),K=38,49)
```

```
      DO 95 K=1,47
   95 INIT(K)=AB(K)
      REWIND4
C START PLOTTING LOOP
      DO 240 L=1,N+1
      READ(4)(AB(K),K=1,13)
      READ(4)(AB(K),K=14,26)
      READ(4)(AB(K),K=27,37)
      READ(4)(AB(K),K=38,49)
      DO 220 K=1,47
      PERC(K)=ABS(AB(K)/INIT(K))*100.0
      IF(PERC(K).GT.200.0)PERC(K)=200.0
  220 CONTINUE
C BLANK THE LINE
      DO 250 M=1,100
  250 LINE(M)=BLANK
      O=BLANK
C PUT IN 50,100,150,200,AXES
      LINE(25)=DOT
      LINE(50)=DOT
      LINE(75)=DOT
      LINE(100)=DOT
C CALCULATE & PLOT PRINTS
      DO 270 M=1,MAX
      IP(M)=IFIX(PERC(NOP(M))/2.0)
      IF(LINE(IP(M)).NE.O.AND.LINE(IP(M)).NE.DOT)LINE(IP(M))=STAR
  270 IF(LINE(IP(M)).EQ.O.OR.LINE(IP(M)).EQ.DOT)LINE(IP(M))=S(M)
      WRITE(2,470)(LINE(M),M=1,100)
      LI=L-1
  240 WRITE(2,471)LI
      GOTO 290
  280 WRITE(2,499)
  290 WRITE(2,500)
      GOTO 81
   83 CONTINUE
  107 FORMAT(F0.0)
  400 FORMAT(15A1)
  410 FORMAT(I0)
  415 FORMAT(I0)
  420 FORMAT(1X,'             UOF    IAF    SRF    MWF    SSF    DOF    OPF
     1    RRF    IAR    UOR    SSR    RSR    RSRD    RRR    RSF  ')
  430 FORMAT(1X,'  MEAN  ',15(F6.1,1X))
  433 FORMAT(10(2X,F6.1),/,T1,5(2X,F6.1))
  440 FORMAT(1X,'    SD  ',15(F6.1,1X))
  431 FORMAT(1X,46(F6.1))
  432 FORMAT(1X,I2,2X,F6.1)
  450 FORMAT(' ',23X,'50 ',22X,'100 ',21X,'150 ',21X,'200 ')
  460 FORMAT(1X,100A1)
  470 FORMAT(1X,100A1)
  471 FORMAT('+',T102,I3)
  480 FORMAT(1X,///,T10,'LIST OF VARIABLES PLOTTED')
  499 FORMAT('    NO GRAPHS REQUIRED')
  500 FORMAT('    END OF OUTPUT')
```

```
505 FORMAT('1',10X,'LIST OF GRAPHED OUTPUT')
510 FORMAT('0',10X,A6,' IS SHOWN AS ',A1)
710 FORMAT('1',20X,'DATA',///)
711 FORMAT(' STOBD=',F6.1,'   STOBF=',F6.1,'   DED=',F6.1,'  DEF=',F6.
   &1,'   SAFD=',F6.1,'  SAFF=',F6.1,'   DRFD=',F6.1,//)
715 FORMAT('    INPUT LEVEL=',F6.1,4X,'CALCULATION INTERVAL=',F4.2,4X,
   &  'OUTPUT INTERVAL=',F5.1,4X,'RUN LENGTH=',F6.1,//)
720 FORMAT(4X,'AIR       AIRD       RRCO        DRR       DRRD          DH
   &R       DUR       DIRI      DIRP       DCR       DTR      DMR')
730 FORMAT(1X,11(2X,F6.1,2X),2X,F6.1,//)
740 FORMAT(1X,'   DRF         AIF         DUF         DHF         DIF       AL
   &F        DCF        DIMF        DPF        DOMF        DOIF        DSPF')
750 FORMAT(1X,11(2X,F6.1,2X),2X,F6.1,//)
760 FORMAT(1X,'NOISE STD DEV;STEP START;STEP  HT ;RAMP START ;RAMP STO
   &P ;RAMP  HT  ;SINE START;  PERIOD  ; AMPLITUDE;')
770 FORMAT(5X,9(F5.2,6X),//)
780 FORMAT(/,4X,'PROB = ',F4.2)
800 FORMAT('1','   UOF       IAF       SRF       MWF       SSF      DOF
   &  OPF       RRF       RSF       CPF       NIF       MIF       OIF')
802 FORMAT(I2,F0.0)
810 FORMAT(1X,13(1X,F7.1,1X),I3)
820 FORMAT('1','  IDF       LDF       LAF       UNF       DFF       STF
   & IMWF       MOF       MDF       DSF       NOIF       MTF       LEAD')
830 FORMAT(1X,13(1X,F7.1,1X),I3)
850 FORMAT('1   IAR       UOR       SSR       RSR       RSRD       CPR
   &  PMR       MTR       RRR       NIR       IDR')
860 FORMAT(1X,11(1X,F7.1,1X),6X,I3)
870 FORMAT('1','  IDRD      RRRC       LAR       UNR       DFR       STR
   &  LDR       PSR       SRR       PDR')
875       FORMAT('+',T94,'AIRD    AIFD')
880 FORMAT(2X,10(F7.1,2X),15X,I3)
885 FORMAT('+',T92,F5.1,1X,F5.1)
8000 FORMAT(5X,'NEGATIVE SQRT IN SD CALC',5X,
    &'BRACKET EXP=',F10.4,5X,'AMEAN(K)=',F10.4,5X,'NUM=',I2,5X,
    &'K=',I2,/)
9997 FORMAT(35X,'NEGATIVE ERD-SMERD(F) IN SERV CALC',//)
9999 FORMAT('  MD1B FIXED AIR & AIF,FIXED AIRD & AIFD 20.6,77.')
     STOP
     END
     FINISH
```

APPENDIX 5 MULTI-SOURCE INDUSTRIAL DYNAMICS MODEL EQUATIONS AND PROGRAM LISTING.

DISTRIBUTOR EQUATIONS

Retail unfilled order level
UOR.K = UOR.J + (DT) (RRR.JK - SSR.JK) 101 L

Retail inventory level
IAR.K = IAR.J + (DT) (SRR.JK - SSR.JK) 102 L

Shipping to be tried
$$STR.K = \frac{UOR.K}{DFR.K.}$$ 103 A

Limit to shipping
$$NIR.K = \frac{IAR.K}{DT}$$ 104 A

Shipping = n/
$$SSR.KL = \begin{cases} STR.K \text{ if } NIR.K \geq STR.K \\ NIR.K \text{ if } NIR.K < STR.K \end{cases}$$ 105 R

Shipping delay
$$DFR.K = DHR + DUR \left(\frac{IDRD.K}{IAR:K}\right)$$ 106 A

Desired inventory
IDR.K = (AIR) (RSR.K) 107 A

Avg Sales at retail
$$RSR.K = RSR.J + \frac{DT}{DRR} (RRR.JK - RSR.J)$$ 108 L

Ideal delay inventory
IDRD.K = AIRD (RSRD.K) 109 A

Avg Sales at retail for delay calc
$$RSRD.K = RSRD.J + \frac{DT}{DRRD} (RRR.JK - RSRD.J)$$ 110 L

Purchase decision rate
$$PDR.KL = RRRC.JK + \frac{1}{DIRI} \left\langle (IDR.K = IAR.K) + (UOR.K - UNR.k) \right\rangle$$
$$+ \frac{1}{DIRP} (LDR.K - LAR.K)$$ 111 R

RRRC.JK = RCO (RRR.JK) 112 A

Desired level in pipeline
LDR.K = (RSR.K) (DCR + DMR + DFF.K + DTR) 113 A

Actual level in pipeline
LAR.K = CPR.K + PMR.K + UOF.K + MTR.K. 114 A

Unfilled normal requisitions at retail
UNR.K = (PSR.K) (DHR + DUR) 115 A

Clerical order delay from retail

CPR.K = CPR.J + (DT) (PDR.JK - PSR.JK) 116 L
PSR.KL = DELAY 3 (PDR.JK, DCR) 117 R

Mail order retail
PMR.K = PMR.J + (DT) (PSR.JK - RRF.JK) 118 L
RRF.KL = DELAY 3 (PSR.JK, DMR) 119 R

Material in transit to retail
MTR.K = MTR.J + DT (SSF.JK - SRR.JK) 120 L
SRR.KL = DELAY 3 (SSF.JK, DTR) 121 R

FACTORY WAREHOUSE EQUATIONS

Unfilled orders at factory
UOF.K = UOF.J + DT (RRF.JK - SSF.JK) 122 L

Requisitions smoothed at factory
RSF.K = RSF.J + (DT/DRF) (RRF.JK - RSF.J) 123 L

Unfilled orders normal at factory
UNF.K = RSF.K (DHF + DUF) 124 A

Actual inventory at factory
IAF.K = IAF.J + DT (SRF.JK - SSF.JK) 125 L

Ideal inventory at factory
IDF.K = AIF (RSF.K) 126 A

Delay in filling orders at factory
DFF.K = DHF + DUF (IDF.K/IAF.K) 127 A

Shipping rate to be tried at factory
STF.KL = UOF.K/DFF.K 128 A

Negative inventory limit at factory
NIF.KL = IAF.K/DT 129 A

Shipping rate sent from factory
SSF.KL = STF.KL if NIF.KL ≥ STF.KL 130 R
= NIF.KL if NIF.KL < STF.KL

Pipeline orders desired at factory
LDF.K = LDS1.K + LDS2K + LDS3.K. 131 A

Pipeline orders actual at the factory

LAF.K = LAS1-K + LAS2.K + LAS3.K + LAS4.K. 132 A

Manufacturing rate wanted at the factory
MWF.KL = RRF.JK + 1/DIF⟨(IDF.K - IAF.K) + (LDF.K - LAF.K)
+ (UOF.K - UNF.K)⟩ 133 A

Shipments received from the factory.
SRF.KL = SRS1.KL + SRS2.KL + SRS3.KL + SRS3.KL 149 R

MULTIPLE SOURCE MODEL - SOURCE ALLOCATION EQUATIONS .

Suffix 1 - Bought out
       2 - Spares manufactured
       3 - Production sourced
       4 - Production sub-contracted
       5 - Total sourced via production

Manufacturing rate wanted at source units

```
MWS(1).KL = PS(1) MWF.KL                     150A
MWS(2).KL = PS(2) MWF.KL                     151A
MWS(5).KL = PS(3) MWF.KL                     152A
```

OE production facility capacity

```
CAPF.K = CAPF.J + DT/DAPF ( (OEDM + MWS(5) ) - CAPF.J)   153A
```

Spares capacity available on production facility

```
SCAP.K = OFAC.(CAPF.K) - OEDM                154A
```

Spares manufacturing rate wanted on production facility

```
MWS(3) = MWS(5) if MWS(5) ≤ SCAP             155A
         SCAP   if MWS(5) > SCAP
```

Manufacturing rate to sub-contract

```
MWS(4) = MWS(5) - MWS(3)                     156A
```

SOURCE UNIT EQUATIONS

Identical for all units, each variable or parameter having the suffix 1,2,3 or 4 added

1 - Bought out
2 - Spares manufacture
3 - OE production
4 - S/Contract

Ideal manufacturing rate at the factory
IMWF.KL = IMWF.JK + DT/DIMF (MWS.KL - IMWF.JK) 134 A

Manufacturing rate decision at source
MDF.KL = MWS.KL 135 R

Manufacturing ordered rate at source
MOF.KL = DELAY 3 (MDF.KL, DCF) 136 R

Clerical orders in process at source
CPF.K = CPF.J + DT (MDF.JK - MOF.JK) 137 L

Orders awaiting issue at the source
OIF.K = OIF.J + DT (MOF.JK - MIF.JK) 138 L

Normal level of orders awaiting issue at the source
NOIF.K = (DOIF + DOMF) IMWF.K. 139 A

Delay in issuing orders to the source
DOF.K = DOMF + DOIF (OIF.K/NOIF.K) 140 A

Material issues to be tried at source
MTF.KL = OIF.K/DOF.K. 141 A

Material issue rate to the source
MIF.KL = MTF.KL if MTF.KL $\leq$ OVT (IMWF.KL) 142 R
= OVT (IMWF.KL) if MTF.KL $>$ OVT (IMWF.KL)

Shipments received from the source - unit
SRF.KL = DELAY 3 (MIF.JK. DPF) 143 R

Orders in progress at the source
OPF.K = OPF.J + DT (MIF.JK - SRF.JK) 144 L

Smoothed delay in issue of material
DSF.K = DSF.J + DT/DSPF (DOF.J - DSF.J) 145 A

Lead time of source unit
LEAD.K = DCF + DPF + DOF.K. 146 A

Actual orders in progress at source unit
LAS.K = OPF.K + OIF.K + CPF.K 147 A

Desired orders in progress at source unit
LDS.K = (RSF.K). (PS). (DCF + DPF + DSF.K) 148 A

MULTIPLE SOURCE MODEL - NEW VARIABLES AND PARAMETERS

LEAD	Lead time through source
LDS	Desired orders in process at source
LAS	Actual orders in process at source
SRS	Shipments received from source
MWS	Manufacturing rate wanted at source
PS	Proportional split between sources
DAPF	Delay in adjusting total production rate at factory
OFAC	Overtime factor at factory
OEDM	OE demand
SCAP	Spares capacity available on production facility
CAPF	Capacity (total) available on production facility

Listing of the Multi-source Industrial Dynamics Model Program

```
      LIST(LP)
      PROGRAM (FXXX)
      INPUT  1= CR0
      INPUT  3= TR0
      INPUT  5= CR1
      OUTPUT 2= LP0
      OUTPUT 6= LP1
      CREATE 4= ED1
      COMPRESS INTEGER AND LOGICAL
      EXTENDED DATA
      TRACE 0
      END
      SUBROUTINE DP(VAR,S,SS)
      S=S+VAR
      SS=SS+(VAR*VAR)
      RETURN
      END
      SUBROUTINE RANDOM(RAND)
      RAND=(RAND+3.141592664)**5.0
      RAND=RAND-IFIX(RAND)
      RETURN
      END
      SUBROUTINE LEVEL(DT,LEV,RAIN,RAOT)
      REAL LEV
      LEV=LEV+DT*(RAIN-RAOT)
      RETURN
      END
      SUBROUTINE AVG(DT,AG,VNEW,DLY)
      AG=AG+(DT/DLY)*(VNEW-AG)
      RETURN
      END
      SUBROUTINE SERV(ERD,RSRD,RRR,SMERD,DT,DED,AIRD,SAFD,STOBD)
      ERD=RSRD-RRR
      SMERD=SQRT((SMERD**2)+((DT/DED)*(ERD-SMERD))*(ERD+SMERD))
      AIRD=SAFD*SMERD/RSRD+STOBD/2
      RETURN
      END
      SUBROUTINE DELAY3(R1,R2,AIN,OUT,DT,DEL)
      R11=R1
      R21=R2
      R1=R1+3.0*(DT/DEL)*(AIN-R1)
      R2=R2+3.0*(DT/DEL)*(R11-R2)
      OUT=OUT+3.0*(DT/DEL)*(R21-OUT)
      RETURN
      END
C MAIN PROGRAM
      MASTER SPARMODA
```

```
CDECLARE REAL & INTEGER
      INTEGER TIM
      INTEGER TM(15),T
      REAL MWF,LDF,LAF,MDF(4),IMWF(4),MOF(4),LDR,LAR,MTR,IAF,NIF
      REAL IDF,NIRK(50),IAR,IDR,IDRD,NIR,M1(4),M2(4),LINE(100),MIF(4)
      REAL NOIF(4),MTF(4),LAS(4),LDS(4),LEAD(4),INIT(117)
      REAL IDFD,MWS(4),MWT
C DIMENSION MODEL VARIABLES
      DIMENSION P(90),AB(117),CPF(4),OIF(4),OPF(4),DSF(4),DOF(4),
     &SF1(4),SF2(4)
      DIMENSION DCF(4),DOMF(4),DOIF(4),DSPF(4),OVT(4),DIMF(4),DPF(4)
      DIMENSION SRS(4),PS(4)
      EQUIVALENCE(AB(1),UOF),(AB(2),IAF),(AB(3),SRF),(AB(4),MWF),
     &(AB(5),SSF),(AB(8),RRF),(AB(9),RSF),
     &(AB(11),NIF),(AB(14),IDF),
     &(AB(15),LDF),(AB(16),LAF),(AB(17),UNF),(AB(18),DFF),(AB(19),STF),
     &(AB(27),IAR),(AB(28),UOR),(AB(29),SSR),
     &(AB(30),RSR),(AB(31),RSRD),(AB(32),CPR),(AB(33),PMR),
     &(AB(35),RRR),(AB(36),NIR),(AB(37),IDR),(AB(38),IDRD),
     &(AB(39),RRRC),
     &(AB(10),OEDM),(AB(12),CAPF),(AB(13),SCAP),
     &(AB(34),MTR)
      EQUIVALENCE(AB(40),LAR),(AB(41),UNR),(AB(42),DFR),(AB(43),STR),
     &(AB(44),LDR),(AB(45),PSR),(AB(46),SRR),(AB(47),PDR),
     &(AB(48),AIRD),(AB(49),AIFD)
      EQUIVALENCE (AB(51),MWS),(AB(55),SRS),(AB(59),MIF),
     &(AB(63),OIF),(AB(67),OPF),(AB(71),CPF),(AB(75),LAS),
     &(AB(79),LDS),(AB(83),NOIF),(AB(87),MOF),(AB(91),MTF),
     &(AB(95),MDF),(AB(99),DOF),(AB(103),DSF),(AB(107),LEAD),
     &(AB(111),IMWF),(AB(115),SHORT),(AB(116),SHOWKS),(AB(117),STKWKS)
C SET-UP PLOTTING FACILITIES
      DIMENSION IP(12),NOP(12),V(120),S(12)
C SET-UP MEAN & SD. FACILITIES
      DIMENSION AMEAN(18),SD(18)
C SET-UP  AGE FACILITIES
      DIMENSION PERC(117)
      DATA PROB/0.5/
      DATA V(1)/'  UOF'/,V(2)/'  IAF'/,V(3)/'  SRF'/,V(4)/'  MWF'/,
     &V(5)/'  SSF'/,V(6)/'  DOF'/,V(7)/'  OPF'/,V(8)/'  RRF'/,
     &V(9)/'  RSF'/,V(10)/' OEDM'/,V(11)/'  NIF'/,V(12)/' CAPF'/,
     &V(13)/' SCAP'/,V(14)/'  IDF'/,V(15)/'  LDF'/,V(16)/'  LAF'/,
     &V(17)/'  UNF'/,V(18)/'  DFF'/,V(19)/'  STF'/,V(20)/'  IMWF'/,
     &V(21)/'  MOF'/,V(22)/'  MDF'/,V(23)/'  DSF'/,V(24)/'  NOIF'/,
     &V(25)/'  MTF'/,V(26)/' LEAD'/,V(27)/'  IAR'/,V(28)/'  UOR'/,
     &V(29)/'  SSR'/,V(30)/'  RSR'/,V(31)/' RSRD'/,V(32)/'  CPR'/,
     &V(33)/'  PMR'/,V(34)/'  MTR'/,V(35)/'  RRR'/,V(36)/'  NIR'/,
     &V(37)/'  IDR'/,V(38)/' IDRD'/,V(39)/' RRRC'/,V(40)/'  LAR'/,
     &V(41)/'  UNR'/,V(42)/'  DFR'/,V(43)/'  STR'/,V(44)/'  LDR'/,
     &V(45)/'  PSR'/,V(46)/'  SRR'/,V(47)/'  PDR'/,V(48)/' AIRD'/,
     &V(49)/' AIFD'/
      DATA V(51)/' MWS1'/,V(52)/' MWS2'/,V(53)/' MWS3'/,V(54)/' MWS4'/,
     &V(55)/'SRS1'/,V(56)/'SRS2'/,V(57)/'SRS3'/,V(58)/'SRS4'/,
     &V(59)/'MIF1'/,V(60)/'MIF2'/,V(61)/'MIF3'/,V(62)/'MIF4'/,
```

```
     &V(63)/'OIF1'/,V(64)/'OIF2'/,V(65)/'OIF3'/,V(66)/'OIF4'/,
     &V(67)/'OPF1'/,V(68)/'OPF2'/,V(69)/'OPF3'/,V(70)/'OPF4'/,
     &V(71)/'CPF1'/,V(72)/'CPF2'/,V(73)/'CPF3'/,V(74)/'CPF4'/,
     &V(75)/' LAS1'/,V(76)/' LAS2'/,V(77)/' LAS3'/,V(78)/' LAS4'/,
     &V(79)/' LDS1'/,V(80)/'LDS2'/,V(81)/'LDS3'/,V(82)/'LDS4'/ ,
     &V(83)/'NOIF1'/,V(84)/'NOIF2'/,V(85)/'NOIF3'/,V(86)/'NOIF4'/,
     &V(87)/'MOF1'/,V(88)/'MOF2'/,V(89)/'MOF3'/,V(90)/'MOF4'/,
     &V(91)/'MTF1'/,V(92)/'MTF2'/,V(93)/'MTF3'/,V(94)/'MTF4'/,
     &V(95)/'MDF1'/,V(96)/'MDF2'/,V(97)/'MDF3'/,V(98)/'MDF4'/,
     &V(99)/'DOF1'/,V(100)/'DOF2'/,V(101)/'DOF3'/,V(102)/'DOF4'/,
     &V(103)/'DSF1'/,V(104)/'DSF2'/,V(105)/'DSF3'/,V(106)/'DSF4'/,
     &V(107)/'LEAD1'/,V(108)/'LEAD2'/,V(109)/'LEAD3'/,V(110)/'LEAD4'/,
     &V(111)/'IMWF1'/,V(112)/'IMWF2'/,V(113)/'IMWF3'/,V(114)/'IMWF4'/
     &,V(115)/'SHORT'/,V(116)/'SHOWKS'/,V(117)/'STKWKS'/
C READ IN VARIABLE DATA
      READ(1,107)(P(I),I=1,88)
      WRITE(6,431)(P(I),I=1,88)
C READ IN PLOTTING SYMBOLS & PLOTTING DATA
      READ(1,400)DOT,STAR,A,B,C,D,E,F,G,H,R,Q,X,Z,BLANK
      P(49)=0.0
C READ IN VARIABLES FOR MSD CALCULATION
      READ(1,401)(TM(I),I=1,15)
      WRITE(6,434)(V(TM(I)),I=1,15)
C READ NO OF GRAPHS REQUIRED
      READ(5,410)MAX
C READ WHICH VARIABLES REQUIRE PLOTTING
      IF(MAX.EQ.0)GOTO 407
      DO 405 K=1,MAX
  405 READ(5,415)NOP(K)
  407 S(1)=A
      S(2)=B
      S(3)=C
      S(4)=D
      S(5)=E
      S(6)=F
      S(7)=G
      S(8)=H
      S(9)=R
      S(10)=Q
      S(11)=X
      S(12)=Z
C READ IN INPUT DATA
   81 READ(3,802)IN,VAL
      WRITE(6,432)IN,VAL
      IF(IN.EQ.60)GOTO 83
      IF(IN.EQ.50)GOTO 82
      P(IN)=VAL
      GOTO 81
   82 CONTINUE
      RRI=P(1)
      DT=P(2)
      OI=P(3)
      RI=P(4)
```

```
AIR=P(5) .
AIRD=P(6)
RRCO=P(7)
 DRR=P(8)
DRRD=P(9)
DHR=P(10)
DUR=P(11)
DIRI=P(12)
DIRP=P(13)
DCR=P(14)
DTR=P(15)
DMR=P(16)
DRF=P(17)
AIF=P(18)
DUF=P(19)
DHF=P(20)
DIF=P(21)
ALF=P(22)
STOBD=P(23)
STOBF=P(24)
DED=P(25)
DEF=P(26)
SAFD=P(27)
SAFF=P(28)
DEV=P(29)
STPT=P(30)
STPH=P(31)
RMPST=P(32)
RMPFT=P(33)
RMPH=P(34)
SNEST=P(35)
PER=P(36)
SNEH=P(37)
DRFD=P(38)
OECAP=P(39)
OEST=P(40)
OEPER=P(41)
OESH=P(42)
OFAC=P(43)
PS(1)=P(44)
PS(2)=P(45)
PS(3)=P(46)
DAPF=P(47)
PS(4)=P(48)
K=0
DO 80 I=1,4
DCF(I)=P(61+K)
DOMF(I)=P(62+K)
DOIF(I)=P(63+K)
DSPF(I)=P(64+K)
OVT(I)=P(65+K)
DIMF(I)=P(66+K)
DPF(I)=P(67+K)
```

```
   80 K=K+7
      WRITE(2,9999)
      WRITE(2,9998)
      WRITE(2,710)
      WRITE(2,715)DT,OI,RI
      WRITE(2,711)
      WRITE(2,712)RRI,DEV
       WRITE(2,713)STPT,STPH
      WRITE(2,714)RMPST,RMPH,RMPFT
      WRITE(2,716)SNEST,SNEH,PER
      WRITE(2,717)
      WRITE(2,718)OECAP,OEST,OESH,OEPER
      WRITE(2,719)
      WRITE(2,720)
      WRITE(2,701)AIR,AIRD,RRCO,DRR,DRRD,DHR,DUR,DIRI,DIRP,DCR,DTR,DMR
      WRITE(2,721)
      WRITE(2,722)
      WRITE(2,701)DRF,AIF,DUF,DHF,DIF,STOBD,STOBF,DED,DEF,SAFD,SAFF,OFAC
      WRITE(2,724)
      WRITE(2,725)
      WRITE(2,726)
      WRITE(2,727)PS(1),DCF(1),DOMF(1),DOIF(1),DSPF(1),OVT(1),DIMF(1)
     &,DPF(1)
      WRITE(2,728)PS(2),DCF(2),DOMF(2),DOIF(2),DSPF(2),OVT(2),DIMF(2)
     &,DPF(2)
      WRITE(2,729)PS(3),DCF(3),DOMF(3),DOIF(3),DSPF(3),OVT(3),DIMF(3)
     &,DPF(3)
      WRITE(2,730)PS(4),DCF(4),DOMF(4),DOIF(4),DSPF(4),OVT(4),DIMF(4)
     &,DPF(4)
      WRITE(2,731)
C INITIAL CONDITIONS
C STEADY STATE DEFINED TERMS (L2 A1 R1)
      NUM=0
      DO 200 K=1,18
      AMEAN(K)=0.0
  200 SD(K)=0
C INITIAL DEFINED TERMS
      RRR=RRI
      RSR=RRR
      RRF=RRR
      RSRD=RRR
      CPR=RRR*DCR
      PMR=RRR*DMR
      MTR=RRR*DTR
      PDR=RRR*RRCO
      SSF=RRR
      IAR=RSR*AIR
      RSF=RRF
      RSFD=RRF
      DO 370 T=1,3
      CPF(T)=PS(T)*RRF*DCF(T)
      OPF(T)=PS(T)*RRF*DPF(T)
  370 IMWF(T)=PS(T)*RRF
```

```
      CPF(4)=0.0
      OPF(4)=0.0
      IMWF(4)=0.0
      OEDM=OECAP
      CAPF=OEDM+RRF*PS(3)
      PSR=PDR
      IAF=RSF*AIF
      IDF=IAF
      IDRD=RSRD*AIRD
      UOR=RSR*(DHR+DUR*IDRD/IAR)
      UOF=RSF*(DHF+DUF*IDF/IAF)
      IAF=RSF*AIF
      SRR=SSF
      DO 371 T=1,3
  371 MDF(T)=PS(T)*RRF
      MDF(4)=0.0
      DO 372 T=1,4
      MOF(T)=MDF(T)
      MIF(T)=MOF(T)
  372 SRS(T)=MIF(T)
      SRF=MIF(1)+MIF(2)+MIF(3)+MIF(4)
      P1=PSR
      P2=PSR
      R1=RRF
      R2=RRF
      S1=SRR
      S2=SRR
      DO 373 T=1,4
      M1(T)=MOF(T)
      M2(T)=M1(T)
      SF1(T)=MIF(T)
      SF2(T)=SF1(T)
      DOF(T)=DOMF(T)+DOIF(T)
  373 DSF(T)=DOF(T)
      DO 374 T=1,3
  374 OIF(T)=PS(T)*RRF*DOF(T)
      OIF(4)=0.0
C INITIAL AUX. EQUATIONS
      NIR=IAR/DT
      IDR=RSR*AIR
      IDRD=RSRD*AIRD
      RRRC=RRR*RRCO
      LAR=CPR+PMR+UOF+MTR
      UNR=RSR*(DHR+DUR)
      NIF=IAF/DT
      IDF=RSF*AIF
      DO 301 T=1,4
      CALL AVG(DT,DSF(T),DOF(T),DSPF(T))
  301 LAS(T)=CPF(T)+OPF(T)+OIF(T)
      DO 350 T=1,3
  350 LDS(T)=PS(T)*RSF*(DCF(T)+DSF(T)+DPF(T))
      LDF=LDS(1)+LDS(2)+LDS(3)
      LAF=LAS(1)+LAS(2)+LAS(3)+LAS(4)
```

```
      UNF=RSF*(DHF+DUF)
      DFR=DHR+DUR*(IDRD/IAR)
      DFF=DHF+DUF*(IDF/IAF)
      MWF=RRF+( (IDF-IAF)+(LDF-LAF)+(UOF-UNF))/DIF
      STR=UOR/DFR
      LDR=RSR*(DCR+DMR+DFF+DTR)
      STF=UOF/DFF
      DO 302 T=1,2
  302 MWS(T)=PS(T)*MWF
      MWT=PS(3)*MWF
      CAPF=CAPF+(DT/DAPF)*(MWT+OEDM-CAPF)
      SCAP=OFAC*CAPF-OEDM
      IF(SCAP.LT.0.0)SCAP=0.0
      IF(MWT.LE.SCAP)GOTO 303
      MWS(3)=SCAP
      GOTO 304
  303 MWS(3)=MWT
  304 IF(PS(4).EQ.0.0)MWS(3)=MWT
      MWS(4)=MWT-MWS(3)
      DO 305 T=1,4
      CALL AVG(DT,IMWF(T),MWS(T),DIMF(T))
      NOIF(T)=IMWF(T)*(DOIF(T)+DOMF(T))
      IF(NOIF(T).LE.0.0)GOTO 316
      DOF(T)=DOMF(T)+DOIF(T)*(OIF(T)/NOIF(T))
      GOTO 317
  316 DOF(T)=DOMF(T)
  317 LEAD(T)=DCF(T)+DOF(T)+DPF(T)
  305 MTF(T)=OIF(T)/DOF(T)
      SHORT=UOF-(DHF*RSF)
      SHOWKS=SHORT/RSF
      STKWKS=IAF/RSF
C INITIAL RATE EQUATIONS
      CALL DELAY3(R1,R2,PSR,RRF,DT,DMR)
      CALL DELAY3(P1,P2,PDR,PSR,DT,DCR)
      CALL DELAY3(S1,S2,SSF,SRR,DT,DTR)
      DO 360 T=1,4
      CALL DELAY3(M1(T),M2(T),MDF(T),MOF(T),DT,DCF(T))
      CALL DELAY3(SF1(T),SF2(T),MIF(T),SRS(T),DT,DPF(T))
      OVL=OVT(T)*IMWF(T)
      IF(MTF(T).LE.OVL)GOTO 361
      MIF(T)=OVL
      GOTO 362
  361 MIF(T)=MTF(T)
  362 MDF(T)=MWS(T)
  360 CONTINUE
      SRF=SRS(1)+SRS(2)+SRS(3)+SRS(4)
      IF(NIF.GE.STF)GOTO 12
      SSF=NIF
      GOTO 13
   12 SSF=STF
   13 IF(NIR.GE.STR)GOTO 14
      SSR=NIR
       GOTO 15
```

```
   14 SSR=STR
   15 PDR=RRRC+((IDR-IAR)+(UOR-UNR))/DIRI+(LDR-LAR)/DIRP
      WRITE(4)(AB(K),K=1,117)
      M=NINT(OI/DT)
      OI=DT*FLOAT(M)
      N=NINT(RI/OI)
      RI=OI*FLOAT(N)
C INPUT GENERATOR
      ISPT=NINT(STPT/DT)
      IRPST=NINT(RMPST/DT)
      IRPFT=NINT(RMPFT/DT)
      ISNST=NINT(SNEST/DT)
      IPER=NINT(PER/DT)
      IOEST=NINT(OEST/DT)
      IOEPER=NINT(OEPER/DT)
      PROB=0.5
C START OF MAIN CALCULATIONS
      L=1
      TIM=1
      DO 21 I=1,N
      DO 20 J=1,M
C NOISE GENERATOR
      CALL RANDOM(PROB)
      IPROB=IFIX(PROB*10.0)
      IF(IPROB.EQ.0)RND=-1.6449
      IF(IPROB.EQ.1)RND=-1.0364
      IF(IPROB.EQ.2)RND=-0.6745
      IF(IPROB.EQ.3)RND=-0.3853
      IF(IPROB.EQ.4)RND=-0.1257
      IF(IPROB.EQ.5)RND=0.1257
      IF(IPROB.EQ.6)RND=0.3853
      IF(IPROB.EQ.7)RND=0.6745
      IF(IPROB.EQ.8)RND=1.0364
      IF(IPROB.EQ.9)RND=1.6449
      RND=RND*DEV
      IF(RND.LT.-1.0)RND=-1.0
C STEP CALCULATION
      IF(TIM.GE.ISPT)GOTO 30
      STP=0.0
      GOTO 31
   30 STP=STPH
C SLOPE CALCULATION
   31 IF(TIM.GE.IRPST.AND.TIM.LT.IRPFT)GOTO 32
      IF(TIM.GE.IRPFT)GOTO 33
      RMP=0.0
      GOTO 34
   32 RMP=(FLOAT(TIM-IRPST)/FLOAT(IRPFT-IRPST))*RMPH
      GOTO 34
   33 RMP=RMPH
C SINE CALCULATION
   34 IF(TIM.GE.ISNST)GOTO 35
      SNE=0.0
      GOTO 36
```

```
   35 SNE=SNEH*SIN(2.0*3.1415927*(FLOAT(TIM-ISNST)/FLOAT(IPER)))
   36 CONTINUE
      IF(TIM.GE.IOEST)GOTO 50
      OEDM=0.0
      GOTO 51
   50 OEDM=OESH*SIN(2.0*3.1415927*(FLOAT(TIM-IOEST)/FLOAT(IOEPER)))
   51 OEDM=OECAP+OEDM
      RII=(1.0+RND)*(RRI+STP+RMP+SNE)
      TIM=TIM+1
      RRR=RII
C     START OF LEVEL CALCS
      CALL LEVEL(DT,UOR,RRR,SSR)
      CALL LEVEL(DT,IAR,SRR,SSR)
      CALL AVG(DT,RSR,RRR,DRR)
      CALL AVG(DT,RSRD,RRR,DRRD)
      CALL LEVEL(DT,CPR,PDR,PSR)
      CALL LEVEL(DT,PMR,PSR,RRF)
      CALL LEVEL(DT,MTR,SSF,SRR)
      CALL LEVEL(DT,UOF,RRF,SSF)
      CALL LEVEL(DT,IAF,SRF,SSF)
      CALL AVG(DT,RSF,RRF,DRF)
      CALL AVG(DT,RSFD,RRF,DRFD)
      DO 300 T=1,4
      CALL LEVEL(DT,CPF(T),MDF(T),MOF(T))
      CALL LEVEL(DT,OPF(T),MIF(T),SRS(T))
  300 CALL LEVEL(DT,OIF(T),MOF(T),MIF(T))
C           START OF AUX EQUATION CALC
      NIR=IAR/DT
      IDR=RSR*AIR
      IDRD=RSRD*AIRD
      RRRC=RRR*RRCO
      LAR=CPR+PMR+UOF+MTR
      UNR=RSR*(DHR+DUR)
      IDF=RSF*AIF
      NIF=IAF/DT
      DO 380 T=1,4
      CALL AVG(DT,DSF(T),DOF(T),DSPF(T))
  380 LAS(T)=CPF(T)+OPF(T)+OIF(T)
      DO 381 T=1,3
  381 LDS(T)=PS(T)*RSF*(DCF(T)+DSF(T)+DPF(T))
      LDF=LDS(1)+LDS(2)+LDS(3)
      LAF=LAS(1)+LAS(2)+LAS(3)+LAS(4)
      UNF=RSF*(DHF+DUF)
      DFR=DHR+DUR*(IDRD/IAR)
      DFF=DHF+DUF*(IDF/IAF)
      MWF=RRF+( (IDF-IAF)+(LDF-LAF)+(UOF-UNF))/DIF
      STR=UOR/DFR
      LDR=RSR*(DCR+DMR+DFF+DTR)
      STF=UOF/DFF
      DO 382 T=1,2
  382 MWS(T)=PS(T)*MWF
      MWT=PS(3)*MWF
      CAPF=CAPF+(DT/DAPF)*(MWT+OEDM-CAPF)
```

```
      SCAP=OFAC*CAPF-OEDM
      IF(SCAP.LT.0.0)SCAP=0.0
      IF(MWT.LE.SCAP)GOTO 383
      MWS(3)=SCAP
      GOTO 384
  383 MWS(3)=MWT
  384 IF(PS(4).EQ.0.0)MWS(3)=MWT
      MWS(4)=MWT-MWS(3)
      DO 385 T=1,4
      CALL AVG(DT,IMWF(T),MWS(T),DIMF(T))
      NOIF(T)=IMWF(T)*(DOIF(T)+DOMF(T))
      IF(NOIF(T).LE.0.0)GOTO 386
      DOF(T)=DOMF(T)+DOIF(T)*(OIF(T)/NOIF(T))
      GOTO 387
  386 DOF(T)=DOMF(T)
  387 LEAD(T)=DCF(T)+DOF(T)+DPF(T)
  385 MTF(T)=OIF(T)/DOF(T)
      SHORT=UOF-(RSF*DHF)
      SHOWKS=SHORT/RSF
      STKWKS=IAF/RSF
C START  OF  RATE  EQUATION  CALCMLATION
      CALL DELAY3(R1,R2,PSR,RRF,DT,DMR)
      CALL DELAY3(P1,P2,PDR,PSR,DT,DCR)
      CALL DELAY3(S1,S2,SSF,SRR,DT,DTR)
      DO 306 T=1,4
      CALL DELAY3(M1(T),M2(T),MDF(T),MOF(T),DT,DCF(T))
      CALL DELAY3(SF1(T),SF2(T),MIF(T),SRS(T),DT,DPF(T))
      OVL=OVT(T)*IMWF(T)
      IF(MTF(T).LE.OVL)GOTO 307
      MIF(T)=OVL
      GOTO 308
  307 MIF(T)=MTF(T)
  308 MDF(T)=MWS(T)
  306 CONTINUE
      SRF=SRS(1)+SRS(2)+SRS(3)+SRS(4)
      IF(NIF.GE.STF)GOTO 42
      SSF=NIF
      GOTO 43
   42 SSF=STF
   43 IF(NIR.GE.STR)GOTO 44
       SSR=NIR
      GOTO 45
   44 SSR=STR
   45 PDR=RRRC+((IDR-IAR)+(UOR-UNR))/DIRI+(LDR-LAR)/DIRP
      KB=1
      DO 205 K=1,15
      KA=TM(KB)
      CALL DP(AB(KA),AMEAN(K),SD(K))
       KB=KB+1
  205 CONTINUE
      NUM=NUM+1
   20 CONTINUE
      L=L+1
```

```
      WRITE(4)(AB(K),K=1,117)
   21 CONTINUE
      REWIND4
      DO 210 K=1,15
      AMEAN(K)=AMEAN(K)/FLOAT(NUM)
      SD(K)=(SD(K)/FLOAT(NUM)-(AMEAN(K)**2))
      IF(SD(K).GE.0.0)GOTO 210
      WRITE(2,8000)SD(K),AMEAN(K),NUM,K
      SD(K)=0.0
  210 SD(K)=SQRT(SD(K))
      WRITE(2,420)(V(TM(I)),I=1,15)
      WRITE(2,430)(AMEAN(L),L=1,15)
      WRITE(6,433)(AMEAN(L),L=1,15)
      WRITE(2,440)(SD(L),L=1,15)
      WRITE(6,433)(SD(L),L=1,15)
      IF(P(49).NE.0.0)GOTO 890
C WRITE TABULAR OUTPUT
      WRITE(2,800)(V(I),I=1,5),(V(J),J=8,10),(V(K),K=12,13)
     &,(V(K),K=115,117)
      DO 90 L=1,N+1
      READ(4)(AB(K),K=1,117)
      LI=L-1
   90 WRITE(2,810)(AB(I),I=1,5),(AB(J),J=8,10),(AB(K),K=12,13),
     &(AB(K),K=115,117),LI
      REWIND4
      WRITE(2,820)V(11),V(14),(V(I),I=15,19)
      DO 91 L=1,N+1
      READ(4)(AB(K),K=1,117)
      LI=L-1
   91 WRITE(2,830)AB(11),AB(14),(AB(I),I=15,19),LI
      REWIND4
      WRITE(2,850)(V(I),I=27,37)
      DO 92 L=1,N+1
      READ(4)(AB(K),K=1,117)
      LI=L-1
   92 WRITE(2,860)(AB(I),I=27,37),LI
      REWIND4
      WRITE(2,870)(V(I),I=38,49)
      DO 93 L=1,N+1
      READ(4)(AB(K),K=1,117)
   93 WRITE(2,880)(AB(I),I=38,49)
      REWIND4
      WRITE(2,732)
      WRITE(2,900)(V(I),I=51,111,4)
      DO 94 L=1,N+1
      READ(4)(AB(K),K=1,117)
      LI=L-1
   94 WRITE(2,901)(AB(I),I=51,111,4),LI
      REWIND4
      WRITE(2,735)
      WRITE(2,900)(V(I),I=52,112,4)
      DO 95 L=1,N+1
      READ(4)(AB(K),K=1,117)
```

```
      LI=L-1
   95 WRITE(2,901)(AB(I),I=52,112,4),LI
      REWIND4
      WRITE(2,736)
      WRITE(2,900)(V(I),I=53,113,4)
      DO 96 L=1,N+1
      READ(4)(AB(K),K=1,117)
      LI=L-1
   96 WRITE(2,901)(AB(I),I=53,113,4),LI
      REWIND4
      WRITE(2,737)
      WRITE(2,900)(V(I),I=54,114,4)
      DO 97 L=1,N+1
      READ(4)(AB(K),K=1,117)
      LI=L-1
   97 WRITE(2,901)(AB(I),I=54,114,4),LI
      REWIND4
  890 CONTINUE
C  PICK UP WHICH OUTPUTS ARE REQUIRED
      WRITE(2,505)
      WRITE(2,9999)
      IF(MAX.EQ.0)GOTO 280
      DO 600 M=1,MAX
  600 WRITE(2,510)V(NOP(M)),S(M)
C PRINT Y AXIS & SHOW SCALE
      WRITE(2,450)
      DO 230 M=1,100
  230 LINE(M)=DOT
      WRITE(2,460)(LINE(M),M=1,100)
      READ(4)(AB(K),K=1,117)
      DO 98 K=1,117
      INIT(K)=AB(K)
       IF(INIT(K).LE.0.0)INIT(K)=100.0
   98 CONTINUE
      REWIND4
C START PLOTTING LOOP
      DO 240 L=1,N+1
      READ(4)(AB(K),K=1,117)
      DO 220 K=1,117
      PERC(K)=ABS(AB(K)/INIT(K))*100.0
      IF(PERC(K).GT.200.0)PERC(K)=200.0
  220 CONTINUE
C BLANK THE LINE
      DO 250 M=1,100
  250 LINE(M)=BLANK
      O=BLANK
C PUT IN 50,100,150,200,AXES
      LINE(25)=DOT
      LINE(50)=DOT
      LINE(75)=DOT
      LINE(100)=DOT
C CALCULATE & PLOT PRINTS
      DO 270 M=1,MAX
```

```
      IP(M)=IFIX(PERC(NOP(M))/2.0)
      IF(LINE(IP(M)).NE.O.AND.LINE(IP(M)).NE.DOT)LINE(IP(M))=STAR
  270 IF(LINE(IP(M)).EQ.O.OR.LINE(IP(M)).EQ.DOT)LINE(IP(M))=S(M)
      WRITE(2,470)(LINE(M),M=1,100)
      LI=L-1
  240 WRITE(2,471)LI
      GOTO 290
  280 WRITE(2,499)
  290 REWIND4
      READ(4)(AB(K),K=1,117)
      DO 99 K=1,MAX
      IF(INIT(NOP(K)).EQ.100.0.AND.AB(NOP(K)).LE.0.0)WRITE(2,498)
     &V(NOP(K))
   99 CONTINUE
      WRITE(2,500)
      GOTO 81
   83 CONTINUE
  107 FORMAT(88F0.0)
  400 FORMAT(15A1)
  401 FORMAT(15I0)
  410 FORMAT(I0)
  415 FORMAT(I0)
  420 FORMAT(9X,15(A6,1X))
  430 FORMAT(1X,'  MEAN  ',15(F6.1,1X))
  431 FORMAT(1X,88(2X,F6.1))
  432 FORMAT(1X,I2,2X,F6.1)
  433 FORMAT(10(2X,F6.1),/,T1,5(2X,F6.1))
  440 FORMAT(1X,'     SD  ',15(F6.1,1X))
  434 FORMAT(1X,15A6)
  450 FORMAT(' ',23X,'50 ',22X,'100 ',21X,'150 ',21X,'200 ')
  460 FORMAT(1X,100A1)
  470 FORMAT(1X,100A1)
  471 FORMAT('+',T102,I3)
  498 FORMAT(1X,/,'VARIABLE WITH ZERO INIT VAL-',A6)
  499 FORMAT('    NO GRAPHS REQUIRED')
  500 FORMAT('    END OF OUTPUT')
  505 FORMAT('1',10X,'LIST OF GRAPHED OUTPUT')
  510 FORMAT('0',10X,A6,' IS SHOWN AS ',A1)
  701 FORMAT(1X,11(2X,F6.1,2X),2X,F6.1,//)
  710 FORMAT(T53,'RUN INFORMATION',/)
  711 FORMAT(T53,'CUSTOMER DEMAND',/)
  712 FORMAT(T4,'INPUT LEVEL=',F6.1,10X,'NOISE STAND. DEV =',F5.2,/)
  713 FORMAT(T4,'STEP START =',F5.2,10X,'STEP HEIGHT =',F5.2,/)
  714 FORMAT(T4,'RAMP START =',F5.2,10X,'RAMP HEIGHT =',F5.2,10X,
     &'RAMP FINISH =',F5.2,/)
  715 FORMAT(T25,'CALCULATION INTERVAL=',F4.2,4X,'OUTPUT INTERVAL=',
     &F5.1,4X,'RUN LENGTH=',F6.1,//)
  716 FORMAT(T4,'SINE START =',F5.2,10X,'SINE AMPLITUDE =',F5.2,7X,
     &'SINE PERIOD =',F5.2,//)
  717 FORMAT(T48,'ORIGINAL EQUIPMENT DEMAND',/)
  718 FORMAT(T4,'OE INPUT LEVEL =',F6.1,10X,'SINE START =',F5.1,10X,
     &'SINE AMPLITUDE =',F5.1,10X,'SINE PERIOD =',F5.1,//)
  719 FORMAT(T53,'DISTRIBUTOR PARAMETER VALUES',/)
```

```
720 FORMAT(4X,'AIR        AIRD        RRCO        DRR        DRRD            DH
   &R        DUR        DIRI        DIRP        DCR        DTR        DMR')
721 FORMAT(T53,'WAREHOUSE & SERVICE PARAMETERS',/)
722 FORMAT(1X,'    DRF        AIF        DUF        DHF        DIF        ST
   &OBD      STOBF       DED        DEF        SAFD       SAFF        OFAC')
724 FORMAT(T53,'SOURCE PARAMETERS',/)
725 FORMAT(T4,'SOURCE 1 - BOUGHT OUT  SOURCE 2 - SPARES MANUF.   SOURC
   &E 3-FACTORY MAN     SOURCE 4-FACT S/CON',/)
726 FORMAT(T16,'PS',T27,'DCF',T39,'DOMF',T51,'DOIF',T63,'DSPF',
   &T75,'OVT',T86,'DIMF',T98,'DPF')
727 FORMAT(T4,'SOURCE 1',T14,F5.2,T26,F5.2,T37,F5.2,T49,F5.2,T61,F5.2,
   &T73,F5.2,T84,F5.2,T96,F5.2)
728 FORMAT(T4,'SOURCE 2',T14,F5.2,T26,F5.2,T37,F5.2,T49,F5.2,T61,F5.2,
   &T73,F5.2,T84,F5.2,T96,F5.2)
729 FORMAT(T4,'SOURCE 3',T14,F5.2,T26,F5.2,T37,F5.2,T49,F5.2,T61,F5.2,
   &T73,F5.2,T84,F5.2,T96,F5.2)
730 FORMAT(T4,'SOURCE 4',T14,F5.2,T26,F5.2,T37,F5.2,T49,F5.2,T61,F5.2,
   &T73,F5.2,T84,F5.2,T96,F5.2,////)
731 FORMAT(T35,'MEANS AND STANDARD DEVIATIONS OF KEY VARIABLES'/)
732 FORMAT('1',T50,'SOURCE 1 - BOUGHT OUT',/)
735 FORMAT('1',T50,'SOURCE 2 - SPARES MANUFACTURED',/)
736 FORMAT('1',T50,'SOURCE 3 - FACTORY MANUFACTURED',/)
737 FORMAT('1',T50,'SOURCE 4 - FACTORY SUB CONTRACTED',/)
802 FORMAT(I2,F0.0)
810 FORMAT(1X,13(1X,F7.1,1X),I3)
800 FORMAT('1',13(2X,A6,1X))
820 FORMAT('1',7(2X,A6,1X))
830 FORMAT(1X,7(1X,F7.1,1X),I3)
850 FORMAT('1',11(2X,A6,1X))
860 FORMAT(1X,11(1X,F7.1,1X),6X,I3)
870 FORMAT('1',12(2X,A6,1X))
880 FORMAT(1X,12(1X,F7.1,1X),I3)
900 FORMAT(1X,16(1X,A6))
901 FORMAT(1X,16(1X,F6.1),4X,I3)
8000 FORMAT(5X,'NEGATIVE SQRT IN SD CALC',5X,'BRACKET EXP=',
    &F10.4,5X,'AMEAN(K)=',F10.4,5X,'NUM=',I2,5X,'K=',I2,/)
9998 FORMAT(T48,'DATE LAST MODIFIED--5. AUG. 77'///)
9999 FORMAT('1',///,T36,'MS1B-MULTIPLE SOURCES,FIXED AIRD&AIFD')
     STOP
     END
```

FULL CODE DESCRIPTION

The following sheets give the detail significance of all the combinations of codes. The value of the 1st digit of the shape code dictates the broad class of components to which the part belongs.

They are defined as:

1st digit	Class	Example Component
0,1,2	Rotational	Shaft, bush
3,4	" with Deviations	Nut, cam.
5	Bought out	Spring, bearing
6	Flat	Cover
7	Long	Throttle lever
8	Cubic	Crankcase

A sheet defining the significance of the remaining shape digits for each class of component is given below in Figs. 1 - 6.

The supplementary code, which remains the same for all classes, is described in Fig. 7.

Further descriptive material, giving examples of the interpretation of the value of each digit of the code can be found in the Opitz manual "A Classification System to Describe Workpieces", H Opitz, Pergamon Press 1970.

Details of the modified code are given in Figure 8-14.

GEOMETRICAL CODE

1st Digit

		Component Class
0	Rotational Components	$\frac{L}{D} \leqslant 0{\cdot}5$
1	Rotational Components	$0{\cdot}5 < \frac{L}{D} < 3$
2	Rotational Components	$\frac{L}{D} \geqslant 3$

2nd Digit

		External Shape, external shape elements
0		Smooth, no shape elements
1	Stepped to one End	no shape elements
2	Stepped to one End or smooth	with screwthread
3	Stepped to one End or smooth	with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5	Stepped to both Ends (Multiple increases)	with screwthread
6	Stepped to both Ends (Multiple increases)	with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 funcional diameters)

3rd Digit

		Internal Shape, internal shape elements
0		Without through bore or blind hole
1	Smooth or Stepped to one End	no shape elements
2	Smooth or Stepped to one End	with screwthread
3	Smooth or Stepped to one End	with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5	Stepped to both Ends (Multiple increases)	with screwthread
6	Stepped to both Ends (Multiple increases)	with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 functional diameters)

4th Digit

Digit	Plane Surface Machining
0	No surface machining
1	External plane surface and/or surface curved in one direction
2	External plane surfaces related to one another by graduation around a circle
3	External groove and/or slot(s)
4	External spline and/or Polygon
5	External plane surface and/or slot and/or groove, spline
6	Internal plane surface and/or groove
7	Internal Spline and/or Polygon
8	External and Internal splines and/or slot and/or groove
9	others

5th Digit

		Auxiliary Hole(s) and Gear Teeth
0	no gear teeth	No auxiliary hole(s)
1	no gear teeth	axial hole(s) not related by a drilling pattern
2	no gear teeth	axial holes related by a drilling pattern
3	no gear teeth	radial hole(s) not related by a drilling pattern
4	no gear teeth	holes axial and/or radial and/or in other directions, not related
5	no gear teeth	holes axial, and/or radial and/in other directions related by drilling pattern
6	with gear teeth	spur gear teeth
7	with gear teeth	bevel gear teeth
8	with gear teeth	other gear teeth
9	with gear teeth	others

Figure 1

GEOMETRICAL CODE

1st Digit

	Group	Component Class
	Rotational Components	
	Rotational Components	
	Rotational Components	
3	Rotational Components	$\frac{L}{D} \leqslant 2$ with deviation
4	Rotational Components	$\frac{L}{D} > 2$ with deviation

2nd Digit

	Group	Overall Shape
0	Around one Axis No Segments	Hexagonal bar
1	Around one Axis No Segments	Square or other regular Polygonal section
2	Around one Axis No Segments	Symmetrical cross-section producing no unbalance
3	Around one Axis No Segments	Cross-sections other than 0 to 2
4		Segments after rotational machining
5		Segments before rotational machining
6	Around more than one axis	Rotational Components with curved axis
7	Around more than one axis	Rotational Components with two or more parallel axes
8	Around more than one axis	Rotational Components with intersecting axes
9		Others

3rd Digit

	Group	Rotational Machining
0		No rotational machining
1	External Shape	machined
2	External Shape	with screwthread(s)
3	Internal Shape	smooth
4	Internal Shape	Stepped towards one or both ends (Multiple increases)
5	Internal Shape	with screwthreads
6	Ext. and Int. Shape	machined
7	Ext. and Int. Shape	screwthread(s)
8		External Shape Elements
9		Other Shape Elements

4th Digit

	Plane Surface Machining
0	No Surface machining
1	External plane surface and/or surface curved in one direction
2	External plane surfaces related to one another by graduation around a circle
3	External groove and/or slot
4	External spline and/or Polygon
5	External plane surface and/or slot and/or groove, spline
6	Internal plane surface and/or groove
7	Internal Spline and/or Polygon
8	External and Internal Spline and/or slot and/or groove
9	Other

5th Digit

	Group	Subgroup	Auxiliary Hole(s), Gear Teeth, Forming
0			No auxiliary holes, gear teeth and forming
1	No forming, No gear teeth		axial hole(s) not related by drilling pattern
2	No forming, No gear teeth		holes axial and/or radial and /or in other directions, not related
3	No forming, No gear teeth	related by a drilling pattern	axial holes
4	No forming, No gear teeth	related by a drilling pattern	holes axial and/or radial and/or in other directions
5	Forming, No Gear Teeth		Formed, no auxiliary holes
6	Forming, No Gear Teeth		Formed, with auxiliary holes
7			Gear teeth, no auxiliary holes
8			Gear teeth, with auxiliary hole(s)
9			Other

Figure 2

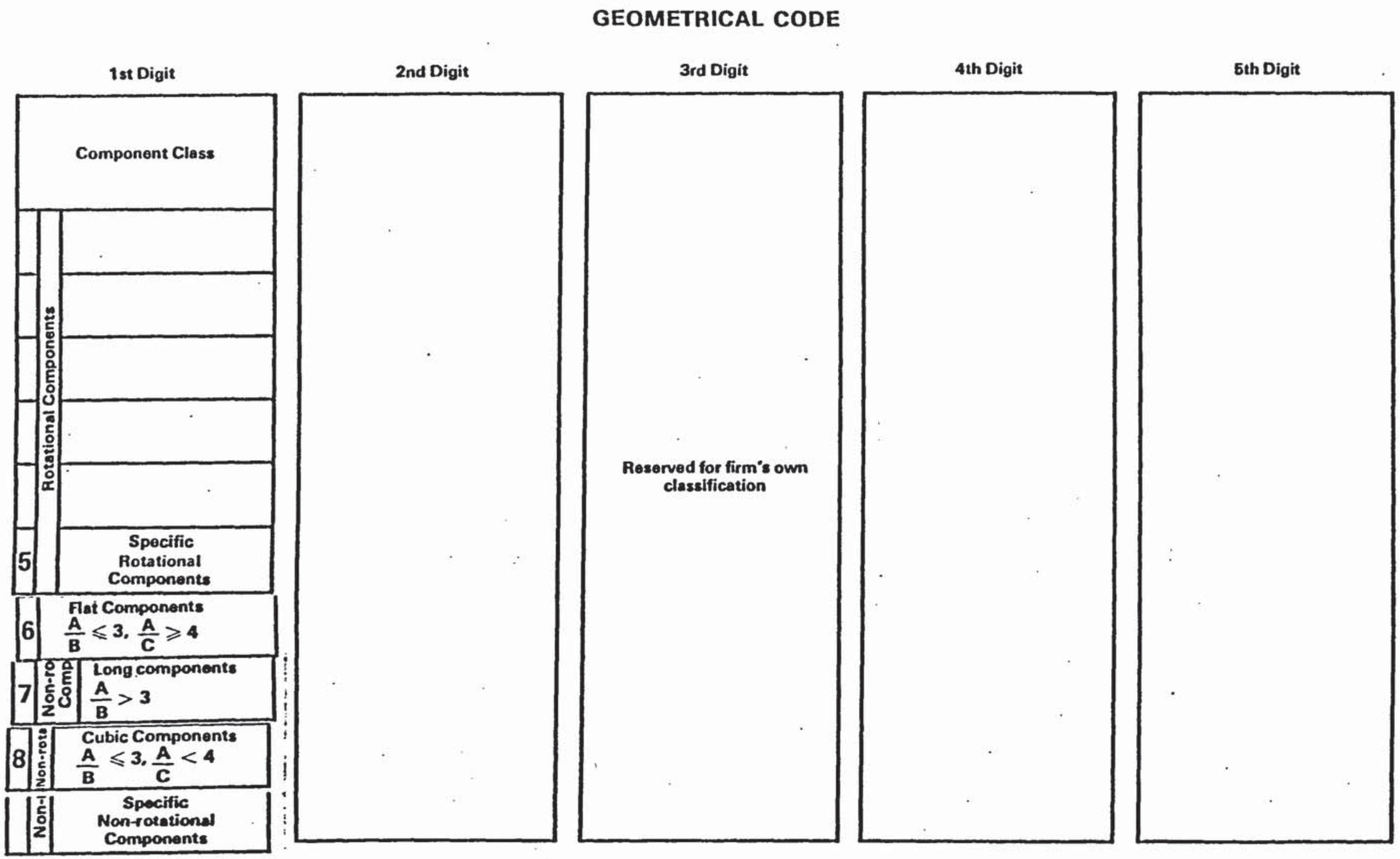
GEOMETRICAL CODE
1st Digit
2nd Digit
3rd Digit
4th Digit
5th Digit
Component Class
Rotational Components
5
Specific Rotational Components
6
Flat Components
$\frac{A}{B} \leqslant 3, \frac{A}{C} \geqslant 4$
7
Non-ro Comp
Long components
$\frac{A}{B} > 3$
8
Non-rota
Cubic Components
$\frac{A}{B} \leqslant 3, \frac{A}{C} < 4$
Non-r
Specific Non-rotational Components
Reserved for firm's own classification

Figure 3

GEOMETRICAL CODE

Code	1st Digit: Component Class	2nd Digit: Overall Shape	3rd Digit: Principal bore, rotational surface machining	4th Digit: Plane Surface Machining	5th Digit: Auxiliary hole(s) Forming, Gear Teeth
0		Plane: Rectangular	No rotational machining or bore(s)	No Surface Machining	No auxiliary holes, gear teeth and forming
1		Plane: Rectangular, with one deviation (Right Angle or Triangular)	One principal bore, smooth	Functional Chamfers (e.g. welding prep.)	No gear teeth, no forming: Holes drilled in one direction only
2		Plane: Rectangular, with angular deviations	One principal bore stepped to one or both ends	One plane surface	No gear teeth, no forming: Holes drilled in more than one direction
3		Plane: Rectangular with circular deviation	One principal bore with shape elements	Stepped plane surfaces	No gear teeth, no forming; related by a drilling pattern: Holes drilled in one direction only
4		Plane: Any flat shape other than 0 to 3	Two principal bores, parallel	Stepped plane surfaces at right angles, inclined and/or opposite	No gear teeth, no forming; related by a drilling pattern: Holes drilled in more than one direction
5		Flat components, rectangular or right angled with small deviations due to casting, welding, forming	Several principal bores, parallel	Groove and/or Slot	Forming, no Gear Teeth: Formed, no auxiliary holes
6	Flat Components $\frac{A}{B} \leqslant 3$, $\frac{A}{C} \geqslant 4$	Flat Components, round or of any shape other than position 5	Several principal bores, other than parallel	Groove and/or Slot and 4	Forming, no Gear Teeth: Formed, with auxiliary holes
7	Non-ro Comp: Long components $\frac{A}{B} > 3$	Flat Components regularly arched or dished	Machined annular surfaces, annular grooves	Curved Surface	Gear teeth, no auxiliary hole(s)
8	Non-rota: Cubic Components $\frac{A}{B} \leqslant 3$, $\frac{A}{C} < 4$	Flat Components irregularly arched or dished	7 + principal bore(s)	Guide Surfaces	Gear teeth, with auxiliary hole(s)
9	Non-r: Specific Non-rotational Components	Others	Others	Others	Others

Figure 4

GEOMETRICAL CODE

1st Digit		2nd Digit			3rd Digit		4th Digit		5th Digit	
Component Class		Overall Shape			Principal bore, rotational surface machining		Plane Surface Machining		Auxiliary hole(s) Forming, Gear Teeth	
	0	Shape Axis—Straight; Uniform Cross-Section	Rectangular	0	No rotational machining or bore(s)	0	No Surface Machining	0		No auxiliary holes, gear teeth and forming
	1	Shape Axis—Straight; Uniform Cross-Section	Rectangular with one deviation (Right Angle or Triangular)	1	One principal bore, smooth	1	Functional Chamfers (e.g. welding prep.)	1	No gear teeth, no forming	Holes drilled in one direction only
	2	Shape Axis—Straight; Uniform Cross-Section	Any cross-section other than 0 and 1	2	One principal bore stepped to one or both ends	2	One plane surface	2	No gear teeth, no forming	Holes drilled in more than one direction
	3	Shape Axis—Straight; Varying Cross-Section	Rectangular	3	One principal bore with shape elements	3	Stepped plane surfaces	3	No gear teeth, no forming; related by a drilling pattern	Holes drilled in one direction only
	4	Shape Axis—Straight; Varying Cross-Section	Rectangular with one deviation (Right Angle or Triangular)	4	Two principal bores, parallel	4	Stepped plane surfaces at right angles, inclined and/or opposite	4	No gear teeth, no forming; related by a drilling pattern	Holes drilled more than one direction
	5	Shape Axis—Straight; Varying Cross-Section	Any cross-section other than 3 and 4	5	Several principal bores, parallel	5	Groove and/or Slot	5	Forming, no Gear Teeth	Formed, no auxiliary holes
Non-rotational Components	6	Shape Axis Curved (bent)	Rectangular, angular and other cross-sections	6	Several principal bores, other than parallel	6	Groove and/or Slot and 4	6	Forming, no Gear Teeth	Formed, with auxiliary holes
7 Non-rotational Components: Long components $\frac{A}{B} > 3$	7	Shape Axis Curved (bent)	Formed Component	7	Machined annular surfaces, annular grooves	7	Curved Surface	7		Gear teeth, no auxiliary hole(s)
8 Non-rota: Cubic Components $\frac{A}{B} \leqslant 3, \frac{A}{C} < 4$	8	Shape Axis Curved (bent)	Formed Component with deviations in the main axis	8	7 + principal bore(s)	8	Guide Surfaces	8		Gear teeth, with auxiliary hole(s)
Non-r: Specific Non-rotational Components	9	Shape Axis Curved (bent)	others	9	Others	9	Others	9		Others

Figure 5

GEOMETRICAL CODE

1st Digit

		Component Class
	Non-rotational Components	
7	Non-rotational Components	
8	Non-rotational Components	Cubic Components $\frac{A}{B} \leqslant 3, \frac{A}{C} < 4$

2nd Digit

			Overall Shape
0	Block and Block-like Components		Rectangular Prism
1	Block and Block-like Components		Rectangular with deviations (Right Angle or Triangular)
2	Block and Block-like Components		Compounded of Rectangular Prisms
3	Block and Block-like Components		Components with a mounting or locating surface and principal bore
4	Block and Block-like Components		Components with a mounting or locating surface, principal bore with dividing surface
5	Block and Block-like Components		Components other than 0 to 4
6	Box and Box-like Components	Not split	Approximate or compounded of rectangular prisms
7	Box and Box-like Components	Not split	Components other than 6
8	Box and Box-like Components	Split	Approximate or compounded of rectangular prisms
9	Box and Box-like Components	Split	Components other than 8

3rd Digit

	Principal bore, rotational surface machining
0	No rotational machining or bore(s)
1	One principal bore, smooth
2	One principal bore stepped to one or both ends
3	One principal bore with shape elements
4	Two principal bores, parallel
5	Several principal bores, parallel
6	Several principal bores, other than parallel
7	Machined annular surfaces, annular grooves
8	7 + principal bore(s)
9	Others

4th Digit

	Plane Surface Machining
0	No Surface Machining
1	Functional Chamfers (e.g. welding prep.)
2	One plane surface
3	Stepped plane surfaces
4	Stepped plane surfaces at right angles, inclined and/or opposite
5	Groove and/or Slot
6	Groove and/or Slot and 4
7	Curved Surface
8	Guide Surfaces
9	Others

5th Digit

			Auxiliary hole(s) Forming, Gear Teeth
0			No auxiliary holes, gear teeth and forming
1	No gear teeth, no forming		Holes drilled in one direction only
2	No gear teeth, no forming		Holes drilled in more than one direction
3	No gear teeth, no forming	related by a drilling pattern	Holes drilled in one direction only
4	No gear teeth, no forming	related by a drilling pattern	Holes drilled in more than one direction
5	Forming, no Gear Teeth		Formed, no auxiliary holes
6	Forming, no Gear Teeth		Formed, with auxiliary holes
7			Gear teeth, no auxiliary hole(s)
8			Gear teeth, with auxiliary hole(s)
9			Others

Figure 6

GEOMETRICAL CODE

1st Digit

		Component Class
0	Rotational Components	$\frac{L}{D} \leqslant 0.5$
1	Rotational Components	$0.5 < \frac{L}{D} < 3$
2	Rotational Components	$\frac{L}{D} \geqslant 3$

2nd Digit

		External Shape, external shape elements
0		Smooth, no shape elements
1	Stepped to one End	no shape elements
2	Stepped to one End or smooth	with screwthread
3	Stepped to one End or smooth	with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5	Stepped to both Ends (Multiple increases)	with screwthread
6	Stepped to both Ends (Multiple increases)	with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 functional diameters)

3rd Digit

		Internal Shape, internal shape elements
0		Without through bore or blind hole
1	Smooth or Stepped to one End	no shape elements
2	Smooth or Stepped to one End	with screwthread
3	Smooth or Stepped to one End	with functional groove
4	Stepped to both Ends (Multiple increases)	no shape elements
5	Stepped to both Ends (Multiple increases)	with screwthread
6	Stepped to both Ends (Multiple increases)	with functional groove
7		functional taper
8		Operating thread
9		Others (> 10 functional diameters)

4th Digit

	Plane Surface Machining
0	No surface machining
1	External plane surface and/or surface curved in one direction
2	External plane surfaces related to one another by graduation around a circle
3	External groove and/or slot(s)
4	External spline and/or Polygon
5	External plane surface and/or slot and/or groove, spline
6	Internal plane surface and/or groove
7	Internal Spline and/or Polygon
8	External and Internal splines and/or slot and/or groove
9	slots or groves on component face

5th Digit

		Auxiliary Hole(s) and Gear Teeth
0		No Holes
1	no gear teeth	Axial Holes
2	no gear teeth	Radial Holes
3	no gear teeth	Other Holes
4	no gear teeth	Combinations of 1,2,3
5		Spur No Holes
6	with gear teeth	Other Gear No Holes
7	with gear teeth	Spur With Holes
8	with gear teeth	Other Gear With Holes
9		Others

Figure 8

GEOMETRICAL CODE

Code	1st Digit: Component Class	2nd Digit: Overall Shape	3rd Digit: Rotational Machining	4th Digit: Plane Surface Machining	5th Digit: Auxiliary Hole(s), Gear Teeth, Forming
0	Rotational Components	Around one Axis No Segments: Hexagonal bar	No rotational machining	No Surface machining	No auxiliary holes, gear teeth and forming
1	Rotational Components	Around one Axis No Segments: Square or other regular Polygonal section	External Shape: machined	External plane surface and/or surface curved in one direction	Axial Holes
2	Rotational Components	Around one Axis No Segments: Symmetrical cross-section producing no unbalance	External Shape: with screwthread(s)	External plane surfaces related to one another by graduation around a circle	Radial Holes
3	Rotational Components: $\frac{L}{D} \leq 2$ with deviation	Around one Axis No Segments: Cross-sections other than 0 to 2	Internal Shape: smooth	External groove and/or slot	Other Holes
4	Rotational Components: $\frac{L}{D} > 2$ with deviation	Segments after rotational machining	Internal Shape: Stepped towards one or both ends (Multiple increases)	External spline and/or Polygon	Combinations of 1,2,3
5		Segments before rotational machining	Internal Shape: with screwthreads	External plane surface and/or slot and/or groove, spline	Forming, No Gear Teeth: Formed, no auxiliary holes
6		Around more than one axis: Rotational Components with curved axis	Ext. and Int. Shape: machined	Internal plane surface and/or groove	Forming, No Gear Teeth: Formed, with auxiliary holes
7		Around more than one axis: Rotational Components with two or more parallel axes	Ext. and Int. Shape: screwthread(s)	Internal Spline and/or Polygon	Gear teeth, no auxiliary holes
8		Around more than one axis: Rotational Components with intersecting axes	Shape Elements	External and Internal Spline and/or slot and/or groove	Gear teeth, with auxiliary hole(s)
9		Others	Other	Other	Other

Figure 9

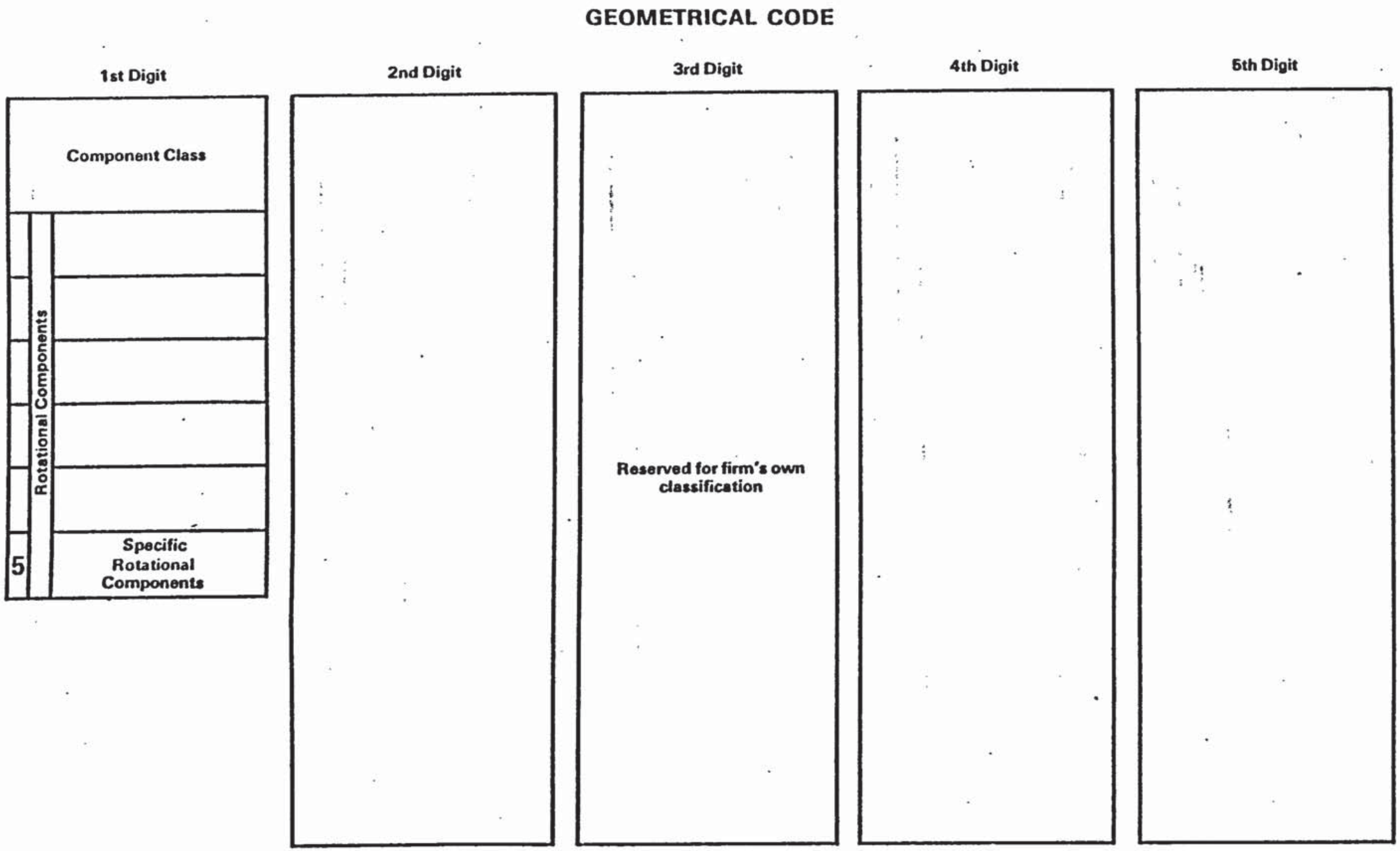
GEOMETRICAL CODE
1st Digit
2nd Digit
3rd Digit
4th Digit
5th Digit
Component Class
Rotational Components
5
Specific Rotational Components
Reserved for firm's own classification

Figure 10

GEOMETRICAL CODE

1st Digit		2nd Digit		3rd Digit		4th Digit		5th Digit	
Component Class		Overall Shape		Principal bore, rotational surface machining		Plane Surface Machining		Auxiliary hole(s) Forming, Gear Teeth	
		0	Plane: Rectangular	0	No rotational machining or bore(s)	0	No Surface Machining	0	No auxiliary holes, gear teeth and forming
		1	Plane: Rectangular, with one deviation (Right Angle or Triangular)	1	One principal bore, smooth	1	Functional Chamfers (e.g. welding prep.)	1	No gear teeth, no forming: Holes in One Direction
		2	Plane: Rectangular with Circular Deviations	2	One Principal Bore Stepped to One End	2	One plane surface	2	No gear teeth, no forming: Holes 2 Directions Axes at 90 or 180
		3	Plane: Circular with or without Deviations	3	Rotational Machining	3	Stepped plane surfaces	3	No gear teeth, no forming: Holes 1+ Direction Axes Inclined
		4	Plane: Any flat shape other than 0 to 3	4	Machined Annular Grooves/Surfaces	4	Stepped plane surfaces at right angles, inclined and/or opposite	4	No gear teeth, no forming: ———
		5	Flat components, rectangular or right angled with small deviations due to casting, welding, forming	5	One Principal Bore Stepped Both Ends	5	Groove and/or Slot	5	Forming, no Gear Teeth: Formed, no auxiliary holes
6	Non-ro Comp: Flat Components $\frac{A}{B} \leqslant 3$, $\frac{A}{C} \geqslant 4$	6	Flat Components, round or of any shape other than position 5	6	One Principal Bore with Shape Elements	6	Groove and/or Slot and 4	6	Forming, no Gear Teeth: Formed, with auxiliary holes
7	Non-ro Comp: Long components $\frac{A}{B} > 3$	7	Flat Components regularly arched or dished	7	2+ Principle Bores Parallel	7	Curved Surface	7	Gear teeth, no auxiliary hole(s)
8	Non-rota: Cubic Components $\frac{A}{B} \leqslant 3$, $\frac{A}{C} < 4$	8	Flat Components irregularly arched or dished	8	2+ Pricipal Bores other than Parallel	8	Guide Surfaces	8	Gear teeth, with auxiliary hole(s)
	Non-r: Specific Non-rotational Components	9	Others	9	Others	9	Others	9	Others

Figure 11

GEOMETRICAL CODE

1st Digit — Component Class

		Component Class
7	Non-rotational Components	Long components $\frac{A}{B} > 3$
8	Non-rotat	Cubic Components $\frac{A}{B} \leqslant 3, \frac{A}{C} < 4$
	Non-r	Specific Non-rotational Components

2nd Digit — Overall Shape

		Overall Shape
0	Block and Block-Like	Rectangular Prism
1	Block and Block-Like	Rect'r with Deviations
2	Block and Block-Like	Compounded of Rect'r Prisms
3	Block and Block-Like	Cylind'l with or W/out Devs
4	Block and Block-Like	Comp'ts other than 0-3
5	Hollow Compounded of Webs and Flanges	Rectangular Prism
6	Hollow Compounded of Webs and Flanges	Rect'r with Deviations
7	Hollow Compounded of Webs and Flanges	Compounded of Rect'r Prisms
8	Hollow Compounded of Webs and Flanges	Cylind'l with or W/out Devs
9	Hollow Compounded of Webs and Flanges	Comp'ts other than 5-8

3rd Digit — Principal bore, rotational surface machining

Digit	Principal bore, rotational surface machining
0	No rotational machining or bore(s)
1	One principal bore, smooth
2	One Principal Bore Stepped to One End
3	Rotational Machining
4	Machined Annular Grooves/Surfaces
5	One Principal Bore Stepped Both Ends
6	One Principal Bore with Shape Elements
7	2+ Principle Bores Parallel
8	2+ Pricipal Bores other than Parallel
9	Others

4th Digit — Plane Surface Machining

Digit	Plane Surface Machining
0	No Surface Machining
1	Functional Chamfers (e.g. welding prep.)
2	One plane surface
3	Stepped plane surfaces
4	Stepped plane surfaces at right angles, inclined and/or opposite
5	Groove and/or Slot
6	Groove and/or Slot and 4
7	Curved Surface
8	Guide Surfaces
9	Others

5th Digit — Auxiliary hole(s) Forming, Gear Teeth

		Auxiliary hole(s) Forming, Gear Teeth
0		No auxiliary holes, gear teeth and forming
1	No gear teeth, no forming	Holes in One Direction
2	No gear teeth, no forming	Holes 2 Directions Axes at 90 or 180
3	No gear teeth, no forming	Holes 1+ Direction Axes Inclined
4	No gear teeth, no forming	———
5	Forming, no Gear Teeth	Formed, no auxiliary holes
6	Forming, no Gear Teeth	Formed, with auxiliary holes
7		Gear teeth, no auxiliary hole(s)
8		Gear teeth, with auxiliary hole(s)
9		Others

Figure 12

GEOMETRICAL CODE

Code	1st Digit: Component Class	2nd Digit: Overall Shape	3rd Digit: Principal bore, rotational surface machining	4th Digit: Plane Surface Machining	5th Digit: Auxiliary hole(s) Forming, Gear Teeth
0		Block and Block-Like: Rectangular Prism	No rotational machining or bore(s)	No Surface Machining	No auxiliary holes, gear teeth and forming
1		Block and Block-Like: Rect'r with Deviations	One principal bore, smooth	Functional Chamfers (e.g. welding prep.)	No gear teeth, no forming: Holes in One Direction
2		Block and Block-Like: Compounded of Rect'r Prisms	One Principal Bore Stepped to One End	One plane surface	No gear teeth, no forming: Holes 2 Directions Axes at 90 or 180
3		Block and Block-Like: Cylind'l with or W/out Devs	Rotational Machining	Stepped plane surfaces	No gear teeth, no forming: Holes 1+ Direction Axes Inclined
4		Block and Block-Like: Comp'ts other than 0-3	Machined Annular Grooves/Surfaces	Stepped plane surfaces at right angles, inclined and/or opposite	No gear teeth, no forming: ———
5		Hollow Compounded of Webs and Flanges: Rectangular Prism	One Principal Bore Stepped Both Ends	Groove and/or Slot	Forming, no Gear Teeth: Formed, no auxiliary holes
6	Non-rotational Components	Hollow Compounded of Webs and Flanges: Rect'r with Deviations	One Principal Bore with Shape Elements	Groove and/or Slot and 4	Forming, no Gear Teeth: Formed, with auxiliary holes
7	Non-rotational Components	Hollow Compounded of Webs and Flanges: Compounded of Rect'r Prisms	2+ Principle Bores Parallel	Curved Surface	Gear teeth, no auxiliary hole(s)
8	Non-rotational Components: Cubic Components $\frac{A}{B} \leqslant 3, \frac{A}{C} < 4$	Hollow Compounded of Webs and Flanges: Cylind'l with or W/out Devs	2+ Pricipal Bores other than Parallel	Guide Surfaces	Gear teeth, with auxiliary hole(s)
9		Hollow Compounded of Webs and Flanges: Comp'ts other than 5-8	Others	Others	Others

Figure 13

1st Digit

	DIAMETER 'D' or EDGE LENGTH 'A'	
	MM's	Inches
0	≤ 20	≤ 0·8
1	> 20 ≤ 50	> 0·8 ≤ 2·0
2	> 50 ≤ 100	> 2·0 ≤ 4·0
3	> 100 ≤ 160	> 4·0 ≤ 6·5
4	> 160 ≤ 250	> 6·5 ≤ 10·0
5	> 250 ≤ 400	> 10·0 ≤ 16·0
6	> 400 ≤ 600	> 16·0 ≤ 25·0
7	> 600 ≤ 1000	> 25·0 ≤ 40·0
8	> 1000 ≤ 2000	> 40·0 ≤ 80·0
9	> 2000	> 80·0

2nd Digit

	EDGE LENGTH b	
	MM's	Inches
0	≤ 20	≤ 0·8
1	> 20 ≤ 50	> 0·8 ≤ 2·0
2	> 50 ≤ 100	> 2·0 ≤ 4·0
3	> 100 ≤ 160	> 4·0 ≤ 6·5
4	> 160 ≤ 250	> 6·5 ≤ 10·0
5	> 250 ≤ 400	> 10·0 ≤ 16·0
6	> 400 ≤ 600	> 16·0 ≤ 25·0
7	> 600 ≤ 1000	> 25·0 ≤ 40·0
8	> 1000 ≤ 2000	> 40·0 ≤ 80·0
9	> 2000	> 80·0

3rd Digit

	INITIAL FORM
0	Round Bar, black
1	Round Bar, bright drawn
2	Bar-triangular, square, hexagonal, others
3	Tubing
4	Angle, U-, T-, and similar sections
5	Sheet
6	Plate and Slabs
7	Cast or forged Components
8	Welded Assembly
9	Pre-machined Components

4th Digit

	ACCURACY IN CODING DIGIT
0	No Accuracy Specified
1	2
2	3
3	4
4	5
5	2 and 3
6	2 and 4
7	2 and 5
8	3 and 4
9	(2+3+4+5)

Figure 14

1st Digit

	DIAMETER 'D' or EDGE LENGTH 'A'	
	MM's	Inches
0	$\leqslant 20$	$\leqslant 0{\cdot}8$
1	$> 20 \leqslant 50$	$> 0{\cdot}8 \leqslant 2{\cdot}0$
2	$> 50 \leqslant 100$	$> 2{\cdot}0 \leqslant 4{\cdot}0$
3	$> 100 \leqslant 160$	$> 4{\cdot}0 \leqslant 6{\cdot}5$
4	$> 160 \leqslant 250$	$> 6{\cdot}5 \leqslant 10{\cdot}0$
5	$> 250 \leqslant 400$	$> 10{\cdot}0 \leqslant 16{\cdot}0$
6	$> 400 \leqslant 600$	$> 16{\cdot}0 \leqslant 25{\cdot}0$
7	$> 600 \leqslant 1000$	$> 25{\cdot}0 \leqslant 40{\cdot}0$
8	$> 1000 \leqslant 2000$	$> 40{\cdot}0 \leqslant 80{\cdot}0$
9	> 2000	$> 80{\cdot}0$

2nd Digit

	MATERIAL
0	Cast Iron
1	Modular graphitic cast iron and malleable cast iron
2	Steel $\leqslant$ 26.5 tonf/in² Not heat treated
3	Steel $>$26.5 tonf/in² Heat treatable low carbon and case hardening steel, not heat treated
4	Steels 2 and 3 Heat treated
5	Alloy Steel (Not heat treated)
6	Alloy Steel Heat treated
7	Non-ferrous Metal
8	Light Alloy
9	Other Materials

3rd Digit

	INITIAL FORM
0	Round Bar, black
1	Round Bar, bright drawn
2	Bar-triangular, square, hexagonal, others
3	Tubing
4	Angle, U-, T-, and similar sections
5	Sheet
6	Plate and Slabs
7	Cast or forged Components
8	Welded Assembly
9	Pre-machined Components

4th Digit

	ACCURACY IN CODING DIGIT
0	No Accuracy Specified
1	2
2	3
3	4
4	5
5	2 and 3
6	2 and 4
7	2 and 5
8	3 and 4
9	(2+3+4+5)

Figure 7

CALCULATION OF BATCH SIZES

The approach proposed by Hagan and Leonard (1) was adopted as recognising most of the factors affecting the batch size. Some simplification of the original formula can be applied where the circumstances at CompAir allow.

Nomenclature

Symbol		Definition	Units
Q	=	Batch Size	(components)
Q_m	=	Minimum stock level	(components)
R	=	Rate of annual usage of parts	(parts/year)
C_p	=	Capital cost per part	(£ per part)
C_s	=	Storage cost per part	(£ per part)
Ir	=	Company interest rate	(% p.a.)
K_c	=	Stock holding cost per part	(£)
	=	$CpIr + C_s$	
L_t	=	Lead time	
D	=	Queuing time in works	
T_{pa}	=	Allowed time per part (for non auto machines)	(years)
P_a	=	Performance on allowed times	
Tpc	=	Cycle time per part (for auto machines etc)	(years)
Pc	=	Performance on cycle hours	
T_T	=	Total time per part	(years)
	=	$\frac{Tpa}{Pa} + \frac{Tpc}{Pc}$	(£ per min)

Oha	=	overhead rate (non auto machines)	
Ohc	=	overhead rate (auto machines)	(£ per min)
Sua	=	Set up time (non auto machines)	(years)
Suc	=	Set up time (auto machines)	(years)
Tc	=	Total Cost	£

Deviation

1. Cost of finished stock

Average number of components in stores

= minimum stock + ½ batch size

$$= \frac{Q}{2} + Q_m$$

Average time of each part in stores

$$= \frac{1}{12}\left(\frac{Q}{2} + Q_m\right)$$

∴ cost of keeping parts in stores

$$KcK\left(\frac{Q}{2} + Q_m\right)\left(\frac{Q}{2} + Q_m\right)\frac{1}{12}$$

Cost per component

$$= Kc\left(\frac{Q}{2} + Q_m\right)\left(\frac{Q}{2} + Q_m\right)\frac{1}{12}\left(\frac{1}{\frac{Q}{2} + Q_m}\right)$$

$$= \frac{Kc}{12}\left(\frac{Q}{2} + Q_m\right)$$

2. Cost of W.I.P.

Lead time

=(Total process time/part x batch size) + queuing time

$$L = Q\left(\frac{Tpa}{Pa} + \frac{Tpc}{Pc}\right) + D$$

Number of batches per year

$$= \frac{R}{Q} \cdot L_t$$

Interest charge on batches in works:-

$$= \frac{R}{Q} \cdot L_t \cdot K_c Q \cdot L_t$$

Interest per part

$$= \frac{R}{Q} \cdot \frac{Q}{R} \cdot \frac{Lt^2}{Lt} \cdot Kc$$

$$= KcLt$$

$$= Kc\ (D + Q.\ Tt)$$

3. Production Cost Per Part

= sum of process times x relevant overhead rate

+ (sum of setting times x relevant overhead rate) per part

$$= Oha\,.\,Tpa + Ohc.\ Tpc. + \frac{1}{Q}\ (Sua\ Oha + Suc.\ Ohc)$$

4. Total Cost

= storage cost + W.I.P. cost + production cost

$$C_t = \frac{Kc}{R}\left(\frac{Q}{2} + \frac{Q}{m}\right) + Kc\left(D + QT_t\right)$$

$$+ Oha\ Tpa + Ohc.TP_c + \left(\frac{Sua.\ Oha + Suc\ Ohc}{Q}\right)$$

To find minimum cost, put $\frac{d\,(Ct)}{dQ} = 0$

$$\text{i.e. } Kc\left(\frac{1}{2R} + T_t\right) - \frac{(Sua\ Oha + Suc\ Ohc)}{Q^2} = 0$$

hence

$$Qopt = \sqrt{\frac{2R\ (Sua\ Oha + Suc.\ Ohc)}{Kc\ (1 + 2\ RT_t}} \quad - (1)$$

Simplification

1. If no auto machines are included in the process Suc. Ohc disappears

The equation then reduces to:

$$Qo = \sqrt{\frac{2R.\ Sua.\ Oha}{Kc\ (1 + 2R\ \frac{Tpa}{Pa}}} \qquad \text{———} (2)$$

If there are automatic cycle machines the equation is

$$Qo = \sqrt{\frac{2R.\ Sua.\ Oha + Suc\ Ohc}{Kc\ (1 + 2R\ (\frac{Tpa}{Pa} + \frac{Tpc}{Pc}))}}$$

But at CompAir, the cycle time allowed is the actual time, i.e. Pc = 1

$$\frac{Tpc}{Pc} = Tpc$$

$$Qo = \sqrt{\frac{2R\ \ Sua\ \ Oha}{Kc\ \ 1+2R\ (\frac{Tpa}{Pa} + Tpc))}}$$

PARTS RANGE DATA

The figures given describe all the important attributes of the selected range of components.

Figure 1.

Parts Range - Key Data

This figure gives, for each component:-

i) Part number, description, code number

ii) Computer Analysis run number

iii) Monthly usage and monthly usage value

iv) Subcontract operations, total number of operations and source.

v) BSC, Material cost

vi) New labour and overhead, new total cost for revised method

vii) Premium per part and per year

viii) Selling price and selling revenue

ix) Change in method

Figure 2.

<u>Parts Range - Manufacturing Data</u>

This figure gives, for each component:-

i) Computer analysis run number

ii) MU - Monthly usage

iii) Qo - Optimum batch size

iv) f - Frequency of manufacture - batches/year

v) for each operation the:

- machine code
- setting time (allowed runs)
- allowed or cycle process time (mins)

The existing method is given on the top line.

The revised method is given on the second line.

vi) Operations which are currently subcontracted (policy) are indicated by a °.

vii) Instances where the revised times have been estimated are indicated by a *.

PARTS RANGE - KEY DATA

Part No.	Description	Code		Computer Run Number	Monthly Usage	Monthly Usage Value	Sub-Contract Ops.	Total Ops	Source	BSC £	Material Cost £	New Method Lab + O'hd £	New Method Total Cost £	Premium Per Part £	Premium Per Year £	Selling Price £ per pt	Selling Revenue £/yr.	Change Method
50045/5	Valve Guard LP	01101	1407	4	45	195	1-5	6	1	4.34	1.50	4.63	6.13	1.79	971.40	17.00	9180	AC2W→CC5
50046/6	Valve Guard HP	01101	0307	4	62	181	1-4	5	1	2.91	0.98	3.58	4.56	1.65	1228.00	12.25	9114	DS6 →DS4
50048/3	Valve Guard LP	01101	0307	4	21	105	1-5	6	1	5.02	0.97	4.71	5.69	0.67	168.80	18.50	4662	" "
C2164/18	Con Rod Bolt	22010	4160	5	15	32	1-3	3	1	2.14	0.82	1.93	2.75	0.61	110.10	8.00	1440	NONE
C2173/1	Delivery Valve Seat,	04200	1307	4	40	273	1-3	3	1	6.82	3.42	3.03	6.45	-0.36	-176.80	21.00	10080	NONE
C2173/2	Delivery Valve Guard	00100	1307	4	47	128		3	1	2.72	0.83	2.03	2.86	0.14	83.00	10.80	6091.2	AC2 →CC5
C2173/6	Cap Nut	30500	1121	3	36	9	1-2	2	1	0.25	0.04	0.40	0.44	0.19	82.80	1.00	432	AB1W→CB4
C2212/1	Delivery Valve Seat	15000	1237	8	58	171		4	1	2.95	0.52	0.84	1.36	-1.59	-1108.50	11.78	8198.88	AC1→AC1P CC4
C2214/1	Delivery Valve Seat	05000	2237	8	126	520		6	1	4.13	0.67	3.01	3.68	-0.44	-679.00	16.00	24192	AC1→AC1P CC5
C2214/2	Delivery Valve Guard	03100	1237	8	143	282		4	1	1.96	0.85	0.94	1.79	-0.18	-310.40	7.80	13384.8	AC1→AC1P
C2214/5	Cap Nut	30500	1121	3	254	60		2	1	0.24	0.04	0.04	0.37	0.41	507.70	0.95	2895.6	AB1W→CB4
C2226/18	Delivery Valve Seat	05000	2337	4	156	791		6	1	5.07	1.13	3.46	4.60	-0.47	-886.90	18.00	33696	AC1→AC1P
C2226/19	Delivery Valve Guard	00100	1337	4	172	417		5	1	2.43	1.13	1.14	2.27	-0.16	-316.90	8.50	17544	AC1→AC1P
C2254/15	Gudgeon Pin	21160	4140	5	12	87	1-1	12	1	7.29	0.75	8.18	8.93	1.64	236.50	25.00	3600	NO (HDN)
C2357/8	Gudgeon Pin	20430	3140	5	8	11	1-3	6	1	1.40	0.23	• 1.41	1.64	0.24	23.20	5.00	480	NO (HDN, OUT)
C2730/6	Reg. Cylinder	32501	2307	4	3	8	2-3	3	1	2.67	0.99	2.90	3.88	1.21	43.80	10.66	383.76	AC2, DS2
C3340/6	Air Delivery Retainer	10100	3307	4	21	48	1-2	2	1	2.29	1.14	1.03	2.17	-0.12	-30.40	8.00	2016.00	CC4→CC5
C3340/25	Lifting Plate	32601	1307	4	9	21	1-2	2	1	2.28	1.00	1.23	2.23	-0.04	- 4.90	7.50	810	CC4, DS2
C3340/26	Lifting Pins	25000	3020	7	47	22	1-2	3	1	0.46	0.02	0.56	0.58	0.12	70.40	1.70	958.80	CB2S, HDN
C3340/31	Spring Collar	00100	0120	3	24	13	1-2	2	1	0.53	0.09	0.54	0.63	0.10	28.60	2.13	613.44	AB3W→CC5
C3365/14	Delivery Valve Seat	04201	1307	4	80	239		6	1	2.98	0.77	1.98	2.76	-0.22	-212.30	11.90	11424	CB25→CB4
C3467/18	Upper Valve Seat	12200	1177	8	46	25		2	1	0.54	0.21	0.36	0.57	0.03	16.30	2.20	1214.4	CC4→CC5
C3467/19A	Valve	14130	1170	5	104	47		3	1	0.44	0.21	0.84	1.06	0.62	768.80	2.00	2496	AT,CB25,M/H/W
C3467/30	Spring Rod	22030	3020	9	60	17	1-2,OUT	3	1	0.28	0.08	• 0.40	0.48	0.20	145.30	1.00	720	AB24,CB2,OUT
C3472/10	Delivery Valve Guard	01101	0307	4	69	149	1-4	4	1	2.16	0.77	1.23	1.99	-0.16	-135.50	8.00	6624	AC1, DS2
C3580/5	Suction Valve	11100	2207	8	3	11	1-2	2	1	3.52	1.90	1.45	3.35	-0.16	- 6.00	9.00	324	CC4→CC5
C3607/7	Air Delivery Retainer	10100	3307	4	20	49	1-3	3	1	2.45	1.14	1.21	2.35	-0.10	- 23.40	8.25	1980	CC4→CC5
C3648/10	Suction Valve	32601	4407	4	3	32	1-3	5	1	10.75	5.04	6.86	11.90	1.15	41.50	43.00	1548	LC→CC5,DR2
C3648/12	Centre Pin	25000	2120	3	11	7	1-2	2	1	0.64	0.13	0.66	0.79	0.15	20.20	2.50	330	CB25→CB4
C3648/13	Delivery Valve Stud	25002	2030	7	113	39	1-2	3	1	0.34	0.05	0.72	0.77	0.42	581.90	1.20	1627.2	" "
C3648/14	Delivery Valve Stud	25000	2020	7	67	41	1-2	2	1	0.62	0.07	0.72	0.79	0.17	135.90	2.00	1608	" "
C3706/9	Suction Valve Seat	04100	0257	8	37	74	1-3	3	1	2.00	0.75	1.31	2.06	0.06	25.50	7.50	3330	AC1→AC1P
C3706/12	Delivery Valve Seat	15000	1237	8	35	109	1-6	6	1	3.11	0.52	2.27	2.78	-0.32	-135.60	11.00	4620	" "
C3706/18	Delivery Valve Guard	00100	1227	8	42	56	1-4	4	1	1.29	0.42	0.87	1.29	0.00	-	5.25	2646	" "
C3711/50	L.P. Gudgeon Pin	20100	2140	3	8	9	1-3,OUT	6	1	1.13	0.20	• 1.27	1.47	0.34	33.10	4.25	408	AB50,KE, OUT
C3711/52	H.P. Gudgeon Pin	10102	1140	3	9	6	1-5,OUT	6	1	0.63	0.11	0.99	1.10	0.46	50.70	2.50	270	" " "
C3711/104	Delivery Valve Guard	11202	1120	3	41	32		5	1	0.78	0.45	1.33	1.78	1.00	493.20	3.00	1476	AB50,CC4,DS2
C3711/106	H.P. Suction Valve Plug	12132	1120	5	5	7	1-4	4	1	1.30	0.12	1.42	1.53	0.23	14.20	5.00	300	DS2, MHW
C3711/107	Suction Valve Guard	11201	0120	3	35	37		5	1	1.05	0.03	1.31	1.34	0.29	125.30	4.00	1680	AB50,DS2,CC4
C3711/55	H.P. Delivery Valve Cap	11220	1107	10	5	5		1	1	1.06	0.28	0.86	1.14	0.08	4.80	4.00	240	CC4 →CC5
C3727/9	L.P. Suction Valve Plug	14222	2107	10	4	7	1-2	2	1	1.73	0.39	1.58	1.97	0.23	11.50	6.50	312	CC4, DS2

FIG 1 Sheet 1 of 2

PARTS RANGE - KEY DATA

Part No.	Description	Code	Computer Run No.	Monthly Usage	Monthly Usage Value	Sub-Contract Ops.	Total Ops.	Source	BSC £	Mtrl. Cost £	New Method: Lab + O'hd £	New Method: Total Cost £	Premium Per Part £	Premium Per Year £	Selling Price £ Per Part	Selling Revenue £/Yr.	Change Method
C 3800/7	HP S & D Valve	11100 0060	7	8	8	Out,Hon	6	1	1.00	0.60	* 0.43	1.03	0.03	2.88	3.25	312.2	HDN CB2,D52 Out
C 3812/44	HP Del.Valve Guard	11202 1120	3	19	14	1-4	4	1	0.76	0.07	1.27	1.34	0.58	132.01	2.90	661.2	AB1W,D52 CC4
C 3839/15	Gudgeon Pin	10102 2140	3	9	10	Out	6	1	1.12	0.23	* 1.27	1.50	0.38	41.56	4.0	432	AB50,KE, HDN Out
C 3839/114	Plunger	13022 2150	5	4	7		6	1	1.75	0.14	2.21	2.35	0.60	29.00	6.50	312	CC4,D52,MHW
C 4011/9	Unloader Piston	13101 1170	3	8	11	1-2,Out	3	1	1.42	0.50	* 0.82	1.32	-0.09	- 9.13	5.30	508.8	CC4 → CC5
C 4188/9	" "	13100 2270	8	10	13	1-2,Out	3	1	1.25	0.74	0.61	1.35	0.10	12.40	5.40	648	" "
C 4188/21	Control Valve Piston	13100 2170	3	7	9	1-2,Out	3	1	1.22	0.79	* 0.54	1.34	0.11	10.07	4.50	378	CB25 → CB4
C 10162/6	Check Valve Body	40702 2171	3	56	47		4	1	0.83		0.59				4.25	2856	
C 10190/38	X Hd.Locking Pin	40200 2051	7	10	8	1-2	2	1	0.78	0.02	0.94	0.96	0.18	22.16	3.00	360	CB25 → CB4
C 10190/77	Oil Pump Lower Bush	13202 2170	3	2	8	1-7	7	1	3.8	0.99	4.00	4.99	1.19	28.67	15.0	360	KE → MH
C 10190/176	Spindle	24132 3060	9	2	7	1-12	12	1	3.7	0.15	4.55	4.70	1.00	24.01	12.50	300	CB25,D52, HDN
C 10540/193	HP Suct.Valve Cover	13101 3407	4	19	82	1-2	7	1	4.31	1.73	6.16	7.89	3.58	816.94	16.0	3648	AC2W,DHUC, D51
C10540/218	" Del. " "	13101 3307	4	22	97	1-5	8	1	4.39	1.73	6.19	7.93	3.53	934.10	16.0	4224	" " "
C 10578/143	Plunger	30200 1090	7	7	5		2	1	0.72	0.06	0.97	1.02	0.31	25.69	2.80	235.2	CB25 → CB4
C 10595/32	Gudgeon Pin	20100 3190	3	13	21	Out	6	1	1.64	1.64	* 2.76				12.0	1872	None
C 10725/11	Big end Brg.Bolt	22012 2160	5	10	7	Out	5	1	0.72	0.15	* 1.06	1.21	0.49	59.34	2.80	336	AB1W → CB4, MAW, MA
C 10725/17	Breather Valve Body	12202 1170	3	5	6		3	1	1.11	0.53	0.63	1.16	0.05	3.27	4.40	264	CC4, D52
C 10806/7	Needle Valve Seat	30700 0171	3	20	10		2	1	0.48	0.067	0.57	0.64	0.16	37.93	1.90	456	CB28
C 10807/8	Del.Valve Plug	12202 2107	8	5	6		2	1	1.18	0.36	0.94	1.30	0.12	7.05	4.75	285	CC4, D52
C 11199/60	Lantern	13201 2307	4	3	12		3	1	3.85	2.06	2.01	4.06	0.22	7.89	14.50	522	" "
C 11304/101	Bolt	12030 2050	9	22	25		2	1	1.13	0.22	0.88	1.10	-0.02	- 7.59	4.20	1108.8	AB30 → CB4
C 11304/10[illegible]	Bolt	22000 2050	7	25	11	1-2	2	1	0.48	0.045	0.73	0.78	0.30	89.46	3.40	1020	CB2 → CB4
C 11304/112	Bolt	22000 2050	7	24	21	1-2	2	1	0.89	0.24	0.81	1.05	0.16	46.30	4.50	1296	CB25 → CB4
C 11304/220	Bolt	12030 2150	5	9	10		3	1	1.14	0.35	1.06	1.40	0.26	28.89	5.60	604.8	" "
CB 211/13	S & D Vlv.Assy Screw	12030 1020	9	162	38	1-2	2	1	0.24	0.01	0.34	0.35	0.11	210.73	0.90	1749.6	CB25, MSL
CB 361	HP Piston Body	01101 2407	4	1	26	1-2	2	1	26.32		14.49				75.0	900	LC, D52
CB 363	HP Piston Junk Ring	01101 1407	4	1	8	1-2	2	1	2.10	2.10	6.56	8.66	0.24	2.92	31.0	372	" "
CB 377	Valve Nut Thick	30500 0121	3	151	60	1-2	2	1	0.40	0.04	0.57	0.61	0.21	382.42	1.50	2781	None
CB 378	¼" Whit.Hex.Nut	30500 0121	3	91	35		2	1	0.39	0.03	0.57	0.60	0.21	230.46	1.50	1638	None
CD 608	Con Rod Bolt	22010 4150	5	2	8	1-3	3	1	4.19	1.37	4.30	5.67	1.48	35.53	16.0	384	None
PT 7374/15	Governor Plate	15131 1140	5	10	19	-	10	1	1.91	0.05	4.18	4.23	2.32	278.4	9.34	1120.8	CB2(S), LSC, HDN, OB.
PT 7374/8	Rotor Shaft	25130 4130	5	2	6		9	1	3.03	0.33	6.02	6.34	3.31	79.61	11.36	272.64	CB2, LPS, LSC

*Note: The new lab + O'hd cost does not include the cost of 'Out' operations, i.e. those permanently sub-contracted.

FIG (1) Sheet 2 of 2.

PARTS RANGE - MANUFACTURING DATA

Part No.	Comp. Run No.	M.U.	Qo	F.	1st OP M/C	1st OP Setting	1st OP All'd Cycle	1st OP Actual	2nd OP M/C	2nd OP Setting	2nd OP All'd Cycle	2nd OP Actual
50045/3	4	45	148	4	AC2W^{o} CC5	240 137	4.1 9.60*		AC2W^{o} CC5	240 205.2*	3.8 30.0*	
50046/6	4	62	240	3	AC2W^{o} CC5	300 150*	4.3 9.7*		AC2W^{o} CC5	120 375*	3.75 20.0*	
50048/3	4	21	96	3	AC2W^{o} CC5	240 164*	8.0 16		AC2W^{o} CC5	240 205*	12.0 20.5*	
C2164/18	5	15	150	1	CB4^{o}	300 460	15.0 23		CB4^{o}	145 222	1.4 2.1	
C2173/1	4	40	109	4	CC5^{o}	276 240	30 26		CC5^{o}	300 260	14 12	
C2173/2	4	47	197	3	AC2 CC5	300 410*	12.4 24.5*		AC2 CC5	180 156*	3.47 2.4*	
C2173/6	3	36	340	1	ABIW^{o} CB4	180 180*	1.8 5.5*		DEB^{o}	15 12	0.24 0.2	
C2212/1	8	58	222	3	AC1 AC1P	240	4.3		AC1 AC1P	180	3.75	
C2214/1	8	126	408	4	AC1P	120	4.4		AC1P	420	11.5	
C2214/2	8	143	466	4	AC1 AC1P	300	4.75		AC1 AC1P	210	4.35	
C2214/5	3	254	900	3	ABIW CB4	180 180*	1.65 5.0*		DEB	15 12	0.26 0.2	
C2226/18	4	156	327	6	AC1 AC1P	120	5.35		AC1P	300	13.3	
C2226/19	4	172	220	9	HDN	-	4.25		AC1 AC1P	240	6.5	
C2254/15	5	12	79	2	CB4^{o} SB^{o}	140 215 -	8.9 13.6 1.0		CB4^{o} DEB^{o}	140 215 15 12	5.4 8.3 4.0 3.2	
C2357/8	5	8	97	1	CB4^{o}	200 307	5.5 8.4		DEB^{o}	15 12	0.5 0.4	
C2730/6	4	3	44	1	AC2 CC5	300 315*	6.9 27*		DS2^{o} DS4^{o}	10 45	9.0 9.4	
C3340/6	4	21	93	3	CC4^{o} CC5	123 107	8.1 7.0		CC4^{o} CC5	140 121	8.8 7.6	
C3340/25	4	9	64	2	CC4^{o} CC5	210 182	13.0 11.3		DS2^{o} DS4	65 68	5.9 6.2	
C3340/26	7	47	318	2	CB25^{o} CB4	120 145	5.5 6.7		CB4^{o}	60 92	0.8 1.2	
C3340/31	3	24	242	1	ABIW^{o} CB4	240 195*	3.1 6.4*		CC4^{o} CC5	130 113*	1.45 1.25*	

Part No.	3rd OP M/C	3rd OP Setting	3rd OP All'd Cycle	3rd OP Actual	4th OP M/C	4th OP Setting	4th OP All'd Cycle	4th OP Actual
50045/3	AC2W^{o} CC5	300 170*	4.8 4.0		DS6^{c} DS4	45 45	13.0 15.6	
50046/6	- CC5	- 170*	- 5.2*		DS6^{o} DS4	45* 45	10.0* 12.0	
50048/3	AC2W^{o} CC5	240 175	2.5 5.8*		DS6^{o} DS4	45 45	15.0 18.0	
C2164/18	MH^{o}	90	3.0 2.3					
C2173/1	DEB^{o}	15 12	6.2 5.0					
C2173/2	VF	-	2.0					
C2173/6								
C2212/1	DEB	15 12	1 0.8		VF	20	0.7	
C2214/1	AC1 AC1P	360	7.0		DEB	15 12	6.5 5.2	
C2214/2	DEB	15 15	1.0 0.8		RF	-	0.7 0.6	
C2214/5								
C2226/18	AC1 AC1P	180	6.4		DEB	15 12	5.9 4.8	
C2226/19	AC1 AC1P	240	2.6		DEB	15 12	2.3 1.9	
C2254/15	HDN^{o} CB4^{o}	- 60 92	64 3.6 5.5		SB^{o} GRE^{o}	- 90 94	1.6 15 15.7	
C2357/8	MH^{o}	96 75	1.5 1.2		HDN	-	23.1	
C2730/6	DS2^{o} DS4	30 45*	4.5 4.7					
C3340/6								
C3340/25								
C3340/26	HDN	-	0.26					
C3340/31								

Part No.	5th OP M/C	5th OP Setting	5th OP All'd Cycle	5th OP Actual	6th OP M/C	6th OP Setting	6th OP All'd Cycle	6th OP Actual	7th OP M/C	7th OP Setting	7th OP All'd Cycle	7th OP Actual
50045/3	DEB^{o}	15 12	7.0 5.6		VF	15	1.0					
50046/6	DEB^{o}	15* 12	4.8* 3.9		VF	-	0.55*					
50048/3	DEB^{o}	15 12	7.0 5.6		VF	20*	1.0					
C2164/18												
C2173/1												
C2173/2												
C2173/6												
C2212/1												
C2214/1	CC4 CC5	155 135	2.8 2.4		CC4 CC5	180 156	4.2 3.6					
C2214/2												
C2214/5												
C2226/18	CC5	100 87	5.2 4.5		CC5	150 130	6.2 5.4					
C2226/19	VF	-	0.25									
C2254/15	CB4^{o} GRE^{o}	120 184 35 36.6	18.0 27.6 6 6.3		MH^{o}	150 117	2.8 2.2		HDN^{o}	-	12.5	
C2357/8	SB	-	0.44		OUT2	-	-					
C2730/6												
C3340/6												
C3340/25												
C3340/26												
C3340/31												

M.U. = Monthly Usage
Qo = Economic batch quantity
F. = Frequency batches/yr.

* Reviewed & estimated times
^{o} Subcontracted operation

FIG. 2. Sheet 1 of 4

Part No.	Comp Run No.	M.U.	Qo	F.	1st OP				2nd OP				3rd OP				4th OP				5th OP				6th OP				7th OP			
					M/C	Setting	All'd Cycle	Actual	M/C	Setting	All'd Cycle	Actual	M/C	Setting	All'd Cycle	Actual	M/C	Setting	All'd Cycle	Actual	M/C	Setting	All'd Cycle	Actual	M/C	Setting	All'd Cycle	Actual	M/C	Setting	All'd Cycle	Actual
C3365/14	4	80	309	3	AC1P	240	8.5		AC1P	240	3.5		CB2S CB4	90 109*	1.9 2.3		DEB	15 12	8.6 6.9		DS2 DS4	15 45*	1.0 1.0		GRE	30 90*	1.5 1.5*					
C3467/18	8	46	255	2	CC4 CC5	120 81	3.3 2.2		CC4 CC5	150 101	4.3 2.9																					
C3467/19A	5	104	674	2	AT1 CB4	400 210*	2.2 6.0*		CB2 CB4	60 90*	1.9 1.2		HHW HI	180 90*	2.2 1.8		GRE	90*	3.0*													
C3467/30	9	60	499	1	AB24* CB4	180 175*	1.3 4*		CB2° CB4	90 104	1.5 1.7		OUTZ																			
C3472/10	4	64	224	4	AC1° AC1P	120	5.1		AC1° AC1P	120	3.4		DS2° DS4	20 45*	1.0 1.0		DEB°	15 12	5.8 4.7													
C3500/5	8	3	44	1	CC4° CC5	220 191	10.3 8.9		CC4 CC5	410 356	13.5 11.7																					
C3607/7	4	20	97	2	CC4° CC5	160 139	7.8 6.8		CC4° CC5	160 139	10.0 8.7		HP°	-	2.4 1.7																	
C3648/10	4	3	22	2	LC° CC5	150 150*	55.0 55*		LC° CC5	150 180*	27 22*		DR2° DS4	10 95*	15.0		RF	- -	2.5 2.0		HP	-	6.4 4.3									
C3648/12	3	11	166	1	CB2S° CB4	200 242	5.75 6.7		CB4°	90 138	1.8 2.7																					
C3648/13	7	113	654	2	CB2S° CB4	150 182	6.5 7.9		CB4°	90 138	1.5 2.3																					
C3648/14	7	67	377	2	CB2S° CB4	150 182	6.5 7.9		CB4°	90 138	1.5 2.3																					
C3706/9	8	37	217	2	AC1° AC1P	200	5.9		AC1° AC1P	240	3.8		DEB	15 12	6.4 5.2																	
C3706/12	8	35	218	2	AC1P°	120	3.75		AC1P°	240	7.2		AC1° AC1P	240	3.7		DEB°	15 12	6.5 5.2		CC5°	120 104	3.5 3.0		CC5°	120 104	4.4 3.8					
C3706/18	8	42	303	2	AC1° AC1P	240	4.3		AC1° AC1P	240	3.6		DEB°	15 12	1.0 0.8		VF°	10 8.0	1.0 0.8													
C3711/50	3	8	90	1	AB50° CB4	60 180*	4.8 12*		DEB°	-	1.0 0.7		KE° MH	15 90*	1.5 1.1		HDN°	-	10.5 10.5		SB°	-	0.4 0.4		OUT2	-	-					
C3711/52	3	9	127	1	AB50° CB4	60 180*	2.3 30*		D&B°	-	1.0 0.7		KE° MH	15 90*	1.5 1.1		HDN°	- -	5.25 5.3		SB°	-	0.4 0.4		OUT2	-	-					
C3711/104	3	41	311	2	AB50 CB4	60 195*	2.3 8.5		DS2 DS4	30 45*	3.0 2.5		CC4 CC5	60 120*	4.0 4.0*		CC4 CC5	60 90*	2.5		DEB	-	2.0 1.4									
C3711/106	5	5	60	1	CB4° CB4	30 90*	18.0 12.2		DS2° DS4	15 45*	3.0 2.5		HHD° MH	15 90*	4.0 3.3		FIT°	- -	3.0 2.1													
C3711/107	3	35	214	2	AB50 CB4	60 150*	3.0 6.5*		DS2 DS4	15 45*	6.0 5.0		CC4 CC5	90 60.1	4.0 2.7		CC4 CC5	120 81	4.0 2.7		DEB	-	2.5 1.8									
C3711/55	10	5	42	1	CC4 CC5	30 90*	18.0 12.2																									

FIG.2. Sheet 2 of 4

Part No.	Comp. Run No.	MU	Qo	F	1ST OP				2ND OP				3RD OP				4TH OP				5TH OP				6TH OP				7TH OP			
					m/c	Setting	All'd Cycle	Actual	m/c	Setting	All'd Cycle	Actual	m/c	Setting	All'd Cycle	Actual	m/c	Setting	All'd Cycle	Actual	m/c	Setting	All'd Cycle	Actual	m/c	Setting	All'd Cycle	Actual	m/c	Setting	All'd Cycle	Actual
C3727/9	10	4	63	1	CC4^o CC5	30 360°	28.0 18.9		DS2^o DS4	10 45°	3.0 3.5																					
C3800/7	7	8	98	1	CH2 CB4	60 90°	3.0 1.9		OUT2				CB2 CB4	90 58	3.75 2.4		CB2 CB4	30 90°	1.25 0.8		DS2 DS4	10 45°	1.25 1.0		HDN	-	-					
C3812/44	3	19	183	1	AB1W^o CB4	300 195°	2.1 8.5°		DS2^o DS4	10 8.2	5.0 4.1		CC4^o CC5	120 120°	4.0 4.0°		FIT*	-	2.0 1.4													
C3839/15	3	9	94	1	AB50 CB4	60 175°	4.5 1.2°		DEB	-	1.0 0.7		KE MH	15 90°	1.5 1.1		HDM		10.5 10.5		SB	-	0.4 0.4		OUT2	- -	- -					
C3839/114	5	4	68	1	CC4 CC5	120 220°	18.0 15.0°		CC4 CC5	90 90°	3.0 3.0°		MHW MH	30 90°	3.7 3.0		DS2 DS4	30 45°	6.0 5.0		DEB	45 32	2.0 1.4		GRE	20 75°	5.0 4.0					
C4011/9	3	8	98	1	CC4^o CC5	300 260	10.3 9.0		CC4^o CC5	165 143	3.1 2.7		OUT2 -	-	-																	
C4188/9	8	10	94	1	CC4^o CC5	160 139	6.0 5.2		CC4^o CC5	140 122	4.0 3.5		OUT2																			
C4188/21	3	7	65	1	CB2S^o CB4	185 224	5.2 6.3		CB2S^o CB4	30 75°	1.2 1.5		OUT2																			
C10162/6	3	56	324	2	CB2R CB4	180 180	2.1 3.2		CB4	60 90°	4.0 2.7		DS3 DS4	20 45°	2.0 1.6		CB2 CB4	20 60°	1.5 1.0													
C10190/38	7	10	149	1	CB2S^o CB4	265 321	9.0 10.9		CB2S^o CB4	65 90°	2.1 2.5																					
C10190/77	3	2	50	≤1	CB4^o	240 368	12.5 19.2		CB4^o	150 230	9.4 14.4		GRE^o	120 125	8.4 8.8		DS^o DS4	10 45°	1.0		KE^o MH	45 90°	3.0 2.3		MH	90 70	1.75 1.4		B4^o	120 184	6.3 9.7	
C10190/176	9	2	46	<1	CB2S^o CB4	120 145	6.0 7.3		CB2S^o CB4	120 145	7.0 8.5		MH^o	150 117	3.5 2.7		MH^o	45 90°	2.0 1.6		DEB^o	15 12	2.4 1.9		HDN^o	-	5.0		B2B^o B4	125 151	7.0 8.5	
					DS2^o DS4	20 45°	2.5 2.6		HDN^o	-	2.5		GRE^o	120 120	5.0 5.0		GRE^o	120 120	23.5 23.5		TR^o	-	-									
C10540/19	4	19	113	2	AC2W^o CC5	180 191°	3.4 14°		AC2W^o CC5	300 410°	14.0 47°		DHVC DS4	60 75°	3.5 20.6		DS1 DS4	15 45°	1.4 0.8		VF	-	1.0 0.8		DEGA	15 17	2.0 2.3		IP	-	2.2 1.5	
C10540/216	4	22	122	2	AC2W^o CC5	180 191°	3.4 14°		AC2W^o CC5	300 410°	14.0 4.7°		DHVC^o DS4	60 75°	3.5 20.6		DS1^o DS4	15 45°	1.4 0.8		DS2^o DS4	30 45°	1.2 1.3		VF	-	1.0 0.8		EGA	15 17	2.0 2.3	
					HP	-	22 15																									
C10578/14	7	7	125	1	CB4	150 230	6.1 9.3		CB2S CB4	125 151	3.6 4.4																					
C10595/35	3	13	136	1	CB4	160 122	20 13.5		CB4	150 101	15.0 10.0		HDM	-	7.84		HDM	-	31.35		SB	-	0.78		OUT2							
C10725/13	5	10	139	1	AB1W CB4	240 240°	3.96 12.5		DEB	-	0.8 0.6		OUT2				MHW MH	150 90°	2.15 1.8		DEB	-	0.3 0.2									
C10725/17	3	5	81	1	CC4 CC5	60 150°	6.0 4.0		CC4 CC5	60 150°	6.0 4.0		DS2 DS4	10 45°	1.2 1.0																	
C1060E/7	3	20	265	1	CB2S CB4	180 218	3.9 4.7		CB4	120 184	2.2 3.4																					

FIG 2.

Sheet 3 of 4

Part No.	Comp. Run No.	M.U.	Qo	F.	1st OP M/C	1st OP Setting	1st OP All'd Cycle	1st OP Actual	2nd OP M/C	2nd OP Setting	2nd OP All'd Cycle	2nd OP Actual	3rd OP M/C	3rd OP Setting	3rd OP All'd Cycle	3rd OP Actual
C10807/8	8	5	34	2	CC4 CC5	30 20	16.0 10.8		DS2 DS4	10 45°	3.0 2.5					
C11199/66	4	3	25	1	CC4 CC5	105 71	27.5 18.6		CC4 CC5	60 90°	10.0 6.8		DS2 DS4	45 37	3.75 3.1	
C11304/101	9	22	173	2	AB30 CB4	200 300°	7.0 11°		MH	90 70	1.95 1.5					
C11304/109	7	25	260	1	CB2° CB4	150 173	6.0 6.9		CB2° CB4	120 138	3.0 3.5					
C11304/112	7	24	202	1	CB25 CB4	180 218	7.0 8.5		CB25° CB4	120 145	2.5 3.0					
C11304/228	5	9	129	1	CB25 CB4	240 290	9.1 11.0		CB25 CB4	120 145	2.0 2.4		MH	90 70	2.0 1.6	
CB211/13	9	162	922	2	CB25° CB4	180 218	3.0 3.6		MSL° MH	30 90°	0.6 1.2					
CB361	4	1	10	1	LC° CC5	15 600°	195.0 195°		DS2° DS4	15 45°	10.0 10.5					
CB363	4	1	18	1	LC° CC5	15 600°	90.0 90.0°		DS2° DS4	15 45°	3.0 3.1					
CB377	3	151	760	2	CB4°	170 260	3.3 5.1		CB4°	80 122	1.95 3.0					
CB378	3	91	604	2	CB4	170 260	3.3 5.1		CB4	80 122	1.90 3.0					
CD608	5	2	37	1	CB4°	340 521	37.0 5.6		CB4°	90 138	1.95 3.0		MH°	25 19.5	2.5 2.0	
PT7374/15	5	10	156	1	CB23 CB4 DEB	240 408 15 15	11.8 20.1 6.6 6.5		CB2 CB4 HDM	140 161	7.3 8.4 1.07		LSC CC5 OB	90 88 -	2.0 5.9 0.43	
PT7374/89	5	2	48	1	CBS LSC CCS	Central bar stores 77 75	 6.8 20.0		CB2 CB4 LSC CC5	90 104 77 75	8.0 9.2 2.5 7.3		LPS CB4 OB	180 148 -	5.7 9.4 1.9	

Part No.	4th OP M/C	4th OP Setting	4th OP All'd Cycle	4th OP Actual	5th OP M/C	5th OP Setting	5th OP All'd Cycle	5th OP Actual	6th OP M/C	6th OP Setting	6th OP All'd Cycle	6th OP Actual	7th OP M/C	7th OP Setting	7th OP All'd Cycle	7th OP Actual
C10807/8																
C11199/66																
C11304/101																
C11304/109																
C11304/112																
C11304/228																
CB211/13																
CB361																
CB363																
CB377																
CB378																
CD608																
PT7374/15	DS DS4	110 110	5.0 5.0		MH	150 128	1.6 1.4		MH	150 128	7.4 6.3		CB2 CB4	60 90°	4.5 5.2	
PT7374/89	LPS CB4	180 148	6.7 11.0		CB2 CB4	60 69	3.25 3.7		KE MH	60 90°	10.0 7.5		GRE	120 120	16.5 16.5	

FIG.2 Sheet 4 of 4

CALCULATION OF DEPARTMENTAL RATES FOR PROPOSED SPARES MANUFACTURING CELL

CONTENTS

APPENDIX 9

Proposed Spares Manufacturing Cell

Summary of labour/overhead costing rate per Minute based on Budget 1977/78

Basis →	ALLOWED HOURS BASIS						MACHINE
Set/Exc % Good output →	20% Set/Exc		40% Set/Exc		50% Set/Exc		53.846% Set/Exc
Machine Tools included →	Second Hand	New	Second Hand	New	Second Hand	New	Existing
	£ dec	£ dec	£ dec	£ dec	£ dec	£ dec	£ dec
METHOD X (Services allocated pro-rata 606 Department for TA 640 Department for MC)							
Allowed hours section	.0654	.0689	.0763	.0804	.0818	.0861	
Auto machine hours Section							.1299
Combined Allowed hours	.0631	.0656	.0703	.0731	.0737	.0766	
METHOD Y (Services allocated on basis service received)							
Allowed hours section	.0564	.0599	.0658	.0698	.0705	.0748	
Auto rate hours section							.0970
Combined allowed hours	.0525	.0550	.0614	.0614	.0643		

EXISTING DEPARTMENTS

606 Light machine	Labour/overhead costing rate "Allowed hour"basis	£.0679
640 Auto machine	Labour/overhead costing rate "Machine hour" basis	£.1108

APPENDIX 9

Proposed Spares Manufacturing Cell

Allowed Hours - Costing Rates for Labour and Overheads

X METHOD:- Services Allocated as Pro-rata 606 Department.	Compare with 606	Spares Manufacturing Cell with Set/Excesses at:		
		20%	40%	50%
	£ dec	£ dec	£ dec	£ dec
Second-hand machines Costing Rates per Allowed Hour				
Direct Labour	.7691	.7717	.9003	.9647
Overhead (Second Hand)	3.3040	3.1538	3.6795	3.9423
TOTAL	4.0731	3.9255	4.5798	4.9070
Total rate per allowed minute	.0679	.0654	.0763	.0818
	100%	96.32%	112.37%	120.47%
	↓ same			
New machines Costing Rates per Allowed Hour				
Direct Labour	.7691	.7717	.9003	.9647
Overhead (new)	3.3040	3.3628	3.9232	4.2035
TOTAL	4.0731	4.1345	4.8235	5.1682
Total rate per allowed minute	.0679	.0689	.0804	.0861
	100%	101.47%	118.41%	126.80%
% increase of new over second-hand =	-	+ 5.35%	+ 5.37%	+ 5.26%
Y METHOD:- Services allocated Basis work done est.				
Second-hand machines Costing Rates per Allowed Hour				
Direct Labour	.7691	.7717	.9003	.9647
Overhead (Second Hand)	3.3040	2.6107	3.0458	3.2634
TOTAL	4.0731	3.3824	3.9461	4.2281
Total rate per allowed minute	.0679	.0564	.0658	.0705
	100%	83.06%	96.91%	103.83%
New machines Costing Rates per Allowed Hour				
Direct Labour	.7691	.7717	.9003	.9647
Overhead (new)	3.3040	2.8196	3.2896	3.5246
TOTAL	4.0731	3.5913	4.1899	4.4893
Total rate per allowed minute	.0679	.0599	.0698	.0748
	100%	88.22%	102.80%	110.16%
% increase of new over second-hand	-	+ 6.21%	+ 6.08%	+ 6.10%

APPENDIX 9

Proposed Spares Manufacturing Cell

(Obsolete Production Items)

Allowed Hours - Service Overhead Allocation pro rata basis

MACHINING ALLOWED HOURS

Gross Allowed Hours	AA31	=	17,811	= 14.1%
Compare 606 Allowed Hours		=	126,297	= 100%

ALLOCATION OF WORKS AND TECHNICAL SERVICES

			£	£
To 606	= £229,173	=	32,313	32,313
Direct charge overhead to spares manufacturing		=	14,498 (s/hand)	17,598 (new)
DL = £11,455	TOTAL OVERHEAD	=	46,811	49,911

GAH RATES

(1)	Spares Manufacturing DL = £.6431 overheads	=	£2,6282	£2.8023
(2)	606 Department DL = £.6463 overheads	=	£2.7765	-

CASTING RATES

		DL	overheads second-hand	overheads new
(1)	Spares Manufacturing			
	(a) 50% set/excess	.9647	3.1423	4.2035
	(b) 40% set/excess	.9003	3.6795	3.9232
	(c) 20% set/excess	.7717	3.1538	3.3628
(2)	606 Department			
	(a) 19% set/excess	.7691	3.3040	

Proposed Spares Manufacturing Cell **APPENDIX 9**

Machine Hours - Costing Rates for Labour & Overheads

	Compare with 640	Spares Manufacturing Cell
X Method:- Service Allocated as pro-rata 640 Dept.	£ dec	£ dec
Machine Hours Basis		
Costing rates per machine hour		
Direct Labour	.4855	1.1058
Overhead	6.1651	6.6871
TOTAL	6.6506	7.7929
Total rate per machine minute	.1108	.1299
	100%	117.24%
Y Method:- Service allocated basis work done estimate		
Costing rates per machine hour		
Direct Labour	.4855	1.1058
Overhead	6.1651	4.7143
TOTAL	6.6506	5.8201
Total rate per machine minute	.1108	.0970
	100%	87.55%
	5 men 23 machines	1 man 2 machines

Proposed Spares Manufacturing Cell

(Obsolete Production Items)

Machine Hours - Service Overhead Allocation Pro Rata Basis

AUTO MACHINING - MACHINE HOURS

Gross Machine Hours AA32	= 3872	=	8%
Compare 640 Machine Hours	= 48576	=	100%

ALLOCATION OF WORKS AND TECHNICAL SERVICES — £

As 640 = £121,801 then 8%		= 9,744
Direct Charge overhead to Spares Manufacturing		= 7,086
DL = £2,783	TOTAL OVERHEAD	= 16,830

G MACHINE RATE

(1) Spares Manufacturing

DL = £.7188 Overhead = £4.3466

(2) 640 Department

DL = £.3156 Overhead = £4.0073

COSTING RATE

(1) Spares Manufacturing

DL = £1.1058 Overhead = £6.6871

(2) 640 Department

DL = £ .4855 Overhead = £6.1651

Proposed Spares Manufacturing Cell

APPENDIX 9

"Combined" Allowed Hours - Costing Rates Labour/Overhead

	Direct Labour	METHOD X		METHOD Y	
		Overheads Second-Hand	Overheads New	Overheads Second-Hand	Overheads New
	£	£	£	£	£
Allowed Hour Section	11,455	46,811	49,911	38,750	41,850
Machine Hour Section	2,783	16,830	16,830	11,865	11,865
TOTALS	14,238	63,641	66,741	50,615	53,715
TOTALS LABOUR & OVERHEAD		77,879	80,979	64,853	67,953
		£ dec	£ dec	£ dec	£ dec
GROSS ALLOWED HOUR LABOUR/ OVERHEAD RATE		2.9235	3.0399	2.4345	2.5509
Costing labour/overhead rate hour:- Assuming "Allowed"-hour Section Set/Exc at varying % of good output ↓ Auto including machine section					
(1) 20% = 29.43%		3.7839	3.9345	3.1510	3.3016
(2) 40% = 44.31%		4.2189	4.3869	3.5132	3.6812
(3) 50% = 51.25%		4.4218	4.5978	3.6822	3.8582
Costing labour/overhead rate minute					
Allow at Set/Excess — Including auto machine					
(1) 20% = 29.43%		.0631	.0656	.0525	.0550
(2) 40% = 44.31%		.0703	.0731	.0586	.0614
(3) 50% = 51.25%		.0737	.0766	.0614	.0643

Proposed Spares Manufacturing Cell

APPENDIX 9

"Combined"Allowed Hours - Good Output/Excess Hours Calculations

	Gross Allowed Hours	Good Output Allowed Hrs	Set/ Exc
Allowed Hours Section 50% set/exc	17,811	11,874	5,937
Machine Hours Section 3872 x 2.28	8,828	5,738	3,090
	26,639	17,612	9,027
		100%	51.25%
Allowed Hours Section 40% Set/exc	17,811	12,722	5,089
Machine Hours Section 3872 x 2.28	8,828	5,738	3,090
	26,639	18,460	8,179
		100%	44.31%
Allowed Hours Section 20% Set/exc	17,811	14,843	2,968
Machine Hours Section 3872 x 2.28	8,828	5,738	3,090
	26,639	20,581	6,058
		100%	29.43%

APPENDIX 9

Proposed Spares Manufacturing Cell

Average Rates Per Man Per Year

	DL	Overheads	Associated Pension
	£	£	£
Direct Labour			
Skilled "Allowed"	2,923	796	135
Semi skilled "Allowed	2,687	731	124
Auto Loader	2,783	740	128
Indirect Labour			
Setter		4,206	153
Staff			
Chargehand			383

Note

Based on budget 1977-78
excluding last quarter increment

MACHINE TOOL PURCHASE COSTS

1. New as at May 1978

Herbert No. 4/5 bar capstan	£17,500
Herbert No. 5 chucking capstan	£18,500
4 spindle drill	£ 6,000
Medium size horizontal mill	£ 6,595
GIEWONT T.U.R. 49" x 12" table	

2. Secondhand as at May 1978

	Bennetts Machine Tool Centre	ADA Machinery Limited
Herbert No. 4/5 bar capstan	£5,500	£7,000
Herbert No. 5 chucking capstan	£5,000	£7,000
4 spindle drill	£3,000	£3,000
Medium horizontal mill	£6,000	£3,000
Rebuilt	£9,750	

CALCULATION OF STOCK & WORK IN PROGRESS SAVINGS

1. Stock Savings

The finished stock saving is expected to be 7.5 weeks. This figure results from a comparison of the stock levels predicted by the stock control simulation for:

a) current lead times

b) the 8 weeks lead times estimated for the pilot unit

This reduction assumes implementation of the new stock control rules. The total monthly usage value of the selected range of parts is £5,000.

The finished stock reduction

= 7.3 x 5,000/4

= £9,125

The reduction in stockholding costs, assuming a cost rate of 20% is therefore

= £9,125 x 0.2

= £1,825 p.a.

2. Work in progress savings

The majority of the components in the group have all or part of the production process sub-contracted. For these parts, the investment in work in progress relates only to the material cost for those operations which are performed by the sub-contractor. The work in progress value calculation therefore takes this factor into account.

The reduction in lead time is estimated as 11 weeks (see Love and Peckett, 1977,App12). The reduction in the value of work in progress has been calculated on the following basis:-

a) Components which are not sub-contracted

Value = sum for all parts {(material cost +) (half labour and) (overhead)} x $\frac{11}{4}$ x {Monthly Usage}

= £4,977

b) Components with some operations sub-contracted

An analysis of this class of component showed that an average of half the operations were sub-contracted. The proportion of the labour and overhead to be included in the calculation was taken to be a quarter rather than half the total for each part.

Value = sum for all parts {(material cost +) (quarter labour) (and overhead)} x $\frac{11}{4}$ x {Monthly Usage}

= £1,380

c) Components totally sub-contracted

In this case only the material cost should be included.

Value = sum for all parts (material cost x $\frac{11}{4}$ x monthly usage)

= £1,129

The total value of the work in progress reduction equals the sum of a, b, and c.

Work in progress reduction	=	£7,486 say £7,500
Reducted stockholding cost	=	£7,500 x 0.2
		= £1,500 p.a.

3. Summary

Total stock saving	=	£16,625	say	£16,600
Total reduction in holding costs	=	£3,325 p.a.	say	£3,300 p.a.

Appendix 12 Simulation Program Listing

```
*COMPILE MAS,NOLIST,NOTABLE,PACK
  THERE ARE  19 MACHIN  SET STOP GROUP 39  WITH TIME TITOBK MACJOB
 & TSET TPROC TCYC
 & SETBK SDTBK MNTBK SEBK SDBK MNBK  STRING MCNAME(5) MACTYP(1)
 & HIST MCREC(8,1,1)
  THERE ARE  13 MAN  SET IDLE  WITH PERF TIME TITOAB TITOFW LIMIT
 & TOTFWK TOTSET TOTPRC TOTCYC
 &   STRING MANAME(5)  HIST MNREC(9,1,1) HRREC(10,1,1)
  THERE ARE  200 JOB  SET WAIT POOL AWISSUE GRPQUE 39 CURJOB MAN
 & TEMP PLAN  WITH TIME SETING RECYTI MCHOUR STDAY
 & RESETI REPRTI LEADTM BATCH DUEDATE ORDERNO PRIORITY
 & STRING PARTNO(16) REAL AVLOAD
  THERE ARE  73 PART  SET PTPOOL WITH BCHQTY  DEMAND STRING NUMBER(16)
  THERE ARE  39 GROUPS  SET ROUTE JOB  PSKILL MAN  SSKILL MAN
 & MROUTE PART  WITH STRING GRNAME(5)
 & HIST HATGP( 30,1,1) HFORGP( 30,1,1)
  THERE ARE 110 SETIME  SET SROUTE JOB  MSROUTE PART  TEMST
 & WITH SVALUE
  THERE ARE  83 PRTIME  SET PROUTE JOB MPROUTE PART  TEMPR
 & MCROUTE PART  CROUTE JOB  WITH PVALUE
  THERE ARE  19 LDTIME SET MLROUTE PART  LROUTE JOB  WITH LVALUE
  THERE ARE  20 ORDER  SET ORPOOL AWPLAN  WITH TIME DUEDAY NORDER
 & QTY  STRING PARTNAME(16)
  HIST  HTWIPA( 30,1,1)
  HIST  HTWIPC( 30,1,1)
  HIST  HISSUA( 30,1,1)
  HIST  HISSUC( 30,1,1)
  HIST  HAWISA( 30,1,1)
  HIST  HAWISC( 30,1,1)
  HIST  HLETIM( 30,1,1)
  HIST  HLEJOB( 30,1,1)
  HIST  HDVTIM( 30,1,1)
  HIST   HLEAD( 40,    100,    100)
  HIST    HDEV( 40,    100,    100)
  HIST  HLDLIS( 40,    100,    100)
  HIST  HLDLTL( 40,    100,    100)
  HIST  HLDLNI( 40,    100,    100)
  HIST  HLDLNT( 40,    100,    100)
  STRING  SPACE(10) SPV(5),CLERK(5),CYCLE(1),OUT(5),GROUTA(5),GROUTB(5)
  HIST  SICK(2,0,1440)
  HIST ZASTOP  (MACHIN+1,0,1)
  HIST WSTOP  (20,   0,  10)
  HIST ZBIDLE  (MAN   +1,0,1)
  HIST WIDLE  (20,   0,  10)
  HIST ZCWAIT  (JOB   +1,0,1)
  HIST WWAIT  (20,  0, 100)
  HIST HPTORD(PART,1,1)
```

```
REAL  WIP REM RBFREC RVM RVSD TOTLED TOTDEV TOTODV
REAL USET UPROC UCYC UTOT
FUNCTION PICTURE  MINOF  FIX   NORMAL  SAMPLE  FREQUENCY FLOAT
FUNCTION   SIN MEAN DEVIATION TOTAL RANDOM
FOR MACHIN A
  READ MCNAME OF MACHIN A
FOR MACHIN A
  READ MACTYP OF MACHIN A
READ FOR MACHIN A (MNBK OF MACHIN A)
READ FOR MACHIN A (SDBK OF MACHIN A)
READ FOR MACHIN A (SEBK OF MACHIN A)
READ FOR MACHIN A (MNTBK OF MACHIN A)
READ FOR MACHIN A (SDTBK OF MACHIN A)
READ FOR MACHIN A (SETBK OF MACHIN A)
FOR GROUPS E
  READ GRNAME OF GROUPS E
FOR MAN B
  READ MANAME OF MAN B
READ FOR MAN B (LIMIT OF MAN B)
READ FOR MAN B (TITOFW OF MAN B)
READ FOR MAN B (PERF OF MAN B)
FOR PART P
  READ NUMBER OF PART P
READ FOR PART P (BCHQTY OF PART P)
READ FOR PART P (DEMAND OF PART P)
READ FOR SETIME S (SVALUE OF SETIME S)
READ FOR PRTIME P (PVALUE OF PRTIME P)
READ FOR LDTIME L (LVALUE OF LDTIME L)
READ NOGRPS
FOR I = 1,NOGRPS
  READ NOMCS
  FOR J = 1,NOMCS
    READ MC
    MACHIN.MC  INTO  GROUP.I
READ NOMEN
FOR I = 1,NOMEN
  READ NOSSK
  CHAIN
    NOSSK  GT  0
    FOR J=1,NOSSK
      READ SSK
      GROUPS SSK  INTO  SSKILL OF MAN I
    OR CONTINUE
  READ NOPSK
  CHAIN
    NOPSK  GT  0
    FOR J=1,NOPSK
      READ PSK
      GROUPS PSK  INTO  PSKILL OF MAN I
    OR CONTINUE
READ NOPART
FOR I = 1,NOPART
  READ NOOPS
```

```
  FOR J = 1,NOOPS
    READ TP,GP,ST,PT,CT,LDT
    GROUPS GP  INTO  MROUTE OF PART I
    FIND FIRST SETIME S
      SVALUE OF SETIME S  EQ  ST
      SETIME S  NOTIN  MSROUTE OF PART I
    FIND FIRST PRTIME P
      PVALUE OF PRTIME P  EQ  PT
      PRTIME P  NOTIN MPROUTE OF PART I
    SETIME S  INTO  MSROUTE OF PART I
    PRTIME P  INTO  MPROUTE OF PART I
    CHAIN
      TP  EQ  999
      FIND FIRST PRTIME Y
          PVALUE OF PRTIME Y  EQ  CT
          PRTIME Y  NOTIN  MCROUTE OF PART I
      PRTIME Y  INTO  MCROUTE OF PART I
      FIND FIRST LDTIME L
          LVALUE OF LDTIME L  EQ LDT
          LDTIME L  NOTIN  MLROUTE OF PART I
      LDTIME L  INTO  MLROUTE OF PART I
      OR CONTINUE
 READ ISSDAY
 FOR MACHIN
   TITOBK=NORMAL( MNTBK , SDTBK , SETBK )+CLOCK
 FOR MAN
   TITOAB=NORMAL( MNTAB , SDTAB , SETAB )+CLOCK
 PRINT // '**MACHINE DATA**'/
 PRINT  '**MACHINE BREAKDOWN DATA**' /
 PRINT' NAME   MNBK   SDBK   SEBK  MNTBK  SDTBK  SETBK'
 FOR MACHIN A
   PRINT *6 MCNAME OF MACHIN A  MNBK OF MACHIN A  SDBK OF MACHIN A
&     SEBK OF MACHIN A  MNTBK OF MACHIN A  SDTBK OF MACHIN A
&     SETBK OF MACHIN A /
 PRINT//'**MAN WORKING DATA**'
 PRINT/' NAME  WORK PERIOD  NO.OF MCS.RUN  PERFORMANCE'
 FOR MAN B
   PRINT / *8 MANAME OF MAN B'  '  TITOFW OF MAN B  '     '
&       LIMIT OF MAN B '     'PERF OF MAN B
 PRINT //'**MEN SICKNESS & ABSENCE DATA**' /
 PRINT'   SICKNESS HISTOGRAM...................' SICK
 PRINT'   MEAN TIME ABSENT.....................' MNAB
 PRINT'   STANDARD DEV. TIME ABSENT............' SDAB
 PRINT'   SEED FOR TIME ABSENT.................' SEAB
 PRINT'   MEAN TIME BETWEEN ABSENCES...........' MNTAB
 PRINT'   STANDARD DEV. TIME BETWEEN ABSENCES..' SDTAB
 PRINT'   SEED FOR TIME BETWEEN ABSENCES.......' SETAB
 PRINT / '**CONTENT OF MACHINE GROUPS**'/
 FOR GROUPS D
   PRINT'   MACHINES IN GROUP 'GRNAME OF GROUPS D
&        FOR MACHIN A IN GROUP D (' 'MCNAME OF MACHIN A)
 PRINT / '**SETTING & PROCESS SKILLS OF THE MEN**'/
 FOR MAN B
```

```
  PRINT' MAN 'MANAME OF MAN B
&       '     CAN SET 'FOR SSKILL OF MAN B (GRNAME' ')
  PRINT'            CAN OPERATE 'FOR PSKILL OF MAN B  (GRNAME' ')
 PRINT / '**ROUTE & PROCESS DATA FOR PARTS RANGE**' /
 FOR PART P
  PRINT / 'PART NUMBER   -'NUMBER OF PART P /
& '-------------'/'BATCH QTY      -'*5 BCHQTY OF PART P
  PRINT 'DEMAND          -' *5 DEMAND OF PART P
  PRINT 'ROUTE           -'FOR MROUTE OF PART P(' 'GRNAME)
  PRINT 'SETTING TIMES -'*5 FOR MSROUTE OF PART P (' 'SVALUE)
  PRINT 'PROCESS TIMES -'*5 FOR MPROUTE OF PART P (' 'PVALUE)
  PRINT '  CYCLE TIMES -'*5 FOR MCROUTE OF PART P(' 'PVALUE)
  PRINT 'LOADING TIMES -'*5 FOR MLROUTE OF PART P (' 'LVALUE)
 CHAIN
  SCHED  EQ  1
  PRINT//'SHOP FLOOR RESCHEDULING SPECIFIED - SELECTION CRITEREA'
  CHAIN
    RULE  LE  2
    PRINT'MIN DUEDATE'
    OR RULE  EQ  3
    PRINT'MIN REMAINING SETTING TIME PER BATCH'
    OR RULE  EQ  4
    PRINT'MIN REMAINING PROCESSING TIME PER BATCH'
    OR RULE  EQ  5
    PRINT'MIN SETTING + PROCESS TIME PER BATCH'
    OR RULE  EQ  6
    PRINT'MIN FLOAT PER BATCH'
    OR RULE  EQ  7
    PRINT'BATCHES SELECTED AT RANDOM'
    OR PRINT'RULE NUMBER OUT OF RANGE'
  OR PRINT'SHOP FLOOR RESCHEDULING NOT SPECIFIED'
 CHAIN
  ORFREQ NE 0
  PRINT // ' AUTOMATIC ORDER GENERATOR ON'
  PRINT/' ORDERING FREQUENCY - ' *6  ORFREQ ' MINUTES'
  PRINT  ' SEED FOR AUTO GENERATOR - ' SEORD
  OR CONTINUE
 CHAIN
  TRACK  EQ  1
  PRINT / '**** JOB TRACK MONITORING ON ****' /
  OR CONTINUE
 CHAIN
  LEADMON  EQ  1
  CHAIN
    LDFRPLAN  EQ  1
    PRINT //'*** LEAD TIME MONITOR ON - FROM PLANNING STAGE ***'/
    OR PRINT //'*** LEAD TIME MONITOR ON - FROM ISSUE STAGE ***'/
  OR CONTINUE
 CHAIN
  MNSTOF  NE  0
  MNENOF  NE  0
  PRINT / '**** QUEUE MONITORING ON ****'// '**MACHINE & MAN NAME'
&          ' / NUMBER EQUIVELENTS**'
```

```
  PRINT / '    MACHINE NO.   MACHINE NAME'
  FOR MACHIN A
    PRINT *2'          ' A '              'MCNAME OF MACHIN A
  PRINT / '          MAN NO.       MAN NAME'
  FOR MAN B
    PRINT *2 '         ' B '              'MANAME OF MAN B
  OR CONTINUE
 PREVCLOCK=RUNINZ
 PRINT //'  LENGTH OF SIMULATION -'*8 RUNTIME ' MINS'
&        '   RECORDING STARTED AFTER -'RUNINZ ' MINS'///
 RECYCLE
 ACTIVITIES  RUNTIME
 BEGIN BATCHFREQ
 CLOCK  EQ 0
 SWITCH ADD ON
 FOR PART P
   YD = 12* DEMAND OF PART P
   BC = BCHQTY OF PART P
   RBFREC = FLOAT(YD)/FLOAT(BC)
   RBFREC = RBFREC + 0.5
   BFREC = FIX(RBFREC)
   ADD P TO HPTORD, BFREC
 TIME OF AUTOGEN = ORFREQ
 TOTBFQ = TOTAL(HPTORD)
 PRINT //' TOTAL NUMBER OF BATCHES ORDERED PER YEAR ='*5 TOTBFQ /
 PRINT  //"BATCH FREQUENCY HISTOGRAM -"HPTORD ///
 BEGIN RECORD
 CLOCK GT RUNINZ
 DURATION=CLOCK-PREVCLOCK
 PREVCLOCK=CLOCK
 ADD AA TO ZASTOP  ,DURATION
 ADD BB TO ZBIDLE  ,DURATION
 ADD CC TO ZCWAIT  ,DURATION
 BEGIN MONITOR START
 CLOCK GE MNSTON
 CLOCK LE MNSTOF
 PRINT'    STATE OF QUEUES BEGINNING  CLOCK ='CLOCK
 PRINT'     STOP CONTAINS' *4 FOR STOP (' 'MCNAME )
 PRINT'     IDLE CONTAINS' *4 FOR IDLE (' 'MANAME )
 PRINT'     WAIT CONTAINS'*4
&     FOR WAIT(' 'ORDERNO '('PRIORITY ')')
 PRINT'     POOL CONTAINS' *4 FOR JOB I IN POOL (I)
 PRINT'  AWISSUE CONTAINS'*4 FOR AWISSUE(' 'ORDERNO )
 PRINT'   AWPLAN CONTAINS'*4 FOR ORDER I IN AWPLAN (I)
 FOR JOB I IN WAIT
   FIND FIRST GROUPS D IN ROUTE OF JOB I
   JOB I INTO GRPQUE D
 FOR GROUPS D
   PRINT'JOBS WAITING AT GROUP ' GRNAME OF GROUPS D
&       *4 FOR GRPQUE D (' 'ORDERNO )
   ZERO GRPQUE D
 BEGIN SETUP
 CLOCK  EQ  0
```

```
ISSDAY  EQ  0
FIND FIRST ORDER R IN ORPOOL
READ PARTNAME OF ORDER R
READ NORDER OF ORDER R,QTY OF ORDER R,DUEDAY OF ORDER R
LORDNO = NORDER OF ORDER R
TIME OF ORDER R  =  0
FIND FIRST PART P IN PTPOOL
  PARTNAME OF ORDER R  EQ  NUMBER OF PART P
THLEAD = 0.0
TCY = 0.0
FOR MPROUTE OF PART P
      THLEAD = THLEAD + (PVALUE * BCHQTY OF PART P)
FOR MSROUTE OF PART P
  THLEAD = THLEAD + SVALUE
FOR MCROUTE OF PART P
  TCY =TCY + PVALUE
FOR MROUTE OF PART P
  CHAIN
    GRNAME  EQ  GROUTA
    THLEAD = THLEAD - SCTIME
    OR GRNAME  EQ  GROUTB
    THLEAD = THLEAD - SCTIME
    OR CONTINUE
THLEAD = THLEAD - TCY
RVM = (FLOAT(THLEAD) / 2.3)
RVM = RVM + FLOAT(TCY)
RVM = (RVM /60.0) + 0.5
THLEAD = FIX(RVM)
X =  QTY OF ORDER R  /BCHQTY OF PART P
Y = X * BCHQTY OF PART P
CHAIN
  Y  LT  QTY OF ORDER R
  X = X + 1
  OR CONTINUE
FOR I =1,X
  FIND FIRST JOB C IN POOL
  ZERO ROUTE OF JOB C,SROUTE OF JOB C,PROUTE OF JOB C
  ROUTE OF JOB C  GAINS  MROUTE OF PART P
  PROUTE OF JOB C  GAINS  MPROUTE OF PART P
  SROUTE OF JOB C  GAINS  MSROUTE OF PART P
  CROUTE OF JOB C  GAINS  MCROUTE OF PART P
  LROUTE OF JOB C  GAINS  MLROUTE OF PART P
  BATCH OF JOB C = BCHQTY OF PART P
  PARTNO OF JOB C = PARTNAME OF ORDER R
  ORDERNO OF JOB C = NORDER OF ORDER R  + I
  PRIORITY OF JOB C = DUEDAY OF ORDER R
  DUEDATE OF JOB C = DUEDAY OF ORDER R
  JOB C  FROM  POOL  INTO  WAIT
  TIME OF JOB C  =0
  FIND FIRST SETIME G IN SROUTE OF JOB C
  RESETI OF JOB C = SVALUE OF SETIME G
  SETING OF JOB C = SVALUE OF SETIME G
  FIND FIRST PRTIME H IN PROUTE OF JOB C
```

```
    REPRTI OF JOB C = PVALUE OF PRTIME H  * BATCH OF JOB C
    RECYTI OF JOB C = 0
    MCHOUR OF JOB C = THLEAD
    PERPLAN = PERPLAN + MCHOUR OF JOB C
    CHAIN
      TRACK  EQ  1
      PRINT'JT'*8 CLOCK' SETUP  '*4' ORD 'NORDER OF ORDER R
 &           ' BCH 'ORDERNO OF JOB C ' QTY 'BATCH OF JOB C
 &           ' DUE 'DUEDATE OF JOB C ' FOR 'PARTNO OF JOB C
      OR CONTINUE
1 READ BNO  OPNO
  CHAIN
    OPNO  NE  0
    FIND FIRST JOB C  IN  WAIT
      ORDERNO OF JOB C  EQ  BNO
    FOR I=1,OPNO
      FIND FIRST PRTIME P  IN PROUTE OF JOB C
      PRTIME P  FROM  PROUTE OF JOB C
      FIND FIRST GROUPS E  IN  ROUTE OF JOB C
      GROUPS E  FROM  ROUTE OF JOB C
      FIND FIRST SETIME S  IN  SROUTE OF JOB C
      SETIME S  FROM  SROUTE OF JOB C
      FIND FIRST MACHIN A IN GROUP E
      CHAIN
        MACTYP OF MACHIN A  EQ  CYCLE
        FIND FIRST PRTIME H  IN  CROUTE OF JOB C
        PRTIME H  FROM  CROUTE OF JOB C
        FIND FIRST LDTIME L  IN LROUTE OF JOB C
        LDTIME L  FROM  LROUTE OF JOB C
        OR CONTINUE
    FIND FIRST SETIME G IN SROUTE OF JOB C
    RESETI OF JOB C = SVALUE OF SETIME G
    SETING OF JOB C = SVALUE OF SETIME G
    FIND FIRST PRTIME H IN PROUTE OF JOB C
    REPRTI OF JOB C = PVALUE OF PRTIME H  * BATCH OF JOB C
    RECYTI OF JOB C = 0
    CHAIN
      TRACK  EQ  1
      PRINT'JT'*8 CLOCK' SETUP  '*4' BCH 'BNO' HAS COMPLETED '
 &           OPNO' OPERATIONS'
      OR CONTINUE
    GO TO 1
    OR CONTINUE
  READ ISSDAY
  REPEAT 50
  BEGIN DAYCALC
  DAYNO = 1 + (CLOCK/1440)
  MONDAY=1+((DAYNO-1)/MONFAC)
  BEGIN BATCHLOAD
  DAYNO  GT  LDAY
  LDAY = DAYNO
  WIP = 0.0
  FOR JOB C
```

```
  JOB C  NOTIN  POOL
  EXISTS (1)  IN  ROUTE OF JOB C
  CHAIN
    LDFRPLAN  EQ  1
    OR JOB C  NOTIN  AWISSUE
    JOB C  NOTIN  PLAN
  TEMPR GAINS  PROUTE OF JOB C
  TEMST  GAINS  SROUTE OF JOB C
  FOR GROUPS D IN ROUTE OF JOB C
    FIND FIRST MACHIN A IN GROUP D
      CHAIN
        MACTYP OF MACHIN A  EQ  CYCLE
        REM = 1.0
        OR REM = 2.3
    FIND FIRST PRTIME P IN TEMPR
    FIND FIRST SETIME S IN TEMST
    CHAIN
      GRNAME OF GROUPS D  NE  GROUTA
      GRNAME OF GROUPS D  NE  GROUTB
      WIP=WIP+((FLOAT(PVALUE OF PRTIME P * BATCH OF JOB C)/REM)/60.0)
      WIP = WIP + ((FLOAT(SVALUE OF SETIME S)/2.3)/60.0)
      OR CONTINUE
    PRTIME P FROM TEMPR
    SETIME S FROM TEMST
  ZERO TEMPR TEMST
 FOR JOB C
  JOB C NOTIN POOL
  CHAIN
    LDFRPLAN  EQ  1
    OR JOB C NOTIN AWISSUE
  AVLOAD OF JOB C = AVLOAD OF JOB C + WIP
 PRINT'JT'*8CLOCK' TOTAL LOAD (EXCLUDING SUB-CON) ='+2WIP
& ' ON DAY 'DAYNO
 BEGIN ORDERGEN
 ISSDAY  LE  DAYNO
 FIND FIRST ORDER R IN ORPOOL
 READ PARTNAME OF ORDER R
 READ NORDER OF ORDER R,QTY OF ORDER R,DUEDAY OF ORDER R
 CHAIN
  TRACK  EQ  1
  PRINT'JT'*8 CLOCK' ORDGEN '*4' ORD 'NORDER OF ORDER R' QTY '
& QTY OF ORDER R' DUE 'DUEDAY OF ORDER R' FOR 'PARTNAME OF ORDER R
  OR CONTINUE
 READ ISSDAY
 ORDER R FROM ORPOOL INTO AWPLAN
 TIME OF ORDER R = 0
 REPEAT 50
 BEGIN AUTOGEN
 ISSDAY  GE  9999
 ORFREQ  GT  0
 TIME OF AUTOGEN  LE  0
 FIND FIRST ORDER R IN ORPOOL
 DUEDAY OF ORDER R  = DAYNO + 20
```

```
PRT = SAMPLE(HPTORD,SEORD)
PARTNAME OF ORDER R  =  NUMBER OF PART PRT
QTY OF ORDER R       =  BCHQTY OF PART PRT
LORDNO = LORDNO +10
NORDER OF ORDER R    =  LORDNO
CHAIN
  CLOCK  GE  ORSNTI
  REM = 2 * 3.14159 * FLOAT(DAYNO) / FLOAT(OPER)
  REM = SIN(REM)
  RVM = (FLOAT(OAMP)*REM*FLOAT(TOTBFQ)/100)+FLOAT(TOTBFQ)
  RVM = RVM + 0.5
  BIRATE = FIX(RVM)
  ORFREQ = 240*24*60/BIRATE
  PRINT //'JTT AUTOGEN DAYNO='*4 DAYNO' REM='REM' BIRATE='BIRATE
&   ' ORFREQ='ORFREQ'RVM='RVM
  OR CONTINUE
TIME OF AUTOGEN  =  ORFREQ
ORDER R  FROM ORPOOL  INTO  AWPLAN
PRINT'JT'*8 CLOCK' AUTOGEN'*4' ORD 'NORDER OF ORDER R' QTY '
& QTY OF ORDER R' DUE 'DUEDAY OF ORDER R' FOR' PARTNAME OF ORDER R
&' ON DAY 'DAYNO
BEGIN PLANNING
FIND FIRST MAN B IN IDLE
  MANAME OF MAN B  EQ  CLERK
FIND FIRST ORDER R IN AWPLAN
FIND FIRST PART P IN PTPOOL
  PARTNAME OF ORDER R  EQ  NUMBER OF PART P
THLEAD = 0.0
TCY = 0.0
FOR MPROUTE OF PART P
      THLEAD = THLEAD + (PVALUE * BCHQTY OF PART P)
FOR MSROUTE OF PART P
  THLEAD = THLEAD + SVALUE
FOR MCROUTE OF PART P
  TCY =TCY + PVALUE
FOR MROUTE OF PART P
  CHAIN
    GRNAME  EQ  GROUTA
    THLEAD = THLEAD - SCTIME
    OR GRNAME  EQ  GROUTB
    THLEAD = THLEAD - SCTIME
    OR CONTINUE
THLEAD = THLEAD - TCY
RVM = (FLOAT(THLEAD) / 2.3)
RVM = RVM + FLOAT(TCY)
RVM = (RVM /60.0) + 0.5
THLEAD = FIX(RVM)
X =  QTY OF ORDER R  /BCHQTY OF PART P
Y = X * BCHQTY OF PART P
CHAIN
  Y  LT  QTY OF ORDER R
  X = X + 1
  OR CONTINUE
```

```
TTFW = TITOFW OF MAN B  - CLOCK
DURATION = MINOF(TTFW,PLANTIME,2)
FOR I =1,X
  FIND FIRST JOB C IN POOL
  ZERO ROUTE OF JOB C,SROUTE OF JOB C,PROUTE OF JOB C
  ROUTE OF JOB C  GAINS  MROUTE OF PART P
  PROUTE OF JOB C  GAINS  MPROUTE OF PART P
  SROUTE OF JOB C  GAINS  MSROUTE OF PART P
  CROUTE OF JOB C  GAINS  MCROUTE OF PART P
  LROUTE OF JOB C  GAINS  MLROUTE OF PART P
  BATCH OF JOB C = BCHQTY OF PART P
  PARTNO OF JOB C = PARTNAME OF ORDER R
  ORDERNO OF JOB C = NORDER OF ORDER R  + I
  PRIORITY OF JOB C = DUEDAY OF ORDER R
  DUEDATE OF JOB C = DUEDAY OF ORDER R
  JOB C  FROM  POOL  INTO  PLAN
  JOB C FROM PLAN INTO AWISSUE AFTER DURATION
  TIME OF JOB C = DURATION
  FIND FIRST SETIME G IN SROUTE OF JOB C
  RESETI OF JOB C = SVALUE OF SETIME G
  SETING OF JOB C = SVALUE OF SETIME G
  FIND FIRST PRTIME H IN PROUTE OF JOB C
  REPRTI OF JOB C = PVALUE OF PRTIME H  * BATCH OF JOB C
  RECYTI OF JOB C = 0
  MCHOUR OF JOB C = THLEAD
  PERPLAN = PERPLAN + THLEAD
  CHAIN
    LDFRPLAN  EQ  1
    LEADTM OF JOB C  =  CLOCK + DURATION
    STDAY OF JOB C = DAYNO
    OR CONTINUE
  CHAIN
    TRACK  EQ  1
    PRINT'JT'*8 CLOCK' PLAN   '*4' ORD 'NORDER OF ORDER R' BCH '
&   ORDERNO OF JOB C' QTY 'BATCH OF JOB C' DUE '
&   DUEDATE OF JOB C' FOR 'PARTNO OF JOB C ' MCHOUR='THLEAD
    OR CONTINUE
ORDER R FROM AWPLAN INTO ORPOOL AFTER DURATION
MAN B FROM IDLE INTO IDLE AFTER DURATION
ADD -TIME OF MAN B TO  WIDLE
ADD  9  TO MNREC OF MAN B , DURATION
ADD  8  TO MNREC OF MAN B , -TIME OF MAN B
TIME OF MAN B = DURATION
REPEAT 50
BEGIN SCHEDULER
EXISTS (2) JOB IN WAIT
SCHED  EQ  1
FOR JOB C IN WAIT
  CHAIN
    RULE  EQ  1
    OR RULE  EQ  2
    PRIORITY OF JOB C = DUEDATE OF JOB C  - DAYNO
    OR RULE  EQ  3
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    PRIORITY OF JOB C =RESETI OF JOB C
    OR RULE  EQ  4
    PRIORITY OF JOB C = REPRTI OF JOB C
    OR RULE  EQ  5
    PRIORITY OF JOB C = RESETI OF JOB C  + REPRTI OF JOB C
    OR RULE  EQ  6
    COUNT GROUPS Y IN ROUTE OF JOB C
    Y  GT  0
    REM = (FLOAT(DUEDATE OF JOB C  - DAYNO)/FLOAT(Y))+0.5
    PRIORITY OF JOB C = FIX(REM)
    OR RULE  EQ  7
    PRIORITY OF JOB C = RANDOM(LEVSCH,SESCH)
    OR CONTINUE
COUNT JOB N IN WAIT
FOR I=1,N
  FIND JOB C IN WAIT WITH MIN PRIORITY
  JOB C FROM WAIT INTO TEMP
WAIT GAINS TEMP
ZERO TEMP
BEGIN INSPEC
FIND   FIRST MAN    A IN IDLE
  COUNT JOB S IN CURJOB OF MAN A
  S  LT  LIMIT OF MAN A
  MANAME OF MAN A  NE  CLERK
  (TITOAB OF MAN A  -  CLOCK)   GT   10
  (TITOFW OF MAN A  -  CLOCK)   GT   10
FIND   FIRST JOB    B IN WAIT
    ROUTE OF JOB B EMPTY
    REPRTI OF JOB    B                          LE 0
DURATION=10
ADD 1 TO INSPEC
CHAIN
  MAN    A FROM IDLE   INTO IDLE   AFTER  DURATION
  ADD -TIME OF MAN    A TO WIDLE
  ADD  4  TO MNREC OF MAN A , DURATION
  ADD  8  TO MNREC OF MAN A , -TIME OF MAN A
  TIME OF MAN    A= DURATION
  JOB    B FROM WAIT   INTO POOL   AFTER  DURATION
  ADD -TIME OF JOB    B TO WWAIT
  CHAIN
    DAYNO  EQ  STDAY OF JOB B
    OR AVLOAD OF JOB B = AVLOAD OF JOB B /(DAYNO-STDAY OF JOB B)
  LEADTM OF JOB B = (CLOCK - LEADTM OF JOB B  + DURATION)/ 60
  CHAIN
    CLOCK  GE  RUNINZ
    LEADMON  GT  0
    ADD LEADTM OF JOB B  TO HLEAD
    NOFIN= FREQUENCY(HLEJOB,MONDAY)
    CURAVE=FREQUENCY(HLETIM,MONDAY)
    XL=LEADTM OF JOB B
    REM=((FLOAT(XL)-FLOAT(CURAVE))/(FLOAT(NOFIN)+1.0))+0.5
    ADDIT=FIX(REM)
    ADD  MONDAY  TO  HLETIM , ADDIT
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      ADD  MONDAY  TO  HLEJOB ,  1
      FIND FIRST PART P
        NUMBER OF PART P  EQ  PARTNO OF JOB B
      COUNT PRTIME O IN MPROUTE OF PART P
      THLEAD = MCHOUR OF JOB B
      PERCOMP = PERCOMP + THLEAD
      LEDEV = LEADTM OF JOB B  -  THLEAD
      CURAVE = FREQUENCY(HDVTIM,MONDAY)
      REM=((FLOAT(LEDEV)-FLOAT(CURAVE))/(FLOAT(NOFIN)+1.0))+0.5
      ADDIT=FIX(REM)
      ADD  MONDAY  TO  HDVTIM  , ADDIT
      ADD  LEDEV  TO  HDEV
      REM=(FLOAT(LEDEV)/FLOAT(O))+0.5
      ODEV=FIX(REM)
      TOTLED = TOTLED + FLOAT(XL)
      TOTDEV = TOTDEV + FLOAT(LEDEV)
      TOTODV = TOTODV + FLOAT(ODEV)
      OR CONTINUE
    TIME OF JOB    B= DURATION
  CHAIN
    LDTRACK  EQ  1
    PRINT'JT'*8 CLOCK'**INSP**'*4' BCH 'ORDERNO OF JOB B
&     ' MAN 'MANAME OF MAN A ' FOR='PARTNO OF JOB B' ON DAY 'DAYNO
&   /*8+1'AV LOAD'AVLOAD OF JOB B' LEAD='*4 LEADTM OF JOB B
&' DEV='LEDEV' DEV/OP='ODEV' NO OF OPS=' O
    OR CONTINUE
  AVLOAD OF JOB B = 0.0
  STDAY OF JOB B = 0
  REPEAT 50
  BEGIN BREAK
  SWBREAK  EQ  1
  FIND   FIRST MACHIN A IN STOP
      TITOBK OF MACHIN A                    LE 0
  CHAIN
    MACJOB OF MACHIN A  GT  0
    FIND FIRST JOB C IN WAIT
        MACJOB OF MACHIN A EQ C
    FIND FIRST MAN B IN IDLE
      JOB C  IN  CURJOB OF MAN B
    OR CONTINUE
  MN = MNBK OF MACHIN A
  SD = SDBK OF MACHIN A
  DURATION = NORMAL(MN,SD,SEBK OF MACHIN A)
  ADD 1 TO BREAK
  CHAIN
    MACHIN A FROM STOP   INTO STOP   AFTER  DURATION
    ADD -TIME OF MACHIN A TO WSTOP
    ADD  7  TO MCREC OF MACHIN A , DURATION
    ADD  8  TO MCREC OF MACHIN A , -TIME OF MACHIN A
    TIME OF MACHIN A= DURATION
    MN = MNTBK OF MACHIN A
    SD = SDTBK OF MACHIN A
    TITOBK OF MACHIN A = NORMAL(MN,SD,SETBK OF MACHIN A)
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 CHAIN
     MACJOB OF MACHIN A  GT  0
     CHAIN
       DURATION  GT  MANTRANS
       DURTWO = MANTRANS
       JOB C FROM CURJOB OF MAN B
       OR DURATION  LE  MANTRANS
       DURTWO = DURATION
     TTFW = TITOFW OF MAN B - CLOCK
     DURTWO = MINOF(TTFW,DURTWO,2)
     MAN    B FROM IDLE   INTO IDLE   AFTER  DURTWO
     ADD -TIME OF MAN    B TO WIDLE
     ADD  7  TO  MNREC OF MAN B , DURATION
     ADD  8  TO MNREC OF MAN B, -TIME OF MAN B
     TIME OF MAN    B= DURTWO
     CHAIN
       (JOBTRANS * SETING OF JOB C)  LE  DURATION
       DURTHR = SETING OF JOB C
       RESETI OF JOB C = SETING OF JOB C
       MACJOB OF MACHIN A = 0
       OR (JOBTRANS * SETING OF JOB C)  GT DURATION
       DURTHR = DURATION
     JOB    C FROM WAIT   INTO WAIT   AFTER  DURTHR
     ADD -TIME OF JOB    C TO WWAIT
     TIME OF JOB    C= DURATION
     OR CONTINUE
 CHAIN
   TRACK  EQ  1
   PRINT'JT'*8 CLOCK ' BREAK  ' *4 ' BCH 'ORDERNO OF JOB C
&  ' MAN 'MANAME OF MAN B' MAC 'MCNAME OF MACHIN A
&  SPACE ' DUR' DURTHR DURTWO DURATION
   OR CONTINUE
 REPEAT 50
 BEGIN SUBCONTRACT
 FIND FIRST JOB C IN WAIT
     RESETI OF JOB C  GT  0
     CHAIN
       FIND FIRST GROUPS D IN ROUTE OF JOB C
       FIND FIRST MACHIN A IN GROUP D
       MCNAME OF MACHIN A  EQ  OUT
 DURATION = RESETI OF JOB C
 JOB C FROM WAIT INTO WAIT AFTER DURATION
 ADD -TIME OF JOB C TO WWAIT
 TIME OF JOB C  = DURATION
 RESETI OF JOB C  - DURATION
 CHAIN
   REPRTI OF JOB C EQ  0
   FIND FIRST SETIME G IN SROUTE OF JOB C
   FIND FIRST PRTIME H IN PROUTE OF JOB C
   FIND FIRST GROUPS D IN ROUTE OF JOB C
   GROUPS D FROM ROUTE OF JOB C
   SETIME G FROM SROUTE OF JOB C
   PRTIME H FROM PROUTE OF JOB C
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    OR CONTINUE
  CHAIN
    REPRTI OF JOB C  LE  0
    EXISTS(1) IN ROUTE OF JOB C
    FIND FIRST SETIME G IN SROUTE OF JOB C
    RESETI OF JOB C = SVALUE OF SETIME G
    SETING OF JOB C = SVALUE OF SETIME G
    FIND FIRST PRTIME H IN PROUTE OF JOB C
    REPRTI OF JOB C = PVALUE OF PRTIME H  *  BATCH OF JOB C
    OR CONTINUE
  CHAIN
    TRACK  EQ  1
    PRINT 'JT'*8CLOCK' SUB-CON'*4' BCH ' ORDERNO OF JOB C
 &  '          '' MAC ' MCNAME OF MACHIN A
 &  ' GRP ' GRNAME OF GROUPS D *5 ' DUR 'DURATION
    OR CONTINUE
  REPEAT 50
  BEGIN PROCES
  FIND FIRST JOB C IN WAIT
      REPRTI OF JOB C  GE  0
      EXISTS (1)  IN  ROUTE OF JOB C
      RESETI OF JOB C  EQ  0
      FIND FIRST GROUPS E IN ROUTE OF JOB C
      FIND FIRST MACHIN A IN STOP
          MACTYP OF MACHIN A  NE  CYCLE
          MACJOB OF MACHIN A  EQ  C
          TITOBK OF MACHIN A  GT  0
      CHAIN
          FIND FIRST MAN B IN  IDLE
              JOB C  IN  CURJOB OF MAN B
              (TITOAB OF MAN B - CLOCK)  GT  0
              (TITOFW OF MAN B - CLOCK)  GT  0
              GROUPS E IN PSKILL OF MAN B
          OR FIND FIRST MAN B IN IDLE
              COUNT JOB S  IN  CURJOB OF MAN B
              S  LT  LIMIT OF MAN B
              (TITOAB OF MAN B - CLOCK)  GT  0
              (TITOFW OF MAN B - CLOCK)  GT  0
              GROUPS E IN PSKILL OF MAN B
              FOR MAN F
                JOB C  IN  CURJOB OF MAN F
                JOB C  FROM  CURJOB OF MAN F
  TTAB=TITOAB OF MAN B - CLOCK
  TTBK=TITOBK OF MACHIN A
  TTFW=TITOFW OF MAN B - CLOCK
  REPRTI OF JOB C = (REPRTI OF JOB C *100/PERF OF MAN B)
  DURATION=MINOF(REPRTI OF JOB C,TTAB,TTBK,TTFW,4)
  ADD 1 TO PROCES
  CHAIN
    MACHIN A FROM STOP   INTO STOP   AFTER  DURATION
    ADD -TIME OF MACHIN A TO WSTOP
    ADD 2  TO  MCREC OF MACHIN A , DURATION
    ADD  8  TO  MCREC OF MACHIN A , -TIME OF MACHIN A
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   TIME OF MACHIN A= DURATION
   MAN     B FROM IDLE    INTO IDLE    AFTER  DURATION
   ADD -TIME OF MAN     B TO WIDLE
   ADD  2  TO  MNREC OF MAN B , DURATION
   ADD  8  TO  MNREC OF MAN B , -TIME OF MAN B
   AH=DURATION * PERF OF MAN B / 100
   ADD  2  TO  HRREC OF MAN B , AH
   TIME OF MAN     B= DURATION
   JOB     C FROM WAIT    INTO WAIT    AFTER  DURATION
   ADD -TIME OF JOB     C TO WWAIT
   TIME OF JOB     C= DURATION
   CHAIN
     REPRTI OF JOB C  EQ  DURATION
     MACJOB OF MACHIN A  =  0
     JOB C  FROM  CURJOB OF MAN B
     OR REPRTI OF JOB C    GT  DURATION
     JOB C  INTO  CURJOB OF MAN B
     OR CONTINUE
   REPRTI OF JOB C  -  DURATION
   REPRTI OF JOB C = (REPRTI OF JOB C *PERF OF MAN B  /100)
   TITOBK OF MACHIN A - DURATIION
   CHAIN
     TRACK  EQ  1
     PRINT'JT'*8 CLOCK ' PROCESS' *4 ' BCH 'ORDERNO OF JOB C
&    ' MAN 'MANAME OF MAN B' MAC 'MCNAME OF MACHIN A
&    ' GRP ' GRNAME OF GROUPS E  ' DUR' DURATION
     OR CONTINUE
   CHAIN
     REPRTI OF JOB C EQ  0
     FIND FIRST SETIME G IN SROUTE OF JOB C
     FIND FIRST PRTIME H IN PROUTE OF JOB C
     FIND FIRST GROUPS D IN ROUTE OF JOB C
     GROUPS D FROM ROUTE OF JOB C
     SETIME G FROM SROUTE OF JOB C
     PRTIME H FROM PROUTE OF JOB C
     OR CONTINUE
   CHAIN
     REPRTI OF JOB C  LE  0
     EXISTS(1) IN ROUTE OF JOB C
     FIND FIRST SETIME G IN SROUTE OF JOB C
     RESETI OF JOB C = SVALUE OF SETIME G
     SETING OF JOB C = SVALUE OF SETIME G
     FIND FIRST PRTIME H IN PROUTE OF JOB C
     REPRTI OF JOB C = PVALUE OF PRTIME H  *  BATCH OF JOB C
     OR CONTINUE
 REPEAT 50
 BEGIN SETT
 FIND FIRST JOB C IN WAIT
     RESETI OF JOB C  GT  0
     CHAIN
       RESETI OF JOB C  EQ  SETING OF JOB C
       FIND FIRST GROUPS D IN ROUTE OF JOB C
       FIND FIRST MACHIN A IN GROUP.D
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        MACHIN A  IN  STOP
        MCNAME OF MACHIN A  NE  OUT
        MACJOB OF MACHIN A  EQ  0
        TITOBK OF MACHIN A  GT  0
    FIND FIRST MAN B IN IDLE
        GROUPS D IN SSKILL OF MAN B
        CURJOB OF MAN B  EMPTY
        (TITOAB OF MAN B - CLOCK)  GT  0
        (TITOFW OF MAN B - CLOCK)  GT  0
    OR RESETI OF JOB C  LT  SETING OF JOB C
    FIND FIRST GROUPS D  IN  ROUTE OF JOB C
    FIND FIRST MACHIN A IN STOP
        MACJOB OF MACHIN A  EQ  C
        TITOBK OF MACHIN A  GT  0
    FIND FIRST MAN B IN IDLE
        JOB C  IN  CURJOB OF MAN B
        (TITOAB OF MAN B - CLOCK)  GT  0
        (TITOFW OF MAN B - CLOCK)  GT  0
TTAB=TITOAB OF MAN B - CLOCK
TTBK=TITOBK OF MACHIN A
TTFW=TITOFW OF MAN B - CLOCK
RESETI OF JOB C = (RESETI OF JOB C * 100/PERF OF MAN B)
DURATION=MINOF(RESETI OF JOB C,TTAB,TTBK,TTFW,4)
ADD 1 TO SETT
CHAIN
  MACHIN A FROM STOP   INTO STOP   AFTER  DURATION
  ADD -TIME OF MACHIN A TO WSTOP
  ADD  1  TO MCREC OF MACHIN A , DURATION
  ADD  8  TO  MCREC OF MACHIN A , -TIME OF MACHIN A
  TIME OF MACHIN A= DURATION
  MAN    B FROM IDLE   INTO IDLE   AFTER  DURATION
  ADD -TIME OF MAN    B TO WIDLE
  ADD  1  TO  MNREC OF MAN B , DURATION
  ADD  8  TO  MNREC OF MAN B , -TIME OF MAN B
  AH=DURATION * PERF OF  MAN B  / 100
  CHAIN
    MACTYP OF MACHIN A  EQ CYCLE
    ADD  4  TO  HRREC OF MAN B ,  AH
    OR ADD  1  TO  HRREC OF MAN B , AH
  TIME OF MAN    B= DURATION
  JOB    C FROM WAIT   INTO WAIT   AFTER  DURATION
  ADD -TIME OF JOB    C TO WWAIT
  TIME OF JOB     C= DURATION
  MACJOB OF MACHIN A = C
  CHAIN
    JOB C INTO CURJOB OF MAN B
    OR CONTINUE
  RESETI OF JOB C - DURATION
  CHAIN
    RESETI OF JOB C  EQ  0
    GROUPS D  NOTIN  PSKILL OF MAN B
    JOB C  FROM  CURJOB OF MAN B
    OR CONTINUE
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    RESETI OF JOB C = (RESETI OF JOB C *  PERF OF MAN B  /100)
    TITOBK OF MACHIN A - DURATION
  CHAIN
    TRACK  EQ  1
    FIND FIRST GROUPS X IN ROUTE OF JOB C
    PRINT'JT'*8 CLOCK ' SETTING' *4' BCH 'ORDERNO OF JOB C
&   ' MAN 'MANAME OF MAN B' MAC 'MCNAME OF MACHIN A
&   ' GRP ' GRNAME OF GROUPS X ' DUR' DURATION
    OR CONTINUE
  REPEAT 50
  BEGIN AUTOPROCESS
  FIND FIRST JOB C  IN  WAIT
      RESETI OF JOB C  EQ  0
      REPRTI OF JOB C  GT  0
      RECYTI OF JOB C  GT  0
      FIND FIRST MACHIN A  IN  STOP
          MACJOB OF MACHIN A  EQ  C
          TITOBK OF MACHIN A  GT  0
          MACTYP OF MACHIN A       EQ  CYCLE
      FIND FIRST MAN B  IN  IDLE
          JOB C  IN  CURJOB OF MAN B
          (TITOAB OF MAN B  - CLOCK)  GT  0
          (TITOFW OF MAN B  - CLOCK)  GT  0
  TTAB = TITOAB OF MAN B  - CLOCK
  TTBK = TITOBK OF MACHIN A
  TTFW = TITOFW OF MAN B  - CLOCK
  DURATION = MINOF(RECYTI OF JOB C,TTAB,TTFW,TTBK,4)
  CHAIN
    MACHIN A FROM STOP   INTO STOP   AFTER  DURATION
    ADD -TIME OF MACHIN A TO WSTOP
    ADD  4  TO  MCREC OF MACHIN A , DURATION
    ADD  8  TO  MCREC OF MACHIN A , -TIME OF MACHIN A
    ADD  6  TO  HRREC OF MAN B, DURATION
    TIME OF MACHIN A= DURATION
    MAN    B FROM IDLE   INTO IDLE   AFTER  0
    ADD -TIME OF MAN    B TO WIDLE
    TIME OF MAN    B= 0
    JOB    C FROM WAIT   INTO WAIT   AFTER  DURATION
    ADD -TIME OF JOB    C TO WWAIT
    TIME OF JOB    C= DURATION
  REPRTI OF JOB C - DURATION
  RECYTI OF JOB C  - DURATION
  TITOBK OF MACHIN A  - DURATION
  CHAIN
    REPRTI OF JOB C  LE  0
    JOB C  FROM  CURJOB OF MAN B
    MACJOB OF MACHIN A = 0
    OR CONTINUE
  CHAIN
      REPRTI OF JOB C LE  0
      FIND FIRST SETIME G IN SROUTE OF JOB C
      FIND FIRST PRTIME H IN PROUTE OF JOB C
      FIND FIRST GROUPS D IN ROUTE OF JOB C
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    FIND FIRST PRTIME P IN CROUTE OF JOB C
    FIND FIRST LDTIME L IN LROUTE OF JOB C
    GROUPS D FROM ROUTE OF JOB C
    SETIME G FROM SROUTE OF JOB C
    PRTIME H FROM PROUTE OF JOB C
    PRTIME P FROM CROUTE OF JOB C
    LDTIME L FROM LROUTE OF JOB C
    RECYTI OF JOB C  = 0
    CHAIN
        EXISTS(1) IN ROUTE OF JOB C
        FIND FIRST SETIME G IN SROUTE OF JOB C
        RESETI OF JOB C = SVALUE OF SETIME G
        SETING OF JOB C = SVALUE OF SETIME G
        FIND FIRST PRTIME H IN PROUTE OF JOB C
        REPRTI OF JOB C = PVALUE OF PRTIME H  *  BATCH OF JOB C
        OR CONTINUE
    OR CONTINUE
CHAIN
  TRACK  EQ  1
  PRINT'JT'*8 CLOCK ' AUTOPR '*4' BCH 'ORDERNO OF JOB C
&  ' MAN 'MANAME OF MAN B' MAC 'MCNAME OF MACHIN A SPACE' DUR'DURATION
  OR CONTINUE
REPEAT 50
BEGIN AUTOLOAD
FIND FIRST JOB C  IN  WAIT
    RESETI OF JOB C  EQ  0
    REPRTI OF JOB C  GT  0
    RECYTI OF JOB C  EQ  0
    FIND FIRST GROUPS E  IN  ROUTE OF JOB C
    FIND FIRST MACHIN A  IN  STOP
        MACJOB OF MACHIN A  EQ  C
        TITOBK OF MACHIN A  GT  0
        MACTYP   OF MACHIN A  EQ  CYCLE
    CHAIN
      FIND FIRST MAN B  IN  IDLE
          JOB C  IN  CURJOB OF MAN B
          (TITOAB OF MAN B  -  CLOCK)  GT  LVALUE OF LDTIME L
          (TITOFW OF MAN B  -  CLOCK)  GT  LVALUE OF LDTIME L
      OR FIND FIRST MAN B  IN  IDLE
          GROUPS E  IN  PSKILL OF MAN B
          JOB C  NOTIN  CURJOB OF MAN B
          COUNT JOB S  IN  CURJOB OF MAN B
          S  LT  LIMIT OF MAN B
          (TITOAB OF MAN B - CLOCK)  GT  LVALUE OF LDTIME L
          (TITOFW OF MAN B - CLOCK)  GT  LVALUE OF LDTIME L
          FOR MAN F
            JOB C  IN  CURJOB OF MAN F
            JOB C FROM CURJOB OF MAN F
DURATION = LVALUE OF LDTIME L
CHAIN
  MACHIN A FROM STOP  INTO STOP  AFTER  DURATION
  ADD -TIME OF MACHIN A TO WSTOP
  ADD  3  TO  MCREC OF MACHIN A , DURATION
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    ADD  8  TO  MCREC OF MACHIN A , -TIME OF MACHIN A
    TIME OF MACHIN A= DURATION
    MAN    B FROM IDLE   INTO IDLE   AFTER  DURATION
    ADD -TIME OF MAN    B TO WIDLE
    ADD  3  TO  MNREC OF MAN B , DURATION
    ADD  8  TO  MNREC OF MAN B , -TIME OF MAN B
    ADD  5  TO  HRREC OF MAN B , DURATION
    TIME OF MAN    B= DURATION
    JOB    C FROM WAIT   INTO WAIT   AFTER  DURATION
    ADD -TIME OF JOB    C TO WWAIT
    CHAIN
      JOB C  INTO  CURJOB OF MAN B
      OR CONTINUE
    TIME OF JOB    C= DURATION
  FIND FIRST PRTIME H IN CROUTE OF JOB C
  RECYTI OF JOB C = PVALUE OF PRTIME H
  CHAIN
    TRACK  EQ  1
    PRINT'JT'*8 CLOCK' AUTOLD '*4' BCH 'ORDERNO OF JOB C
&   ' MAN 'MANAME OF MAN B' MAC 'MCNAME OF MACHIN A
&   ' GRP 'GRNAME OF GROUPS E' DUR'DURATION
    OR CONTINUE
  REPEAT 50
  BEGIN ABSENT
  SWABSENT  EQ  1
  FIND   FIRST MAN    B IN IDLE
      TITOAB OF MAN    B- CLOCK                  LE 0
      MANAME OF MAN B  NE  CLERK
  DURATION=NORMAL( MNAB  , SDAB  , SEAB  )
  ADD 1 TO ABSENT
  CHAIN
    DURATION + CLOCK  GT  TITOFW OF MAN B
    DURATION = TITOFW OF MAN B - CLOCK
    OR CONTINUE
  CHAIN
    MAN    B FROM IDLE   INTO IDLE   AFTER  DURATION
    ADD -TIME OF MAN    B TO WIDLE
    ADD  5  TO  MNREC OF MAN B , DURATION
    ADD  8  TO  MNREC OF MAN B , -TIME OF MAN B
    TIME OF MAN    B= DURATION
    TITOAB OF MAN    B=NORMAL( MNTAB , SDTAB , SETAB )+CLOCK
    CHAIN
      EXISTS(1) JOB IN CURJOB OF MAN B
      FOR  C = CURJOB OF MAN B
       CHAIN
        JOB C  IN  WAIT
        JOB C  FROM  WAIT  INTO  WAIT  AFTER DURATION
        ADD -TIME OF JOB C  TO  WWAIT
        TIME OF JOB C = DURATION
        FIND FIRST MACHIN A  IN  STOP
            MACJOB OF MACHIN A  EQ  C
        MACHIN A  FROM  STOP  INTO  STOP  AFTER DURATION
        ADD -TIME OF MACHIN A  TO  WSTOP
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        ADD  5  TO  MCREC OF MACHIN A , DURATION
        ADD  8  TO  MCREC OF MACHIN A , -TIME OF MACHIN A
        TIME OF MACHIN A = DURATION
        CHAIN
          TRACK  EQ  1
          PRINT'JT'*8 CLOCK ' ABSENT '*4' BCH 'ORDERNO OF JOB C
&          ' MAN 'MANAME OF MAN B' MAC 'MCNAME OF MACHIN A
&         SPACE' DUR'DURATION
          OR CONTINUE
        OR CONTINUE
      OR CONTINUE
  CHAIN
    TRACK  EQ  1
    CURJOB OF MAN B EMPTY
    PRINT'JT'*8 CLOCK ' ABSENT '*4 SPACE' MAN 'MANAME OF MAN B
&   SPACE SPACE' DUR' DURATION
    OR CONTINUE
  REPEAT 50
  BEGIN FINWOR
  FIND   FIRST MAN    B IN IDLE
      TITOFW OF MAN    B- CLOCK                    LE 0
  CHAIN
    CLOCK  GT  LASTCLOCK
    WPSEL = WPSEL * (-1)
    CHAIN
      WPSEL  LT  0
      DUR=60
      OR WPSEL  GT  0
      DUR=900
    FOR WAIT
      LEADTM = LEADTM  +  DUR
    LASTCLOCK = CLOCK
    OR CONTINUE
  CHAIN
    WPSEL  LT  0
    DURATION = 60
    OR WPSEL  GT  0
    DURSICK = SAMPLE(SICK,SESICK)
    DURATION = 900 + DURSICK
  ADD 1 TO FINWOR
  CHAIN
    MAN    B FROM IDLE   INTO IDLE   AFTER  DURATION
    ADD -TIME OF MAN    B TO WIDLE
    ADD  6  TO  MNREC OF MAN B , DURATION
    ADD  8  TO  MNREC OF MAN B , -TIME OF MAN B
    TIME OF MAN    B= DURATION
    TITOFW OF MAN B = CLOCK + 240 + DURATION
    TITOAB OF MAN B + DURATION
    TIMEOUT = TIMEOUT + DURATION
  CHAIN
    TRACK  EQ  1
    PRINT'JT'*8 CLOCK ' FINWOR' *4 SPACE ' MAN 'MANAME OF MAN B
&   SPACE SPACE' DUR' DURATION
```

```
  OR CONTINUE
 REPEAT 50
 BEGIN ISSUE
 FIND FIRST MAN B IN IDLE
   COUNT JOB S IN CURJOB OF MAN B
   S  LT  LIMIT OF MAN B
 FIND   FIRST JOB    A IN AWISSUE
   FIND FIRST GROUPS E IN ROUTE OF JOB A
   N = 0
   FOR JOB Y IN WAIT
     CHAIN
       FIND FIRST GROUPS X IN ROUTE OF JOB Y
       X  EQ  E
       N = N + 1
       OR CONTINUE
   N  LT  JOBQUEUE
 DURATION=0
 ADD 1 TO ISSUE
 CHAIN
   JOB    A FROM AWISSUE   INTO WAIT   AFTER  DURATION
   TIME OF JOB    A= DURATION
   CHAIN
     LDFRPLAN  EQ  1
     OR LEADTM OF JOB A = CLOCK
     STDAY OF JOB A = DAYNO
 CHAIN
   TRACK  EQ  1
   PRINT'JT'*8 CLOCK ' ISSUE   ' *4' BCH 'ORDERNO OF JOB A
&  ' MAN 'MANAME OF MAN B' TO GRP 'GRNAME OF GROUPS E
&  ' JQ='N' ON DAY'DAYNO
   OR CONTINUE
 PRINT'JT'*8 CLOCK*4' ISSUE  OF BATCH 'ORDERNO OF JOB A
&' FOR PART'PARTNO OF JOB A' ON DAY 'DAYNO' LOAD 'MCHOUR OF JOB A
 REPEAT 50
 BEGIN MAN-MACHIN MONITOR
 MANMCM  EQ  1
 XYZ=LASTEN+(MONINT*1440)
 CLOCK  GE  XYZ
 PRINT //'**** CUMULATIVE MAN/MACHINE UTILISATION AT CLOCK= '
& CLOCK' ****'
 PRINT //'**MAN ACTIVITY DATA**'/
&     /'      MINUTES SPENT IN EACH ACTIVITY'/
 PRINT SPACE SPACE SPACE SPACE SPACE SPACE SPACE SPACE
& SPACE 'UTILISATIONS  '
 PRINT'        TOTAL   SET    PROC   LOAD   INSP  ABSENT'
& ' FINWK  BRKDN   IDLE   PLAN  - '
& '  SET    PROC  CYCLE  TOTAL'
 FOR MAN
   TFW = FREQUENCY(MNREC,6)
   HAT = (CLOCK-LASTEN) - (TFW-TOTFWK)
   TS  = (FREQUENCY(HRREC,1)) + (FREQUENCY(HRREC,4))
   PS  = TS - TOTSET
   USET= (FLOAT(PS)*10000)/(PERF*FLOAT(HAT))
```

```
    TP   = FREQUENCY(HRREC,2)
    PP   = TP - TOTPRC
    UPROC= FLOAT(PP)*10000/(PERF*FLOAT(HAT))
    TC   = (FREQUENCY(HRREC,6)) + (FREQUENCY(HRREC,5))
    PC   = TC - TOTCYC
    UCYC= FLOAT(PC)*100/(FLOAT(HAT))
    UTOT=USET + UPROC + UCYC
    TOTFWK = TFW
    TOTSET = TS
    TOTPRC = TP
    TOTCYC = TC
    PRINT *7 +2 ' ' MANAME MNREC ' - ' USET UPROC UCYC UTOT
  PRINT / '**ALLOWED / CYCLE HOURS PRODUCED**'/
  PRINT /'      TOTAL   ALLOWED MINS          CYCLE MINS'
&       '                 PERFORMANCE'
  PRINT'NAME  FREQ  SET   PROC  TOT    SET  LOAD  CYCLE'
&      ' TOT  ATTN  ALLD  CYCLE'
  PRINT *6 FOR MAN ( MANAME HRREC /)
  PRINT //'**MACHINE ACTIVITY DATA**'
&       //'      MINUTES SPENT IN EACH ACTIVITY'/
  PRINT SPACE SPACE SPACE SPACE SPACE SPACE SPACE SPACE
& 'UTILISATIONS  '
  PRINT'       TOTAL   SET    PROC   LOAD  AUTOPR  ABS  '
& ' FINWOR BREAK   STOP  - '
& '  SET    PROC  CYCLE  TOTAL'
  FOR MACHIN
    TS   = FREQUENCY(MCREC,1)
    PS   = TS - TSET
    USET= FLOAT(PS)*100/(FLOAT(HAT))
    TP   = FREQUENCY(MCREC,2)
    PP   = TP - TPROC
    UPROC=FLOAT(PP)*100/(FLOAT(HAT))
    TC   = (FREQUENCY(MCREC,3))+(FREQUENCY(MCREC,4))
    PC   = TC - TCYC
    UCYC= FLOAT(PC)*100/(FLOAT(HAT))
    UTOT= USET + UPROC + UCYC
    TSET= TS
    TPROC=TP
    TCYC= TC
    PRINT *7 +2 ' ' MCNAME MCREC ' - ' USET UPROC UCYC UTOT /
  LASTEN=CLOCK
  BEGIN WIPMONITOR
  WIPMON  GT  0
  CLOCK  GE  RUNINZ
  MONDAY  GT  LASTDAY
  LASTDAY=MONDAY
  FOR JOB C  IN  WAIT
    FIND FIRST GROUPS D  IN  ROUTE OF JOB C
    JOB C  INTO  GRPQUE D
  FOR GROUPS D
    FIND FIRST MACHIN A  IN  GROUP D
    CHAIN
      MACTYP OF MACHIN A  EQ  CYCLE
```

```
    REM = 1.0
    OR REM = 2.3
  WIP=0.0
  FOR JOB C  IN  GRPQUE D
    FIND FIRST PRTIME P  IN  PROUTE OF JOB C
    WIP=WIP+(FLOAT(PVALUE OF PRTIME P *BATCH OF JOB C)/(60.0*REM))
    FIND FIRST SETIME S  IN  SROUTE OF JOB C
    WIP=WIP+(FLOAT(SVALUE OF SETIME S)/(60.0*2.3))
  WIP = WIP + 0.5
  ADD  MONDAY  TO  HATGP OF GROUPS D , FIX(WIP)
  ZERO GRPQUE D
FOR JOB C
  JOB C  NOTIN  POOL
  EXISTS (1)  IN  ROUTE OF JOB C
  TEMPR  GAINS  PROUTE OF JOB C
  TEMST  GAINS  SROUTE OF JOB C
  WIP=0.0
  FOR GROUPS D  IN  ROUTE OF JOB C
    FIND FIRST MACHIN A  IN  GROUP D
    CHAIN
      MACTYP OF MACHIN A  EQ  CYCLE
      REM = 1.0
      OR REM = 2.3
    FIND FIRST PRTIME P  IN  TEMPR
    FIND FIRST SETIME S  IN  TEMST
    WIP =FLOAT(PVALUE OF PRTIME P  * BATCH OF JOB C)/REM
    WIP = WIP + (FLOAT(SVALUE OF SETIME S)/2.3)
    WIP=(WIP/60.0)+0.5
    ADD  MONDAY  TO  HFORGP  OF GROUPS D , FIX(WIP)
    CHAIN
      MACTYP OF MACHIN A  EQ  CYCLE
      ADD  MONDAY  TO  HTWIPC , FIX(WIP)
      CHAIN
        JOB C  NOTIN  AWISSUE
        JOB C  NOTIN  PLAN
        ADD  MONDAY  TO  HISSUC , FIX(WIP)
        OR ADD  MONDAY  TO  HAWISC , FIX(WIP)
      OR ADD  MONDAY  TO  HTWIPA , FIX(WIP)
      CHAIN
        JOB C  NOTIN  AWISSUE
        JOB C  NOTIN  PLAN
        ADD  MONDAY  TO  HISSUA , FIX(WIP)
        OR ADD  MONDAY  TO  HAWISA , FIX(WIP)
    PRTIME P  FROM  TEMPR
    SETIME S  FROM  TEMST
  ZERO TEMPR TEMST
CHAIN
  WIPMON  GT  0
  PRINT /// '***WORK IN PROGRESS MONITOR***'
  PRINT/ ' AT THE START OF PERIOD '*4 MONDAY ' DAY '*5 DAYNO
  PRINT//'** WIP MONITOR TIME PERIOD WAS 'MONFAC' DAYS'
  RUNIND = 1 + ((RUNINZ/1440)/MONFAC)
  PRINT//'**RECORDING OF WIP BEGAN AFTER '*3 RUNIND' PERIODS'
```

```
  PRINT//' *NOTE - WIP LEVEL WAS RECORDED AT THE START OF EACH PERIOD'
  PRINT'         - LEVELS IN ACTUAL HRS ASSUMING PERF OF 230 '
  PRINT //'**LOAD IN ACTUAL HOURS AT EACH GROUP**'/
  PRINT'  PERIOD   ' *5 FOR I=1,MONDAY (I)
  PRINT/'NAME  TOTAL '  / *5 FOR GROUPS (GRNAME HATGP /)
  PRINT // '**LOAD IN ACTUAL HOURS FOR EACH GROUP**'/
  PRINT'  PERIOD   ' *5 FOR I=1,MONDAY (I)
  PRINT / 'NAME  TOTAL '  / *5 FOR GROUPS ( GRNAME HFORGP /)
  RSLOAD = 0
  SCLOAD = 0
  FOR GROUPS
    GRLOAD = FREQUENCY(HFORGP,MONDAY)
    CHAIN
      GRNAME  EQ  GROUTA
      SCLOAD = SCLOAD + GRLOAD
      OR GRNAME  EQ  GROUTB
      SCLOAD = SCLOAD + GRLOAD
      OR RSLOAD = RSLOAD + GRLOAD
  PRINT/'TOTAL LOAD AT THE START OF PERIOD '*5 MONDAY' DAY'DAYNO
  PRINT'     FOR SUB-CONTRACT '*6 SCLOAD ' ACTUAL HOURS'
  PRINT'     FOR ALL OTHER MC '*6 RSLOAD ' ACTUAL HOURS'
  PRINT' TOTAL MC HOURS OF BATCHES PLANNED IN PERIOD ='*6 PERPLAN
  PERPLAN=0
  PRINT' TOTAL MC HOURS OF BATCHES FINISHED IN PERIOD='*6 PERCOMP
  PERCOMP=0
CHAIN
  LEADMON  GT  0
  PRINT ///'***LEAD TIME MONITORING***'
  PRINT /'*AVERAGE LEAD TIMES  V  SIMULATED TIME*'
  PRINT /'PERIOD     AVERAGE LEAD TIME (HRS) '/
  PICTURE(HLETIM)
  N = MONDAY - 1
  NOFIN = FREQUENCY(HLEJOB,N)
  REM = FLOAT(NOFIN)
  CHAIN
    NOFIN  EQ  0
    REM = 1.0
    OR CONTINUE
  TOTLED = TOTLED/REM
  TOTDEV = TOTDEV/REM
  TOTODV = TOTODV/REM
  PRINT /'AVERAGE LEAD TIME IN PERIOD '*4 N *10 +2 ' = 'TOTLED
  TOTLED=0.0
  PRINT //'*LEAD TIME DISTRIBUTION*'
  PRINT /'LEAD (HRS)     FREQUENCY'/
  PICTURE(HLEAD)
  PRINT //'*BATCHES COMPLETED  V  SIMULATED TIME*'
  PRINT / 'PERIOD     NO. BATCHES COMPLETED'/
  PICTURE(HLEJOB)
  PRINT//'*AVERAGE DEVIATION OF LEAD TIME FROM SUM OF PROC/SET TIMES*'
  PRINT / 'DEVIATION    FREQUENCY'/
  PICTURE(HDEV)
  PRINT // '*AVERAGE DEVIATION  V  SIMULATED TIME*'
```

```
   PRINT /'PERIOD     DEVIATION (HRS)'/
   PICTURE(HDVTIM)
   PRINT/'AVERAGE DEVIATION IN PERIOD '*4 N *10 +2 ' = 'TOTDEV
   TOTDEV = 0.0
   PRINT/'AVERAGE DEVIATION PER OPERATION IN PERIOD '*4 N
&   *10 +2 ' = 'TOTODV
   TOTODV = 0.0
 BEGIN MONITOR END
 CLOCK GE MNENON
 CLOCK LE MNENOF
 PRINT'     STATE OF QUEUES AT END  CLOCK ='CLOCK
 PRINT'     STOP CONTAINS' *4 FOR STOP(' 'MCNAME )
 PRINT'     IDLE CONTAINS' *4 FOR IDLE(' 'MANAME )
 PRINT'     WAIT CONTAINS' *4
& FOR WAIT(ORDERNO '('PRIORITY ')')
 PRINT'     POOL CONTAINS' *4 FOR JOB I IN POOL (I)
 PRINT'  AWISSUE CONTAINS' *4  FOR AWISSUE(' 'ORDERNO )
 PRINT'   AWPLAN CONTAINS' *4  FOR ORDER I IN AWPLAN (I)
 FOR JOB I IN WAIT
   FIND FIRST GROUPS D IN ROUTE OF JOB I
   JOB I INTO GRPQUE D
 FOR GROUPS D
   PRINT'JOBS WAITING AT GROUP 'GRNAME OF GROUPS D *4
&  FOR GRPQUE D (' 'ORDERNO )
   ZERO GRPQUE D
 BEGIN MONITOR CORRECT
 CLOCK  GE  RUNINZ
 MONCOR  NE  1
 FOR MACHIN A  IN  STOP
   ADD 8 TO MCREC OF MACHIN A ,TIME OF MACHIN A
 MONCOR=1
 BEGIN COUNT QUEUES
 COUNT AA IN STOP
 COUNT BB IN IDLE
 COUNT CC IN WAIT
 LASTCLOCK = CLOCK
 CHAIN
   EXISTS (NOMCS) MACHIN  IN  STOP
   EXISTS (NOMEN) MAN     IN  IDLE
   EXISTS (20) JOB    IN  POOL
   FIND MACHIN J IN STOP WITH MIN TITOBK
   TBK=TITOBK OF MACHIN J
   FIND MAN K IN IDLE WITH MIN TITOAB
   TABB = TITOAB OF MAN K - CLOCK
   FIND MAN L IN IDLE WITH MIN TITOFW
   TFW = TITOFW OF MAN L - CLOCK
   TIME OF NEXACT = MINOF(TBK,TABB,TFW,3)
   PRINT'TIME ADVANCE USED   TIME TO NEXACT =' TIME OF NEXACT
   OR CONTINUE
 CHAIN
   (CLOCK+DURATION) GE RUNTIME
   FOR MACHIN A  IN  STOP
     ADD  8  TO  MCREC OF MACHIN A , -TIME OF MACHIN A
```

```
   FOR MAN B  IN  IDLE
    ADD  8  TO  MNREC OF MAN B , -TIME OF MAN B
   PRINT//'***** STATE OF ACTIVE ORDERS & JOBS AT THE'
&   ' END OF THE RUN *****'
   PRINT//' **** ORDERS AWAITING PLANNING ****'
   CHAIN
     AWPLAN EMPTY
     PRINT/ '     NO ACTIVE ORDERS'
     OR PRINT/'      ORDERS     PART NUMBER   QUANTITY   DUEDAY'
     PRINT *5 FOR AWPLAN ( SPV  NORDER PARTNAME SPV QTY SPV DUEDAY/)
     OR CONTINUE
   PRINT//' **** JOBS AWAITING ISSUE ****'
   CHAIN
     AWISSUE EMPTY
     PRINT/'     NO JOBS AWAITING ISSUE'
     OR PRINT/'      BATCH     PART NUMBER   QUANTITY   DUEDAY'
&    '  AT GROUP REM PROCESS & SETTING TIMES'
     FOR  JOB C IN  AWISSUE
       FIND FIRST GROUPS D IN ROUTE OF JOB C
       PRINT SPV *5 ORDERNO OF JOB C ' 'PARTNO OF JOB C SPV
&     BATCH OF JOB C SPV
&      DUEDATE OF JOB C SPV GRNAME OF GROUPS D  SPV REPRTI OF JOB C SPV
&      RESETI OF JOB C
     OR CONTINUE
   PRINT//' **** JOBS ISSUED ****'
   CHAIN
     WAIT EMPTY
     PRINT/'     NO JOBS ISSUED'
     OR PRINT/'      BATCH     PART NUMBER   QUANTITY   DUEDAY'
&    '  AT GROUP REM PROCESS & SETTING TIMES'
     FOR  JOB C IN  WAIT
       FIND FIRST GROUPS D IN ROUTE OF JOB C
       PRINT SPV *5 ORDERNO OF JOB C ' 'PARTNO OF JOB C SPV
&     BATCH OF JOB C  SPV
&      DUEDATE OF JOB C SPV GRNAME OF GROUPS D  SPV REPRTI OF JOB C SPV
&      RESETI OF JOB C
     OR CONTINUE
   PRINT / '  AUTOGEN SEED = ' SEORD /
   FINISH
   OR CONTINUE
 CHAIN
   POOL  EMPTY
   PRINT *8 '********POOL EMPTY AT CLOCK=' CLOCK ' MINS*******'
   FINISH
   OR CONTINUE
 BEGIN DUMPSTATE
 TIME OF DUMPST  LE  0
 PRINT//'***** STATE OF ACTIVE ORDERS & JOBS AT THE'
&  ' AT CLOCK TIME'*8CLOCK' *****'
 PRINT//' **** ORDERS AWAITING PLANNING ****'
 CHAIN
   AWPLAN EMPTY
   PRINT/ '     NO ACTIVE ORDERS'
```

```
  OR PRINT/'      ORDERS     PART NUMBER    QUANTITY    DUEDAY'
  PRINT *5 FOR AWPLAN ( SPV  NORDER PARTNAME SPV QTY SPV DUEDAY/)
  OR CONTINUE
 PRINT//' **** JOBS AWAITING ISSUE ****'
 CHAIN
  AWISSUE EMPTY
  PRINT/'      NO JOBS AWAITING ISSUE'
  OR PRINT/'      BATCH     PART NUMBER    QUANTITY    DUEDAY'
&    '  AT GROUP REM PROCESS & SETTING TIMES'
  FOR  JOB C IN  AWISSUE
    FIND FIRST GROUPS D IN ROUTE OF JOB C
    PRINT SPV *5 ORDERNO OF JOB C ' 'PARTNO OF JOB C SPV
&     BATCH OF JOB C SPV
&      DUEDATE OF JOB C SPV GRNAME OF GROUPS D  SPV REPRTI OF JOB C SPV
&      RESETI OF JOB C
  OR CONTINUE
 PRINT//' **** JOBS ISSUED ****'
 CHAIN
  WAIT EMPTY
  PRINT/'      NO JOBS ISSUED'
  OR PRINT/'      BATCH     PART NUMBER    QUANTITY    DUEDAY'
&    '  AT GROUP REM PROCESS & SETTING TIMES'
  FOR  JOB C IN  WAIT
    FIND FIRST GROUPS D IN ROUTE OF JOB C
    PRINT SPV *5 ORDERNO OF JOB C ' 'PARTNO OF JOB C SPV
&     BATCH OF JOB C  SPV
&      DUEDATE OF JOB C SPV GRNAME OF GROUPS D  SPV REPRTI OF JOB C SPV
&      RESETI OF JOB C
  OR CONTINUE
 PRINT / ' AUTOGEN SEED VALUE = 'SEORD
 TIME OF DUMPST = DUMPINT
 FINALISATION
 PRINT'PROCES WAS STARTED'PROCES' TIMES'
 PRINT'SETT   WAS STARTED'SETT  ' TIMES'
 PRINT'BREAK  WAS STARTED'BREAK ' TIMES'
 PRINT'ABSENT WAS STARTED'ABSENT' TIMES'
 PRINT'FINWOR WAS STARTED'FINWOR' TIMES'
 PRINT'INSPEC WAS STARTED'INSPEC' TIMES'
 PRINT'ISSUE  WAS STARTED'ISSUE ' TIMES'
 PRINT/'HISTOGRAM OF LENGTH OF QUEUE STOP  '
 NOMCS=1
 FOR MACHIN
  NOMCS=NOMCS+1
 FOR J=1,NOMCS
  I=J-1
  F=FREQUENCY(ZASTOP,I)
  ADD I TO ZASTOP, -F
  F=F/60
  ADD I TO ZASTOP,F
 PICTURE(ZASTOP  )
 TA = TOTAL(ZASTOP)
 CHAIN
  TA  GT  0
```

```
  RVM = MEAN(ZASTOP)
  PRINT /'   MEAN CELL = 'RVM
  OR CONTINUE
PRINT/'HISTOGRAM OF DELAYS AT STOP  '
PICTURE(WSTOP  )
TA = TOTAL(WSTOP)
CHAIN
  TA  GT  0
  RVM = MEAN(WSTOP)
  RVSD = DEVIATION(WSTOP)
  PRINT /'   MEAN CELL = 'RVM' STANDARD DEVIATION = 'RVSD
  OR CONTINUE
PRINT/'HISTOGRAM OF LENGTH OF QUEUE IDLE  '
NOMEN=1
FOR MAN
  NOMEN=NOMEN+1
FOR J=1,NOMEN
  I=J-1
  F=FREQUENCY(ZBIDLE,I)
  ADD I TO ZBIDLE, -F
  F=F/60
  ADD I TO ZBIDLE,F
PICTURE(ZBIDLE  )
TA = TOTAL(ZBIDLE)
CHAIN
  TA  GT  0
  RVM = MEAN(ZBIDLE)
  PRINT /'   MEAN CELL = 'RVM
  OR CONTINUE
PRINT/'HISTOGRAM OF DELAYS AT IDLE  '
PICTURE(WIDLE  )
TA = TOTAL(WIDLE)
CHAIN
  TA  GT  0
  RVM = MEAN(WIDLE)
  RVSD = DEVIATION(WIDLE)
  PRINT /'   MEAN CELL = 'RVM' STANDARD DEVIATION = 'RVSD
  OR CONTINUE
PRINT/'HISTOGRAM OF LENGTH OF QUEUE WAIT  '
NOJOB=1
FOR JOB
  NOJOB=NOJOB+1
FOR J=1,NOJOB
  I=J-1
  F=FREQUENCY(ZCWAIT,I)
  ADD I TO ZCWAIT, -F
  F=F/60
  ADD I TO ZCWAIT,F
PICTURE(ZCWAIT  )
TA = TOTAL(ZCWAIT)
CHAIN
  TA  GT  0
  RVM = MEAN(ZCWAIT)
```

```
    PRINT /'   MEAN CELL = 'RVM
    OR CONTINUE
  PRINT/'HISTOGRAM OF DELAYS AT WAIT  '
  PICTURE(WWAIT  )
  TA = TOTAL(WWAIT)
  CHAIN
    TA  GT  0
    RVM = MEAN(WWAIT)
    RVSD = DEVIATION(WWAIT)
    PRINT /'   MEAN CELL = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  PRINT //'**MACHINE ACTIVITY DATA**'
&      //'     MINUTES SPENT IN EACH ACTIVITY'/
  PRINT /'        TOTAL    SET   PROC   LOAD  AUTOPR   ABS'
&     '  FINWOR  BREAK  STOP'/
  PRINT *7 FOR MACHIN (' ' MCNAME MCREC /)
  PRINT //'**MAN ACTIVITY DATA**'/
&     /'      MINUTES SPENT IN EACH ACTIVITY'/
  PRINT /'        TOTAL    SET  PROC  LOAD  INSP   ABS'
&     '  FWOR  BRKN  IDLE  PLAN'/
  PRINT *6 FOR MAN (' ' MANAME MNREC /)
  PRINT / '**ALLOWED / CYCLE HOURS PRODUCED**'/
  FOR MAN
    AS= FREQUENCY(HRREC,1)
    AP= FREQUENCY(HRREC,2)
    CS= FREQUENCY(HRREC,4)
    CL= FREQUENCY(HRREC,5)
    CC= FREQUENCY(HRREC,6)
    HFW=FREQUENCY(MNREC,6)
    HAT= CLOCK + DURATION - HFW - RUNINZ
    ATOT=AS+AP
    CTOT=CS+CL+CC
    REM = FLOAT(ATOT)/FLOAT(HAT)
    REM = 100.0 * REM
    APF = FIX(REM)
    REM = FLOAT(CTOT)/FLOAT(HAT)
    REM = 100.0 * REM
    CPF = FIX(REM)
    ADD  3  TO  HRREC , ATOT
    ADD  7  TO  HRREC  , CTOT
    ADD  8  TO  HRREC  ,  HAT
    ADD  9  TO  HRREC  ,  APF
    ADD  10  TO  HRREC  ,  CPF
    FOR I=1,8
      HRS = FREQUENCY(HRREC,I)
      ADD I TO HRREC , -HRS
      REM=(FLOAT(HRS)/60.0)+0.5
      HRS = FIX(REM)
      ADD I TO HRREC, HRS
  PRINT /'        TOTAL   ALLOWED HRS          CYCLE HRS'
&      '                PERFORMANCE'
  PRINT'NAME  FREQ  SET   PROC  TOT    SET  LOAD  CYCLE'
&     '  TOT  ATTN  ALLD  CYCLE'
```

```
PRINT *6 FOR MAN ( MANAME HRREC /)
CHAIN
  WIPMON  GT  0
  PRINT /// '***WORK IN PROGRESS MONITOR***'
  PRINT
  PRINT//'** WIP MONITOR TIME PERIOD WAS 'MONFAC' DAYS'
  RUNIND = 1 + ((RUNINZ/1440)/MONFAC)
  PRINT//'**RECORDING OF WIP BEGAN AFTER '*3 RUNIND' PERIODS'
  PRINT//' *NOTE - WIP LEVEL WAS RECORDED AT THE START OF EACH PERIOD'
  PRINT'        - LEVELS IN ACTUAL HRS ASSUMING PERF OF 230 '
  PRINT //'**LOAD IN ACTUAL HOURS AT EACH GROUP**'/
  PRINT'  PERIOD   ' *5 FOR I=1,MONDAY (I)
  PRINT/'NAME  TOTAL '  / *5 FOR GROUPS (GRNAME HATGP /)
  PRINT // '**LOAD IN ACTUAL HOURS FOR EACH GROUP**'/
  PRINT'  PERIOD   ' *5 FOR I=1,MONDAY (I)
  PRINT / 'NAME  TOTAL '  / *5 FOR GROUPS ( GRNAME HFORGP /)
  PRINT // '**TOTAL LOAD AWAITING ISSUE**'
  PRINT / '*FOR ALLOWED HOUR OPERATIONS*'
  PRINT / 'PERIOD    ACTUAL HOURS'/
  PICTURE(HAWISA)
  TA = TOTAL(HAWISA)
  CHAIN
    TA  GT  0
    RVM = MEAN(HAWISA)
    RVSD = DEVIATION(HAWISA)
    PRINT /'    MEAN LOAD = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  PRINT / '*FOR CYCLE HOUR OPERATIONS*'
  PRINT / 'PERIOD    ACTUAL HOURS'/
  PICTURE(HAWISC)
  PRINT // '**TOTAL  LOAD  ISSUED**'
  PRINT / '*FOR ALLOWED HOUR OPERATIONS*'
  PRINT /'PERIOD    ACTUAL HOURS' /
  PICTURE(HISSUA)
  PRINT / '*FOR CYCLE HOUR OPERATIONS*'
  PRINT / 'PERIOD    ACTUAL HOURS' /
  PICTURE(HISSUC)
  PRINT // '**TOTAL LOAD ISSUED + AWAITING ISSUE**'
  PRINT / '*FOR ALLOWED HOUR OPERATIONS*'
  PRINT / 'PERIOD    ACTUAL HOURS' /
  PICTURE(HTWIPA)
  TA = TOTAL(HTWIPA)
  CHAIN
    TA  GT  0
    RVM = MEAN(HTWIPA)
    RVSD = DEVIATION(HTWIPA)
    PRINT/'   MEAN = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  PRINT / '*FOR CYCLE HOUR OPERATIONS*'
  PRINT / 'PERIOD    ACTUAL HOURS' /
  PICTURE(HTWIPC)
  TA =TOTAL(HTWIPC)
  CHAIN
```

```
    TA  GT  0
    RVM = MEAN(HTWIPC)
    RVSD = DEVIATION(HTWIPC)
    PRINT / '    MEAN = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  OR CONTINUE
CHAIN
  LEADMON  GT  0
  PRINT ///'***LEAD TIME MONITORING***'
  PRINT /'*AVERAGE LEAD TIMES  V  SIMULATED TIME*'
  PRINT /'PERIOD       AVERAGE LEAD TIME (HRS) '/
  PICTURE(HLETIM)
  TA = TOTAL(HLETIM)
  CHAIN
    TA  GT  0
    RVM = MEAN(HLETIM)
    RVSD = DEVIATION(HLETIM)
    PRINT / '    MEAN = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  PRINT //'*LEAD TIME DISTRIBUTION*'
  PRINT /'LEAD (HRS)      FREQUENCY'/
  PICTURE(HLEAD)
  TA = TOTAL(HLEAD)
  CHAIN
    TA  GT  0
    RVM = MEAN(HLEAD)
    RVSD = DEVIATION(HLEAD)
    PRINT /'   MEAN CELL = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  PRINT //'*BATCHES COMPLETED  V  SIMULATED TIME*'
  PRINT / 'PERIOD      NO. BATCHES COMPLETED'/
  PICTURE(HLEJOB)
  PRINT//'*AVERAGE DEVIATION OF LEAD TIME FROM SUM OF PROC/SET TIMES*'
  PRINT / 'DEVIATION    FREQUENCY'/
  PICTURE(HDEV)
  TA = TOTAL(HDEV)
  CHAIN
    TA  GT  0
    RVM = MEAN(HDEV)
    RVSD = DEVIATION(HDEV)
    PRINT /'   MEAN CELL = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  PRINT // '*AVERAGE DEVIATION  V  SIMULATED TIME*'
  PRINT /'PERIOD      DEVIATION (HRS)'/
  PICTURE(HDVTIM)
  TA = TOTAL(HDVTIM)
  CHAIN
    TA  GT  0
    RVM = MEAN(HDVTIM)
    RVSD = DEVIATION(HDVTIM)
    PRINT /'   MEAN = 'RVM' STANDARD DEVIATION = 'RVSD
    OR CONTINUE
  OR CONTINUE
```

```
 CHAIN
   LEADMON  GT  0
   WIPMON   GT  0
   FOR I=1,MONDAY
     LIA = FREQUENCY(HISSUA,I)
     LIC = FREQUENCY(HISSUC,I)
     LTA = FREQUENCY(HTWIPA,I)
     LTC = FREQUENCY(HTWIPC,I)
     LED = FREQUENCY(HDVTIM,I)
     TLI = LIA + LIC
     NOENT = FREQUENCY(HLDLNI,TLI)
     CURAVE =FREQUENCY(HLDLIS,TLI)
     ADDIT = (LED - CURAVE)/(NOENT+1)
     ADD  TLI  TO  HLDLIS , ADDIT
     ADD  TLI  TO  HLDLNI , 1
     TLT  = LTA + LTC
     NOENT= FREQUENCY(HLDLNT,TLT)
     CURAVE=FREQUENCY(HLDLTL,TLT)
     ADDIT = (LED - CURAVE)/(NOENT + 1)
     ADD  TLT  TO  HLDLTL , ADDIT
     ADD  TLT  TO  HLDLNT, 1
   PRINT ///'***LEAD TIME  V  LOAD MONITOR***'
   PRINT  //'*LEAD TIME DEVIATION  V  ISSUED LOAD*'
   PRINT  /'LOAD (HRS)     LEAD TIME DEVIATION (HRS)'/
   PICTURE(HLDLIS)
   PRINT //'*LEAD TIME DEVIATION  V  TOTAL LOAD*'
   PRINT  /'LOAD (HRS)     LEAD TIME DEVIATION (HRS)'/
   PICTURE(HLDLTL)
   OR CONTINUE
 DATA
STOP    1 TO *
IDLE    1 TO *
POOL    1 TO *
ORPOOL    1 TO *
PTPOOL    1 TO *
SESICK   4921
WPSEL   1
JOBQUEUE       100
SPACE   '           '
SPV     '     '
CLERK   'CLERK'
CYCLE  'C'
OUT  'OUT2 '
GROUTA     'OUTA '
GROUTB     'OUTB '
SCTIME  14400
LEVSCH   10
SESCH   4281
SEAB   6589
SETAB   8921
MANTRANS    60
JOBTRANS    10
PLANTIME    5
```

```
LDFRPLAN    1
OPER   1100
OAMP   40
ORSNTI    3000000
LDTRACK    1
SWBREAK   0
SWABSENT  0
DUMPINT    115200
TIME OF DUMPST    1440
SICK           100        100        0
MNTAB       3000000
SDTAB             1
MNAB             10
SDAB              2
ORFREQ          1271
SEORD    7531
WIPMON   1
LEADMON   1
MONFAC  20
MANMCM   1
MONINT  20
RUNTIME   203040
RUNINZ         0
TRACK  0
MNSTON     5000
MNSTOF        0
MNENON     5000
MNENOF        0
SCHED     1
RULE      2
  END
*EXECUTE   ,500,5000
CB4
CC5
AC11
****
```

Appendix 13 Examples of the Simulation Program Monitoring Output

This appendix contains examples of the various monitoring routines which can be activated during a simulation run.

Initial Data Specification - Machines, Men, and Groups

MACHINE DATA

MACHINE BREAKDOWN DATA

NAME	MNBK	SDBK	SEBK	MNTBK	SDTBK	SETBK
CB4	500	5	3457	999999	1	5033859
CC5	500	5	7859	999999	1	4015417
AC11	500	5	3457	999999	1	5033859
AC12	500	5	7845	999999	1	8260411
DS4	500	5	3459	999999	1	2022897
DEB	500	5	3479	999999	1	2825571
MH	500	5	4357	999999	1	8260411
TRUCK	500	5	8943	999999	1	8260411
GRE	500	5	4357	999999	1	4675373
FTRUC	500	5	6873	999999	1	2022897
DEGA	500	5	2341	999999	1	258975
FIT	500	5	9875	999999	1	8260411
HP	500	5	4579	999999	1	6625843
INSP	500	5	4569	999999	1	2825571
HDN	500	5	7653	999999	1	1162495
VFRF	500	5	3421	999999	1	5823169
SB	500	5	3421	999999	1	2825571
OB	500	5	3215	999999	1	3212743
OUT2	500	5	4561	999999	1	258975

MAN WORKING DATA

NAME	WORK PERIOD	NO.OF MCS.RUN	PERFORMANCE
MAN1	240	2	230
MAN2	240	3	230
MAN3	240	3	230
MAN4	240	2	230
MAN5	240	2	230
CLERK	240	2	100

CONTENT OF MACHINE GROUPS

```
MACHINES IN GROUP CB4A  CB4
MACHINES IN GROUP CB4B  CB4
MACHINES IN GROUP CC5A  CC5
MACHINES IN GROUP CC5B  CC5
MACHINES IN GROUP AC1A  AC11  AC12
MACHINES IN GROUP AC1B  AC11  AC12
MACHINES IN GROUP DS4A  DS4
MACHINES IN GROUP DS4B  DS4
MACHINES IN GROUP DEBA  DEB
MACHINES IN GROUP DEBB  DEB
MACHINES IN GROUP MHA   MH
MACHINES IN GROUP MHB   MH
MACHINES IN GROUP TRA   TRUCK
MACHINES IN GROUP TRB   TRUCK
MACHINES IN GROUP TRC   TRUCK
MACHINES IN GROUP TRD   TRUCK
MACHINES IN GROUP TRE   TRUCK
MACHINES IN GROUP AC1C  AC11  AC12
MACHINES IN GROUP CB4C  CB4
MACHINES IN GROUP CC5C  CC5
```

SETTING & PROCESS SKILLS OF THE MEN

```
MAN MAN1  CAN SET CB4A CB4B CB4C CB4D FITA MHA  MHB  GREA GREB DS4
     CAN OPERATE CB4A CB4B CB4C CB4D FITA MHA  MHB  GREA GREB DS4

MAN MAN2  CAN SET CC5A CC5B CC5C HPA  DS4A DS4B DS4C DEBA DEBB AC1
     CAN OPERATE CC5A CC5B CC5C HPA  DS4A DS4B DS4C DEBA DEBB AC1

MAN MAN3  CAN SET AC1A AC1B AC1C DEGA CC5A CC5B CC5C HPA  CB4A CB4
     CAN OPERATE AC1A AC1B AC1C DEGA CC5A CC5B CC5C HPA  CB4A CB4

MAN MAN4  CAN SET DS4A DS4B DS4C DEBA DEBB CB4A CB4B CB4C CB4D DEG
     CAN OPERATE DS4A DS4B DS4C DEBA DEBB CB4A CB4B CB4C CB4D DEG

MAN MAN5  CAN SET MHA  MHB  GREA GREB AC1A AC1B AC1C FITA CC5A CC5
     CAN OPERATE MHA  MHB  GREA GREB AC1A AC1B AC1C FITA CC5A CC5
```

****ROUTE & PROCESS DATA FOR PARTS RANGE****

PART NUMBER -C2173/1

BATCH QTY	- 109						
DEMAND	- 40						
ROUTE	-	CC5A	CC5B	TRB	DEBA	TRC	INSA
SETTING TIMES	-	240	260	10	12	10	30
PROCESS TIMES	-	26	12	0	5	0	0
CYCLE TIMES	-						
LOADING TIMES	-						

PART NUMBER -C2164/ 18

BATCH QTY	- 150						
DEMAND	- 15						
ROUTE	-	CB4A	CB4B	TRA	MHA	TRB	INSA
SETTING TIMES	-	460	222	10	90	10	30
PROCESS TIMES	-	23	2	0	2	0	0
CYCLE TIMES	-						
LOADING TIMES	-						

PART NUMBER -C2214/2

BATCH QTY	- 450						
DEMAND	- 143						
ROUTE	-	AC1A	AC1B	TRA	DEBA	TRB	INSA
SETTING TIMES	-	300	240	10	15	10	30
PROCESS TIMES	-	4	3	0	1	0	0
CYCLE TIMES	-	1800	1350				
LOADING TIMES	-	1	1				

PART NUMBER -C3472/10

BATCH QTY	- 224							
DEMAND	- 69							
ROUTE	-	AC1A	AC1B	TRA	DS4A	TRB	DEBA	INSA
SETTING TIMES	-	120	120	10	45	10	12	30
PROCESS TIMES	-	4	2	0	1	0	5	0
CYCLE TIMES	-	896	448					
LOADING TIMES	-	1	1					

Detail Activity (Job Track) Monitor

```
JT  177125 ISSUE  OF BATCH  1461 FOR PARTPT7374/89  ON DAY  124 LOAD 52
JT  177420**INSP** BCH  741 MAN OSCAR FOR=C3365/14          ON DAY  124
AV LOAD  2673.6 LEAD= 512 DEV= 412 DEV/OP=  37 NO OF OPS=   11
JT  177476**INSP** BCH  751 MAN ANONA FOR=C2212/1           ON DAY  124
AV LOAD  2688.4 LEAD= 508 DEV= 458 DEV/OP=  92 NO OF OPS=   5
JT  177940 AUTOGEN ORD  1470 QTY  242 DUE  144 FORC3340/31  ON DAY  124
JT  178560 TOTAL LOAD (EXCLUDING SUB-CON) = 3570.67 ON DAY      125
JT  178565 ISSUE  OF BATCH  1471 FOR PARTC3340/31   ON DAY  125 LOAD 15
JT  178713**INSP** BCH  1001 MAN OSCAR FOR=C11304/101       ON DAY  125
AV LOAD  3006.7 LEAD= 336 DEV= 317 DEV/OP=  79 NO OF OPS=   4
JT  178763**INSP** BCH  941 MAN ANONC FOR=C10725/17         ON DAY  125
AV LOAD  2936.5 LEAD= 379 DEV= 371 DEV/OP=  74 NO OF OPS=   5
JT  179211 AUTOGEN ORD  1480 QTY  377 DUE  145 FORC3648/14  ON DAY  125
JT  180000 TOTAL LOAD (EXCLUDING SUB-CON) = 3468.93 ON DAY      126
JT  180005 ISSUE  OF BATCH  1481 FOR PARTC3648/14   ON DAY  126 LOAD 30
JT  180482 AUTOGEN ORD  1490 QTY  197 DUE  146 FORC2173/2   ON DAY  126
JT  180487 ISSUE  OF BATCH  1491 FOR PARTC2173/2    ON DAY  126 LOAD 59
JT  181440 TOTAL LOAD (EXCLUDING SUB-CON) = 3522.63 ON DAY      127
JT  181753 AUTOGEN ORD  1500 QTY   97 DUE  147 FORC3607/7   ON DAY  127
JT  181758 ISSUE  OF BATCH  1501 FOR PARTC3607/7    ON DAY  127 LOAD 15
JT  182880 TOTAL LOAD (EXCLUDING SUB-CON) = 3489.58 ON DAY      128
JT  183024 AUTOGEN ORD  1510 QTY  327 DUE  148 FORC2226/18  ON DAY  128
JT  183029 ISSUE  OF BATCH  1511 FOR PARTC2226/18   ON DAY  128 LOAD  173
JT  184295 AUTOGEN ORD  1520 QTY   93 DUE  148 FORC3340/6   ON DAY  128
JT  184320 TOTAL LOAD (EXCLUDING SUB-CON) = 3633.91 ON DAY      129
JT  184325 ISSUE  OF BATCH  1521 FOR PARTC3340/6    ON DAY  129 LOAD 12
JT  184393**INSP** BCH  791 MAN IRVIN FOR=C2212/1           ON DAY  129
AV LOAD  2805.3 LEAD= 513 DEV= 463 DEV/OP=  93 NO OF OPS=   5
JT  184679**INSP** BCH  1031 MAN OSCAR FOR=CB211/13         ON DAY  129
AV LOAD  3092.3 LEAD= 349 DEV= 313 DEV/OP=  63 NO OF OPS=   5
JT  184751**INSP** BCH  1151 MAN ANONB FOR=C10725/17        ON DAY  129
AV LOAD  3229.6 LEAD= 263 DEV= 255 DEV/OP=  51 NO OF OPS=   5
```

Note: The degree of detail monitored is adjustable. In this instance only the ISSUE, AUTOGEN, INSP, and LOAD (W.I.P) monitors were activated in order to limit the quantity of information printed. Similar levels of monitoring are available for activities such as SETTING, PROCESS, AUTOLOAD, ABSENCE etc.

Utilisation Monitoring During the Run

++++ CUMULATIVE MAN/MACHINE UTILISATION AT CLOCK= 201600 ++++

MAN ACTIVITY DATA

MINUTES SPENT IN EACH ACTIVITY

	TOTAL	SET	PROC	LOAD	INSP	ABSENT	FINWK	BRKDN	IDLE
MAN1	201840	4549	39123	0	0	0	134400	0	23768
MAN2	201600	3214	20594	17	0	0	134400	0	43375
MAN3	201630	5321	31394	19	0	0	134400	0	30496
MAN4	201600	3378	42652	0	0	0	134400	0	21170
MAN5	201590	4445	12935	29	0	0	134400	0	49781
CLERK	201605	600	0	0	0	0	134400	0	65820

ALLOWED / CYCLE HOURS PRODUCED

	TOTAL	ALLOWED MINS			CYCLE MINS					PERFORMANCE	
NAME	FREQ	SET	PROC	TOT	SET	LOAD	CYCLE	TOT	ATTN	ALLD	CYCLE
MAN1	100341	10407	89934	0	0	0	0	0	0	0	0
MAN2	96916	3440	47346	0	3919	17	42194	0	0	0	0
MAN3	111256	8556	72175	0	3643	19	26863	0	0	0	0
MAN4	105731	7703	98028	0	0	0	0	0	0	0	0
MAN5	89511	3515	29729	0	6684	29	49554	0	0	0	0
CLERK	600	600	0	0	0	0	0	0	0	0	0

MACHINE ACTIVITY DATA

MINUTES SPENT IN EACH ACTIVITY

	TOTAL	SET	PROC	LOAD	AUTOPR	ABS	FINWOR	BREAK	STOP
CB4	201630	6165	57618	0	0	0	0	0	137847
CC5	197583	5735	50713	0	0	0	0	0	141135
AC11	201840	3537	0	38	60231	0	0	0	138034
AC12	201840	2670	0	27	58380	0	0	0	140763
DS4	193278	721	11057	0	0	0	0	0	181500
DEB	200170	241	20341	0	0	0	0	0	179588
MH	184621	709	3070	0	0	0	0	0	180842
TRUCK	199074	643	0	0	0	0	0	0	198431
GRE	201840	479	3529	0	0	0	0	0	197832
FTRUC	0	0	0	0	0	0	0	0	0
DEGA	197422	7	98	0	0	0	0	0	197317
FIT	152841	0	52	0	0	0	0	0	152789
HP	199172	0	220	0	0	0	0	0	198952
INSP	199202	2700	0	0	0	0	0	0	196502
HDN	201840	39458	0	0	0	0	0	0	162382
VFRF	201840	38363	0	0	0	0	0	0	163477
SB	200302	10800	0	0	0	0	0	0	189502

Selected Examples of Results Printed at Termination

Queue Monitoring

```
 HISTOGRAM OF LENGTH OF QUEUE STOP
CELL  FREQUENCY
   10   5
   11  51**
   12 192*********
   13 438*********************
   14 258************
   15 119*****
   16  18
   17  23*
   18  14
   192246*********************************************************

   MEAN CELL =  17.125747

HISTOGRAM OF DELAYS AT STOP
CELL  FREQUENCY
    0  945*********************************************************
   10    6
   20    2
   30    6
   40    7
   50    4
   60  796*********************************************************
   70    2
   80    4
   90    3
  100    2
  110    4
  120    3
  130    5
  140    4
  150    5
  160    1
  170    3
  180    8
  190 1103*********************************************************

   MEAN CELL =  90.590478 STANDARD DEVIATION =  82.077792
```

WORK IN PROGRESS MONITOR

** WIP MONITOR TIME PERIOD WAS 20 DAYS

**RECORDING OF WIP BEGAN AFTER 1 PERIODS

*NOTE - WIP LEVEL WAS RECORDED AT THE START OF EACH PERIOD
- LEVELS IN ACTUAL HRS ASSUMING PERF OF 230

LOAD IN ACTUAL HOURS AT EACH GROUP

PERIOD		1	2	3	4	5	6	7	8
NAME	TOTAL								
CB4A	1903	0	96	127	217	222	308	416	517
CB4B	0	0	0	0	0	0	0	0	0
CC5A	476	0	0	45	53	119	78	76	105
CC5B	15	4	0	0	0	11	0	0	0
AC1A	2309	0	124	184	306	365	473	467	390
AC1B	0	0	0	0	0	0	0	0	0
DS4A	0	0	0	0	0	0	0	0	0
DS4B	0	0	0	0	0	0	0	0	0
DEBA	4	0	1	0	0	0	3	0	0
DEBB	0	0	0	0	0	0	0	0	0
MHA	2	0	0	0	0	0	2	0	0
MHB	0	0	0	0	0	0	0	0	0
TRA	0	0	0	0	0	0	0	0	0
TRB	0	0	0	0	0	0	0	0	0

LOAD IN ACTUAL HOURS FOR EACH GROUP

PERIOD		1	2	3	4	5	6	7	8
NAME	TOTAL								
CB4A	2132	0	125	165	256	254	372	432	528
CB4B	526	0	18	39	46	68	101	93	161
CC5A	927	0	24	130	171	161	118	131	192
CC5B	967	7	26	112	126	175	151	194	176
AC1A	2809	0	172	278	320	419	548	520	552
AC1B	3030	0	139	434	331	361	513	634	618
DS4A	458	0	9	48	50	77	79	97	98
DS4B	5	0	0	2	0	1	1	1	0
DEBA	1177	0	78	141	156	171	199	226	206
DEBB	0	0	0	0	0	0	0	0	0
MHA	138	0	15	0	6	15	37	35	30
MHB	30	0	0	0	0	2	10	9	9
TRA	0	0	0	0	0	0	0	0	0
TRB	0	0	0	0	0	0	0	0	0

*****LEAD TIME MONITORING*****

```
*AVERAGE LEAD TIMES  V  SIMULATED TIME*

PERIOD     AVERAGE LEAD TIME (HRS)
   1   152******************************
   2   150******************************
   3   223********************************************
   4   261****************************************************
   5   338******************************************************
   6   401******************************************************
   7   471******************************************************
   8   486******************************************************

*LEAD TIME DISTRIBUTION*

LEAD (HRS)      FREQUENCY
   100    16****************
   200    30******************************
   300    23***********************
   400    13*************
   500    12************
   600     2**
   70 0    1*

   MEAN CELL =  284.53615 STANDARD DEVIATION =  138.72783

*BATCHES COMPLETED  V  SIMULATED TIME*

PERIOD      NO. BATCHES COMPLETED
     1    14**************
     2    11***********
     3    18******************
     4    11***********
     5    15***************
     6    14**************
     7    13*************
     8     1*
```

Appendix 14 Listing of the Interactive Program and Operationg Macros

Listing of the Interactive Program

```
      LIST(LP)
      PROGRAM (FXXX)
      INPUT  1= CR0
      INPUT  6= ED1/(HOLD)
      OUTPUT 2= LP0
      OUTPUT 3= LP1
      OUTPUT 4= LP2
      OUTPUT 5= LP3
      OUTPUT 7= ED2
      CREATE 8= ED3
      EXTENDED DATA
      TRACE 0
      END
      TRACE 0
      MASTER IT6
      IMPLICIT INTEGER(A-Z)
      DIMENSION MANAME(11),TITOFW(11),PERF(11),SSKILL(11,40),RLIMIT(11)
      DIMENSION PSKILL(11,40),NSSK(11),NPSK(11)
      DIMENSION DUEDAY(51),NORDER(51),PARTNAME(102),ISSDAY(51)
      DIMENSION QTY(51),SBCH(51,2),OP(51,2),BCH(2)
      DIMENSION PNAME(150),POPGP(75,17),POPST(75,17),POPPR(75,17)
      DIMENSION POPCY(75,17),POPLD(75,17),TYP(17)
      DIMENSION NOOPS(75),BQTY(75),SVALUE(400),PVALUE(400),LVALUE(400)
      DIMENSION DEMAND(75)
      DIMENSION EXECUTE(3)
      DIMENSION MCNAME(21),MBINF(21,6),GRNAME(41),MINGP(41,3),MACTYP(21)
      DIMENSION NMINGP(41)
      DIMENSION MCT(6),HISTNAMES(15)
C  THIS VERSION SHOULD SUPPORT THE FOLLOWING
C    10  MEN
C   40  GROUPS
C   75  PARTS
C   17  OPS/PART
C   51  ORDERS
C    2  BATCHES/ORDER
C   20  MACHINES
C    3  MACHINES/GROUP
C   40  SKILLS/MAN
C  400  SE/PR/LDTIMES
C
C
      DATA BLANK/'           '/,NO/'N'/,Q/1H'/
      DATA MCT(1)/'MNBK     '/,MCT(2)/'SDBK      '/,MCT(3)/'SEBK      '/
      DATA MCT(4)/'MNTBK    '/,MCT(5)/'SDTBK     '/,MCT(6)/'SETBK     '/
      DATA CYCLE/'C'/,ALLD/'A'/
```

```
      DATA HISTNAMES/'HTWIPA','HTWIPC','HISSUA','HISSUC','HAWISA',
     & 'HAWISC',
     & 'HLETIM','HLEJOB','HDVTIM',' HLEAD','  HDEV','HLDLIS','HLDLTL',
     & 'HLDLNI','HLDLNT'/
       WRITE(2,200)
C
C
C  CHECK IF THIS IS A NEW SIMULATION, IF SO, THERE IS NO
C  'HOLD' FILE IN EXISTANCE. THEREFOR ALL THE MOD &
C  DELETION SECTIONS MUST BE JUMPED. TO ACHIEVE THIS
C  INDIC IS SET = 1 BY DEFAULT & ALL THE ENTITY
C  COUNTERS ARE SET = 1.
C
C
      WRITE(2,4999)
      READ(1,102)ANS
      INDIC=1
      IF(ANS.EQ.NO)INDIC=0
C
C  RESET COUNTERS
C
      IF(INDIC.EQ.0)GOTO 9
      NMC=1
      NGP=1
      NIG=1
      NOMEN=1
      NGS=1
      NGPK=1
      NPT=1
      NOP=1
      NPRO=1
      NSET=1
      NOR=1
    9 CONTINUE
C
C
C  MACHINE & GROUP INFORMATION ENTRY
C
C
      IF(INDIC.EQ.1)GOTO 12
      WRITE(2,5000)
C     MODIFY COUPLING DATA
      WRITE(2,5001)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GO TO 20
      GOTO 11
   10 CONTINUE
      IF(INDIC.EQ.0)REWIND 6
      REWIND 7
   11 READ(6)NMC
      DO 1    I=1,NMC
    1 READ(6)MCNAME(I),MACTYP(I),(MBINF(I,J),J=1,6)
C
```

```
      WRITE(2,1200)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 6002
C
      WRITE(2,2200)
      DO 6001 I=1,NMC
 6001 WRITE(2,3200)I,MCNAME(I),MACTYP(I),(MBINF(I,J),J=1,6)
C
 6002 WRITE(2,4200)
      READ(1,100)NAME
      IF(NAME.EQ.BLANK)GOTO 6005
C
      DO 6003 I=1,NMC
      CALL COMP8(NAME,MCNAME(I),L)
      IF(L.EQ.1)GOTO 6004
 6003 CONTINUE
C
      WRITE(2,5200)NAME
      GOTO 6002
 6004 WRITE(2,5002)MCNAME(I),MACTYP(I),(MBINF(I,J),J=1,6)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GO TO 6002
      WRITE(2,5003)
      READ(1,100)MCNAME(I)
      READ(1,102)MACTYP(I)
      READ(1,108)(MBINF(I,J),J=1,6)
C
      GOTO 6002
C
 6005 CONTINUE
C   DELETION OF MACHINES
      WRITE(2,5004)
    2 READ(1,100)NAME
      IF(NAME.EQ.BLANK)GO TO 6
      DO 3    I=1,NMC
      CALL COMP8(NAME,MCNAME(I),L)
      IF(L.EQ.1)GOTO 4
    3 CONTINUE
    4 DO 5    J=I,(NMC-1)
      CALL COPY8(MCNAME(J),MCNAME(J+1))
      MACTYP(J)=MACTYP(J+1)
      DO 5    K=1,6
    5 MBINF(J,K)=MBINF((J+1),K)
      NMC=NMC-1
      GOTO 2
C
    6 WRITE(2,5005)NMC
C
      WRITE(2,5006)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 22
      NMC=NMC+1
C
```

```
   12 WRITE(2,201)
      GOTO 16
   15 WRITE(2,202)
   16 READ(1,100)MCNAME(NMC)
      IF(MCNAME(NMC).EQ.BLANK)GOTO 17
      READ(1,102)MACTYP(NMC)
      READ(1,101)(MBINF(NMC,I),I=1,3)
      READ(1,101)(MBINF(NMC,I),I=4,6)
      WRITE(2,203)MCNAME(NMC),MACTYP(NMC),(MBINF(NMC,I),I=1,6)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 15
      NMC=NMC+1
      GOTO 15
C
   17 NMC=NMC-1
      WRITE(2,204)NMC
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 10
      GOTO 22
C
   20 READ(6)NMC
      DO 21 I=1,NMC
   21 READ(6)MCNAME(I),MACTYP(I),(MBINF(I,J),J=1,6)
C
   22 WRITE(7)NMC
      DO 23 I=1,NMC
   23 WRITE(7)MCNAME(I),MACTYP(I),(MBINF(I,J),J=1,6)
C
C  GROUP INFORMATION ENTRY
C
      IF(INDIC.EQ.1)GOTO 34
C     CHANGE GROUP DATA?
      WRITE(2,5007)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 55
C
      READ(6)NGP
      DO 24 I=1,NGP
      READ(6)GRNAME(I),NMINGP(I)
   24 READ(6)(MINGP(I,J),J=1,NMINGP(I))
C
      WRITE(2,1204)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 7026
C
      WRITE(2,2204)
      DO 7025 I=1,NGP
 7025 WRITE(2,3204)GRNAME(I),(MINGP(I,J),J=1,NMINGP(I))
C
 7026 WRITE(2,4204)
      READ(1,100)NAME
      IF(NAME.EQ.BLANK)GOTO 27
C
```

```
      DO 7027 I=1,NGP
      CALL COMP8(NAME,GRNAME(I),L)
      IF(L.EQ.1)GOTO 7028
 7027 CONTINUE
C
      WRITE(2,5024)NAME
      GOTO 7026
C
 7028 WRITE(2,5008)GRNAME(I),NMINGP(I),(MINGP(I,J),J=1,NMINGP(I))
      READ(1,102)ANS
      IF(ANS.EQ.NO)GO TO 7026
C
   25 WRITE(2,5009)
      READ(1,100)GRNAME(I)
      X=0
   26 X=X+1
      READ(1,100)MINGP(I,X)
      IF(MINGP(I,X).NE.BLANK)GOTO 26
C
      NMINGP(I)=X-1
      WRITE(2,5008)GRNAME(I),NMINGP(I),(MINGP(I,J) ,J=1,NMINGP(I))
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 25
C
      GOTO 7026
C
   27 CONTINUE
C
C  DELETION OF GROUPS
      WRITE(2,5010)
C
   28 READ(1,100)NAME
      IF(NAME.EQ.BLANK)GOTO 32
C
      DO 29 I=1,NGP
      CALL COMP8(NAME,GRNAME(I),L)
      IF(L.EQ.1)GOTO 30
   29 CONTINUE
C
   30 DO 31 J=I,(NGP-1)
      CALL COPY8(GRNAME(J),GRNAME(J+1))
      NMINGP(J)=NMINGP(J+1)
      DO 31 K=1,NMINGP(J)
      CALL COPY8(MINGP(J,K),MINGP((J+1),K))
   31 CONTINUE
      NGP=NGP-1
      GOTO 28
C
   32 WRITE(2,5011)NGP
C
C  ADDITION OF NEW GROUPS
      WRITE(2,6011)
      READ(1,102)ANS
```

```
      IF(ANS.EQ.NO)GOTO 57
      NGP=NGP+1
   34 WRITE(2,205)
      GOTO 40
   35 WRITE(2,206)
   40 READ(1,100)GRNAME(NGP)
      IF(GRNAME(NGP).EQ.BLANK)GOTO 52
   45 NIG=1
   50 READ(1,100)MINGP(NGP,NIG)
      IF(MINGP(NGP,NIG).EQ.BLANK)GOTO 51
       NIG=NIG+1
      GOTO 50
   51 NIG=NIG-1
      WRITE(2,207)GRNAME(NGP),(MINGP(NGP,I),I=1,NIG)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 35
      NMINGP(NGP)=NIG
      NGP=NGP+1
      GOTO 35
C
C
   52 NGP=NGP-1
      WRITE(2,208)NGP
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 10
      GOTO 57
C
   55 READ(6)NGP
      DO 56 I=1,NGP
      READ(6)GRNAME(I),NMINGP(I)
   56 READ(6)(MINGP(I,J),J=1,NMINGP(I))
   57 WRITE(7)NGP
      DO 58 I=1,NGP
      WRITE(7)GRNAME(I),NMINGP(I)
   58 WRITE(7)(MINGP(I,J),J=1,NMINGP(I))
C
C
C  TEST TO FIND THE MC NUMBERS CORRES TO THE MC NAMES IN EACH GRP.
C  ASSIGN THE NUMBER IN PLACE OF THE MC NAME
C
      LC=0
      CE=1
      DO 65 I=1,NGP
      DO 65 J=1,NMINGP(I)
      IF(LC.EQ.CE)GOTO 66
      LC=CE
      DO 65 K=1,NMC
      CALL COMP8(MINGP(I,J),MCNAME(K),L)
      IF(L.EQ.1)GOTO 64
      GOTO 65
C
   64 CE=CE+1
      MINGP(I,J)=K
```

```
C
   65 CONTINUE
      GOTO 67
C
   66 WRITE(2,250)MINGP(I,J),J,GRNAME(I),(MCNAME(N),N=1,NMC)
      WRITE(2,251)
      GOTO 10
   67 CONTINUE
C
C   MAN DATA ENTRY SECTION
C
      IF(INDIC.EQ.1)GOTO 599
C   ASK CHANGE MAN DATA
      WRITE(2,5012)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GO TO 621
C
      READ(6)NOMEN
      DO 70 I=1,NOMEN
      READ(6)MANAME(I),TITOFW(I),PERF(I),RLIMIT(I),NSSK(I),NPSK(I)
      READ(6)(SSKILL(I,J),J=1,NSSK(I))
   70 READ(6)(PSKILL(I,J),J=1,NPSK(I))
C
      WRITE(2,1210)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 72
C
      WRITE(2,2210)(MANAME(I),I=1,NOMEN)
C
   72 WRITE(2,3210)
      READ(1,100)NAME
      IF(NAME.EQ.BLANK)GOTO 583
C
      DO 74 I=1,NOMEN
      CALL COMP8(NAME,MANAME(I),L)
      IF(L.EQ.1)GOTO 76
C
   74 CONTINUE
C
      WRITE(2,4210)NAME
      GOTO 72
C
   76 WRITE(2,5013)MANAME(I),TITOFW(I),PERF(I),RLIMIT(I)
      WRITE(2,5014)(SSKILL(I,J),J=1,NSSK(I))
      WRITE(2,5015)(PSKILL(I,J),J=1,NPSK(I))
      WRITE(2,5016)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 72
C     READ NEW VALUES
  580 WRITE(2,5017)
      READ(1,100)MANAME(I)
      READ(1,101)TITOFW(I),PERF(I),RLIMIT(I)
      WRITE(2,5018)
```

```
      X=0
  581  X=X+1
      READ(1,100)SSKILL(I,X)
      IF(SSKILL(I,X).NE.BLANK)GOTO 581
      NSSK(I)=X-1
      WRITE(2,5019)
      Y=0
  582 Y=Y+1
      READ(1,100)PSKILL(I,Y)
      IF(PSKILL(I,Y).NE.BLANK)GOTO 582
      NPSK(I)=Y-1
C     DO YOU WISH TO CHANGE ANYTHING JUST ENTERED
      WRITE(2,5020)
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 580
C
      GOTO 72
C
  583  CONTINUE
C
C  DELETION OF MEN
      WRITE(2,5021)
C
  584 READ(1,100)NAME
C
      IF(NAME.EQ.BLANK)GOTO 588
C
      DO 585 I=1,NOMEN
      CALL COMP8(NAME,MANAME(I),L)
      IF(L.EQ.1)GOTO 1585
  585 CONTINUE
C
 1585 DO 587 J=I,(NOMEN-1)
      CALL COPY8(MANAME(J),MANAME(J+1))
      TITOFW(J)=TITOFW(J+1)
      PERF(J)=PERF(J+1)
      RLIMIT(J)=RLIMIT(J+1)
      NSSK(J)=NSSK(J+1)
      NPSK(J)=NPSK(J+1)
      DO 586 K=1,NSSK(J)
  586 CALL COPY8(SSKILL(J,K),SSKILL((J+1),K))
      DO 587 K=1,NPSK(J)
  587 CALL COPY8(PSKILL(J,K),PSKILL((J+1),K))
C
      NOMEN=NOMEN-1
      GOTO 584
C
  588 WRITE(2,5022)NOMEN
C   ADD NEW MEN
C
      WRITE(2,5023)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 623
```

```
      NOMEN=NOMEN+1
C   NORMAL SECTION
  599 WRITE(2,210)
      GOTO 601
  600 WRITE(2,211)
  601 READ(1,100)MANAME(NOMEN)
      IF(MANAME(NOMEN).EQ.BLANK)GOTO 620
      READ(1,101)TITOFW(NOMEN),PERF(NOMEN),RLIMIT(NOMEN)
C
  602 NGS=1
      IF(NOMEN.NE.1)GOTO 605
      WRITE(2,212)MANAME(NOMEN)
      GOTO 610
  605 WRITE(2,213)MANAME(NOMEN)
  610 READ(1,100)SSKILL(NOMEN,NGS)
      IF(SSKILL(NOMEN,NGS).EQ.BLANK)GOTO 611
      NGS=NGS+1
      GOTO 610
  611 NGS=NGS-1
      WRITE(2,214)MANAME(NOMEN),NGS,(SSKILL(NOMEN,I),I=1,NGS)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 602
      NSSK(NOMEN)=NGS
C
  614 NGPK=1
      WRITE(2,215)MANAME(NOMEN)
  615 READ(1,100)PSKILL(NOMEN,NGPK)
      IF(PSKILL(NOMEN,NGPK).EQ.BLANK)GOTO 616
      NGPK=NGPK+1
      GOTO 615
C
  616 NGPK=NGPK-1
      WRITE(2,216)MANAME(NOMEN),NGPK,(PSKILL(NOMEN,I),I=1,NGPK)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 614
      NPSK(NOMEN)=NGPK
      NOMEN=NOMEN+1
      GOTO 600
C
  620 NOMEN=NOMEN-1
      WRITE(2,217)NOMEN
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 10
      GOTO 623
C  NEED DATA FOR CASE WHERE NO CHANGES REQUIRED
  621 READ(6)NOMEN
      DO 622 I=1,NOMEN
      READ(6)MANAME(I),TITOFW(I),PERF(I),RLIMIT(I),NSSK(I),NPSK(I)
      READ(6)(SSKILL(I,J),J=1,NSSK(I))
  622 READ(6)(PSKILL(I,J),J=1,NPSK(I))
C
C  WRITE DATA TO NEW HOLD FILE
  623 WRITE(7)NOMEN
```

```
      DO 624 I=1,NOMEN
      WRITE(7)MANAME(I),TITOFW(I),PERF(I),RLIMIT(I),NSSK(I),NPSK(I)
      WRITE(7)(SSKILL(I,J),J=1,NSSK(I))
  624 WRITE(7)(PSKILL(I,J),J=1,NPSK(I))
C
C  READ SICKNESS & ABSENCE DATA FOR ALL MEN
C
      IF(INDIC.EQ.1)GOTO 625
C
C
C   READ DATA FROM OLD HOLD
      READ(6)SICKPER,MNAB,SDAB,MNTAB,SDTAB
      WRITE(2,5025)SICKPER,MNAB,SDAB,MNTAB,SDTAB
C
C   DO YOU WISH TO CHANGE ANY
      WRITE(2,5024)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 626
C
  625 WRITE(2,218)
      READ(1,103)SICKPER
C
      WRITE(2,219)
      READ(1,104)MNAB,SDAB
      READ(1,104)MNTAB,SDTAB
      WRITE(2,220)
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 625
C
  626 TFREQ=100
      NSICK=100-SICKPER
      WRITE(7)SICKPER,MNAB,SDAB,MNTAB,SDTAB
C
C  CALCULATE THE GROUP NO FOR EACH GROUP NAME IN SSKILL & PSKILL
C
      DO 632 I=1,NOMEN
      IF(NSSK(I).EQ.0)GOTO 632
      DO 631 J=1,NSSK(I)
      DO 629 K=1,NGP
      CALL COMP8(SSKILL(I,J),GRNAME(K),L)
      IF(L.EQ.1)GOTO 630
  629 CONTINUE
C
C
      WRITE(2,252)SSKILL(I,J),J,MANAME(I),(GRNAME(N),N=1,NGP)
      WRITE(2,251)
      GOTO 10
C
  630 SSKILL(I,J)=K
C
C
  631 CONTINUE
C
```

```
  632 CONTINUE
C
C  REPEAT FOR PSKILL
C
      DO 637 I=1,NOMEN
      IF(NPSK(I).EQ.0)GOTO 637
      DO 636 J=1,NPSK(I)
C
      DO 634 K=1,NGP
      CALL COMP8(PSKILL(I,J),GRNAME(K),L)
      IF(L.EQ.1)GOTO 635
  634 CONTINUE
C
      WRITE(2,253)PSKILL(I,J),J,MANAME(I),(GRNAME(N),N=1,NGP)
      WRITE(2,251)
      GOTO 10
C
  635 PSKILL(I,J)=K
C
  636 CONTINUE
C
  637 CONTINUE
C
C
C  PART DATA ENTRY SECTION
C
C
      IF(INDIC.EQ.1)GOTO 700
      WRITE(2,5026)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 735
C
C  READ OLD DATA & ASK FOR IF REVISION IS REQUIRED
C
      READ(6)NPT
      DO 642 I=1,NPT
      Z=2*I
      READ(6)PNAME(Z-1),PNAME(Z),BQTY(I),DEMAND(I),NOOPS(I)
      DO 640 J=1,NOOPS(I)
  640 READ(6)POPGP(I,J),POPST(I,J),POPPR(I,J),POPCY(I,J),POPLD(I,J)
C
  642 CONTINUE
C
      WRITE(2,1234)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 646
C
      WRITE(2,2234)
      DO 644 I=1,NPT
      Z=2*I
  644 WRITE(2,3234)I,PNAME(Z-1),PNAME(Z),BQTY(I),DEMAND(I),NOOPS(I)
C
  646 WRITE(2,4234)
```

```
      READ(1,105)NAME,NAMET
C
      IF(NAME.EQ.BLANK)GOTO 654
C
      DO 648 I=1,NPT
      Z=2*I
      CALL COMP8(NAME,PNAME(Z-1),L)
      CALL COMP8(NAMET,PNAME(Z),M)
      IF(L.EQ.1.AND.M.EQ.1)GOTO 650
  648 CONTINUE
C
      WRITE(2,5234)NAME,NAMET
      GOTO 646
C
  650 WRITE(2,5027)PNAME(Z-1),PNAME(Z)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 651
      WRITE(2,235)PNAME(Z-1),PNAME(Z)
      WRITE(2,236)BQTY(I),DEMAND(I),NOOPS(I),(POPGP(I,K),K=1,NOOPS(I))
      WRITE(2,237)(POPST(I,K),K=1,NOOPS(I))
      WRITE(2,238)(POPPR(I,K),K=1,NOOPS(I))
      WRITE(2,1238)(POPCY(I,K),K=1,NOOPS(I))
      WRITE(2,2238)(POPLD(I,K),K=1,NOOPS(I))
C  ASK IF REVISION REQUIRED
  651 WRITE(2,5028)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 646
C   READ NEW DATA
C
      WRITE(2,5029)
      READ(1,105)PNAME(Z-1),PNAME(Z)
      READ(1,104)BQTY(I),DEMAND(I)
      X=0
      WRITE(2,5030)
  652 X=X+1
      READ(1,100)POPGP(I,X)
      IF(POPGP(I,X).EQ.BLANK)GOTO 653
      READ(1,107)POPST(I,X),POPPR(I,X),POPCY(I,X),POPLD(I,X)
      GOTO 652
C
  653 NOOPS(I)=X-1
C  ASK IF WANT TO CHANGE ANYTHING
      WRITE(2,5031)
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 650
C
C
      GOTO 646
  654 CONTINUE
C  DO WISH TO DELETE ANY PARTS, READ LIST UNTIL BLANK OCCURS
      WRITE(2,5032)
  655 READ(1,105)NAME,NAMET
      IF(NAME.EQ.BLANK)GOTO 659
```

```
C   FIND THE PART
      DO 656 I=1,NPT
      Z=2*I
      CALL COMP8(NAME,PNAME(Z-1),L)
      CALL COMP8(NAMET,PNAME(Z),M)
      IF(L.EQ.1.AND.M.EQ.1)GOTO 657
  656 CONTINUE
      GOTO 655
C   RESHUFFLE THE REMAINDER
  657 DO 658 J=I,NPT
      Z=2*J
      REWIND 8
      WRITE(8) PNAME(Z+1),PNAME(Z+2)
      REWIND 8
      READ(8) PNAME(Z-1),PNAME(Z)
      BQTY(J)=BQTY(J+1)
      DEMAND(J)=DEMAND(J+1)
      NOOPS(J)=NOOPS(J+1)
      DO 658 K=1,NOOPS(J)
      CALL COPY8(POPGP(J,K),POPGP((J+1),K))
      POPST(J,K)=POPST((J+1),K)
      POPPR(J,K)=POPPR((J+1),K)
      POPCY(J,K)=POPCY((J+1),K)
  658 POPLD(J,K)=POPLD((J+1),K)
C   MODIFY NPT AND READ NEXT NAME
      NPT=NPT-1
      GOTO 655
C  WRITE NO OF PARTS AT END OF DELETIONS
  659 WRITE(2,5033)NPT
C
C   DO WISH TO ADD ANY NEW PARTS
      WRITE(2,5034)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 737
      NPT=NPT+1
  700 WRITE(2,231)
      GOTO 720
C
  710 WRITE(2,232)
  720 Z=2*NPT
      READ(1,105)PNAME(Z-1),PNAME(Z)
      IF(PNAME(Z-1).EQ.BLANK)GOTO 732
      READ(1,104)BQTY(NPT),DEMAND(NPT)
C
C  ENTRY OF ROUTE/SETTING/PROCESS/CYCLE/LOAD DATA FOR EACH PART
C
      NOP=1
      IF(NPT.NE.1)GOTO 725
      WRITE(2,233)
      GOTO 730
C
  725 Z=2*NPT
      WRITE(2,234)PNAME(Z-1),PNAME(Z)
```

```
C
  730 READ(1,100)POPGP(NPT,NOP)
      IF(POPGP(NPT,NOP).EQ.BLANK)GOTO 731
      READ(1,107)POPST(NPT,NOP),POPPR(NPT,NOP),POPCY(NPT,NOP),
     &POPLD(NPT,NOP)
      NOP=NOP+1
      GOTO 725
C
  731 NOP=NOP-1
      NOOPS(NPT)=NOP
      Z=2*NPT
      I=NPT
      WRITE(2,235)PNAME(Z-1),PNAME(Z)
      WRITE(2,236)BQTY(I),NOOPS(I),(POPGP(I,K),K=1,NOOPS(I))
      WRITE(2,237)(POPST(I,K),K=1,NOOPS(I))
      WRITE(2,238)(POPPR(I,K),K=1,NOOPS(I))
      WRITE(2,1238)(POPCY(I,K),K=1,NOOPS(I))
      WRITE(2,2238)(POPLD(I,K),K=1,NOOPS(I))
C  ASK IF REVISION REQUIRED
      WRITE(2,239)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 710
      NPT=NPT+1
      GOTO 710
C
  732 NPT=NPT-1
      WRITE(2,240)NPT
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 10
C
      GOTO 737
C  READ DATA FOR CASE WHERE NO AMMENDMENTS
C
  735 READ(6)NPT
      DO 736 I=1,NPT
      Z=2*I
      READ(6)PNAME(Z-1),PNAME(Z),BQTY(I),DEMAND(I),NOOPS(I)
      DO 736 J=1,NOOPS(I)
  736 READ(6)POPGP(I,J),POPST(I,J),POPPR(I,J),POPCY(I,J),POPLD(I,J)
C   WRITE DATA TO NEW HOLD FILE
  737 WRITE(7)NPT
      DO 738 I=1,NPT
      Z=2*I
      WRITE(7)PNAME(Z-1),PNAME(Z),BQTY(I),DEMAND(I),NOOPS(I)
      DO 738 J=1,NOOPS(I)
  738 WRITE(7)POPGP(I,J),POPST(I,J),POPPR(I,J),POPCY(I,J),POPLD(I,J)
C
C  CALCULATE THE GROUP NO FOR EACH GROUP NAME IN ROUTE
C
      LE=0
      ER=1
      DO 745 I=1,NPT
      DO 745 J=1,NOOPS(I)
```

```
      IF(LE.EQ.ER)GOTO 746
      LE=ER
      DO 745 K=1,NGP
      CALL COMP8(POPGP(I,J),GRNAME(K),L)
      IF(L.EQ.1)GOTO 744
      GOTO 745
C
  744 ER=ER+1
      POPGP(I,J)=K
C
  745 CONTINUE
      GOTO 747
C
  746 Z=2*I
      WRITE(2,254)POPGP(I,J),J,PNAME(Z-1),PNAME(Z)
     &,(GRNAME(N),N=1,NGP)
      WRITE(2,251)
      GOTO 10
C
  747 CONTINUE
C
C  CALCULATE THE NO OF SETIMES & FIND THEIR VALUES
C
C***** SET DUMMY VALUE OF SVALUE(1)
      SVALUE(1)=0
      NSET=2
C*** START OF MAIN LOOPS
      DO 760 I=1,NPT
      DO 760 J=1,NOOPS(I)
C*** TEST TO ELIMINATE ZERO ARRAY SUBSCRIPT IN POPST(I,L)
      RN=0
      IF(J.EQ.1)GOTO 752
C*** TEST IF A PREVIOUS EQUAL VALUE EXISTS
      DO 750 L=1,(J-1)
      IF(POPST(I,J).EQ.POPST(I,L))RN=RN+1
  750 CONTINUE
C
  752 CONTINUE
C
C ** TEST IF A PREVIOUS EQUAL VALUE OF SVALUE EXISTS
      SN=0
      DO 755 K=1,(NSET-1)
      IF(POPST(I,J).EQ.SVALUE(K))SN=SN+1
  755 CONTINUE
C*** ASSIGN NEW VALUE TO SVALUE & INCREMENT COUNTER
      IF(SN.GT.RN)GOTO 759
      SVALUE(NSET)=POPST(I,J)
      NSET=NSET+1
C
  759 CONTINUE
C
  760 CONTINUE
C
```

```
      NSET=NSET-1
      WRITE(2,242)NSET,(SVALUE(K),K=1,NSET)
C
C  REPEAT FOR PROCESS TIMES
C
      PVALUE(1)=0
      NPRO=2
      DO 770 I=1,NPT
      DO 770 J=1,NOOPS(I)
      RN=0
      IF(J.EQ.1)GOTO 763
      DO 762 L=1,(J-1)
      IF(POPPR(I,J).EQ.POPPR(I,L))RN=RN+1
  762 CONTINUE
C
  763 CONTINUE
C
      PN=0
      DO 765 K=1,(NPRO-1)
      IF(POPPR(I,J).EQ.PVALUE(K))PN=PN+1
  765 CONTINUE
C
      IF(PN.GT.RN)GOTO 769
      PVALUE(NPRO)=POPPR(I,J)
      NPRO=NPRO+1
C
  769 CONTINUE
C
  770 CONTINUE
C
C
C  REPEAT FOR CYCLE TIMES
C   NOTE - CYCLE TIMES ALSO USE PRTIME, THIS SECTION IS THEREFOR
C          LINKED TO THE PROCESS TIME CALCULATION
C
      DO 780 I=1,NPT
      DO 780 J=1,NOOPS(I)
      RN=0
      IF(J.EQ.1)GOTO 773
      DO 772 L=1,(J-1)
      IF(POPCY(I,J).EQ.POPCY(I,L))RN=RN+1
  772 CONTINUE
C
  773 CONTINUE
      PN=0
      DO 775 K=1,(NPRO-1)
      IF(POPCY(I,J).EQ.PVALUE(K))PN=PN+1
  775 CONTINUE
C
      IF(PN.GT.RN)GOTO 779
      PVALUE(NPRO)=POPCY(I,J)
      NPRO=NPRO+1
C
```

```
  779 CONTINUE
C
  780 CONTINUE
      NPRO=NPRO-1
      WRITE(2,243)NPRO,(PVALUE(K),K=1,NPRO)
C
C  REPEAT FOR LOADING TIMES
C
      LVALUE(1)=0
      NLO=2
      DO 790 I=1,NPT
      DO 790 J=1,NOOPS(I)
      RN=0
      IF(J.EQ.1)GOTO 783
      DO 782 L=1,(J-1)
      IF(POPLD(I,J).EQ.POPLD(I,L))RN=RN+1
  782 CONTINUE
C
  783 CONTINUE
C
      LN=0
      DO 785 K=1,(NLO-1)
      IF(POPLD(I,J).EQ.LVALUE(K))LN=LN+1
  785 CONTINUE
C
      IF(LN.GT.RN)GOTO 789
      LVALUE(NLO)=POPLD(I,J)
      NLO=NLO+1
C
  789 CONTINUE
C
  790 CONTINUE
C
      NLO=NLO-1
      WRITE(2,1243)NLO,(LVALUE(K),K=1,NLO)
      IF(NLO.EQ.0)NLO=NLO+1
C
C
C  ORDER DATA ENTRY SECTION
C
C
      IF(INDIC.EQ.1)GOTO 792
C
C  ASK IF ANY CHANGES TO ORDERS ARE REQUIRED
C
      WRITE (2,5035)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 855
C
C  READ ALL EXISTING ORDER DATA
      READ(6) NOR
      DO 796 I=1,NOR
      Z=2*I
```

```
      READ(6)PARTNAME(Z-1),PARTNAME(Z),ISSDAY(I),QTY(I),DUEDAY(I),
     &NORDER(I)
      IF(ISSDAY(I).NE.0)GOTO 796
      J=0
  795 J=J+1
      READ(6)SBCH(I,J),OP(I,J)
      IF(OP(I,J).NE.0)GOTO 795
      DO 1795 K=1,J
 1795 SBCH(I,K)=SBCH(I,K)-NORDER(I)
C
  796 CONTINUE
C   ASK IF THE EXISTING DATA IS TO BE REVISED
      WRITE(2,5036)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 799
C
      WRITE(2,5137)
      DO 798 I=1,NOR
      Z=2*I
      WRITE(2,5037)NORDER(I),PARTNAME(Z-1),PARTNAME(Z),ISSDAY(I),QTY(I),
     &DUEDAY(I)
      IF(ISSDAY(I).NE.0)GOTO 798
      J=0
  797 J=J+1
      WRITE(2,5038)SBCH(I,J),OP(I,J)
      IF(OP(I,J).NE.0)GOTO 797
C
  798 CONTINUE
C
C  ASK IF ANY ORDERS ARE TO BE DELETED,E FOR THEIR ORDER NOS.
C
  799 WRITE(2,5039)
  800 READ(1,103)NORD
      IF(NORD.EQ.0)GOTO 1805
C   FIND THE ORDER E SHUFFLE
      DO 801 I=1,NOR
      IF(NORD.EQ.NORDER(I))GOTO 802
  801 CONTINUE
C
      GOTO 799
C   SHUFFLE
  802 DO 804 J=I,NOR
      Z=J*2
      REWIND 8
      WRITE(8) PARTNAME(Z+1),PARTNAME(Z+2)
      REWIND 8
      READ(8) PARTNAME(Z-1),PARTNAME(Z)
      ISSDAY(J)=ISSDAY(J+1)
      QTY(J)=QTY(J+1)
      DUEDAY(J)=DUEDAY(J+1)
      NORDER(J)=NORDER(J+1)
C     I
      IF(ISSDAY(J).NE.0)GOTO 804
```

```
      K=0
  803 K=K+1
      SBCH(J,K)=SBCH((J+1),K)
      OP(J,K)=OP((J+1),K)
      IF(OP(J,K).NE.0)GOTO 803
C
  804 CONTINUE
C
      NOR=NOR-1
      GOTO 800
C
 1805 WRITE(2,5040)NOR
C
C   ASK IF ANY ADDITIONS ARE REQUIRED.
      WRITE(2,5041)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 820
C
      NOR=NOR+1
C
  792 WRITE(2,260)
      GOTO 793
  805 WRITE(2,261)
  793 Z=2*NOR
      READ(1,105)PARTNAME(Z-1),PARTNAME(Z)
      IF(PARTNAME(Z-1).EQ.BLANK)GOTO 815
      READ(1,101)ISSDAY(NOR),QTY(NOR),DUEDAY(NOR)
C  TEST FOR ISSDAY=0 - IE. SOME BATCHES ISSUED
C   IF SO, FIND THE PART NO OF THIS ORDER
C
      IF(ISSDAY(NOR).NE.0)GOTO 810
C
      Y=0
      DO 806 K=1,NPT
      X=2*K
      CALL COMP8(PARTNAME(Z-1),PNAME(X-1),L)
      CALL COMP8(PARTNAME(Z),PNAME(X),M)
      IF(L.EQ.1.AND.M.EQ.1)Y=K
  806 CONTINUE
C
C  TEST FOR ERRORS
      IF(Y.NE.0)GOTO 807
      WRITE(2,1261)PARTNAME(Z-1),PARTNAME(Z)
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 10
      GOTO 805
C
C  CALCULATE THE NO OF BATCHES & ASK FOR THE STATE OF THOSE ISSUED
C
  807 NOBCH=QTY(NOR)/BQTY(Y)
      IF(NOBCH*BQTY(Y).NE.QTY(NOR))NOBCH=NOBCH+1
      DO 808 J=1,NOBCH
  808 BCH(J)=J
```

```
C
      WRITE(2,2261)NOBCH,(BCH(J),J=1,NOBCH)
      WRITE(2,3261)
C
C  THEN READ STATE OF ISSUED BATCHES UNTIL NO OF OPS COMP=0
C
      J=0
  809 J=J+1
      READ(1,104)SBCH(NOR,J),OP(NOR,J)
      IF(OP(NOR,J).NE.0)GOTO 809
C
  810 WRITE(2,262)
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 805
      NORDER(NOR)=NOR*10
      NOR=NOR+1
      GOTO 805
C
  815 NOR=NOR-1
      WRITE(2,263)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 820
      WRITE(2,264)(PARTNAME((2*I)-1),PARTNAME(2*I),I=1,NOR)
      WRITE(2,265)(ISSDAY(I),I=1,NOR)
      WRITE(2,266)(QTY(I),I=1,NOR)
      WRITE(2,267)(DUEDAY(I),I=1,NOR)
      WRITE(2,239)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 799
C
  820 WRITE(2,268)NOR
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 799
C
C     RE-ORDER THE ORDERS INTO ASSENDING ISSDAY & REASSIGN NORDER
C
  830 TEST=0
      DO 850 I=2,NOR
      IF(ISSDAY(I).GE.ISSDAY((I-1)))GOTO 845
C
      Z=2*(I-1)
      REWIND 8
      WRITE(8) PARTNAME(Z-1),PARTNAME(Z),PARTNAME(Z+1),PARTNAME(Z+2)
      REWIND 8
      READ(8) PARTNAME(Z+1),PARTNAME(Z+2),PARTNAME(Z-1),PARTNAME(Z)
      T=ISSDAY(I-1)
      ISSDAY(I-1)=ISSDAY(I)
      ISSDAY(I)=T
      T=QTY(I-1)
      QTY(I-1)=QTY(I)
      QTY(I)=T
      T=DUEDAY(I-1)
      DUEDAY(I-1)=DUEDAY(I)
```

```
      DUEDAY(I)=T
      IF(ISSDAY(I).NE.0.AND.ISSDAY(I-1).NE.0)GOTO 850
      DO 832 K=1,10
      IF(OP((I-1),K).EQ.0)GOTO 834
  832 CONTINUE
C
  834 DO 836 L=1,10
      IF(OP(I,L).EQ.0)GOTO 838
  836 CONTINUE
C
  838 M=L
      IF(K.GE.L)M=K
C
      DO 840 J=1,M
      T=SBCH((I-1),J)
      SBCH((I-1),J)=SBCH(I,J)
      SBCH(I,J)=T
      T=OP((I-1),J)
      OP((I-1),J)=OP(I,J)
  840 OP(I,J)=T
      GOTO 850
C
C
  845 TEST=TEST+1
C
  850 CONTINUE
      IF(TEST.NE.(NOR-1))GOTO 830
C   REASSIGN NORDER
  853 DO 854 I=1,NOR
      NORDER(I)=I*10
      DO 854 J=1,2
      SBCH(I,J)=SBCH(I,J)+NORDER(I)
  854 CONTINUE
C
      GOTO 858
  855 READ(6)NOR
      DO 857 I=1,NOR
      Z=2*I
      READ(6)PARTNAME(Z-1),PARTNAME(Z),ISSDAY(I),QTY(I),DUEDAY(I),
     &NORDER(I)
      IF(ISSDAY(I).NE.0)GOTO 857
      J=0
  856 J=J+1
      READ(6)SBCH(I,J),OP(I,J)
      IF(OP(I,J).NE.0)GOTO 856
C
  857 CONTINUE
C
C   OUTPUT DATA TO HOLD FILE
  858 WRITE(7)NOR
      DO 860 I=1,NOR
      Z=2*I
      WRITE(7)PARTNAME(Z-1),PARTNAME(Z),ISSDAY(I),QTY(I),DUEDAY(I),
```

```
     &NORDER(I)
C
      IF(ISSDAY(I).NE.0)GOTO 860
      J=0
  859 J=J+1
      WRITE(7)SBCH(I,J),OP(I,J)
      IF(OP(I,J).NE.0)GOTO 859
C
  860 CONTINUE
C
C    AUTOMATIC ORDER GENERATOR
C
      NAOR=0
      WRITE(2,269)
      READ(1,104)ORFREQ,SEORD
      IF(ORFREQ.EQ.0)GOTO 862
C
      WRITE(2,1269)
      READ(1,103)NAOR
C
C
  862 CONTINUE
C
C
C
C
C
C  CALCULATE THE NO OF JOBS WHICH CAN BE DECLARED. TEST THE TOTAL
C  NO OF ENTITIES AGAINST THE USER DEFINED LIMIT. ASK IF THE
C  NO OF JOBS WHICH RESULT IS ENOUGH, IF NOT ASK FOR A HIGHER LIMIT.
C
C
      WRITE(2,244)
 1000 READ(1,103)LIMIT
      NOJOB=LIMIT-(NMC+NGP+NOMEN+NPT+NSET+NPRO+NLO+NOR+NAOR)
      WRITE(2,245)NOJOB
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 1001
      WRITE(2,246)
      GOTO 1000
C
 1001 WRITE(2,270)
C
C
C  RUN DATA ENTRY SECTION
C
C
      IF(INDIC.EQ.0)GOTO 865
      WRITE(2,280)
      WRITE(2,281)
      READ(1,103)RUNTIME
      WRITE(2,282)
      READ(1,103)RUNINZ
```

```
      WRITE(2,283)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 875
      WRITE(2,284)
      READ(1,104)MNSTON,MNSTOF
      READ(1,104)MNENON,MNENOF
      GOTO 875
  865 CONTINUE
C   ASK IF WISH TO CHANGE THE RUNLENGTH OF RECORDING
C
      READ(6)RUNTIME,RUNINZ
      WRITE(2,5042)RUNTIME,RUNINZ
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 870
      WRITE(2,5043)
      READ(1,104)RUNTIME,RUNINZ
C
  870 CONTINUE
C   ASK IF CHANGE TO MONITORING REQUIRED
      READ(6)MNSTON,MNSTOF,MNENON,MNENOF
      WRITE(2,5044)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 875
C     QUEUE MONITORING CHANGE
      WRITE(2,5045)MNSTON,MNSTOF,MNENON,MNENOF
C
      WRITE(2,284)
      READ(1,107)MNSTON,MNSTOF,MNENON,MNENOF
  875 CONTINUE
      WRITE(7)RUNTIME,RUNINZ
      WRITE(7)MNSTON,MNSTOF,MNENON,MNENOF
C
C       READ DATA & ASK IF FURTHER CHANGES REQUIRED
C
C
      READ(6)WIPMON,LEDMON,WIPDIM,LEDIM,NCELL,CELWID,LLNOC,LLCW
     &,MONFAC,SCHED,RULE,TRACK,EXECUTE,MONINT,MANMCM
      WRITE(2,1284)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 930
C
C  ASK IF WIP MONITORING IS REQUIRED
C
      WRITE(2,291)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 880
      WIPMON=1
      WIPDIM= 1+(RUNTIME/1440)
      GOTO 885
C
  880 WIPMON=0
      WIPDIM=1
C
```

```
C  ASK IF LEAD TIME MONITORING REQUIRED,IF SO ASK FOR NO CELLS &
C  WIDTH OF THE CELLS OF THE HISTOGRAMS
C
  885 WRITE(2,292)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 887
      LEDMON=1
      LEDIM=1+(RUNTIME/1440)
      WRITE(2,293)
      READ(1,104)NCELL,CELWID
      GOTO 890
  887 LEDMON=0
      NCELL=1
      CELWID=1
      LEDIM=1
C
C
C  IF EITHER WIP OR LEAD MONITOR ON ASK FOR TIMESPAN
C
  890 IF(LEDMON.EQ.1.OR.WIPMON.EQ.1)GOTO 891
      MONFAC=1
  891 WRITE(2,1293)
      READ(1,103)MONFAC
      WIPDIM=1+(WIPDIM/MONFAC)
      LEDIM=1+(LEDIM/MONFAC)
C
C  IF BOTH LEAD & WIP MONITORING ON ASK FOR CELL NO & WIDTH
C
  892 IF(LEDMON.EQ.1.AND.WIPMON.EQ.1)GOTO 895
      LLNOC=1
      LLCW=1
      GOTO 900
  895 WRITE(2,294)
      READ(1,104)LLNOC,LLCW
C
  900 WRITE(2,285)
      READ(1,102)ANS
      IF(ANS.NE.NO)GOTO 905
      TRACK=0
      GOTO 906
C
  905 TRACK=1
C
  906 WRITE(2,286)
      READ(1,102)ANS
      IF(ANS.EQ.NO)GOTO 910
      WRITE(2,287)
      READ(1,103)RULE
      SCHED=1
      GOTO 920
C
  910 RULE=0
      SCHED=0
```

```
C
C
C  ASK IF CONTINUOUS MAN/MC MONITORING REQUIRED
C
  920 WRITE(2,1288)
      READ(1,103)MONINT
      MANMCM=0
      IF(MONINT.NE.0)MANMCM=1
C
      WRITE(2,288)
      READ(1,106)EXECUTE
  930 WRITE(7)WIPMON,LEDMON,WIPDIM,LEDIM,NCELL,CELWID,LLNOC,LLCW,
     &MONFAC,SCHED,RULE,TRACK,EXECUTE,MONINT,MANMCM
      WRITE(2,289)
C
C
C  HEAD FILE OUTPUT - MACHINE DATA
C
      WRITE(3,300)NMC,NGP
C
C  WRITE ALL ENTITY DATA TO HEAD FILE
C
C
      NOR=NOR+NAOR
      WRITE(3,301)NOMEN
      WRITE(3,302)NOJOB,NGP
      WRITE(3,303)NPT
      WRITE(3,304)NGP,WIPDIM,WIPDIM
      WRITE(3,305)NSET
      WRITE(3,306)NPRO
      WRITE(3,1306)NLO
      WRITE(3,307)NOR
      WRITE(3,308)(HISTNAMES(I),WIPDIM,I=1,6)
      WRITE(3,309)(HISTNAMES(I),LEDIM,I=7,9)
      WRITE(3,310)(HISTNAMES(I),NCELL,CELWID,CELWID,I=10,11)
      NOR=NOR-NAOR
      WRITE(3,310)(HISTNAMES(I),LLNOC,LLCW,LLCW,I=12,15)
C
C  DATA FILE OUTPUT -
C
      WRITE(4,407)TFREQ,NSICK,SICKPER
      WRITE(4,408)MNTAB
      WRITE(4,409)SDTAB
      WRITE(4,410)MNAB
      WRITE(4,411)SDAB
      WRITE(4,1411)ORFREQ,SEORD
C
C
C
C  WRITE RUN CONTROL DATA TO THE DATA FILE
C
      WRITE(4,418)WIPMON,LEDMON,MONFAC,MANMCM,MONINT
      WRITE(4,417)RUNTIME,RUNINZ,TRACK,MNSTON,MNSTOF,MNENON,MNENOF
```

```
     &,SCHED,RULE,EXECUTE
C
C  TAIL FILE OUTPUT - MACHINE & GROUP DATA
C
      WRITE(5,400)(MCNAME(I),I=1,NMC)
      WRITE(5,401)(MACTYP(I),I=1,NMC)
      DO 170 J=1,6
  170 WRITE(5,402)(MCT(J),MBINF(I,J),I=1,NMC)
      WRITE(5,403)(GRNAME(I),I=1,NGP)
C
C  WRITE MAN DATA TO TAIL FILE
C
      WRITE(5,404)(MANAME(I),I=1,NOMEN)
      WRITE(5,1404)(RLIMIT(I),I=1,NOMEN)
      WRITE(5,405)(TITOFW(I),I=1,NOMEN)
      WRITE(5,406)(PERF(I),I=1,NOMEN)
C
C  WRITE PART DATA TO TAIL FILE
C
      WRITE(5,412)(PNAME((2*I)-1),PNAME(2*I),I=1,NPT)
      WRITE(5,413)(BQTY(I),I=1,NPT)
      WRITE(5,1413)(DEMAND(I),I=1,NPT)
      WRITE(5,414)(SVALUE(I),I=1,NSET)
      WRITE(5,415)(PVALUE(I),I=1,NPRO)
      WRITE(5,1415)(LVALUE(I),I=1,NLO)
C
C  TAIL FILE OUTPUT - GROUP DATA
C
      WRITE(5,500)NGP
      DO 80 I=1,NGP
      WRITE(5,501)NMINGP(I)
   80 WRITE(5,502)(MINGP(I,J),J=1,NMINGP(I))
C
C
C  WRITE DATA TO TAIL FILE
C
C  WRITE SKILL DATA TO TAIL FILE
C
      WRITE(5,503)NOMEN
      DO 1010 I=1,NOMEN
      WRITE(5,504)NSSK(I)
      IF(NSSK(I).EQ.0)GOTO 1005
      WRITE(5,505)(SSKILL(I,J),J=1,NSSK(I))
 1005 WRITE(5,506)NPSK(I)
      IF(NPSK(I).EQ.0)GOTO 1010
      WRITE(5,507)(PSKILL(I,J),J=1,NPSK(I))
 1010 CONTINUE
C
C  WRITE PART DATA TO TAIL FILE
C
      WRITE(5,508)NPT
      DO 1020 I=1,NPT
      WRITE(5,509)NOOPS(I)
```

```
      DO 1015 K=1,NOOPS(I)
      TYP(K)=999
      IF(POPCY(I,K).EQ.0.AND.POPLD(I,K).EQ.0)TYP(K)=888
 1015 CONTINUE
 1020 WRITE(5,510)(TYP(K),POPGP(I,K),POPST(I,K),POPPR(I,K),POPCY(I,K),
     &POPLD(I,K),K=1,NOOPS(I))
C
C  WRITE ORDER DATA TO TAIL FILE
C
C
C  WRITE STD ORDER DATA
C
      DO 1040 I=1,NOR
      Z=2*I
      WRITE(5,511)ISSDAY(I),PARTNAME(Z-1),PARTNAME(Z),NORDER(I),
     &QTY(I),DUEDAY(I)
C
C  TEST IF INITIAL SET UP REQUIRED, IF SO OUTPUT
C
      IF(ISSDAY(I).NE.0)GOTO 1040
      J=0
 1030 J=J+1
      WRITE(5,1511)SBCH(I,J),OP(I,J)
      IF(OP(I,J).NE.0)GOTO 1030
C
 1040 CONTINUE
      I=9999
      WRITE(5,512)I
C
C  WRITE FINAL MESSAGE
C
      WRITE(2,290)
C
C
C FORMAT STATEMENTS
C
C
C
C  CONVERSATION READ FORMATS
C
  100 FORMAT(A5)
  101 FORMAT(3I0)
  102 FORMAT(A1)
  103 FORMAT(I0)
  104 FORMAT(2I0)
  105 FORMAT(2A8)
  106 FORMAT(3A8)
  107 FORMAT(4I0)
  108 FORMAT(6I0)
C
C
C  CONVERSATION WRITE FORMATS
C
```

```
 200 FORMAT(///,1X,'******INTERACTIVE INPUT TO JOB SHOP MODEL******',
    &///,' PLEASE TYPE ANSWERS TO THE QUESTIONS THAT FOLLOW,STARTING'
    &,/,' IN THE FIRST COLUMN AND SENDING THE INFORMATION TO THE',
    &/,' COMPUTER BY PRESSING ESC. IF A LIST IS REQUESTED A BLANK',
    &/,' RESPONSE WILL BE TAKEN TO INDICATE THE END OF THE LIST')
1200 FORMAT(' VIEW ALL THE MC DATA?')
2200 FORMAT('   MC NO NAME   TYP   MNBK   SDBK   SEBK  MNTBK'
    &,'  SDTBK  SETBK')
3200 FORMAT(1X,I6,2X,A5,3X,A1,1X,6(I6,1X))
4200 FORMAT(' GIVE MC NAME TO BE MODIFIED -')
5200 FORMAT(' I CANNOT FIND A MACHINE CALLED ',A5,' TRY AGAIN')
 201 FORMAT(/,1X,'***ENTRY OF MACHINE & GROUP INFORMATION***',/,
    &/,' PLEASE GIVE THE NAME & TYPE OF THE FIRST MACHINE, FOLLOW THIS',
    &/,' BY GIVING THE MEAN,STD. DEV.,& SEED FOR -',
    &/,'         A.  THE BREAKDOWN TIME OF THE MACHINE, &',
    &/,'         B.  THE TIME BETWEEN BREAKDOWNS',
    &/,' ON THE TWO SUBSEQENT LINES',
    &/,' THIS INFORMATION WILL THEN BE REQUESTED UNTIL ALL THE ',
    &/,' MACHINES HAVE BEEN DESCRIBED, WHEN A BLANK LINE SHOULD BE ',
    &/,' SENT')
 202 FORMAT(1X,'PLEASE GIVE THE NAME, TYPE & BREAKDOWN DATA FOR',
    &/,' THE NEXT MACHINE')
 203 FORMAT(1X,'YOU HAVE GIVEN THE FOLLOWING DATA FOR MACHINE ',A5,
    &' (',A1,')',
    &/,' MNBK=',I6,' SDBK=',I6,' SEEDBK=',I6,
    &/,' MNTBK=',I6,' SDTBK=',I6,' SEEDTBK=',I6,
    &/,' IS THIS CORRECT?? ANSWER Y OR N ')
 204 FORMAT(1X,'FROM WHAT YOU HAVE SAID THERE MUST BE ',I2,
    &' MACHINES',/,' IS THIS CORRECT??')
1204 FORMAT(' VIEW GROUP DATA?')
2204 FORMAT(' NAME                MACHINE CONTENT')
3204 FORMAT(1X,A5,2X,9(9(A5,2X),/))
4204 FORMAT(' GIVE NAME OF GROUP TO BE MODIFIED -')
5204 FORMAT(' I CANNOT FIND A GROUP CALLED ',A5,' TRY AGAIN')
 205 FORMAT(1X,'PLEASE TYPE THE NAME OF THE FIRST GROUP & FOLLOW',
    &/,' THIS ON SUBSEQUENT LINES BY THE NAMES OF THE MACHINES IN THE',
    &/,' GROUP. WHEN THE LIST OF MACHINES IS COMPLETE PLEASE SEND',
    &/,' A BLANK LINE. THIS PROCEDURE SHOULD BE REPEATED UNTIL ALL',
    &/,' THE GROUPS HAVE BEEN DESCRIBED, WHEN A BLANK LINE SHOULD',
    &/,' BE SENT IN REPLY TO THE REQUEST FOR ANOTHER GROUP NAME.')
 206 FORMAT(1X,'PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT')
 207 FORMAT(1X,'FROM WHAT YOU HAVE SAID GROUP ',A5,' CONTAINS',
    &/,' THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N',/,1X,
    &5(2X,A5))
 208 FORMAT(1X,'FROM WHAT YOU HAVE SAID THERE MUST BE ',I2,' GROUPS',
    &/,' IS THIS CORRECT ?? ')
 210 FORMAT(1X,'FOR THE FIRST MAN PLEASE GIVE ON :-',
    &/,'          LINE 1 - THE MANS NAME',
    &/,'          LINE 2 - THE LENGTH OF HIS NORMAL WORK PERIOD',
    &/,'          LINE 3 - THE MANS PERFORMANCE RATE ( )',
    &/,'          LINE 4 - THE MAX NUMBER OF MACHINES THE MAN CAN RUN',
    &' AT ONCE')
1210 FORMAT(' VIEW MAN DATA?')
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2210 FORMAT(' YOU HAVE PREVIOUSLY DESCRIBED THE FOLLOWING MEN -',/,
    &10(10(2X,A5),/))
3210 FORMAT(' GIVE THE NAME OF THE MAN TO BE MODIFIED -')
4210 FORMAT(' I CANNOT FIND A MAN CALLED ',A5,' TRY AGAIN')
 211 FORMAT(1X,'FOR THE NEXT MAN PLEASE GIVE- NAME,WORK PERIOD,',
    &/,'  PERFORMANCE, & NO OF MACHINES RUN')
 212 FORMAT(1X,'PLEASE GIVE ON SUCCESSIVE LINES THE NAMES OF THE',
    &/,' GROUPS WHICH MAN ',A5,' CAN SET. FOLLOW THE LAST GROUP BY',
    &/,' A BLANK LINE')
 213 FORMAT(1X,'PLEASE GIVE THE GROUPS WHICH MAN ',A5,' CAN SET')
 214 FORMAT(1X,'CAN I TAKE IT THAT MAN ',A5,' CAN SET THE FOLLOWING',
    &/,1X,I2,' GROUPS?',/,1X,10(2X,A5),/,1X,5(2X,A5))
 215 FORMAT(1X,'PLEASE GIVE THE GROUPS WHICH MAN ',A5,' CAN RUN')
 216 FORMAT(1X,'CAN I TAKE IT THAT MAN ',A5,' CAN RUN THE FOLLOWING',
    &/,1X,I2,' GROUPS?',/,1X,10(2X,A5),/,1X,5(2X,A5))
 217 FORMAT(1X,'FROM WHAT YOU HAVE SAID THERE MUST BE ',I2,' MEN',
    &/,' IS THIS CORRECT? Y OR N')
 218 FORMAT(1X,'PLEASE GIVE THE PERCENTAGE SICKNESS RATE')
 219 FORMAT(1X,'PLEASE GIVE ON THE NEXT TWO LINES :-',
    &/,'         LINE 1 - MEAN & STD.DEV. OF THE TIME MEN ARE ABSENT',
    &/,'         LINE 2 - MEAN & STD.DEV. OF THE TIME BETWEEN ABSENCES
    &')
 220 FORMAT(1X,'DO YOU WISH TO ALTER ANY OF THIS DATA?')
 221 FORMAT(//,' ***INPUT COMPLETED FOR YHE ENTITY MAN***')
C
C CONVERSATION WRITE FORMATS - PART DATA
C
 230 FORMAT(1X,'***ENTRY OF DATA ABOUT THE PARTS RANGE TO BE',
    &' SIMULATED***',//)
 231 FORMAT(1X,'PLEASE GIVE THE PART NUMBER OF THE FIRST PART',
    &/,' FOLLOWED, ON THE NEXT LINE, BY THE NORMAL BATCH QUANTITY',
    &/' AND THE MONTHLY DEMAND')
 232 FORMAT(1X,'PLEASE GIVE THE PART NO & BATCH QUANTITY FOR THE NEXT',
    &' PART')
 233 FORMAT(1X,'PLEASE GIVE THE FOLLOWING DATA FOR THE FIRST OP.',
    &/,' REQUIRED BY THIS PART -',
    &/,'         A.  THE NAME OF THE MACHINE GROUP',
    &/,'         B.  THE SETTING TIME & PROCESS TIME / PART',
    &/,'         C.  THE CYCLE TIME & LOADING TIME FOR AUTO MACHINES',
    &/,'             IF THE MACHIN IS NOT AN AUTO THESE VALUES SHOULD',
    &/,'             BE GIVEN AS ZEROS',
    &/,' WHEN THE DATA FOR THE LAST OP. HAS BEEN GIVEN, SEND A',
    &/,' BLANK LINE.')
 234 FORMAT(1X,'PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,',
    &/,' & LOADING TIMES FOR THE NEXT OP PART ',2A8)
1234 FORMAT(' VIEW PARTS RANGE DATA?')
2234 FORMAT('        PART NUMBER         BATCH QTY        DEMAND',
    &'   NO OF OPS')
3234 FORMAT(1X,I3,3X,2A8,5X,I6,8X,I6,5X,I6)
4234 FORMAT(' GIVE PART NO TO BE MODIFIED -')
5234 FORMAT(' I CANNOT FIND A PART CALLED ',2A8,' TRY AGAIN')
 235 FORMAT(1X,'YOU HAVE GIVEN THE FOLLOWING DATA ABOUT PART ',2A8)
 236 FORMAT(1X,'    BATCH QUANTITY............',I6,
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     &/,'      MONTHLY DEMAND............',I6,
     &/,'      NUMBER OF OPERATIONS......',I6,
     &/,'      GROUPS VISITED............',5(1X,A5),
     &/,31X,5(1X,A5))
  237 FORMAT(1X,'    SETTING TIMES.............',5(1X,I6,1X),
     &/,31X,5(1X,I6,1X))
  238 FORMAT(1X,'    PROCESS TIMES / PART......',5(1X,I6,1X),
     &/,31X,5(1X,I6,1X))
 1238 FORMAT(1X,'    CYCLE TIMES...............',5(1X,I6,1X),
     &/,31X,5(1X,I6,1X))
 2238 FORMAT(1X,'    LOADING TIMES.............',5(1X,I6,1X),
     &/,31X,5(1X,I6,1X))
  239 FORMAT(1X,'IS THIS CORRECT? Y OR N')
  240 FORMAT(1X,'FROM WHAT YOU HAVE SAID THERE MUST BE ',I3,' PARTS',
     &/,' IS THIS CORRECT?')
  242 FORMAT(1X,'THERE ARE ',I3,' UNIQUE VALUES OF SETTING TIME -',
     &90(/,10(1X,I5)))
  243 FORMAT(1X,'THERE ARE ',I3,' UNIQUE VALUES OF PROCESS TIME -',
     &90(/,10(1X,I5)))
 1243 FORMAT(1X,' THERE ARE ',I3,' UNIQUE VALUES OF LOADING TIME -',
     &90(/,10(1X,I5)))
  244 FORMAT(1X,'PLEASE GIVE THE UPPER LIMIT FOR THE NUMBER OF ENTITIES'
     &,' TO BE USED')
  245 FORMAT(1X,'THE LIMIT YOU HAVE GIVEN WILL ALLOW A MAX OF ',I3,
     &'JOB IN THE SYSTEM',/,' IS THIS SUFFICIENT? Y OR N')
  246 FORMAT(1X,'PLEASE GIVE AN ALTERNATIVE LIMIT')
  250 FORMAT(1X,'******ERR0R******',
     &/,' I CANNOT FIND THE MACHINE CALLED ',A5,
     &/,' WHICH YOU SPECIFIED AS THE ',I2,'TH MEMBER OF GROUP ',
     &A5,//,' THE MACHINES YOU PREVIOUSLY DEFINED WERE -',
     &//,10(2X,A5),/,10(2X,A5))
  251 FORMAT(//,' I WILL NOW RETURN YOU TO THE BEGINNING OF THE PROGRAM
     &')
  252 FORMAT(1X,'******ERROR******',
     &/,' I CANNOT FIND THE GROUP CALLED ',A5,
     &/,' WHICH YOU SPECIFIED AS THE ',I2,'TH SETTING SKILL OF MAN',A5,
     &//,' THE GROUPS YOU PREVIOUSLY DEFINED WERE -',
     &//,10(2X,A5),/,10(2X,A5))
  253 FORMAT(1X,'******ERROR******',
     &/,' I CANNOT FIND THE GROUP CALLED ',A5,
     &/,' WHICH YOU SPECIFIED AS THE ',I2,'TH PROCESS SKILL OF MAN ',
     &A5,//,' THE GROUPS YOU PREVIOUSLY DEFINED WERE -',
     &//,10(2X,A5),/,10(2X,A5))
  254 FORMAT(1X,'******ERROR******',
     &/,' I CANNOT FIND THE GROUP CALLED ',A5,
     &/,' WHICH YOU SPECIFIED IN OPERATION NO ',I2,' ON PART NO ',2A8,
     &//,' THE GROUPS TOU PREVIOUSLY DEFINED WERE -',
     &//,10(2X,A5),/,10(2X,A5))
C
C CONVERSATION FORMATS - ORDER DATA
C
  260 FORMAT(1X,'**INPUT OF ORDER DATA**',
     &//,' FOR THE FIRST ORDER PLEASE GIVE THE FOLLOWING DATA ON -',
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    &/,'          LINE 1 - PART NUMBER',
    &/,'          LINE 2 - DAY OF ISSUE, QUANTITY,DELIVERY DATE',
    &' (DAY)',
    &//,' PLEASE SEPARATE THE DATA BY TWO, OR MORE, SPACES')
 261 FORMAT(1X,'PLEASE GIVE THE PART NUMBER,ISSUE DAY,QUANTITY',
    &/,' & DELIVERY DAY, FOR THE NEXT ORDER')
1261 FORMAT(1X,'I CANNOT FIND A PART NUMBER CALLED ',2A8,
    &/,' HAVE YOU ENTERED THE CORRECT NUMBER?',
    &/,'   - IF YOU ANSWER YES YOU WILL BE RETURNED TO THE START OF',
    &/,'                           THE BEGINNING OF THE PROGRAM.',
    &/,'   - IF YOU ANSWER NO YOU WILL BE ASKED TO RE-ENTER THE DATA',
    &/,'                           ABOUT THIS ORDER.')
2261 FORMAT(1X,'THE ',I3,' BATCHES ASSOCIATED WITH THIS ORDER',
    &' ARE -',5(/,12(2X,I3)))
3261 FORMAT(/,1X,'PLEASE INDICATE THE STATE OF PART-WORKED BATCHES',
    &' BY GIVING',/,' ON SUBSEQUENT LINES -',
    &//,'          THE BATCH NUMBER  &  THE NUMBER OF OPS COMPLETED',
    &//,'    NOTE.',
    &/,'          - IF A BATCH IS OMITTED IT WILL BE TAKEN TO BE ISSUED',
    &/,'            BUT NOT STARTED',
    &/,'          - THE END OF THE LIST SHOULD BE INDICATED BY GIVING A',
    &/,'            FICTICIOUS BATCH NO. OR GIVING THE NUMBER OF OPS',
    &/,'            COMPLETED AS EQUAL TO ZERO')
 262 FORMAT(1X,'DO YOU WISH TO CHANGE THE DATA YOU HAVE JUST',
    &' ENTERED?')
 263 FORMAT(1X,'DO YOU WISH TO CHECK THE DATA YOU HAVE JUST ENTERED?')
 264 FORMAT(1X,'PART NUMBERS -',3(2X,2A8),6(/,15X,3(2X,2A8)))
 265 FORMAT(1X,'DAY OF ISSUE -',10(1X,I6),/,15X,10(1X,I6))
 266 FORMAT(1X,'QUANTITY     -',10(1X,I6),/,15X,10(2X,I6))
 267 FORMAT(1X,'DAY DUE      -',10(1X,I6),/,15X,10(1X,I6))
 268 FORMAT(1X,'FROM WHAT YOU HAVE SAID THERE MUST BE ',I2,' ORDERS',
    &/,' IS THIS CORRECT?')
 269 FORMAT(//,'IF YOU REQUIRE AUTOMATIC GENERATION OF ORDERS',
    &/' GIVE A NON ZERO VALUE FOR THE ORDERING INTERVAL',
    &/' FOLLOWED BY AN ODD SEED NUMBER')
1269 FORMAT(/,' HOW MANY EXTRA ORDERS WILL BE REQUIRED BY THE AUTO ',
    &'GENERATOR?')
 270 FORMAT(1X,'***THE ENTRY OF ALL ENTITY BASED DATA IS NOW',
    &' COMPLETED***')
 280 FORMAT(//,1X,'***INPUT OF SIMULATION CONTROL DATA***')
 281 FORMAT(//,1X,'PLEASE GIVE THE LENGTH OF THE RUN IN MINS')
 282 FORMAT(1X,'PLEASE GIVE THE TIME FROM WHICH THE RECORDING OF',
    &' RESULTS SHOULD START')
 283 FORMAT(1X,'DO YOU WANT QUEUE MONITORING TO TAKE PLACE?')
 284 FORMAT(1X,'GIVE THE START & FINISH TIMES OF  -',
    &/,'      LINE 1 - MONITORING AT THE START OF EACH ACTIVITY CYCLE',
    &/,'      LINE 2 - MONITORING AT THE END OF EACH ACTIVITY CYCLE')
1284 FORMAT(' ANY FURTHER CHANGES REQUIRED?')
 285 FORMAT(1X,'DO YOU WANT DETAILED MONITORING OF JOB MOVEMENTS?')
 286 FORMAT(1X,'DO YOU WANT SHOP FLOOR RESCHEDULING TO TAKE PLACE?')
 287 FORMAT(1X,'PLEASE GIVE THE NUMBER OF THE APPROPRIATE RULE -',
    &/,' PRIORITY WILL BE GIVEN TO THE JOB WITH THE MIN. -',
    &/,'      RULE 1 - DUE DATE',
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     &/,'      RULE 2 - UNAVAILABLE',
     &/,'      RULE 3 - SETTING TIME
     &',/,'      RULE 4 - PROCESS TIME',
     &/,'      RULE 5 - SETTING + PROCESS TIME',
     &/,'      RULE 6 - FLOAT')
 1288 FORMAT(/,' IF YOU REQUIRE CONTINUOUS MAN/MACHINE',
     & ' PERFORMANCE MONITORING,',/,' GIVE THE MONITOR PERIOD IN DAYS',
     & /,' IF NOT REQUIRED SEND A ZERO')
  288 FORMAT(1X,'PLEASE GIVE THE PARAMETERS FOR THE EXECUTE CARD')
  289 FORMAT(//,' ******INPUT OF ALL DATA IS NOW COMPLETE******')
  290 FORMAT(//,' ***THE DATA HAS NOW BEEN PROCESSED & PASSED TO',
     &' THE MODEL***')
  291 FORMAT(1X,'DO YOU WANT WORK IN PROGRESS MONITORING?')
  292 FORMAT(1X,'DO YOU WANT LEAD TIME MONITORING?')
  293 FORMAT(1X,'PLEASE GIVE THE NUMBER & WIDTH (IN HRS)',
     & ' OF THE CELLS IN THE HISTOGRAMS')
 1293 FORMAT(' GIVE MONITOR TIMESPAN IN DAYS -')
  294 FORMAT(1X,'PLEASE GIVE THE NUMBER & WIDTH (IN HRS)',
     & ' OF THE CELLS IN THE LEAD / LOAD HISTOGRAM')
C
C  ADDITIONAL FORMATS FOR HOLD VERSION
C
 4999 FORMAT(//,1X,'IS THIS A NEW SIMULATION - Y OR N ?')
 5000 FORMAT(//,' THIS PROGRAM ALLOWS THE DATA FOR A PREVIOUS RUN TO',
     &' BE MODIFIED')
 5001 FORMAT(/,' DO YOU WISH TO CHANGE ANY OF THE MACHINE DATA?')
 5002 FORMAT(1X,'DO YOU WISH TO ALTER ANY OF THE DATA FOR THE',
     &' FOLLOWING MACHINE -',//,' NAME TYPE MNAB  SDAB SEAB MNTAB ',
     &' SDTAB SETAB',/,1X,A5,2X,A1,6(2X,I6),//,' ANS Y OR N')
 5003 FORMAT(' PLEASE RE-ENTER ALL THE DATA FOR THIS MACHINE')
 5004 FORMAT(' IF YOU WISH TO DELETE ANY MACHINES, GIVE THEIR NAMES,',
     &/,' COMPLETING THE LIST WITH A BLANK. IF YOU DO NOT WISH ANY',
     &' DELETED',/,' SEND A BLANK IMMEDIATELY')
 5005 FORMAT(1X,'THERE ARE NOW ',I3,' MACHINES')
 5006 FORMAT(' DO YOU WISH TO ADD ANY NEW MACHINES?')
 5007 FORMAT(' DO YOU WISH TO CHANGE ANY OF THE GROUP DATA?')
 5008 FORMAT(' DO YOU WISH TO CHANGE THE CONTENT OF GROUP ',A5,
     &/,' WHICH CURRENTLY HOLDS THE FOLLOWING ',I2, ' MACHINES',
     &/,10(2X,A5))
 5009 FORMAT(' PLEASE RE-ENTER THE NAME AND CONTENT OF THIS GROUP')
 5010 FORMAT(' IF YOU WISH TO DELETE ANY OF THE GROUPS, GIVE THEIR',
     &' NAMES, ENDING',/,' THE LIST WITH A BLANK. IF YOU DONT WANT',
     &' ANY DELETED, SEND',/,' A BLANK IMMEDIATELY')
 5011 FORMAT(' THERE ARE NOW ',I3,' GROUPS')
 6011 FORMAT(' DO YOU WISH TO ADD ANY NEW GROUPS? Y OR N')
 5012 FORMAT(' DO YOU WISH TO CHANGE ANY OF THE DATA ABOUT THE MEN?')
 5013 FORMAT(' THE MAN CALLED ',A5,' HAS -',
     &/,'          A WORK PERIOD OF     ',I6,' MINS',
     &/,'          A PERFORMANCE OF     ',I6,'  ',
     &/,'          & CAN WORK..........',I6,' MACHINES')
 5014 FORMAT(' HE CAN SET THE FOLLOWING GROUPS -',/,10(2X,A5))
 5015 FORMAT(' HE CAN RUN THE FOLLOWING GROUPS -',/,10(2X,A5))
 5016 FORMAT(' DO YOU WISH TO MODIFY ANY OF THIS INFORMATION? - Y OR N')
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5017 FORMAT(' PLEASE RE-ENTER ALL THE DATA FOR THIS MAN GIVING THE',
    &' NEW',/,' NAME,WORK PERIOD,PERFORMANCE, & NO. OF MACHINES',
    &' WORKED ON SEPARATE LINES')
5018 FORMAT(' PLEASE GIVE THE MACHINE GROUPS THE MAN CAN SET',
    &' ,FINISHING WITH A BLANK')
5019 FORMAT(' PLEASE GIVE THE MACHINE GROUPS THE MAN CAN RUN',/,
    P' FINISHING WITH A BLANK')
5020 FORMAT(' DO YOU WISH TO CHANGE ANYTHING YOU HAVE JUST ENTERED?')
5021 FORMAT(' DO YOU WISH TO DELETE ANY OF THE MEN? IF SO GIVE A LIST',
    &/,' IF YOU DO NOT WANT ANY DELETED SEND A BLANK IMMEDIATELY')
5022 FORMAT(' THERE ARE NOW ',I3, ' MEN')
5023 FORMAT(' DO YOU WISH TO ADD ANY NEW MEN?')
5024 FORMAT(' DO YOU WISH TO CHANGE THE SICKNESS & ABSENCE DATA?')
5025 FORMAT(' THE PRESENT SICKNESS & ABSENCE DATA IS -',
    &/,'        SICKNESS  ....................',I7,
    &/,'        MEAN TIME ABSENT..............',I7,
    &/,'        STD. DEV  TIME ABSENT.........',I7,
    &/,'        MEAN TIME BETWEEN ABSENCE.....',I7,
    &/,'        STD. DEV. TIME BTWN ABSENCE...',I7)
5026 FORMAT(' DO YOU WISH TO CHANGE ANY OF THE PARTS RANGE DATA?')
5027 FORMAT(' DO YOU WISH TO SEE THE DATA FOR PART NUMBER =', 2A8)
5028 FORMAT(' DO YOU WISH TO CHANGE THE DATA FOR THIS PART?')
5029 FORMAT(' PLEASE RE-ENTER ALL THE DATA FOR THIS PART,',
    &/,' GIVE THE PART NUMBER, FOLLOWED ON THE NEXT LINE BY THE',
    &' BATCH QUANTITY')
5030 FORMAT(' PLEASE GIVE, FOR ALL THE OPS. ON THIS PART :',
    &/,'         A. THE MACHINE GROUP NAME FOR THE OP. & ON THE NEXT',
    &' LINE',
    &/,'         B. THE SETTING, PROCESS, CYCLE & LOADING TIMES',
    &/,' END THE LIST WITH A BLANK RESPONSE')
5031 FORMAT(' DO YOU WISH TO MODIFY THE DATA YOU HAVE JUST ENTERED?')
5032 FORMAT(' DO YOU WISH TO DELETE ANY OF THE PARTS?, IF SO, SEND',
    &/' A LIST OF THEM, ENDING WITH A BLANK')
5033 FORMAT(' THERE ARE NOW ',I3,' PARTS')
5034 FORMAT(' DO YOU WISH TO ADD ANY NEW PARTS?')
5035 FORMAT(' DO YOU WISH TO MAKE ANY CHANGES TO THE ORDER SECTION?')
5036 FORMAT(' UNLIKE THE OTHER SECTIONS, IT IS NOT POSSIBLE TO',
    &/,' MODIFY EXISTING ORDERS, ONLY DELETIONS AND INSERTIONS ARE',
    &/,' ALLOWED. DO YOU WISH TO SEE THE EXISTING ORDER DATA?')
5137 FORMAT('  ORDER NO   PART NUMBER    ISSUEDAY  QUANTITY   DUEDAY')
5037 FORMAT(4X,I6,1X,2A8,2X,3(1X,I6,3X))
5038 FORMAT(' BATCH NUMBER ',I6,' HAS COMPLETED ',I2,' OPERATIONS')
5039 FORMAT(' DO YOU WISH TO DELETE ANY ORDERS?.IF NOT, SEND A ZERO,'
    &/,' IF YOU DO , GIVE THE ORDER NUMBERS ON SUBSEQUENT LINES,',
    &/,' ENDING THE LIST BY GIVING A NUMBER EQUAL TO ZERO')
5040 FORMAT(' THERE ARE NOW ',I3,' ORDERS')
5041 FORMAT(' DO YOU WISH TO ADD ANY NEW ORDERS?')
5042 FORMAT(' DO YOU WANT TO ALTER THE RUNLENGTH =',I7,' OR THE TIME'
    &/,' AFTER WHICH THE RECORDING OF RESULTS STARTS-',I6)
5043 FORMAT(' PLEASE GIVE THE NEW VALUES OF RUN LENGTH & RECORD TIME')
5044 FORMAT(' DO YOU WISH TO MODIFY THE MONITORING STRUCTURE?')
5045 FORMAT(' AT PRESENT QUEUE MONITORING-',
    &/,'         STARTS AT ',I7,' & FINISHES AT ',I7,' FOR THE START',
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    &' OF EACH TIME CYCLE',
    &/,'          STARTS AT ',I7,' & FINISHES AT ',I7,' FOR THE END',
    &' OF EACH TIME CYCLE')
 5046 FORMAT(
    &/' IF YOU DO WISH TO DELETE ANY, SEND A BLANK IMMEDIATELY')
C
C
C HEAD FORMATS - MACHINES
C
C
  300 FORMAT(1X,'  THERE ARE ',I3,' MACHIN  SET STOP GROUP ',I2,
    &'  WITH TIME TITOBK MACJOB',
    &/,'  & SETBK SDTBK MNTBK SEBK SDBK MNBK  STRING MCNAME(5)',
    &' MACTYP(1)',/,2X,'& HIST MCREC(8,1,1)')
  301 FORMAT(1X,'  THERE ARE ',I2,' MAN  SET IDLE  WITH PERF TIME ',
    &'TITOAB TITOFW LIMIT ',
    &/,'  &   STRING MANAME(5)  HIST MNREC(9,1,1) HRREC(10,1,1)')
  302 FORMAT(1X,'  THERE ARE ',I3,' JOB  SET WAIT POOL AWISSUE GRPQUE ',
    &I2,' CURJOB MAN',/,'  & TEMP PLAN  WITH TIME SETING RECYTI',
    &' MCHOUR STDAY',
    &/,'  & RESETI REPRTI LEADTM BATCH DUEDATE ORDERNO PRIORITY',
    &/,'  & STRING PARTNO(16) REAL AVLOAD')
  303 FORMAT(1X,'  THERE ARE ',I3,' PART  SET PTPOOL WITH BCHQTY ',
    &' DEMAND STRING NUMBER(16)')
  304 FORMAT(1X,'  THERE ARE ',I3,' GROUPS  SET ROUTE JOB  PSKILL MAN',
    &'  SSKILL MAN',/,'  & MROUTE PART  WITH STRING GRNAME(5)',
    &/,'  & HIST HATGP(',I3,',1,1) HFORGP(',I3,',1,1)')
  305 FORMAT(1X,'  THERE ARE ',I3,' SETIME  SET SROUTE JOB',
    &'  MSROUTE PART  TEMST',/,'  & WITH SVALUE')
  306 FORMAT(1X,'  THERE ARE ',I3,' PRTIME  SET PROUTE JOB',
    &' MPROUTE PART  TEMPR',
    &/,'  & MCROUTE PART  CROUTE JOB  WITH PVALUE')
 1306 FORMAT(1X,'  THERE ARE ',I3,' LDTIME SET MLROUTE PART  ',
    &'LROUTE JOB  WITH LVALUE')
  307 FORMAT(1X,'  THERE ARE ',I3,' ORDER  SET ORPOOL AWPLAN  WITH',
    &' TIME DUEDAY NORDER',/,'  & QTY  STRING PARTNAME(16)')
  308 FORMAT(1X,'  HIST  ',A6,'(',I3,',1,1)')
  309 FORMAT(1X,'  HIST  ',A6,'(',I3,',1,1)')
  310 FORMAT(1X,'  HIST  ',A6,'(',I3,',',I6,',',I6,')')
C
C  TAIL FILE MACHINE & GROUP FORMATS
C
  400 FORMAT(1X,A5)
  401 FORMAT(1X,A1)
  402 FORMAT(1X,A8,1X,I6)
  403 FORMAT(1X,A5)
C
C TAIL FILE FORMATS-MAN
  404 FORMAT(1X,A5)
 1404 FORMAT(1X,'LIMIT  ',1X,I6)
  405 FORMAT(1X,'TITOFW  ',1X,I6)
  406 FORMAT(1X,'PERF    ',1X,I6)
C
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C  DATA FILE SICKNESS & ABSENCE FORMATS
C
  407 FORMAT(1X,'SICK     ',3(2X,I6))
  408 FORMAT(1X,'MNTAB    ',2X,I7)
  409 FORMAT(1X,'SDTAB    ',2X,I6)
  410 FORMAT(1X,'MNAB     ',2X,I6)
  411 FORMAT(1X,'SDAB     ',2X,I6)
 1411 FORMAT(' ORFREQ       ',I7,/,' SEORD        ',I7)
C
C TAIL FILE FORMATS -PART
C
  412 FORMAT(1X,2A8)
  413 FORMAT(1X,'BCHQTY  ',1X,I6)
 1413 FORMAT(1X,'DEMAND  ',1X,I6)
  414 FORMAT(1X,'SVALUE  ',1X,I6)
  415 FORMAT(1X,'PVALUE  ',1X,I6)
 1415 FORMAT(1X,'LVALUE  ',1X,I6)
C
C DATA FILE FORMATS-RUN
C
  417 FORMAT(1X,'RUNTIME  ',I7,/,' RUNINZ  ',I7,/,' TRACK  ',I1,
     &/,' MNSTON  ',I7,/,' MNSTOF  ',I7,/,' MNENON  ',I7,/,' MNENOF  ',
     &I7,/,' SCHED  ',I2,/,' RULE    ',I2,/,'   END',
     &/,' *EXECUTE ',3A8)
  418 FORMAT(1X,'WIPMON  ',I1,/,' LEADMON  ',I1,/,' MONFAC ',I4,
     &/,' MANMCM  ',I1,/,' MONINT ',I4)
C
C
C TAIL FILE FORMATS-MACHINES & GROUPS
C
C
  500 FORMAT(1X,'NUMBER OF GROUPS  ',I2)
  501 FORMAT(1X,'NO OF MCS IN GRP',I3)
  502 FORMAT(1X,'MCS IN GROUP      ',10(/,2X,I2))
C DATA FILE FORMATS-MAN
  503 FORMAT(1X,'NUMBER OF MEN     ',I3)
  504 FORMAT(1X,'NO OF GROUPS SET  ',I2)
  505 FORMAT(1X,'GROUPS SET BY MAN ',20(/,2X,I3))
  506 FORMAT(1X,'NO OF GROUPS RUN  ',I2)
  507 FORMAT(1X,'GROUPS RUN BY MAN ',20(/,2X,I3))
C
C
C TAIL FILE FORMATS-PARTS
  508 FORMAT(1X,'NUMBER OF PARTS  ',I3)
  509 FORMAT(1X,'NO OF OPS FOR PART',I3)
  510 FORMAT(1X,20(1X,I3,'/',I6,'/',I6,'/',I6,'/',I6,'/',I6,/))
C
C
C TAIL FILE FORMATS-ORDERS
  511 FORMAT(1X,'ISSDAY',2X,I6,/,1X,2A8,/,3(1X,I6,1X))
 1511 FORMAT(2X,I6,2X,I2)
  512 FORMAT(1X,'ISSDAY',2X,I6)
      STOP
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      END
      FINISH
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Listing of the Operating Macros

Overall Package Control Macro

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TA ALL
 IF PRES(BRIEF),(SP U,(IT9))ELSE(SP U,(IT10))
 IF PRES(BRIEF),(SP P,(MJ23))ELSE(SP P,(MJ23))
 IF PRES(REPEAT),GOTO 4
 IF PRES(FROM),(GOTO 1)ELSE(GOTO 2)
1 LIT3  U,NEWT A,OLDT (FROM )
 GOTO 3
2 LIT3  U,NEWT A
3 IF HALTED OR FAILED,EX
@
 CY COMP,MAS A
 CY HEAD,MAS A (APPEND)
 CY  P,MAS A (APPEND)
 CY DATA,MAS A (APPEND)
 CY TAIL,MAS A (APPEND)
@
 ED MAS A,,REMLINE
 UAER MAS A
@
4 IF PRES(USER),(SP P,( (USER)))ELSE(SP P,( P))
   IF NOT EXI(MAS A) AND EXI(DIS A),((MCASS  A,NOQU),(DP 0,FILE BEING R
 TG MAS A, P,READ,EXECUTE
@
 IF PRES(PROGLIST),(LF MAS A,NU,*LP0)
 IF PRES(DATALIST),(LF MAS A,FR/SICK/,*LP0)
 IF PRES(NORUN),EX
@
 IF PRES(TIME),(SP T,VALUE( (TIME)-20))ELSE(SP T,VALUE(95))
 IF PRES(TIME),(SP S,VALUE( (TIME)))ELSE(SP S,VALUE(100))
 IF PRES(OUTLIST),(SP V,(,LIST))ELSE(SP V,( ))
 IF PRES(SHORT),(SP X,(,SHORT))ELSE(SP X,( ))
 IF PRES(PY1),(SP W,(,PY1))ELSE(SP W,( ))
 IF PRES(SMALL),(SP R,(,SMALL))ELSE(SP R,( ))
 IF PRES(NOREP),(SP Q,())ELSE(SP Q,(,RERUN))
@
 IF PRES(NOCOM),(SP N,(NC))ELSE(SP N,())
 IF PRES(NOLOG),(GOTO 6)ELSE(GOTO 5)
@
5 IF PRES(REPEAT),(SP O,(,REPEAT))ELSE(SP O,())
 MCLOGIN N MAS, (TIME), A, P, U O R Q V W X
@
@
6 RJB :EPS8055.MAS A,OUT A, T, A, S, P R V X W Q
@
 DP 10,
```

```
  DP 10,
  DP 0, THE JOB TIME HAS BEEN SET TO  S SECONDS
  DP 10,
  DP 0, THE JOB HAS BEEN TRANSFERRED TO JOBSTORE IN USER  P
  DP 10,
@
  IF PRES(LOSE),ER MAS A
  IF PRES(LOSET),ER T A
  IF PRES(NOLT),EX
  IF PRES(MON),(LT NONE,RETAIN(MON A))ELSE(LT)
```

<u>Interactive Program Control Macro</u>

```
  LOAD  ABIN
  MONITOR ON,OPEN
  IF EXISTS(HOLD),(GOTO 2)ELSE(GOTO 1)
1 CE HOLD(*DA,KWOR10)
2 IF PRES(OLD),(GOTO 3)ELSE(GOTO 4)
3 CY  (OLD),HOLD
  AS *DA1,HOLD
4 CE !(*DA,BUCK1,KWOR1)
  AS *DA2,! (WRITE)
  CE !(*DA,KWOR1)
  AS *DA3,! (OVERLAY)
  AS *LP1,HEAD
  AS *LP2,DATA
  AS *LP3,TAIL
  OL *CR0
  OL *LP0
  TI 30
  EN
  TA ALL
  IF HALTED OR FAILED,GOTO 4
  IF NOT EXISTS( (NEW)),CE  (NEW)(*DA,BUCK1,KWOR1)
  CY !1, (NEW)
  ER !1,!
  ER HOLD
  EX
4 DP 0,PROGRAM HAS HALTED OR FAILED
  ER !1,!
  ER HOLD
  DL
  EX
@
```

Simulation Control Macro

```
@ REPEAT RJ MACRO
@
@    INITIAL SECTION
@
   WE COMERR,GOTO 30
@
   IF PRES(RERUN),GOTO 50
@
   IF EXI(TEMP (SUFFIX)),ER TEMP (SUFFIX)
@
   CE !(*DA,BUCKET4,KWORDS40)
   CE TEMP (SUFFIX)(*DA,BUCKET4,KWORDS40)
@
  SP A,VALUE(1)
@
   IF PRES(SMALL),(SP Q,(BIG))ELSE(SP Q,(HUGE))
@
   IF EXI(MAST (SUFFIX)),ER MAST (SUFFIX)
@
   CY  (SOURCE),MAST (SUFFIX)
   CY :LAS8129. QCCSL,!
@
   LOAD :LAS8129. QFCSL
@
   AS *CR0,MAST (SUFFIX) (GDR)
   AS *LP0, (*LP)
   AS *DA1,! (WRITE)
@
   TI  (TIME)
@
   EN 0
@
   IF FAILED(TIME UP),(GOTO 100)
   IF FAILED(FILE *CR0  EXHAUSTED),(GOTO 10)ELSE(GOTO 40)
@
@
@     FINAL SECTION REPEATS COMPLETED
@
10  RL *LP0
   IF PRES(SHORT),SHOUT  (*LP)
   IF PRES(LIST),(LF  (*LP),FRC/*EXECUTE/,*LP)
@
   MCTG OUT (SUFFIX)
@
   POST :EPS8055, ECSL JOB  (SUFFIX) FINAL RUN  A COMPLETED SEE OUT (S
   POST :EPS6049, ECSL JOB  (SUFFIX) FINAL RUN  A COMPLETED SEE OUT (S
@
    IF EXI(TPROG (SUFFIX)),ER TPROG (SUFFIX)
```

```
   ER MAST (SUFFIX),TEMP (SUFFIX)
@
   SP W,(,SUCCEED)
@
@       ENDJOB
@
20 MCLOGFIN    :EPS8055.MAS, (SUFFIX), A W
   EJ NONE ,RETAIN(OUT (SUFFIX) AMON)
   EX
@
@      COMMAND ERROR POST
@
30 POST :EPS8055, ECSL JOB  (SUFFIX) RUN  A OR  K COMMAND ERROR
   POST :EPS6049, ECSL JOB  (SUFFIX) RUN  A OR  K COMMAND ERROR
   SP W,(,FAIL)
   GOTO 20,BACK
@
@      UNEXPECTED FAILURE POST
@
40 POST :EPS8055, ECSL JOB  (SUFFIX) RUN  A OR  K UNEX FAILURE
   POST :EPS6049, ECSL JOB  (SUFFIX) RUN  A OR  K UNEX FAILURE
   SP W,(,FAIL)
   GOTO 20,BACK
@
@
@      RE-LOAD SECTION ( RERUN PARAMETER PRESENT)
@
@
50 CE !(*DA,BUCKET4,KWORDS40)
   CY TEMP (SUFFIX),!
@
   IF PRES(SMALL),(SP Q,(BIG))ELSE(SP Q,(HUGE))
@
   LOAD TPROG (SUFFIX)
@
   AS *CR0,MAST (SUFFIX) (GDR)
   AS *LP0, (*LP) (APPEND)
       AS *DA0,:LAS8129. QFCSL
   AS *DA1,! (OFFS)
@
   TI  (TIME)
@
   RESUME
@
   IF FAILED(TIME UP),GOTO 100
   IF FAILED(FILE *CR0  EXHAUSTED),(GOTO 10,BACK)ELSE(GOTO 40,BACK)
@
@       SAVE & RUN SECTION
@
100 IF EXI(TPROG (SUFFIX)),ER TPROG (SUFFIX)
@
   SAVE TPROG (SUFFIX)
@
```

```
    RL *DA1
@
    CY !,TEMP (SUFFIX)
    SP K,VALUE( A)
    SP A,VALUE( A+1)
@
    HB OUT (SUFFIX)
     SP W,REPLY(1,10)
     IF NEG( W-300),GOTO 110
     CY OUT (SUFFIX),OUT (SUFFIX)P K
    MCTG OUT (SUFFIX)P K
     IN OUT,T....
*EXECUTE
....
     CY OUT,OUT (SUFFIX)
110 IF PRES(SMALL),(SP S,(,SMALL))ELSE(SP S,())
    IF PRES(LIST),(SP L,(,LIST))ELSE(SP L,())
    IF PRES(SHORT),(SP R,(,SHORT))ELSE(SP R,())
    IF PRES(PY1),(SP P,(,PY1))ELSE(SP P,())
@
    SP T,VALUE( (TIME)+20)
@
    IF PRES(SMALL),(SP M,(40K))ELSE(SP M,(80K))
     RL *LP0
@
@
    RJ MOP418 (SUFFIX) A,REPRUN,PARAM( A,SOURCE MAST (SUFFIX),*LP OUT (
@
@
    EJ NONE,RETAIN(OUT (SUFFIX) KMON)
****
```

INTERACTIVE INPUT OF SIMULATION DATA

The following section of the appendix is a complete record of the dialogue which took place between the user and the computer during the definition of a small manufacturing cell. The exercise was performed in order to test certain features of the simulation program which are under development. For this reason, some of the data entered may appear unrealistic.

The dialogue with the computer starts with the statement

xxxxxx INTERACTIVE INPUT TO JOB SHOP MODEL xxxxxx

and ends with the message

xxxxxx INPUT OF ALL DATA IS NOW COMPLETE xxxxxx

The replies given by the user are indicated by a '_' at the beginning of the line.

```
13.46.32_ LN MOP418C206,:EPS7057,JD(JT 40,MZ 13K)
TYPE PASSWORD_
STARTED :EPS7057,MOP418C206,15JUN78  13.47.05 TYPE:MOP I13
THERE IS NO MOP NEWS TODAY.
13.47.06_ RUN 206,TIME 290,OUTLIST,PROGLIST
13.47.39 JOB IS NOW FULLY STARTED
13.47.44 0.01 CORE GIVEN 12672
******INTERACTIVE INPUT TO JOB SHOP MODEL******


PLEASE TYPE ANSWERS TO THE QUESTIONS THAT FOLLOW,STARTING
IN THE FIRST COLUMN AND SENDING THE INFORMATION TO THE
COMPUTER BY PRESSING ESC. IF A LIST IS REQUESTED A BLANK
RESPONSE WILL BE TAKEN TO INDICATE THE END OF THE LIST

***ENTRY OF MACHINE & GROUP INFORMATION***

PLEASE GIVE THE NAME & TYPE OF THE FIRST MACHINE, FOLLOW THIS
BY GIVING THE MEAN,STD. DEV.,& SEED FOR -
       A.  THE BREAKDOWN TIME OF THE MACHINE, &
       B.  THE TIME BETWEEN BREAKDOWNS
ON THE TWO SUBSEQENT LINES
THIS INFORMATION WILL THEN BE REQUESTED UNTIL ALL THE
MACHINES HAVE BEEN DESCRIBED, WHEN A BLANK LINE SHOULD BE
SENT
_ CB4
_ ALLOWED
_ 200  20  4567
_ 9999  9  5735
YOU HAVE GIVEN THE FOLLOWING DATA FOR MACHINE CB4   (A)
MNBK= 200 SDBK=  20 SEEDBK=4567
MNTBK=9999 SDTBK=   9 SEEDTBK=5735
IS THIS CORRECT?? ANSWER Y OR N
_ Y
```

```
PLEASE GIVE THE NAME, TYPE & BREAKDOWN DATA FOR
THE NEXT MACHINE
_ CC5
_ A
_ 200  20  5731
_ 9999  9  7853
YOU HAVE GIVEN THE FOLLOWING DATA FOR MACHINE CC5   (A)
MNBK= 200 SDBK=  20 SEEDBK=5731
MNTBK=9999 SDTBK=   9 SEEDTBK=7853
IS THIS CORRECT?? ANSWER Y OR N
_ Y
PLEASE GIVE THE NAME, TYPE & BREAKDOWN DATA FOR
THE NEXT MACHINE
_ DS4
_ A
_ 200  20  4563
_ 9999  9  8793
YOU HAVE GIVEN THE FOLLOWING DATA FOR MACHINE DS4   (A)
MNBK= 200 SDBK=  20 SEEDBK=4563
MNTBK=9999 SDTBK=   9 SEEDTBK=8793
IS THIS CORRECT?? ANSWER Y OR N
_ Y
PLEASE GIVE THE NAME, TYPE & BREAKDOWN DATA FOR
THE NEXT MACHINE
_ DEB
_ A
_ 200  20  4321
_ 9999  9  5683
YOU HAVE GIVEN THE FOLLOWING DATA FOR MACHINE DEB   (A)
MNBK= 200 SDBK=  20 SEEDBK=4321
MNTBK=9999 SDTBK=   9 SEEDTBK=5683
IS THIS CORRECT?? ANSWER Y OR N
_ Y
PLEASE GIVE THE NAME, TYPE & BREAKDOWN DATA FOR
THE NEXT MACHINE
```

```
_ TRUCK
_ A
_ 200  20  9867
_ 9999  9   6741
YOU HAVE GIVEN THE FOLLOWING DATA FOR MACHINE TRUCK (A)
NNBK= 200 SDBK=  20 SEEDBK=9867
NNTBK=9999 SDTBK=   9 SEEDTBK=6741
IS THIS CORRECT?? ANSWER Y OR N
_ Y
PLEASE GIVE THE NAME, TYPE & BREAKDOWN DATA FOR
THE NEXT MACHINE

FROM WHAT YOU HAVE SAID THERE MUST BE  5 MACHINES
IS THIS CORRECT??
_ Y
PLEASE TYPE THE NAME OF THE FIRST GROUP & FOLLOW
THIS ON SUBSEQUENT LINES BY THE NAMES OF THE MACHINES IN THE
GROUP. WHEN THE LIST OF MACHINES IS COMPLETE PLEASE SEND
A BLANK LINE. THIS PROCEDURE SHOULD BE REPEATED UNTIL ALL
THE GROUPS HAVE BEEN DESCRIBED, WHEN A BLANK LINE SHOULD
BE SENT IN REPLY TO THE REQUEST FOR ANOTHER GROUP NAME.
_ CB4A
_ CB4

FROM WHAT YOU HAVE SAID GROUP CB4A  CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  CB4
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ CB4B
_ CB4

FROM WHAT YOU HAVE SAID GROUP CB4B  CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  CB4
```

```
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ CC5A
_ CC5

FROM WHAT YOU HAVE SAID GROUP CC5A  CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  CC5
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ CC5B
_ CC5

FROM WHAT YOU HAVE SAID GROUP CC5B  CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  CC5
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ DS4A
_ DS4

FROM WHAT YOU HAVE SAID GROUP DS4A  CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  DS4
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ DS4B
_ DS4

FROM WHAT YOU HAVE SAID GROUP DS4B  CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  DS4
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ DEBR
```

```
_ DEB

FROM WHAT YOU HAVE SAID GROUP DEBR  CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  DEB
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ TRA
_ TRUCK

FROM WHAT YOU HAVE SAID GROUP TRA   CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  TRUCK
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ TRB
_ TRUCK

FROM WHAT YOU HAVE SAID GROUP TRB   CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  TRUCK
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ TRC
_ TRUCK

FROM WHAT YOU HAVE SAID GROUP TRC   CONTAINS
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  TRUCK
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT
_ TRD
_ TRUCK

FROM WHAT YOU HAVE SAID GROUP TRD   CONTAINS
```

```
THE MACHINES LISTED BELOW. IS THIS CORRECT ?? Y OR N
  TRUCK
_ Y
PLEASE ENTER THE NEXT GROUPS NAME & MACHINE CONTENT

FROM WHAT YOU HAVE SAID THERE MUST BE 11 GROUPS
IS THIS CORRECT ??
_ Y
FOR THE FIRST MAN PLEASE GIVE ON :-
       LINE 1 - THE MANS NAME
       LINE 2 - THE LENGTH OF HIS NORMAL WORK PERIOD
       LINE 3 - THE MANS PERFORMANCE RATE (%)
       LINE 4 - THE MAX NUMBER OF MACHINES THE MAN CAN RUN AT ONCE
_ CAPA
_ 240  230  2
PLEASE GIVE ON SUCCESSIVE LINES THE NAMES OF THE
GROUPS WHICH MAN CAPA  CAN SET. FOLLOW THE LAST GROUP BY
A BLANK LINE
_ CB4A
_ CB4B
_ CC5A
_ CC5B
_ TRA
_ TRB
_ TRC
_ TRD

CAN I TAKE IT THAT MAN CAPA  CAN SET THE FOLLOWING
 8 GROUPS?
  CB4A   CB4B   CC5A   CC5B   TRA   TRB   TRC   TRD
_ Y
PLEASE GIVE THE GROUPS WHICH MAN CAPA  CAN RUN
_ CB4A
_ CB4B
_ CC5A
```

```
_ CC5B
_ TRA
_ TRB
_ TRC
_ TRD
_
CAN I TAKE IT THAT MAN CAPA  CAN RUN THE FOLLOWING
 8 GROUPS?
  CB4A   CB4B   CC5A   CC5B   TRA    TRB    TRC    TRD
_ Y
FOR THE NEXT MAN PLEASE GIVE- NAME,WORK PERIOD,
 PERFORMANCE, & NO OF MACHINES RUN
_ CAPB
_ 240  230  2
PLEASE GIVE THE GROUPS WHICH MAN CAPB  CAN SET
_ CB4A
_ CB4B
_ CC5A
_ CC5B
_ TRA
_ TRB
_ TRC
_ TRD
_
CAN I TAKE IT THAT MAN CAPB  CAN SET THE FOLLOWING
 8 GROUPS?
  CB4A   CB4B   CC5A   CC5B   TRA    TRB    TRC    TRD
_ Y
PLEASE GIVE THE GROUPS WHICH MAN CAPB  CAN RUN
_ CB4A
_ CB4B
_ CC5A
_ CC5B
_ TRA
_ TRB
```

```
_ TRC
_ TRD
_
CAN I TAKE IT THAT MAN CAPB  CAN RUN THE FOLLOWING
 8 GROUPS?
  CB4A   CB4B   CC5A   CC5B   TRA    TRB    TRC    TRD
_ Y
FOR THE NEXT MAN PLEASE GIVE- NAME,WORK PERIOD,
 PERFORMANCE, & NO OF MACHINES RUN
_ GENOP
_ 240  230, _
CANCEL
_240  230  2
PLEASE GIVE THE GROUPS WHICH MAN GENOP CAN SET
_ DS4A
_ DS4B
_ DEBR
_ TRA
_ TRB
_ TRC
_ TRD
_
CAN I TAKE IT THAT MAN GENOP CAN SET THE FOLLOWING
 7 GROUPS?
  DS4A   DS4B   DEBR   TRA    TRB    TRC    TRD
_ Y
PLEASE GIVE THE GROUPS WHICH MAN GENOP CAN RUN
_ DS4A
_ DS4B
_ DEBR
_ TRA
_ TRB
_ TRC
_ TRD
_
```

```
CAN I TAKE IT THAT MAN GENOP CAN RUN THE FOLLOWING
 7 GROUPS?
  DS4A   DS4B   DEBR   TRA    TRB    TRC    TRD
_ Y
FOR THE NEXT MAN PLEASE GIVE- NAME,WORK PERIOD,
 PERFORMANCE, & NO OF MACHINES RUN
_ CLERK
_ 240  100  2
PLEASE GIVE THE GROUPS WHICH MAN CLERK CAN SET

CAN I TAKE IT THAT MAN CLERK CAN SET THE FOLLOWING
 0 GROUPS?

_ Y
PLEASE GIVE THE GROUPS WHICH MAN CLERK CAN RUN

CAN I TAKE IT THAT MAN CLERK CAN RUN THE FOLLOWING
 0 GROUPS?

_ Y
FOR THE NEXT MAN PLEASE GIVE- NAME,WORK PERIOD,
 PERFORMANCE, & NO OF MACHINES RUN

FROM WHAT YOU HAVE SAID THERE MUST BE  4 MEN
IS THIS CORRECT? Y OR N
_ Y
PLEASE GIVE THE PERCENTAGE SICKNESS RATE
_ 10
PLEASE GIVE ON THE NEXT TWO LINES :-
       LINE 1 - MEAN & STD.DEV. OF THE TIME MEN ARE ABSENT
       LINE 2 - MEAN & STD.DEV. OF THE TIME BETWEEN ABSENCES
_ 10  2
_ 120  5
DO YOU WISH TO ALTER ANY OF THIS DATA?
_ N
```

```
***ENTRY OF DATA ABOUT THE PARTS RANGE TO BE SIMULATED***


PLEASE GIVE THE PART NUMBER OF THE FIRST PART
FOLLOWED, ON THE NEXT LINE, BY THE NORMAL BATCH QUANTITY
_ C3467/18
_ 200
PLEASE GIVE THE FOLLOWING DATA FOR THE FIRST OP.
REQUIRED BY THIS PART -
       A.  THE NAME OF THE MACHINE GROUP
       B.  THE SETTING TIME & PROCESS TIME / PART
       C.  THE CYCLE TIME & LOADING TIME FOR AUTO MACHINES
           IF THE MACHIN IS NOT AN AUTO THESE VALUES SHOULD
           BE GIVEN AS ZEROS
WHEN THE DATA FOR THE LAST OP. HAS BEEN GIVEN, SEND A
BLANK LINE.
_ CC5A
_ 81  2  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3467/18
_ CC5B
_ 101  3  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3467/18

YOU HAVE GIVEN THE FOLLOWING DATA ABOUT PART C3467/18
    BATCH QUANTITY............ 200
    NUMBER OF OPERATIONS......   2
    GROUPS VISITED............ CC5A  CC5B
    SETTING TIMES.............   81   101
    PROCESS TIMES / PART......    2     3
    CYCLE TIMES...............    0     0
    LOADING TIMES.............    0     0
IS THIS CORRECT? Y OR N
_ Y
```

```
PLEASE GIVE THE PART NO & BATCH QUANTITY FOR THE NEXT PART
_ C3580/5
_ 20
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3580/5
_ CC5A
_ 191   9  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3580/5
_ CC5B
_ 356  12  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3580/5

YOU HAVE GIVEN THE FOLLOWING DATA ABOUT PART C3580/5
    BATCH QUANTITY............  20
    NUMBER OF OPERATIONS......   2
    GROUPS VISITED............ CC5A  CC5B
    SETTING TIMES.............  191   356
    PROCESS TIMES / PART......    9    12
    CYCLE TIMES...............    0     0
    LOADING TIMES.............    0     0
IS THIS CORRECT? Y OR N
  Y
PLEASE GIVE THE PART NO & BATCH QUANTITY FOR THE NEXT PART
_ C3711/104
_ 200
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ CB4A
_ 195   9   0   0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ TRA
_ 5  15  0   0
```

```
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ DS4A
_ 45  3  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ TRB
_ 6  16   0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ CC5A
_ 120  4  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ CC5B
_ 90  2  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ TRC
_ 7  17  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104
_ DEBR
_ 10  1  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3711/104

YOU HAVE GIVEN THE FOLLOWING DATA ABOUT PART C3711/104
    BATCH QUANTITY............ 200
    NUMBER OF OPERATIONS......   8
    GROUPS VISITED............ CB4A  TRA   DS4A  TRB   CC5A
                               CC5B  TRC   DEBR
    SETTING TIMES.............  195     5    45     6   120
                                 90     7    10
    PROCESS TIMES / PART......    9    15     3    16     4
```

```
                                        2     17     1
    CYCLE TIMES................         0      0     0      0      0
                                        0      0     0
    LOADING TIMES.............          0      0     0      0      0
                                        0      0     0
IS THIS CORRECT? Y OR N
_ Y
PLEASE GIVE THE PART NO & BATCH QUANTITY FOR THE NEXT PART
_ C3340/26
_ 200
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3340/26
_ CB4A
_ 145   7  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3340/26
_ CB4B
_ 92  1  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3340/26
_ TRA
_ 5  15  0  0
PLEASE GIVE THE GROUP NAME,SETTING, PROCESS, CYCLE,
& LOADING TIMES FOR THE NEXT OP PART C3340/26

YOU HAVE GIVEN THE FOLLOWING DATA ABOUT PART C3340/26
    BATCH QUANTITY............. 200
    NUMBER OF OPERATIONS......    3
    GROUPS VISITED............. CB4A  CB4B  TRA
    SETTING TIMES.............   145    92    5
    PROCESS TIMES / PART......     7     1   15
    CYCLE TIMES...............     0     0    0
    LOADING TIMES.............     0     0    0
IS THIS CORRECT? Y OR N
_ Y
```

```
PLEASE GIVE THE PART NO & BATCH QUANTITY FOR THE NEXT PART

FROM WHAT YOU HAVE SAID THERE MUST BE   4 PARTS
IS THIS CORRECT?
_ Y
THERE ARE 14 UNIQUE VALUES OF SETTING TIME -
   81   101   191   356   195     5    45     6   120    90
    7    10   145    92
THERE ARE 10 UNIQUE VALUES OF PROCESS TIME -
    2     3     9    12    15    16     4    17     1     0

  THERE ARE  0 UNIQUE VALUES OF LOADING TIME -
    0
**INPUT OF ORDER DATA**

FOR THE FIRST ORDER PLEASE GIVE THE FOLLOWING DATA ON -
       LINE 1 - PART NUMBER
       LINE 2 - DAY OF ISSUE, QUANTITY,DELIVERY DATE (DAY)

PLEASE SEPARATE THE DATA BY TWO, OR MORE, SPACES
_ C3580/5
_ 0  20  6
THE   1 BATCHES ASSOCIATED WITH THIS ORDER ARE -
  11

PLEASE INDICATE THE STATE OF PART-WORKED BATCHES BY GIVING
ON SUBSEQUENT LINES -

       THE BATCH NUMBER  &  THE NUMBER OF OPS COMPLETED

   NOTE.
       - IF A BATCH IS OMITTED IT WILL BE TAKEN TO BE ISSUED
         BUT NOT STARTED
       - THE END OF THE LIST SHOULD BE INDICATED BY GIVING A
         FICTICIOUS BATCH NO. OR GIVING THE NUMBER OF OPS
```

```
     COMPLETED AS EQUAL TO ZERO
_ 11  1
_ 99  0
DO YOU WISH TO CHANGE THE DATA YOU HAVE JUST ENTERED?
_ N
PLEASE GIVE THE PART NUMBER,ISSUE DAY,QUANTITY
& DELIVERY DAY, FOR THE NEXT ORDER
_ C3711/104
_ 0  350  7
THE   2 BATCHES ASSOCIATED WITH THIS ORDER ARE -
  21   22

PLEASE INDICATE THE STATE OF PART-WORKED BATCHES BY GIVING
ON SUBSEQUENT LINES -

      THE BATCH NUMBER  &  THE NUMBER OF OPS COMPLETED

   NOTE.
       - IF A BATCH IS OMITTED IT WILL BE TAKEN TO BE ISSUED
         BUT NOT STARTED
       - THE END OF THE LIST SHOULD BE INDICATED BY GIVING A
         FICTICIOUS BATCH NO. OR GIVING THE NUMBER OF OPS
         COMPLETED AS EQUAL TO ZERO
_ 21  4
_ 22  0
DO YOU WISH TO CHANGE THE DATA YOU HAVE JUST ENTERED?
_ N
PLEASE GIVE THE PART NUMBER,ISSUE DAY,QUANTITY
& DELIVERY DAY, FOR THE NEXT ORDER
_ C3467/18
_ 1  200   8
DO YOU WISH TO CHANGE THE DATA YOU HAVE JUST ENTERED?
_ N
PLEASE GIVE THE PART NUMBER,ISSUE DAY,QUANTITY
& DELIVERY DAY, FOR THE NEXT ORDER
```

```
_ C3340/26
_ 1  200   9
DO YOU WISH TO CHANGE THE DATA YOU HAVE JUST ENTERED?
_ N
PLEASE GIVE THE PART NUMBER,ISSUE DAY,QUANTITY
& DELIVERY DAY, FOR THE NEXT ORDER

DO YOU WISH TO CHECK THE DATA YOU HAVE JUST ENTERED?
_ Y
PART NUMBERS -  C3580/5          C3711/104        C3467/18
                C3340/26
DAY OF ISSUE -    0    0    1    1
QUANTITY     -   20  350  200  200
DAY DUE      -    6    7    8    9
IS THIS CORRECT? Y OR N
_ Y
FROM WHAT YOU HAVE SAID THERE MUST BE  4 ORDERS
IS THIS CORRECT?
_ Y
PLEASE GIVE THE UPPER LIMIT FOR THE NUMBER OF ENTITIES TO BE USED
_ 65
THE LIMIT YOU HAVE GIVEN WILL ALLOW A MAX OF  12JOB IN THE SYSTEM
IS THIS SUFFICIENT? Y OR N
_ Y
***THE ENTRY OF ALL ENTITY BASED DATA IS NOW COMPLETED***


***INPUT OF SIMULATION CONTROL DATA***


PLEASE GIVE THE LENGTH OF THE RUN IN MINS
_ 2000
PLEASE GIVE THE TIME FROM WHICH THE RECORDING OF RESULTS SHOULD START
_ 0
DO YOU WANT QUEUE MONITORING TO TAKE PLACE?
```

```
  N
DO YOU WANT DETAILED MONITORING OF JOB MOVEMENTS?
  Y
DO YOU WANT SHOP FLOOR RESCHEDULING TO TAKE PLACE?
  Y
PLEASE GIVE THE NUMBER OF THE APPROPRIATE RULE -
PRIORITY WILL BE GIVEN TO THE JOB WITH THE MIN. -
    RULE 1 - DUE DATE
    RULE 2 - UNAVAILABLE
    RULE 3 - SETTING TIME
    RULE 4 - PROCESS TIME
    RULE 5 - SETTING + PROCESS TIME
    RULE 6 - FLOAT
  1
PLEASE GIVE THE PARAMETERS FOR THE EXECUTE CARD
-    ,2000,200


******INPUT OF ALL DATA IS NOW COMPLETE******


***THE DATA HAS NOW BEEN PROCESSED & PASSED TO THE MODEL***
14.14.36 FREE *LP3 ,154 TRANSFERS
14.14.36 FREE *LP2 ,42 TRANSFERS
14.14.37 FREE *LP1 ,18 TRANSFERS
14.14.37 FREE *CR0 ,226 TRANSFERS

14.14.37 FREE *LP0 ,347 TRANSFERS
0.17 :DELETED : 00
14.14.38 0.17 DELETED,CLOCKED 0.03
DISPLAY: RNECSLL LOADED
DISPLAY: SIMULATION PROGRAM LOADED
14.15.14 0.19 FINISHED : 1 LISTFILES
14.15.15 JOBTIME USED 20 ; MAXIMUM CORE USED 12672
14.15.15 JOB UNITS 264
```