ASPECTS OF CONTROL FOR A SPARE PARTS ORGANISATION

Thesis submitted for the degree of

Doctor of Philosophy

of the University of Aston in Birmingham
Department of Production Technology
and Production Management

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September 1979

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SUMMARY

This thesis describes the investigations carried out by the author into the spare parts operation of CompAir Industrial Limited.

The initial investigations showed that the level of activity in the department and various measures of performance had historically varied in a cyclical manner, approximately in phase with the general level of industrial activity.

An Industrial Dynamics model of the complete spares system, including the distribution and provisioning aspects, was constructed to study this effect, and experimental results supported the theory that the system itself progressively amplified any small variations in true customer demand.

Further experiments with the same model identified those areas in the system primarily responsible, one of the most important being the central warehouse stock control system. This area was not amenable to further analysis using the existing model due to the approximations inherent in Industrial Dynamics, and the inability of the technique to represent adequately the interactions between piece-part demand variability, stock levels, and service. The author therefore developed an approach based on Industrial Dynamics, but operating at a greater level of detail where relevant.

This new technique made it possible to assess the effect of piece-part supply and demand characteristics on the long term dynamic behaviour of the system, and also how this behaviour responded to various stock and production control systems.

Using this approach, comparison of the existing warehouse stock control system with one based on statistical theory suggested that the latter would improve the financial performance of the Spares Department and also reduce the effects of the trade cycle.

Key Words:-

Spares Provisioning
Industrial Dynamics
Stock Control
Simulation

ACKNOWLEDGEMENTS

I should like to register my appreciation of the co-operation and assistance encountered throughout CompAir. In particular, Mr. J. Broom Smith, Mr. C.S.W. Harte and Mr. A.P. Townsend of the Spares and Service Division, and Mr. R. Upchurch, Mr. J. Schofield and the late Mr. D. Youers of the E.D.P. Department all provided invaluable help.

My thanks are also due to Mr. H. Craig of CompAir and Mr. J. Sawyer and Prof. R. Thornley of Aston University for their continued support and guidance.

These acknowledgements would not be complete without recognising the contribution of my colleague Mr. D. Love who proved a most stimulating partner.

Finally, I must express my gratitude to Miss. S. Stevens of CompAir, who can claim the credit for the presentation of the thesis.

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CHAPTER 1

INTRODUCTION

1.1. The Significance of Spares Provisioning

In a company supplying capital machinery to an industrial market, the provision of an efficient after-sales service is essential. Not only does the original purchase of the machine represent a considerable investment by the customer, but frequently a large proportion of his operation may depend upon its continuous operation. The original purchase decision assumes that any parts which need replacement, may be obtained quickly and easily. Failure of the original supplier to meet these expectations would result in a loss of confidence of the purchaser, which would quickly be reflected in reduced sales of original equipment. Faced with the need to maintain a supply of spare parts, many companies decide to run this aspect of their operation as a highly profitable activity.

Such are the circumstances at CompAir BroomWade, a company within the CompAir Group, which is the largest U.K. manufacturer of air compressors and compressed air tools and equipment. Founded before the turn of the century, the company had established a reputation based on the longevity and reliability of its reciprocating compressors, a reputation supported by a high level of after-sales service.

Following the amalgamation of Broom and Wade, as the company was previously known, into the CompAir Group, conditions began to change in a manner which made the provision of such a high level of service increasingly difficult.

The principal cause was the faster rate of product change the company adopted to meet the demands for more efficient and economic compressed air. This resulted in the withdrawal from the market of various models of compressor as they were superseded by improved designs. As well as increasing the range of parts to be stocked, this also created difficulties in the sourcing of parts for obsolete machines, as such parts were no longer included in the normal factory production programme. However, because of their general similarity in form to current production parts, special spares batches could still be manufactured using existing facilities. The introduction of the packaged screw compressor added a new dimension to the problem.

From a spares provisioning viewpoint, the reciprocating compressor is characterised by its regular requirement for the replacement of wearing parts, most notably the valves, but also piston rings, bearings, etc. The oil flooded screw compressor represents a totally different concept. The compressor itself (known as the "air end") contains very few moving parts, and since metal-to-metal contact is minimal, its design life extends to many thousands of hours. This compressor is marketed as part of a self-contained compressed air supply unit, comprising all the ancillary control and drive units as well as the equipment necessary to filter and cool the air, the whole unit being housed in a free-standing sound-proofed cabinet. Of these items, the air end and the cabinet were the only significant items made within the company, so the unit contained a high proportion of proprietary parts.

The appeal of the package is largely based on its low maintenance requirements, merely needing the air/oil separator and filter elements to be changed at extended intervals.

The introduction of these models thus represented a double threat to the spares system. Firstly, the conversion of the manufacturing facilities to make the screw compressor would reduce their ability to supply the traditional type of spare part. Secondly, the screw package spares requirement would contain a higher proportion of proprietary parts, available to the customer from other sources, so that the market was no longer captive.

The company management was concerned at the ability of the spares division to respond to these new demands and as a result included in the 1973 version of its rolling five years corporate plan a proposal to review the total spares provisioning activity.

At the same time, discussions were taking place with the Department of Industry and Aston University on the establishment of a "Teaching Company" scheme within CompAir BroomWade. It was jointly agreed that the spares investigation represented a suitable project, combining the requirements of a detailed and systematic investigation into an area deeply involved with batch manufacture, but operating under the usual commerical constraints of timescale and finance.

A team was therefore appointed under the aegis of the teaching company scheme to undertake the investigation of the spares division.

1.2. Project Objectives

The original terms of reference asked the team "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 ranges". In order to bring the task into sharper definition, the following secondary objectives were agreed:-

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

ii. To identify from studying the historical performance of the division those factors which affect the performance, and obtain an understanding of how their influence is exerted.

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

iv. To decide on what action is necessary to improve/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 described in the previous section.

CHAPTER 2

THE EXISTING SYSTEM

2.1. The Company

CompAir BroomWade at High Wycombe designs, manufactures and markets a wide range of compressed air equipment for the industrial market, with some 40% of their output being exported each year.

Their product range includes large and small compressors, air tools and product finishing equipment and auxiliary equipment such as air receivers, air dryers, etc.

The compressor range, which is easily the most significant in turnover, includes both the screw and reciprocating types and embraces a wide range of specifications to suit the wide variety of customer, from small family firms to multi-national companies. Some examples of typical compressors are shown in Fig 1.

A total of some 1,400 people are employed at the High Wycombe factories, with 450 being engaged on manufacture. The spares and service division is managed by the spares director and employs 94 people, of which 42 are directly concerned with the supply and provisioning of spare parts.

2.2. The Scale of the Spares Operation

The spares division is a semi autonomous unit within CompAir Industrial. It is responsible for its own sales

and marketing but is heavily dependent upon and interlinked with the stock and production control systems used by the original equipment factories, although different parameters are applied to the control of spares stock. The turnover in the financial year ending 31st October, 1977 was £6.7M. Establishment is for 46 people under one manager, 15 on sales and seven in provisioning, and 23 in the warehouse under another. Two fitters are employed building special spares assemblies. An organisation chart is given in Fig 2.

For compressor spares, the company normally deals with the distributor network in the U.K. and its overseas agents, exceptions being made for a number of customers who deal direct and those sales made across the counter at High Wycombe (a practice actively discouraged by the company). Direct dealing is more usual for spares for power tools and product finishing equipment.

On average, the department receives over 330 orders per week for some 3,500 lines, two-thirds of the orders having more than one item. The warehouse occupies 17,000 sq.ft. and handles 2½ M parts per annum.

2.3. The Spare Parts Range

The present spares range comprises over 12,000 part numbers, both piece parts and assemblies, of which over 50% are in frequent demand.

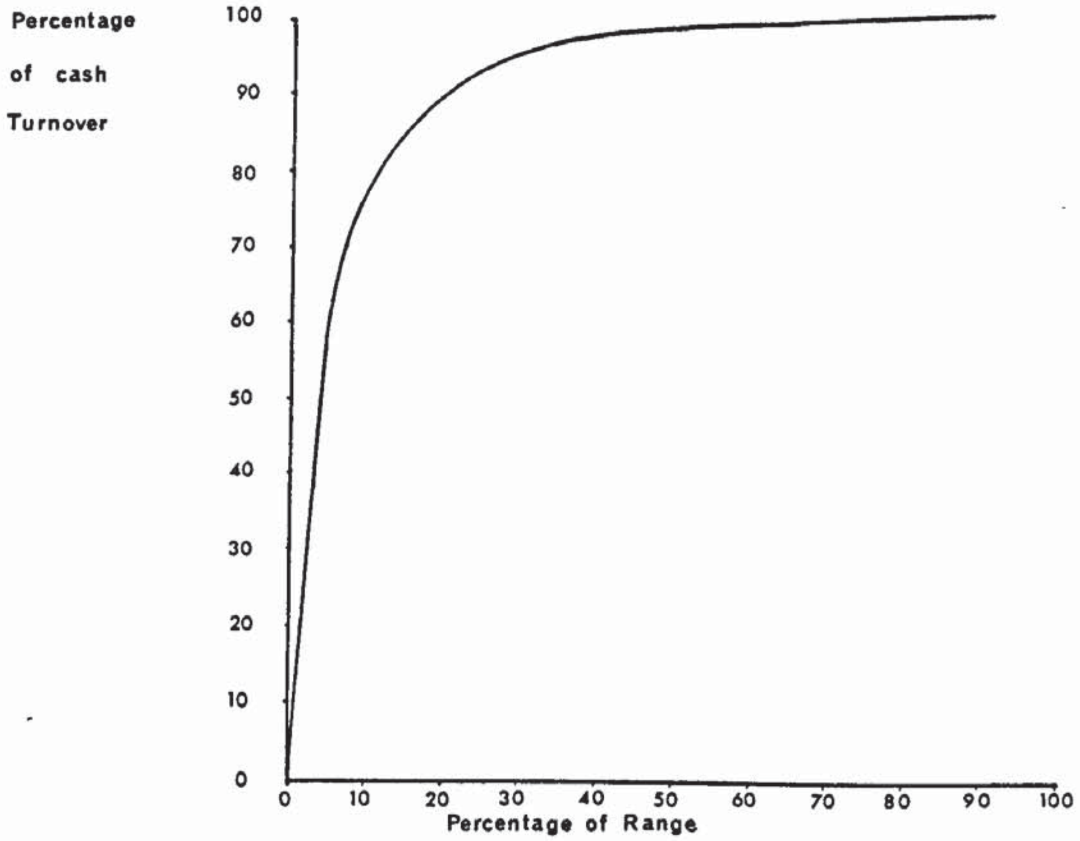
An analysis of demand by value shows very steep pareto characteristics with 10% of the range accounting for 80% of the turnover (see Fig. 3).

Analysis of the basis of demand only gives a similar curve (See Fig. 4) with only 2.4% of the total range having an annual demand of 1,000 or more. The demand is highly variable at piece part level and the average coefficient of variation of those items with a regular usage was 3.48 over a seven year period. At the gross level, demand has previously shown strong cyclical characteristics, varying by as much as 17½% from the average over an eight year period. This feature has become less pronounced in the last 24 months. The range embraces a wide variety of components including small fastenings, complex assemblies and large sheet metal fabrications. Their individual sales prices could be pence, or over £1,000.

2.4. The Spares Distributor Network

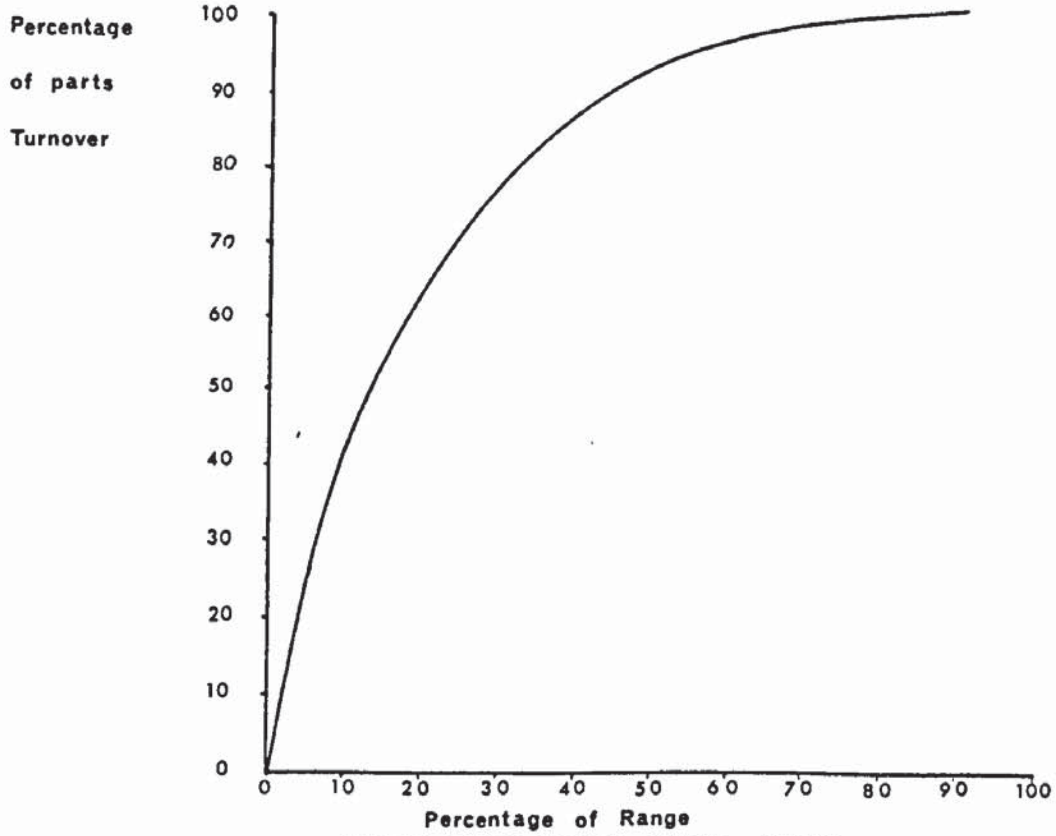
U.K. Sales

The U.K. market absorbs 65% of the annual sales, 90% of which are handled by the main distributor. These are completely independent companies operating on a local basis in the principal industrial centres of the U.K. The smallest turns over less than £10,000 per annum on CompAir Industrial spare parts, while annual sales of the largest approaches £500,000. The complete analysis given in Fig. 5. is on the basis of 1976-77 figures.



SPARES RANGE PARETO CURVE — CASH

Figure 3



SPARES RANGE PARETO CURVE— ITEMS

Figure 4

NUMBER OF DISTRIBUTORS	ANNUAL TURNOVER
3	over £250,000
8	between £100,000 and £250,000
3	between £50,000 and £100,000
6	between £25,000 and £50,000
5	less than £25,000

FIG 5. DISTRIBUTOR TURNOVER

A survey was carried out on six U.K. distributors at the beginning of the project to determine the way they operate and to listen to any comments or criticisms. Many of the distributors are principally plant hirers, with the spares business a very small adjunct. Very few deal exclusively with CompAir and many have their own workshops and service mechanics.

Stock holding policy varies from distributor to distributor, the range of parts usually being between 2,000 and 8,000 lines. A typical distributor aims to hold between three and six months stock of the items with regular sales. Although most, but not all, keep proper stock records, none are computerised at present. The stock control rules being applied are extremely simple and in most cases liberally interpreted, intuition often influencing purchasing decisions. The manual stock records are also prone to small but frequent clerical errors. One or two have "Olivetti" type accounting machines but did not seem to really understand their capabilities. Although CompAir allows two bulk or stock replenishment orders each month, none of the distributors reviews his stock more frequently than once per month.

All those distributors visited had a thorough knowledge of local conditions and machine populations. In general, they were critical of inconsistent lead times from High Wycombe and the lack of delivery promises on non stock items. There were no complaints about the "breakdown order" service.

Overseas

The company has over 100 outlets for its spares abroad but only 25 maintain a level of spares business comparable with the U.K. distributors. Over one-third of the business is handled by CompAir companies. Because of the problems of transport and payment, the lead time for normal overseas spares orders is much longer than for the U.K. and the influence that the company can exert on these lead times is correspondingly less.

2.5. The Warehouse Operation

Three classes of incoming order are recognised by the system:-

i. Breakdown orders

Those orders for the parts required to repair an urgent machine breakdown. Dealers discount - 20%

ii. Stock orders

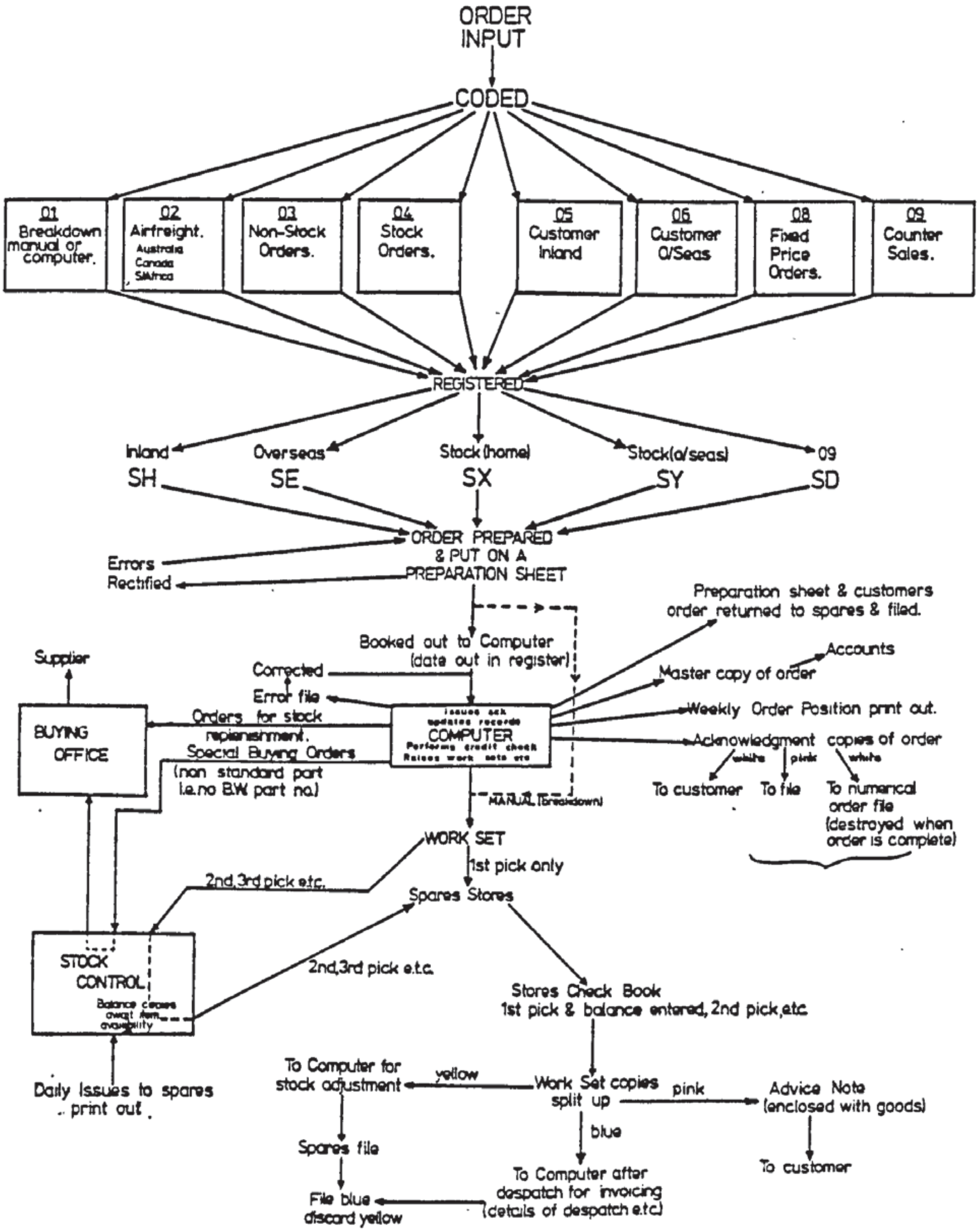
Orders raised by distributors as and when required. Dealers discount - 20%.

iii. Bulk orders

Orders raised by distributors on a monthly or fortnightly basis as part of the stock replenishment procedure. Dealers discount - 30%.

At High Wycombe incoming orders are classified according to priority and type by the sales staff. The very large orders are then forwarded to the data processing department to be entered on to the "open order file" during an overnight run of the computer. The other orders are entered via the V.D.U. in the spares department after checking the credit status of the customer (also via the V.D.U.).

The latter system enables the stock controller to examine the free stock available on the items being entered before accepting the order. If the item is entered, the free stock is immediately allocated and a new free stock balance calculated. From the orders entered during the previous 24 hours, each night the computer generates the picking documents, order acknowledgements, delivery notes, etc. (See Fig. 6). On the return of the documents to the warehouse, the items are picked by one of the 12 storemen. Partially satisfied orders are manually amended and returned to data processing for re-cycling.



SPARES PAPERWORK FLOW CHART

Figure 6

Except for certain export orders, the partially filled order proceeds and is despatched as with the complete orders. When the required components have been marshalled, they are transported to the despatch department to await packing and despatch. The computer relies on the return of documents from completion of the picking operation and final despatch to maintain the "open order" records.

2.6. The Existing Spares Stock & Production Control System

The spares stock control system is totally integrated with the stock and production control systems used for original equipment, forming part of a suite of programmes run on the company's ICL 1902 computer. Every month a forecast demand is calculated for each item on the spares stock file. This is done by taking an average of the demand over the previous twelve months. On the rare occasions that significant forward orders for spares do occur, these are taken into account.

A minimum stock objective and float factor for each item is then derived by considering its monthly usage value. (See Table in Fig. 7).

Monthly Usage Value Range	Value Category	Min Stock	Float	Delivery Quantity	
				Source 1	Source 2
		(wks)	(wks)	(wks)	(wks)
Over £150	1	4	4	4	8
Between £35 & £150	2	4	4	6	12
Between £10 & £35	3	4	4	8	24
Between £5 & £10	4	4	6	8	32
Less than £10	5	4	8	24	40

£5

FIG. 7. TABLE OF STOCK CONTROL PARAMETERS FOR SPARE PARTS

The stock re-ordering routine is run weekly with a separate routine for bought out and factory sourced items. (Henceforth referred to as Source 2 and Source 1 respectively). In each case, the routine uses the forecast demand figure to predict the theoretical free stock balance at the end of each week,for up to 60 weeks ahead for Source 1 items (or for Source 2, the delivery time + four weeks + standard float). The routine generates orders when necessary,which are carried across to the "Spares Forecast requirements" file (or the bought out W.I.P. file for Source 2).

Starting from the latest free stock figure, the routine initially looks four weeks ahead, netting off one weeks demand from the stock each week. If a predicted negative stock is shown for any week, a requirement is generated for that week and is assumed to be satisfied on time.

On the fifth week, the minimum stock objective is also netted off from the theoretical stock balance, as well as one weeks demand. However, if the predicted stock balance is negative at this point, the requirement is generated for one week earlier (one week float). In the following week a further one week requirement is netted off the theoretical stock balance and any requirement generated would be for two weeks earlier than that date. This process is repeated until the full float factor is reached. The routine then continues, checking the theoretical stock balances and generating forward orders until planning horizon of 60 weeks is reached.

Except for orders raised for delivery in the first four weeks, the delivery quantity is also derived from reference to the usage value of the item. In the case of the spares bought out items, the resulting forecast is used to modify and update the existing order position every week. However, for items sourced on the factory, the requirements are only carried across and added into the production requirements file once every month. Once an order is placed for Source 2 or "sanctioned" for Source 1 (i.e. the required date is within 13 weeks), the quantity is fixed and only the due date can be adjusted. At this point, the requirement is accepted as a firm demand and a notional "spares demand" note number is allocated to it.

For production planning, the system carries for each item a normal lead time which includes floats and allowances for inter-operational delays. It also carries a "crash" lead time which is purely the sum of the process times for the relevant batch sizes. Each batch of work on the shop floor is allocated a requirement date which is regularly updated according to the latest demand figures.

When the batch is first loaded it carries its full allowance of "float time" and, as it progresses through the shop, the float is adjusted recognising the latest requirement dates and the number of operations completed. If the float goes negative, the batch is allocated Priority 1 and further scheduling is on the basis of "the crash" lead time which is used until the float reverts to zero. A recent refinement has been the addition of a further priority class, Priority 2, for those jobs with negative float and also required within the next month. Thus the highest priority is always allocated with regard to the latest information on both requirements and actual progress. To actually transfer stock from the factory to the spares warehouse the spares forecast file is used. Any requirement, (i.e. S.D. number) shown against the current date is authority to the departmental production controller to release the required parts to the spares department at his discretion. Thus parts are only released if they are required and if they are available.

Contingency reports

As its name implies, these reports are issued where outside intervention may be required as the system may not be adequate to meet the special situation which has arisen.

It is produced when an item is ordered which meets the following conditions:-

(a) the free stock after allocating the item is less than the normal usage in the delivery cycle (i.e. free stock $<$ monthly usage x delivery time)

or

(b) the customers requirement is greater than three weeks usage

or

(c) it is a Source 1 item and the customer's requirement is greater than one weeks total production usage.

Where the monthly usage is less than one, for the purposes of testing condition (a) a value of one is used.

Low usage items

Since the forecasting routine rounds off usages to the nearest whole number, an annual requirement of six or less is shown as zero. These items are dealt with on an exception basis. Briefly, if a part is common to spares and production, the system relies of the probability that there will be stock available in production to meet occasional spares demands.

Where a part is unique to spares, the management have the following reports to prompt the ordering action.

i. A list of those parts unique to spares with a monthly usage of zero and which have sold one or more in the past twelve months (issued monthly).

ii. Contingency report, when any item is sold, if adequate stock not available.

For zero usage items, orders must be raised manually by the spares department.

This order or requirement is carried across to the production requirements or bought out requirements file in the usual way but the requirement date is only progressed as far as the month following the current one, where it is held until an actual requirement appears, i.e. the spares free stock goes negative.

2.7. Provisioning sources

The spares division obtains its components from three sources. It may raise purchase requisitions directly on the purchasing department (Source 2) or it may obtain supplies from the original equipment manufacturing department (Source 1). These departments can in turn, either buy from outside or manufacture in-house, (i.e. Source 1.2 or Source 1.1).

Outside suppliers are used for proprietary parts or parts requiring specialist manufacturing techniques.

For example:

electrical control gear
piston rings
certain air coolers
filters
etc.

This source should not be confused with sub-contract which is, for most purposes, regarded as an adjustable addition to the factory capacity or is used for specialist processes on parts otherwise made "in-house".

The sources are decided by policy so if a part is used on a current model it will be automatically sourced from the factory. In addition, a part will be sourced from the factory even if non current (i.e. for a machine not belonging in the current range) if it had been previously manufactured in-house. Thus spares direct purchasing in general is restricted to proprietary parts for non-current machines. A breakdown of the spares range by source is shown in Fig 8. These figures are obtained from two sources:-

i. "HVC Report" In which all spares components with usage are divided into the three principle classifications, Source 1, Source 2 and assemblies,and then listed in order of descending monthly usage value, also showing the accumulated monthly usage value. The figures shown are for June 1977.

ii. A special print prepared by the E.D.P. Department showing the spares load on production department facilities. These figures are to standard hours in June 1976.

Source	% of total by value	Route	Type of component
Warehouse	10	Parts Div Fitting Shop	Assemblies
Bought out	26	Parts Div - Central Purchasing	Proprietary items unique to spares
Production Bought Out	39	Parts Div - OE production control - central purchasing	Proprietary items common to spares and production
Production-Manufactured	25	Parts Div - production control - production department and/or sub-contractor*	all manufactured items

FIG 8.

(* In February 1977, 20% of the spares manufacturing load (std hrs) was sub-contracted).

CHAPTER 3

HISTORICAL PERFORMANCE OF THE SPARES SYSTEM

In the course of the investigation, it became clear that the spares division at High Wycombe could not be considered in isolation since it was influenced by both the distributors and suppliers. The performance of all three areas must therefore be considered.

3.1. The Spares Warehouse

3.1.1. Data Sources

At the beginning of the project, the company had no clear statement of the objectives of the division, so that it was impossible to refer to any one statistic as "the performance". However, from the many operating statistics available, there were certain figures which the management team used as a measure of performance. These figures were either extracted directly or calculated from figures contained in various reports which had been available in one form or another for between seven and ten years.

3.1.1.1. Daily Movement Analysis

A report generated daily by the computer which shows how many line item orders were received and how many line items were issued to despatch in the previous working day. Each separate mention of a part number is counted as a line item but the quantity is ignored.

3.1.1.2. Spares Stores Forward Load

A weekly report giving the total number of line items outstanding for immediate delivery 1, 2, 3 and 4 weeks ahead, and for any period further ahead. The report divides the figures into those awaiting picking and those not available (out of stock).

3.1.1.3. Analysis of Spares Items with a Shortage for Customers' Orders

This report, known as "Customer Shortages" is issued monthly and has only been available in its present form since late 1975. It classifies the spares for which there is no stock and an outstanding customer requirement, firstly according to product group and secondly, according to whether the part is unique to spares or not. Obviously, these product groups have changed over the years as the product range has changed and as various products have been transferred to other companies in the group.

Within each of the separate listings, the part numbers are arranged in order of descending value of total customer shortage. Against each part number is shown the number of customers' orders outstanding, and the total value and quantity of the components required. This is followed by an indicator showing the length of time each customer order has been outstanding according to one of the following classes:-

Over 9 months; 6 to 9 months; 3 to 6 months; 2 to 3 months; 1 to 2 months; and up to 1 month. The final column shows whether there are any forward requirements for the next month.

At the end of each list is shown the total number of line items shortaged and the total value (at standard cost) involved. Fig. 9 illustrates one of the shorter listings.

3.1.1.4. The Spares Value Report

This is a report issued monthly on the financial aspects of the spares operation. It summarises the following information for the previous accounting period (month):-

(a) The value of all items issued to despatch

(b) The value of incoming orders

(c) The value of stock allocated to orders, but awaiting picking

(d) The gross stock value, also showing what value should be classified as surplus or obsolete, i.e. the total excess where the stock value exceeds 12 months usage. In the net value, this proportion is written down

```
PROGRAM:-SW23      ANALYSIS OF SPARES ITEMS WITH A SHORTAGE FOR CUSTOMERS ORDERS          M.PRODUCTION              06/03/78

                                                  <- - - - - - - - - - - - - OVERDUE ORDERS - - - - - - - - - - - ->
REF'                                              NO.OF  TOTAL   TOTAL   OVER     6-9    3-6    2-3    1-2    0-1   DUE IN THE
NO.   PART NUMBER     DESCRIPTION                 ITEMS  B.S.C.  O/DUE   9 MTHS   MTHS   MTHS   MTHS   MTHS   MTH   NEXT 4 WKS
  1   A  3777/53      PRESSURE GAUGE 0-60 LB                                                                                39
  2   A 10301/69      OIL PRESSURE SWITCH             2     £83      4                                             4        15
  3   C 11359/10      MAIN BEARING BUSH              13    £101    121                                           121        70
  4   C 11359/68      FILTER                                                                                                13
  5   C 11359/72      BEARING HOUSING                 1     £46      3                                             3         1
  6   C 11359/73      BEARING HOUSING                 1     £32      3                                             3
  7   C 11359/79      UNLOADER FORK ASSY              7     £68     69                                            69        16
  8   C 11359/322     LANTERN ASSY V130 V300          1     £18      2                                             2
  9   C 11359/74A     OIL PUMP ASSY                   7    £289     14                                            14        12
 10   C 11359/139B    CONNECTION ROD ASSEMBLY         1     £79      6                                             6        17
 11   C 11360/18      CRANKSHAFT ASSEMBLY             1     £40      1                                             1
 12   C 11400/130     CONN ROD                       10    £391     27                              4     15       8         3
 13   C 11344/28      HP CYLINDER ASSY V100/200                                                                              1
 14   C 11344/110     QUIETFLO DAMPENER               1              1                                             1
 15   C 11345/10      PRESSURE RING V150/300          1     £80      4                                             4        10
 16   C 11345/11      GUIDE RING V150/300                                                                                    1
 17   C 11345/14      HP CYLINDER ASSY V150/300       3    £127      4                                     1       3
 18   C 11345/24      UNLOADER FORK                  23    £161    177                                    30     147        38
                TOTAL NUMBER OF CUSTOMER ORDER LINES:-   72                                     2      7      63        42
                TOTAL BASIC STANDARD COST          :-          £1315                          £58   £276   £1181     £1239
```

EXAMPLE OF CUSTOMER SHORTAGE LIST

Figure 9

to 10% of its nominal standard cost.

(e) The total value of goods received, showing sub-totals for:-

   i. Goods received from the factory on Issue to Spares (I.S.) notes.

   ii. Goods received from outside suppliers on G.R. notes.

   iii. Goods received from customers.

(f) The value of items scrapped.

(g) Stock adjustments.

These figures are calculated at standard cost and are given for the principal product groups and totalled for the spares division as a whole.

3.1.1.5. "Oasis" Action Report

A daily report showing the number of line items picked at the first attempt in the previous working day (known as the "first pick count").

3.1.2. Measures of the Spares Warehouse Performance

In their unprocessed form, the figures extracted showed a high degree of random variation and it was usually necessary to take a three month moving average before any pattern emerged. In exceptional cases, six month and even twelve month averaging was necessary.

3.1.2.1. Spares Order Receipt Rate

The order receipt rate was recorded in two ways:-

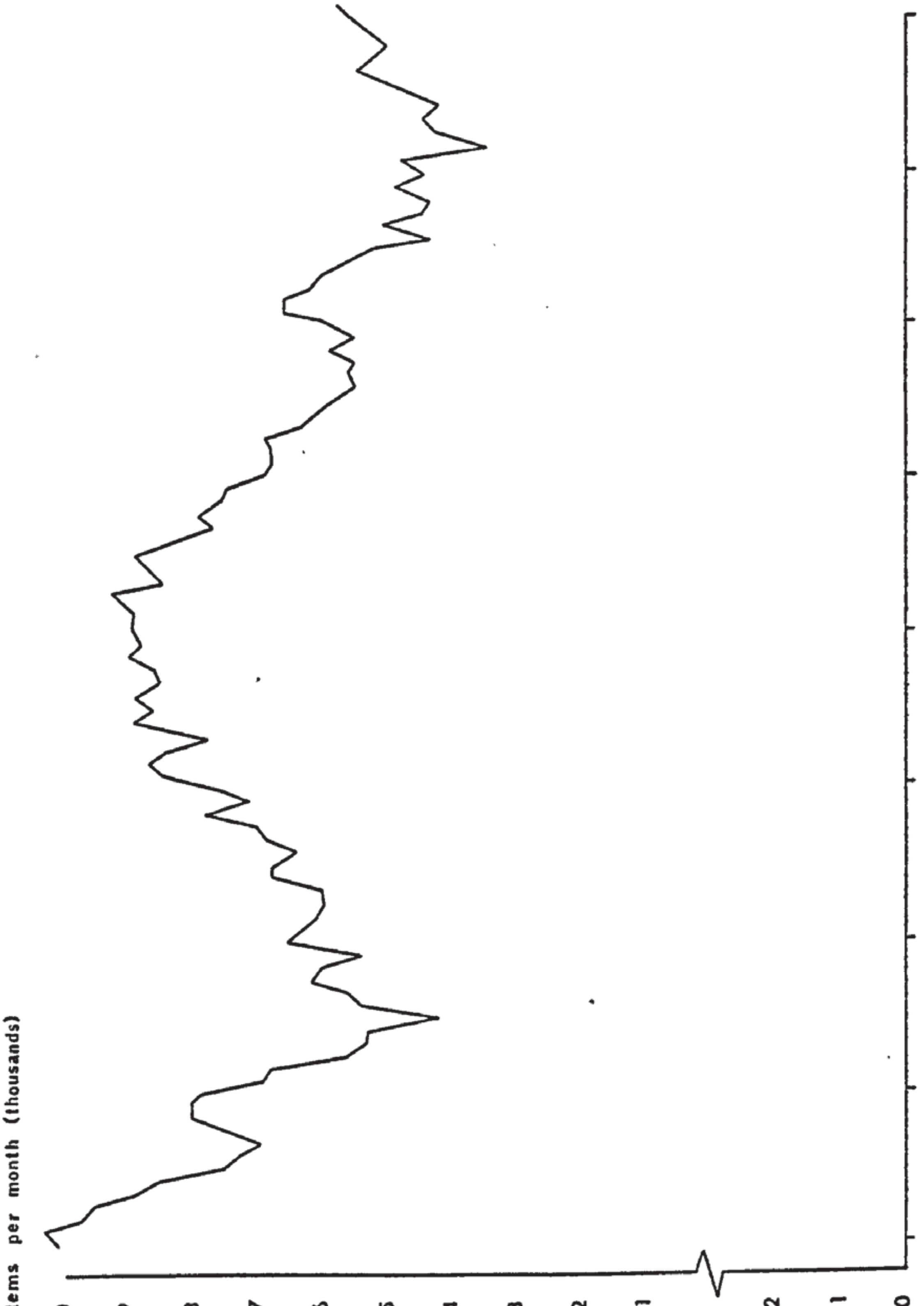
i. As value of spares orders received per month at company standard cost

and

ii. The number of line items on in-coming orders. This statistic originated as a measure of the stores' activity, but has the advantage that it provides an inflation proof measure of the general level of spares trading. Before processing, this figure is highly random, but as the graph in Fig 10 illustrates, there is the strong suggestion of a cyclical effect in the smoothed figures. Unfortunately, earlier records were not available to confirm its previous existence.

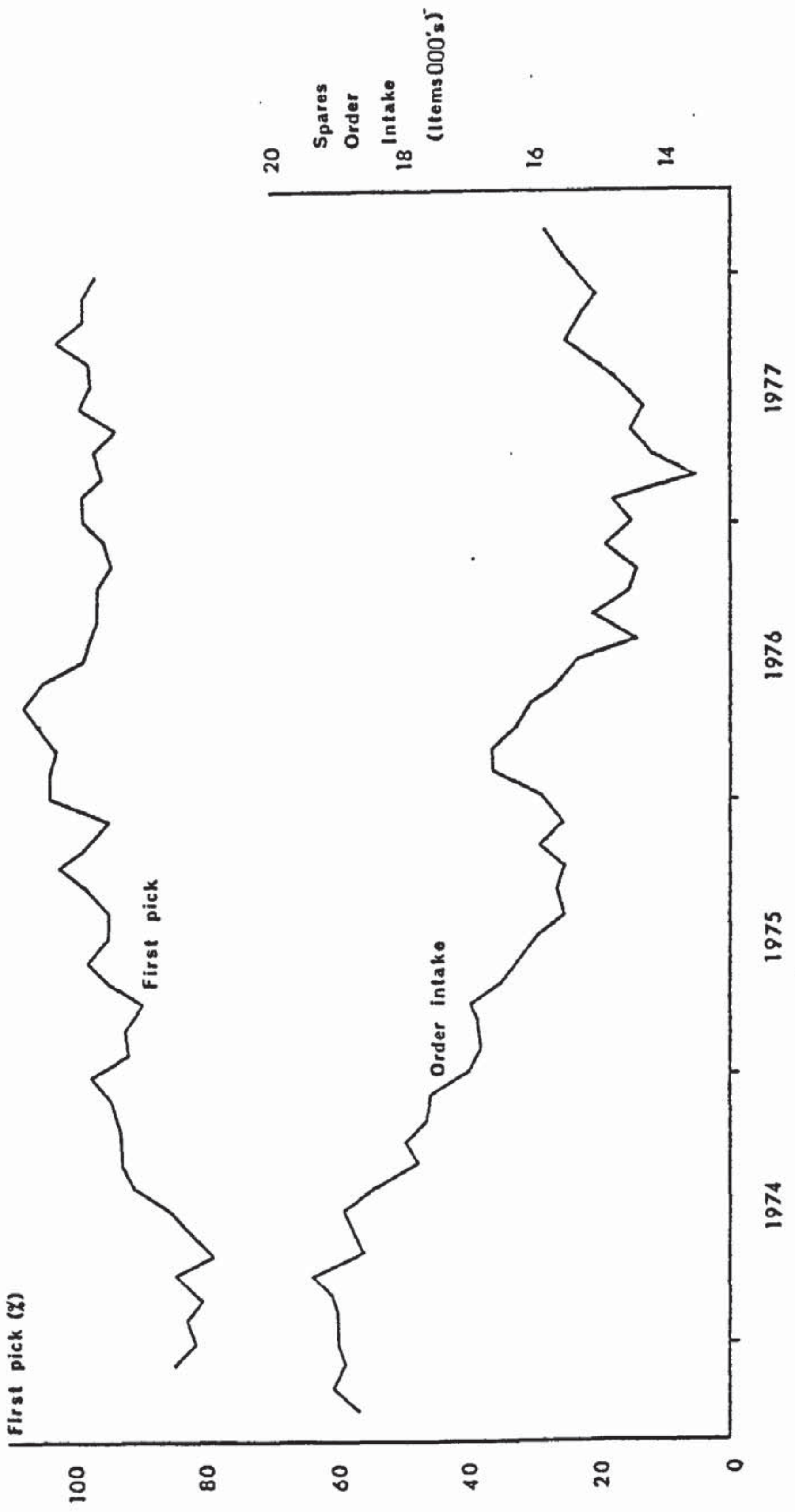
3.1.2.2. "First Pick" Count

Used as a measure of customer service. It is the number of items picked from the warehouse at the first attempt expressed as a ratio of the number of line items ordered in that same month. Because of the delay between order receipt and order picking, it is possible for this figure to exceed 100% for short periods. The graph in Fig. 11 compares this figure with the order intake and, although only 4½ years figures are available, it does seem that as activity decreases, the first pick count increases.



SPARES ORDER INTAKE
(6 MONTH MOVING AVERAGE)

Fig. 10



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

Fig. 11

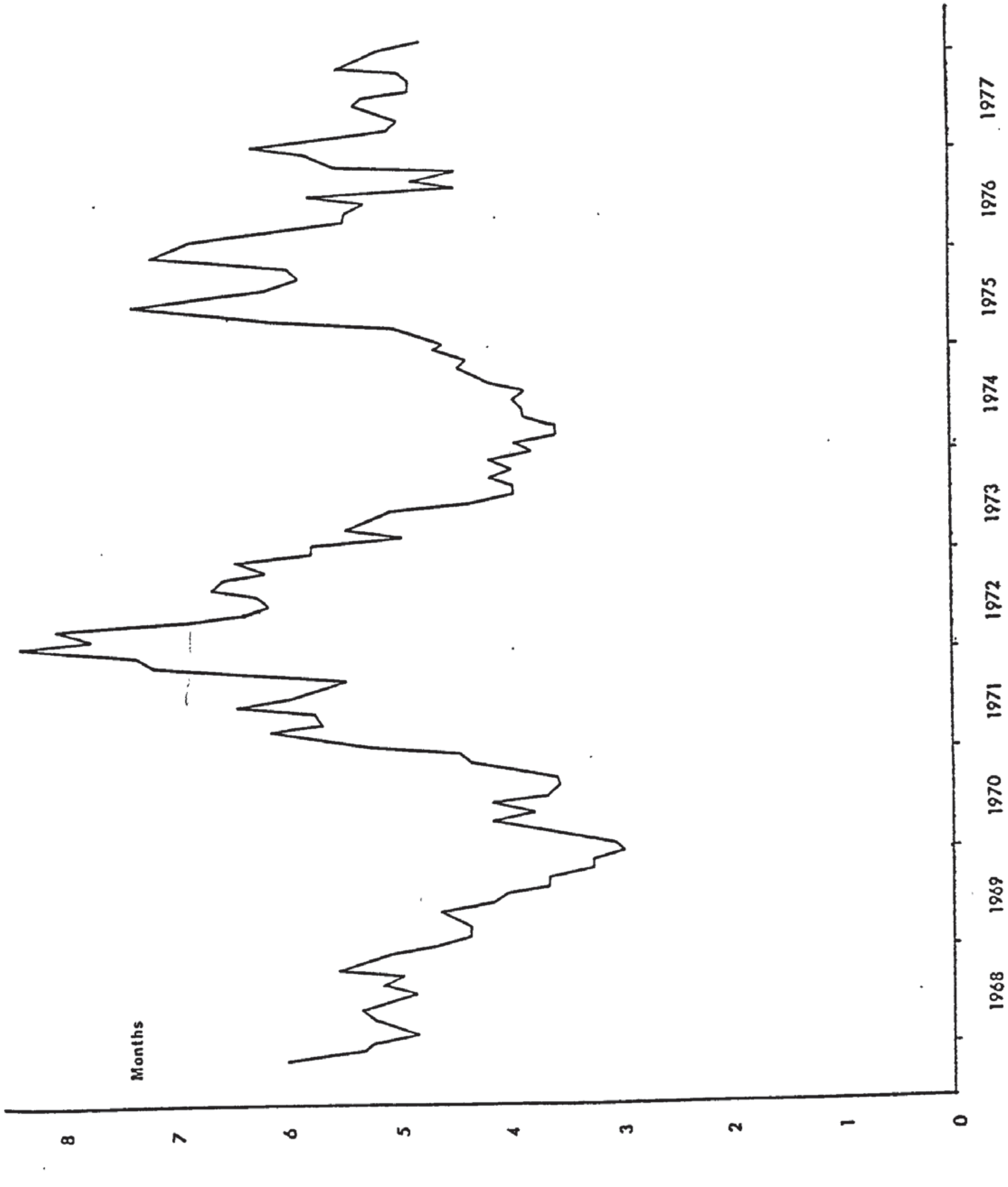
3.1.2.3. Stock Level

The stock valuation, available monthly, shows the value, at company standard cost, of the stock in the warehouse at the end of the previous month. This figure does not include items picked and awaiting packing or despatch. It also ignores any accounting practices, such as the provision to write-off obsolete stock.

The problem in examining the variations in this figure over any period of time is the effect of inflation. It is therefore more sensible to reduce this to a more stable dimension, such as stock value in terms of value of order receipt rate, which gives the stock holding in months. (Fig. 12). In this case, the cyclical pattern is quite clear and helps to explain the variation in first pick count, as low stocks would tend to give rise to more stockouts.

3.1.2.4. Shortages

As an additional measure of customer service and also to monitor the effectiveness of the stock control and provisioning systems, there is a monthly report on customer shortages. This is the number of line items and their total value which cannot be supplied to customers as there is no stock. As with the stock value, it is necessary to express the shortage value in terms of order receipts to remove the effects of inflation, but when this is done, a cyclical pattern can again



STOCK VALUE IN TERMS OF ORDER INTAKE

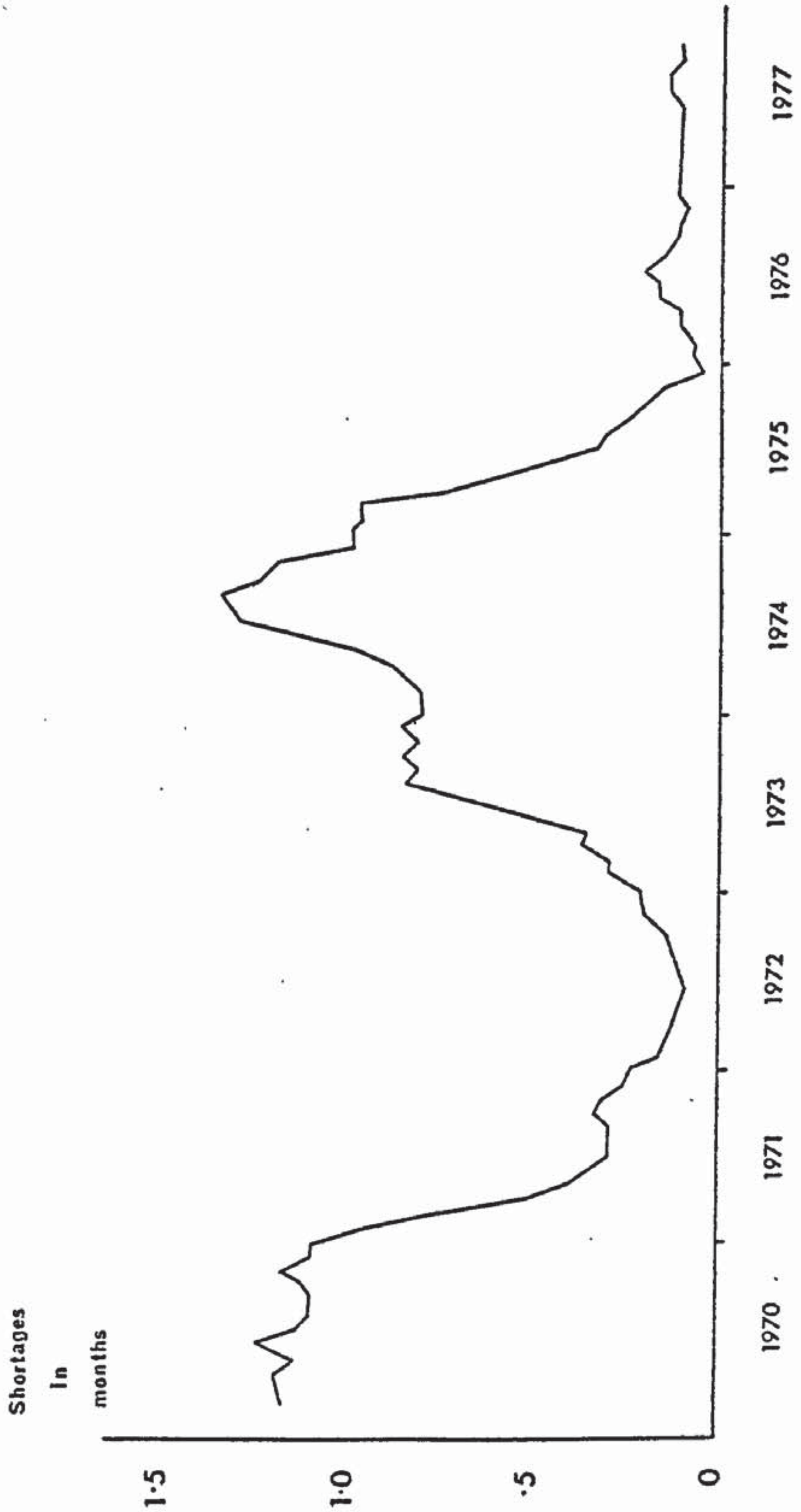
(RATIO OF 3 MONTH MOVING AVERAGES)

Fig. 12

be seen, but of much greater amplitude in relation to the mean than any previously observed (see Fig.13).

Although not generally available, there were also records kept of how the shortages could be attributed in each of the sources -"bought out" and "made in" - and further, how the "made in" shortages could be attributed to the responsible factories. Graphs of these figures are shown in Figs 14 and 15. Comparison between the "total" figure in Fig.14 and the previous illustration shows how closely the number of items relates to the value of shortages. The disparity in the more recent months has arisen since the introduction of new controls on factory shortages, which has encouraged the factory production controllers to clear the more expensive items more quickly. It can be seen that while the value of factory shortages has decreased the number of line items has shown no sustained improvement. While the immediate advantages to the company are obvious, the benefits to the customer are more dubious, as often the value of the item is irrelevant compared with the cost of an interrupted air supply.

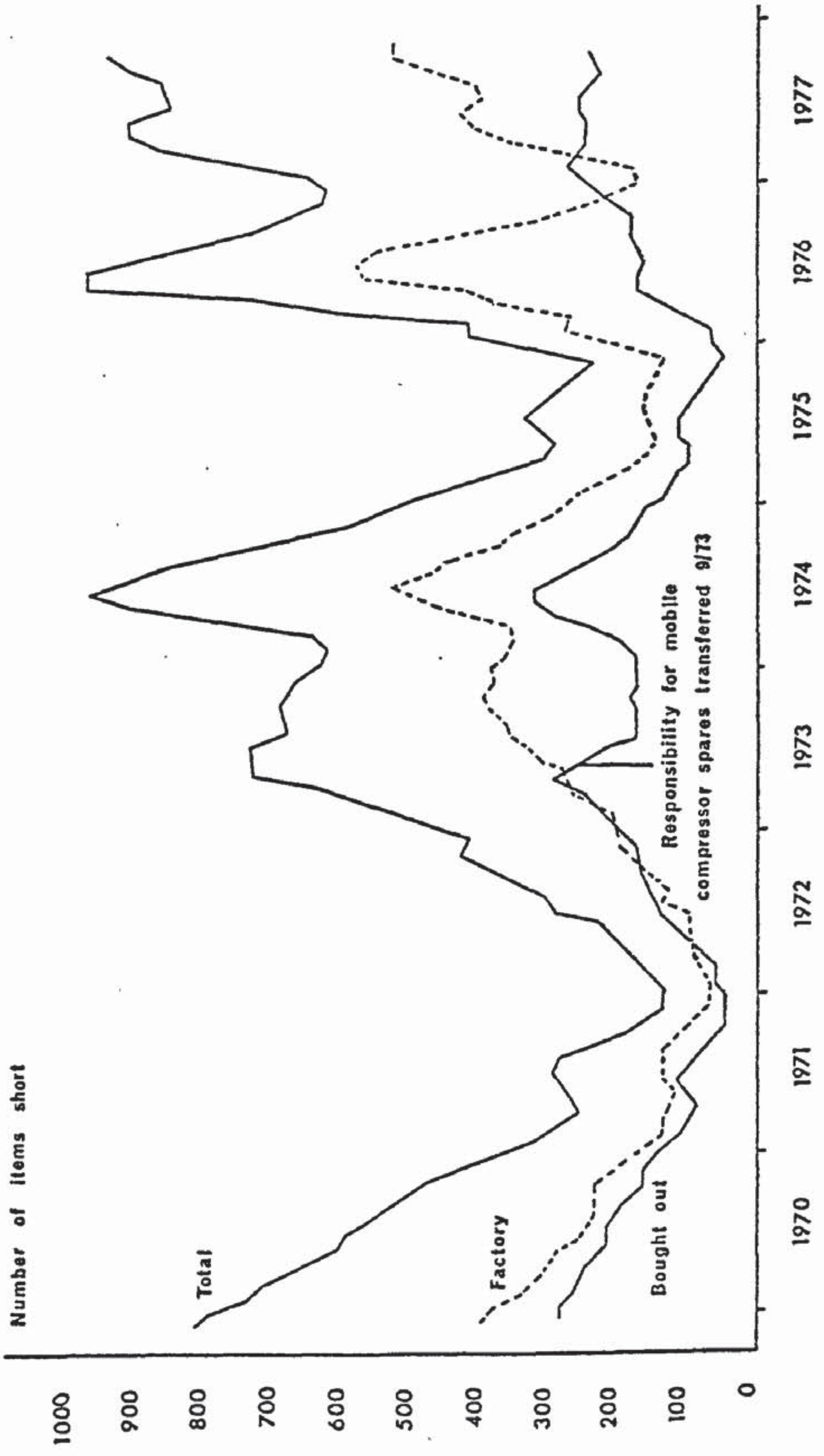
Other points worth noting are that not only are the outside suppliers affected in a similar fashion to the factories, but the small machine factory responds in a similar pattern to the factory producing large and medium machines.



SHORTAGES IN TERMS OF ORDERS RECEIVED

(3 MONTH MOVING AVERAGES)

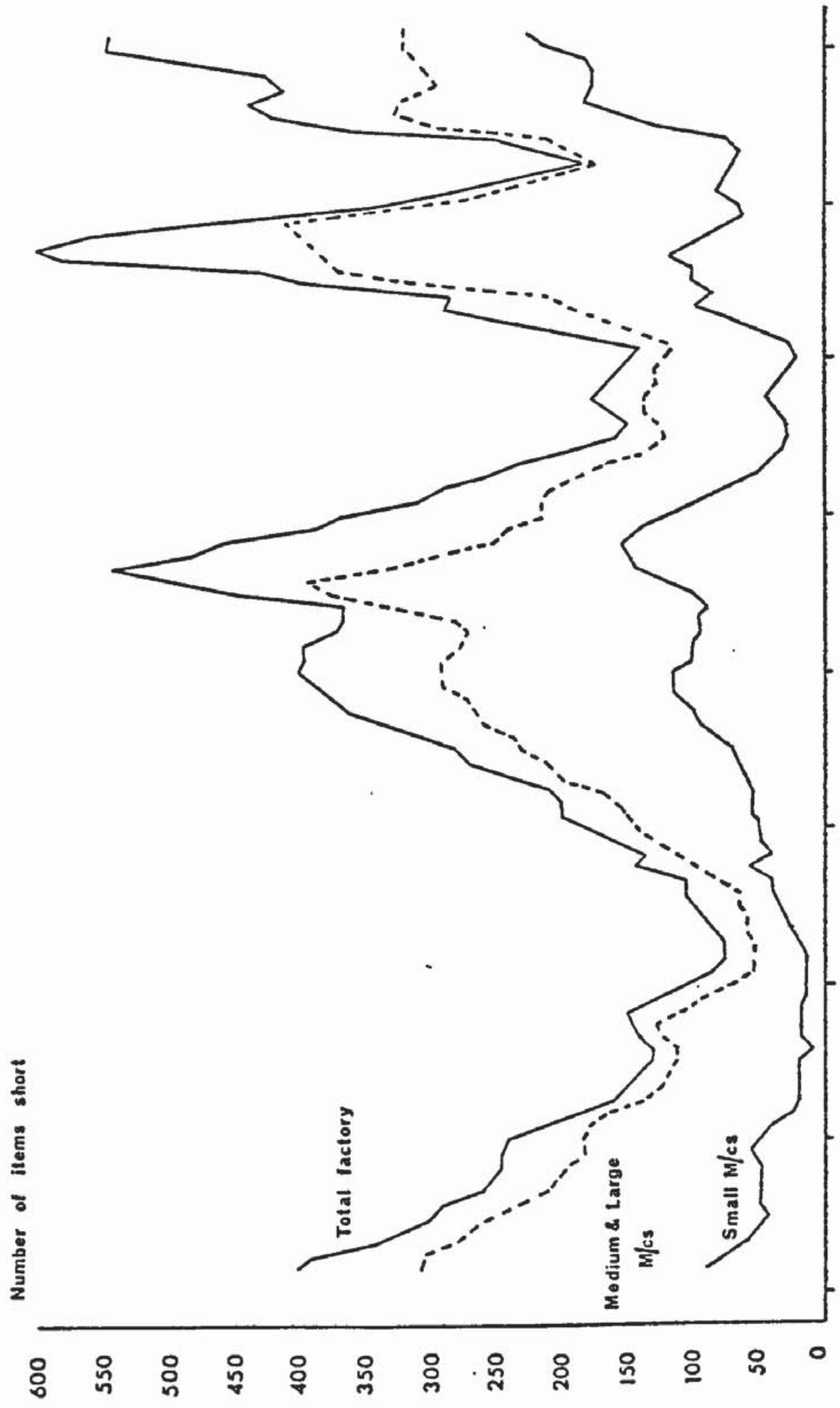
Fig. 13



SPARES SHORTAGES (ITEMS)

(3 MONTH MOVING AVERAGES)

Fig. 14



SPARES SHORTAGES (ITEMS) FACTORY SOURCED

(3 MONTH MOVING AVERAGE)

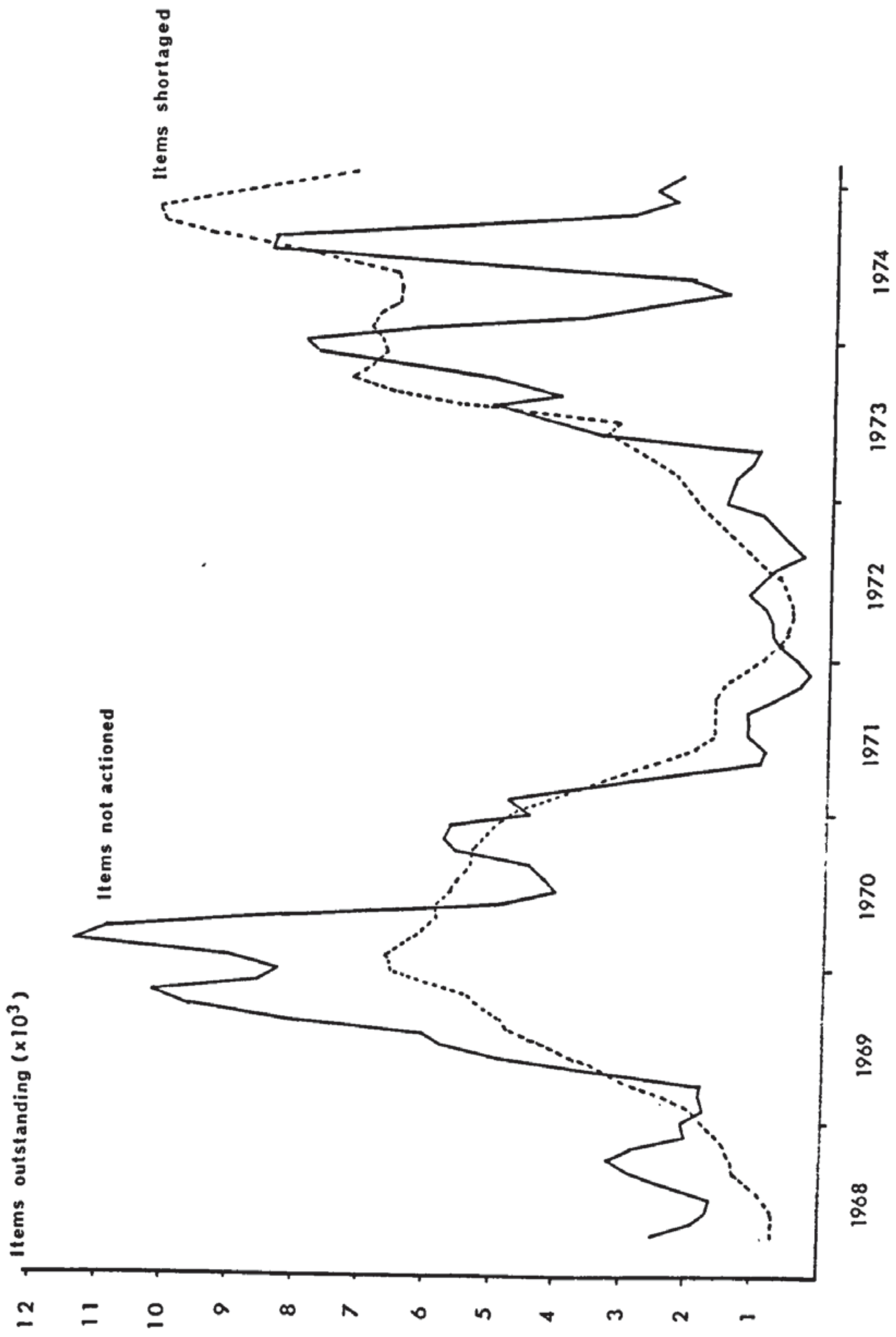
Fig. 15

Since the small machine range has been stable for many years, the non-current spares required from this source are negligible. It can thus be deduced that problems with providing a consistent level of service cannot be isolated to any single class of component.

3.1.2.5. Order Turnround

Although the "first pick" and shortages gave some indication of what proportion of customers were being satisfied at the first attempt, neither measure indicated how long it took to turn round an order and how long it took to clear any shortaged items. An analysis of the unactioned orders showed that there were on average usually as many items awaiting action as there were shortaged (see Fig. 16). However, there was no indication of the period of time a typical order took to action. It was thus necessary to undertake an exercise to establish this figure.

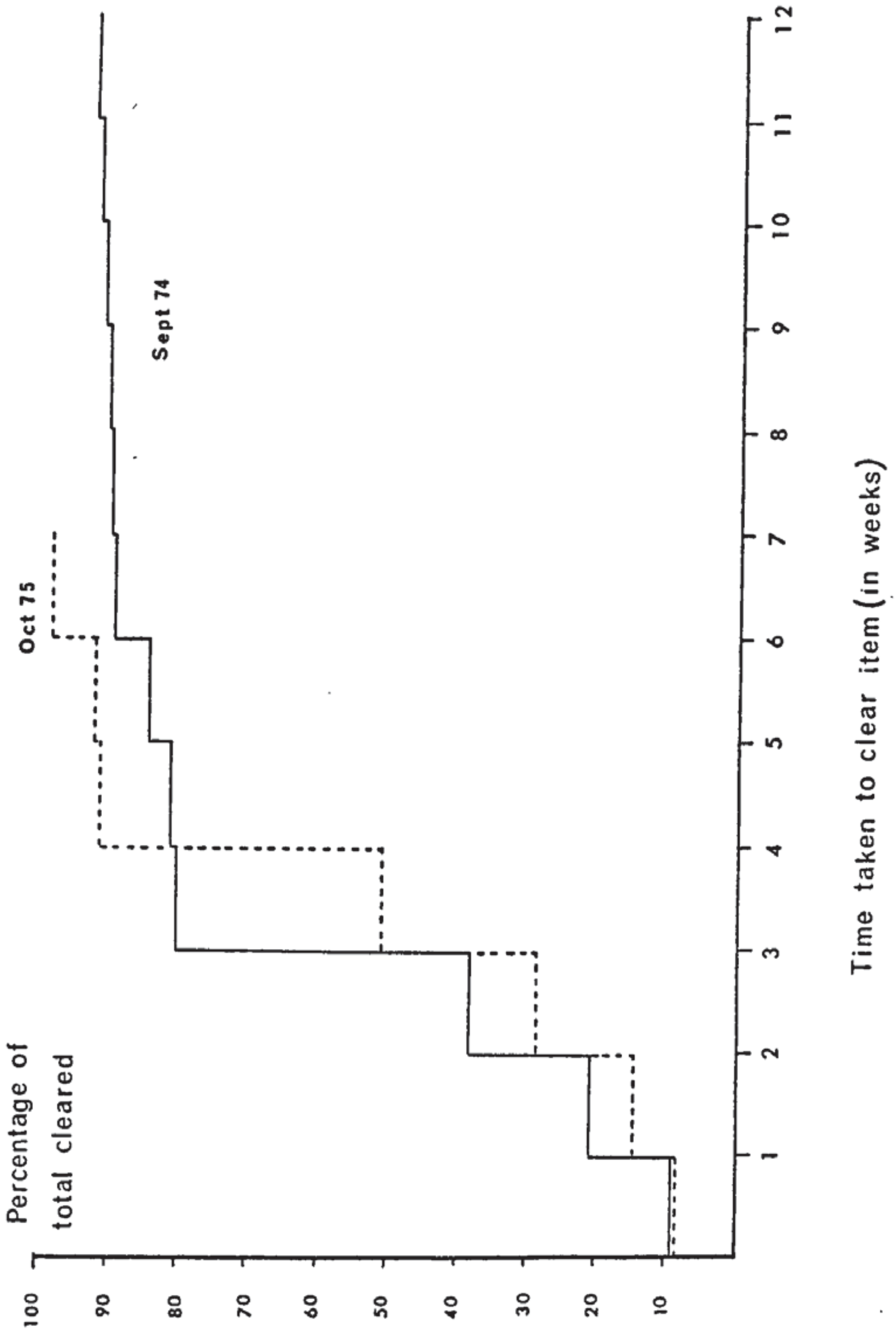
Two periods in time were selected - one month in a period of high activity and one month when business was slower. The two dates were September 1974 and October 1975 respectively. All the orders received in the relevant period from the largest U.K. distributor were examined and the time taken to satisfy each item checked from the record copy of the picking document. The resulting figure shows the time from receipt of order to its being picked and does not take into account the time taken for



SPARES PICKING LOAD

(3 MONTH MOVING AVERAGES)

Fig. 16



VARIATIONS IN SERVICE TO DISTRIBUTORS

Fig. 17

packing and despatch. Nevertheless, the results shown in Fig.17 do show that the four week performance (the company's objective) of the division was marginally worse when the order intake was high.

A separate exercise established the total throughput time for orders by monitoring the progress of specific orders. The results are shown below in Fig.18.

Type of Order		Days In Order Prep'n	Days In Data Process	Days in Picking	Days in Packing & Despatch	Days Total
All breakdown orders	Ave	0.8	2.3	3.4	3.73	8.22
	Std Devn	.87	3.0	4.9	2.02	5.5
Home breakdown Orders	Ave	.65	1.6	2.4	2.2	5.9
	Std Devn	.74	2.0	3.9	1.95	3.7
Bulk Orders	Ave	2.87	5.17	6.8	3.8	18.4
	Std Devn	2.5	5.02	5.9	4.32	7.78

Fig. 18 - Order Turnround Elements

3.2. Spares Suppliers' Performance

It is common experience that supply lead times expand as activity increases, and this effect could explain part of the dramatic changes in stocks and shortages in the Spares Warehouse. However, there were no figures generally available to confirm the presence of this phenomenon or give any indication of its extent. Two separate exercises were necessary to measure the effect, firstly for outside suppliers and secondly for the factories.

3.2.1. Outside Suppliers

Using a similar approach to that used to measure the spares division's own lead time to distributors, all the purchasing orders placed on behalf of the spares division in the same two months (September 1974 and October 1975) were checked against their delivery dates. The expected pattern emerged, showing longer deliveries when activity was higher (see Fig. 19).

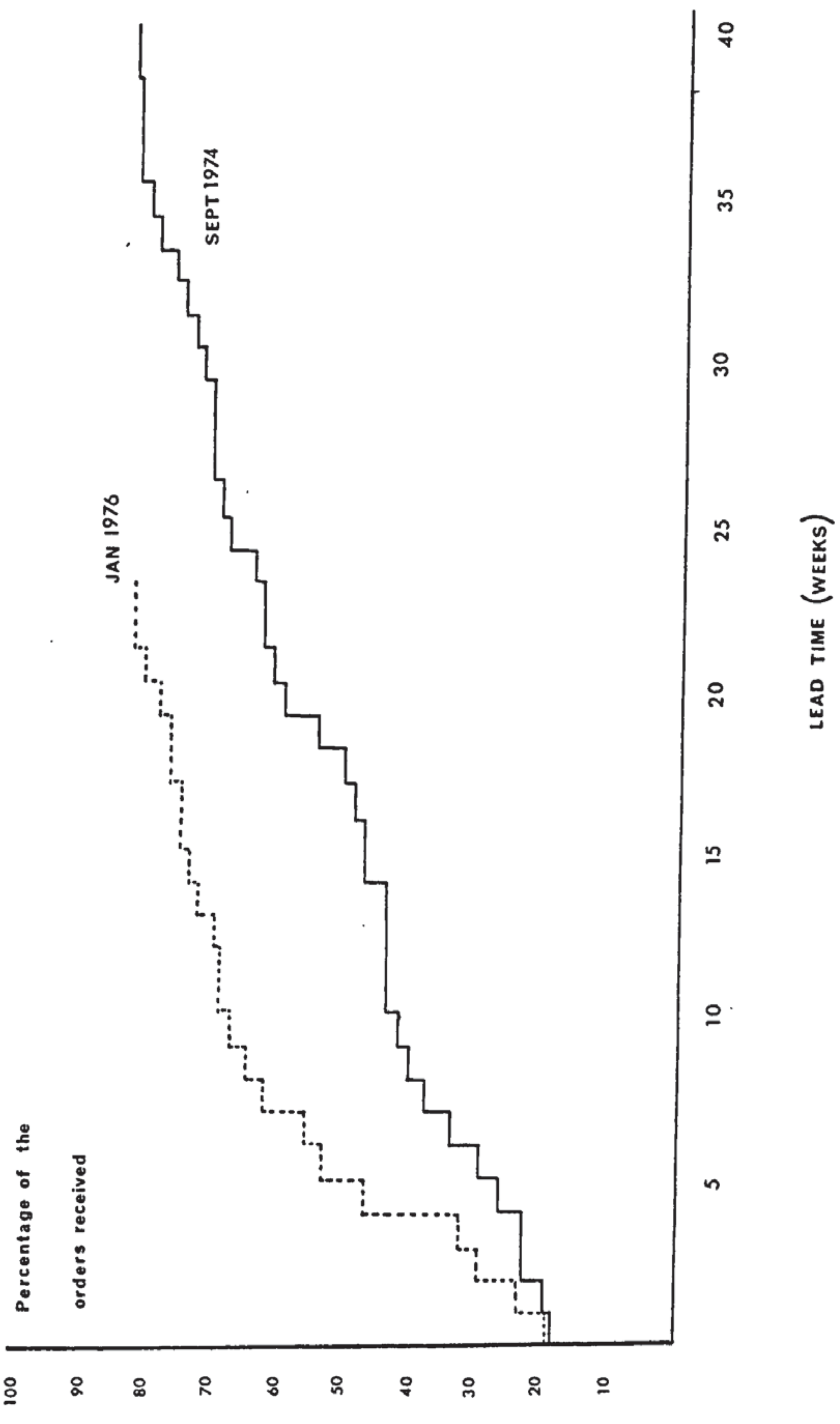
3.2.2. CompAir Factories

The measurement of lead time in the context of the company production control system is an extremely complex matter, as the batches of work are constantly being re-scheduled. Consequently, the time taken from issuing a manufacturing order to its completion is partly dependent upon the relative priority of the batch.

In any case, spares requirements are theoretically available ex-stock from the factory, as the forward requirement from spares should have been taken into account when scheduling the factory. There are thus two aspects of factory performance which affect the spares division:-

i. How effectively and promptly it supplies parts against a given S.D. note.

ii. How long it takes to respond to a general increase in demand. This is reflected in (i) above, but while the system can readily accommodate changing relative priorities, there was some doubt about how it would perform when all batches were high priority.



BOUGHT-OUT LEAD TIME ANALYSIS

Fig. 19

The first aspect was measured easily. As mentioned, once an S.D. note (a spares' requirement) is shown against the present date, it is due for immediate satisfaction. By checking the S.D. notes outstanding against a specific date and then checking subsequent issues to spares, it was possible to determine the actual delay the factories required to clear the demands. The illustration in Fig. 20 shows that even with the rescheduling capability, the service from the factory was lower in a period of high activity than in a less busy period.

The measurement of gross lead times was more complex as it was impossible to tell from the records whether any delay which occurred was deliberate. Other factors which complicated the issue included the large and varying allowances in the production control system for pre-production planning and inter-operational delays.

By taking the relevant delay factors into account on a wide sample of components, and measuring the time taken from the first issue of a spares requirement (S.D. note) to its eventual clearance, then an estimate of the total average lead time for the factories was obtained - after eliminating those items with obvious anomalies. It was concluded that the gross lead time varied from 28 weeks when activity was low to 37 weeks when activity was higher (Fig. 21). This question of

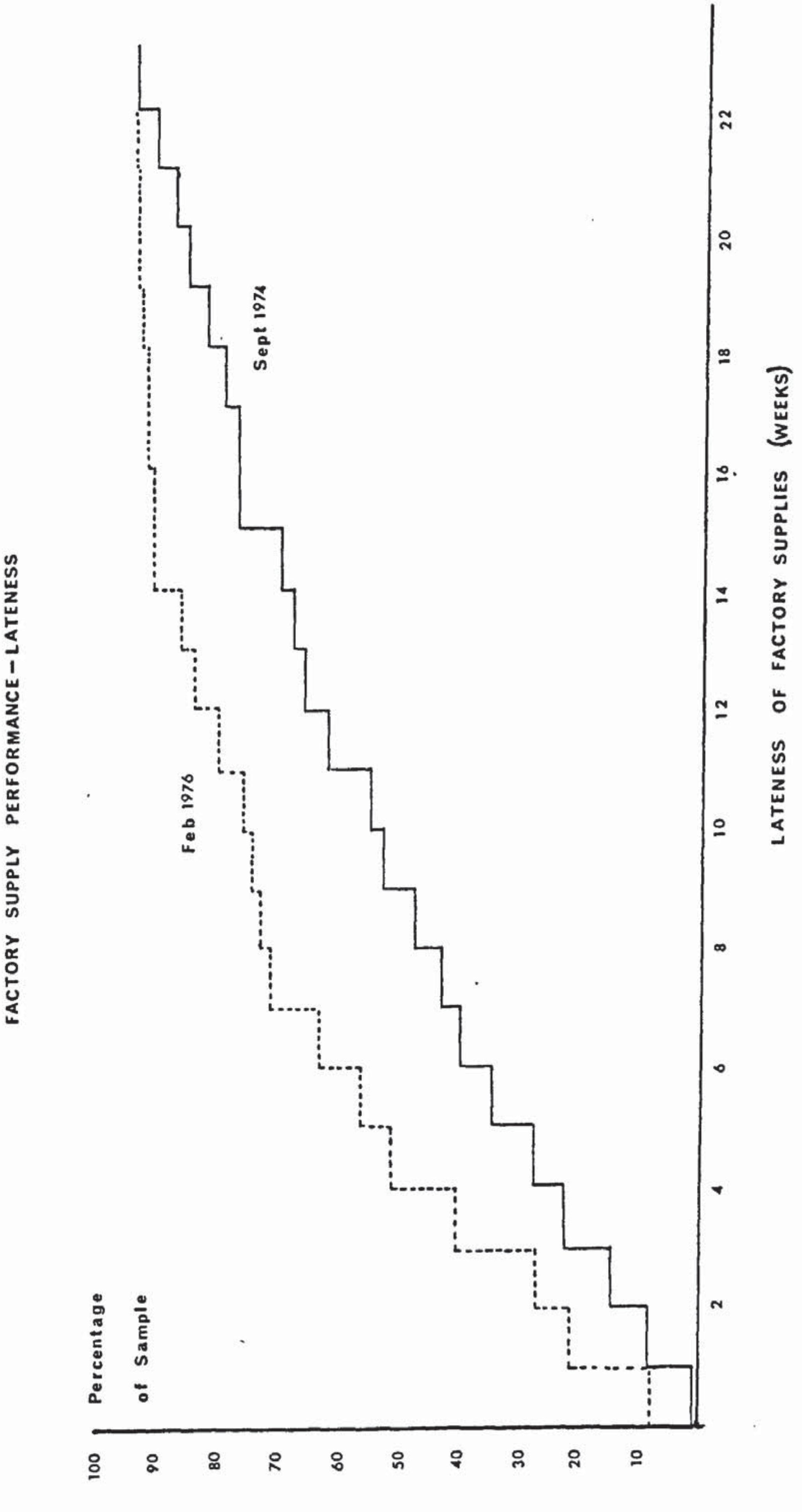

FACTORY SUPPLY PERFORMANCE – LATENESS
Percentage of Sample
100
90
80
70
60
50
40
30
20
10
2
4
6
8
10
12
14
16
18
20
22
LATENESS OF FACTORY SUPPLIES (WEEKS)
Feb 1976
Sept 1974

Fig. 20

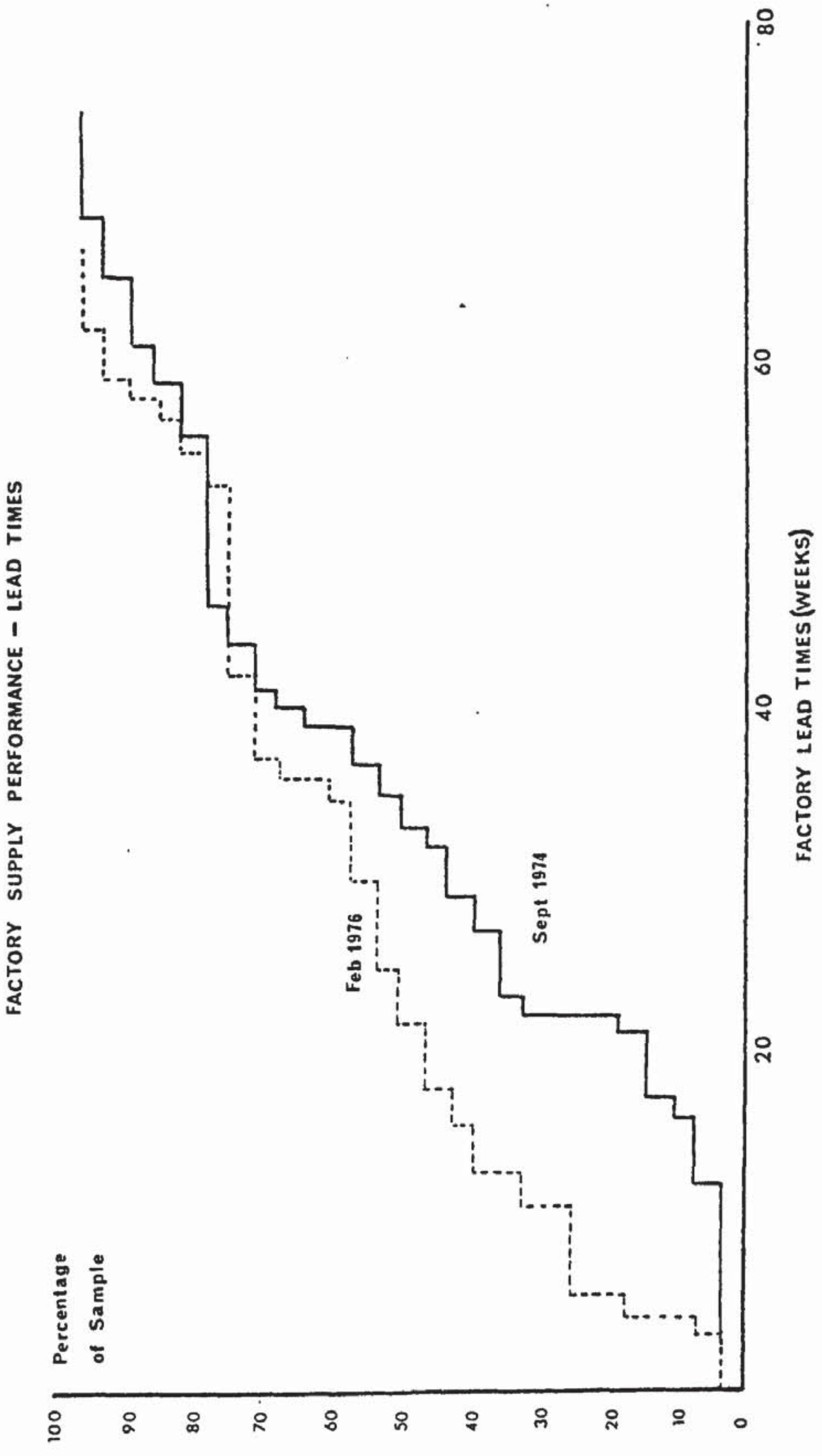

FACTORY SUPPLY PERFORMANCE - LEAD TIMES
Percentage of Sample
100
90
80
70
60
50
40
30
20
10
0
Feb 1976
Sept 1974
20
40
60
80
FACTORY LEAD TIMES (WEEKS)

Fig. 21

manufacturing lead times is discussed more comprehensively in Mr. D. Love's thesis (Ref. 72).

3.3. Distributors' Performance

As the principal intermediary between the real customer and the company, the distributors can influence the performance of the system in many ways.

The characteristics and efficiency of their stock control systems will not only dictate the level of service that the customer receives, but will also affect the ordering pattern on the spares warehouse. However, because they are autonomous and independent companies, little information was available within CompAir on the way they operated.

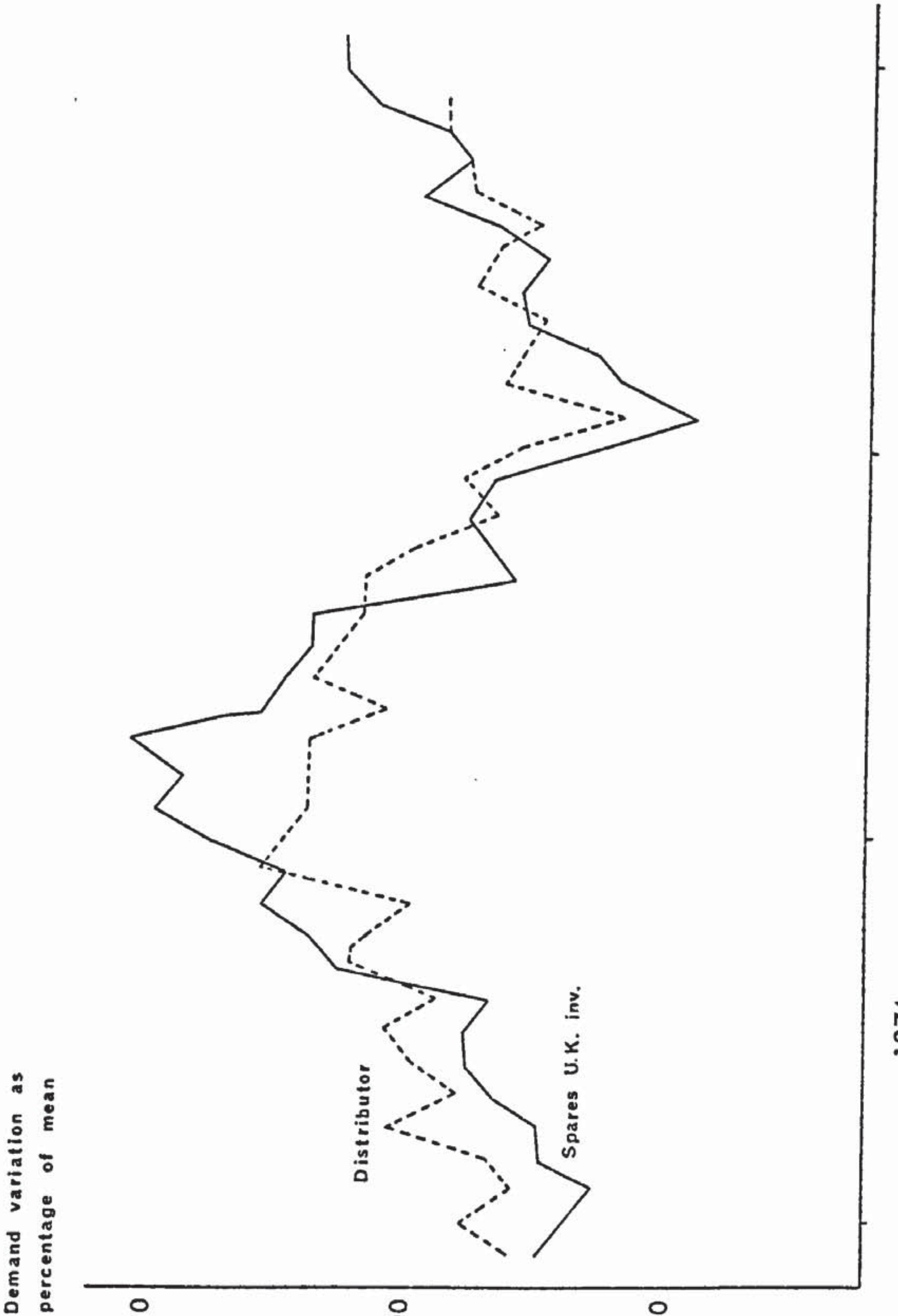
3.3.1. Ordering Pattern

A number of the larger distributors were approached for information on monthly turnover on CompAir Industrial spares. Only four companies were able to provide the information covering a common period of four years and, to preserve confidentiality, two of these indexed their figures relative to the first month. However, they jointly represented 28% of the total U.K. market.

In order to obtain the correct weighting, all the figures were indexed and then weighted according to the gross annual spares turnover in the year 1974-5 as recorded at High Wycombe. These figures were also corrected for price rises and totalled (see Appendix 2). This enabled a comparison with the total U.K. spares invoicing of the spares division (after it had also been corrected for price rises).

The graph in Fig. 22 shows the smoothed percentage variation in each of these figures over the relevant period and it can be seen that even after averaging the figures over twelve months, the degree of variation at High Wycombe was significantly greater than that at the distributors.

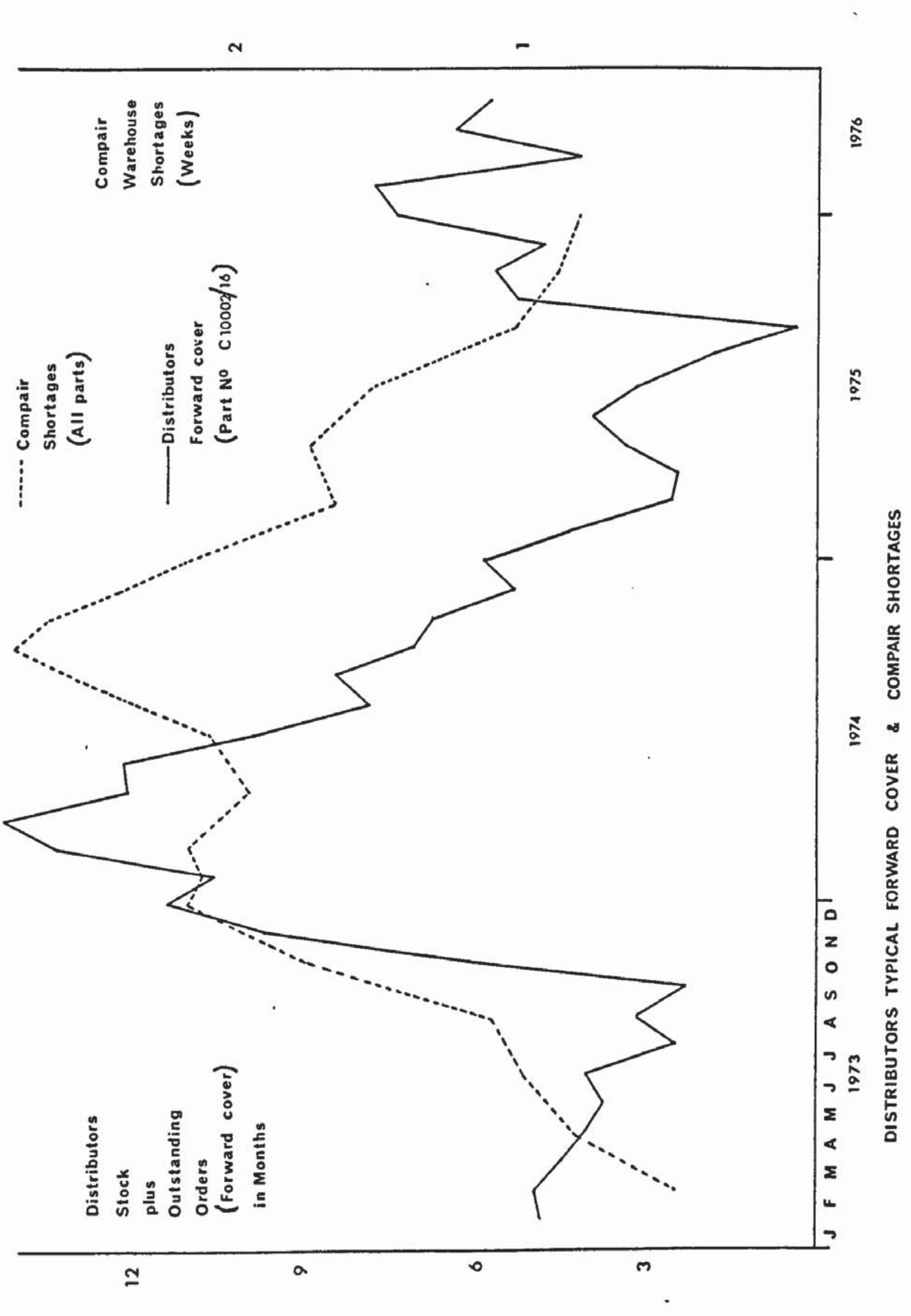
Visits to a representative selection of distributors had shown that their stock control systems were generally very simple, and the sample ordering pattern shown in Fig. 23 helps to explain why the variations in demand were greater at the High Wycombe spares warehouse than at any individual distributor. Had the distributor maintained a consistent policy on stocks and forward orders, then the "forward cover" line in the illustration should be more or less horizontal. The marked variation in the forward cover is too great to be explained by a conscious decision to allow for a greater lead time and represents a purely subjective reaction to a noticeably increasing level of general demand. This ordering pattern, while not universal, occured in over half the 17 sample records examined.



VARIATIONS IN DEMAND

COMPARISON BETWEEN COMPAIR AND DISTRIBUTORS

Fig. 22



DISTRIBUTORS TYPICAL FORWARD COVER & COMPAIR SHORTAGES

Fig. 23

CHAPTER 4

THE GENERAL SPARES PROBLEM

4.1. Current Practice

Before attempting to determine a specific solution to the spares provisioning problem at CompAir, it was obviously sensible to assess the relevance of work which had already been reported on the problems of supplying spare parts.

At a superficial level, the popular technical press has published a number of articles on the data processing aspects of a spares organisation. Although the automotive industry is naturally well represented, with descriptions of systems used by certain Ford distributors (1), Vauxhall distributors (2) and a system once tried by the U.K. Daimler Benz network (71) there are also articles on large nationwide networks, one in France, supplying spares for contractors' plant (64) and one in Canada operated by a tractor distributor (5). These articles describe the use of computer based systems of varying degress of sophistication for handling the transfer of information within the network and while they describe either the hardware or the procedures in some detail, they do not deal with the question of technical or economic justification to any depth. This is also true of two other articles, again featuring computers, but in the environment of the spares warehouse. One describes the very modern computer controlled warehouse established by Ford in America (3) while the other describes an equally complex system installed by Pan-Am at Kennedy Airport for distributing aircraft parts from the central warehouse to each of the various service points (4).

These articles demonstrate what can be done and each system represents someone's solution to a specific problem, but these problems are so poorly defined that, although interesting in themselves, the articles add little to the reader's understanding of the problems associated with spares provisioning.

That there are problems is underlined in articles by Beisel (13) who emphasises the necessity for a reliable supply for maintaining overseas plant, and by Khanin (68) deploring the state of the spare parts supply from certain USSR instrument manufacturers. While the latter demonstrates that the problems transcend all political, economic and idealogical boundaries, again they contribute little towards a solution.

Some small contribution is made by Perowne (90) who describes some of the operational research techniques applicable to the study of spares provisioning. However, in describing these techniques, he does little more than point out their relevance - completely glossing over the practical or economic difficulties which can (and will) arise in their application.

Returning to the question of automotive spares, K.J. Cohen (28) suggests the use of simulation to determine optimum stock levels where lead times are varying, but his treatment of the interaction between demand variability and safety stock is naive.

In contrast to the majority of work dealing with spares suppliers' problems, that which has been published on the problems of the spares user is much more analytical in its approach.

A large proportion of the work on spare parts concerns itself with balancing the investment in spare parts against maintaining a given level of operational efficiency. A review by Harris and Kelly (59) gives some of the techniques available without mentioning specific applications. Flowers (43) describes how the application of an "ABC" classification system based on usage and value reduced the spare parts investment in a capital intensive plant, without prejudicing the operational efficiency.

Apte (10) deals with the problem of specifying spare parts "back up" levels in the absence of operational experience. By examining the storage cost and breakdown cost implications of certain spare parts, he reduces the accuracy required in assessing the probable failure rate attributable to the specified part in order to establish the minimum economic stock level.

At a more specific level, Melese, Barache, Comes, Elina et Hestaux published their results of a study in the French Steel Industry (77). They classified spares into two types - consumable, or regularly wearing items, and catastrophic, or break-down spares. These latter tend to be less predictable and, in the case being studied, often consisted of very expensive items. By assuming a Poisson distribution for the failure of such items, and considering the cost implications of their non-availability, the authors derived some very simple stocking rules.

A similar study within the National Coal Board is described in the work of Mitchell (80), Lampkin and Flowerdew (70) and Boothroyd and Tomlinson (16). Mitchell concentrates on those items with a low usage (less than one per annum) and uses a graphical technique to establish the optimum stocking policy. Lampkin and Flowerdew are concerned with items more regularly used at a number of different collieries, and constructed a series of tables based on lead time and "back-up" cost considerations to be used for the manual control of stocks at these different points. To construct these tables they built up a cost equation from the investment and shortage costs and used a computer based iterative method to determine the minimum. The paper by Boothroyd and Tomlinson describes some of the problems in implementing the system.

The armed forces are vitally concerned with the supply of spares, and a number of studies have been undertaken. Spence (107) describes how an investigation into the consumption of spares at various centres in the R.A.F. prompted a change from a blanket policy of a re-order level of two months usage and a stock objective of four months usage to one in which the objectives are adjusted according to the operational strategic value of the part concerned. A number of authors have examined the distribution problems of maintaining military equipment in an operational state (25, 56, 57 and 96) using a variety of techniques and these papers are discussed further in Chapter 9.

Whereas the above authors treat the problem as a multi echelon system, and consider the total system cost, or examine the optimum allocation of specific parts within the system, an approach by Powell and Lutz (91) seeks to minimise the investment within the lowest (i.e. operational) level. They propose an iterative computer based method which examines the marginal contribution to operational effectiveness (for a given period ahead) made by each spare part and,by considering its cost, determine the most effective spares list for a given level of expenditure or, conversely, the minimum level of investment necessary to provide a specified level of full operational capability for the period specified. The technique obviously requires prior knowledge of the expected failure rate of each component, and the number of components in service, and also requires very large investment in computing facilities for realistically sized lists of parts.

A paper by Nikanorov and Raikin (85) examines the hypothetical situation in which spares are provisioned through a multi-stage system but are subject to deterioration at the lowest level. Given the "shelf life" of the part at this level they seek to determine at what intervals inspection and replenishment should take place to maintain a given level of serviceability. This approach relies on probability theory as does the approach developed by Birolini who examined the case of components subject to gradual failure, with the objective of establishing a replenishment schedule which would maintain a given level of operational reliability.

Viewed against the background of the situation at CompAir, none of the papers described so far appear very relevant. The descriptive case-study type articles are insufficiently detailed to allow a critical evaluation to be made, while the more serious articles tend to concern themselves with the users problems, concerning a known population of parts with known failure rates operating under known conditions. Predicting usage from this data is relatively straightforward compared with the task for most suppliers who have to deal with an unknown population of a wide variety of parts operating under widely differing sets of conditions.

Nevertheless, a number of investigators have examined some of the suppliers' problems. Debeau, James and Drozda (36) suggested that the usage of specific spare parts could be predicted by considering the size and age profile of the population of parts in the field and the life expectancy of the parts concerned. They do not suggest how such information may be obtained in a commercial environment, nor do they quote any specific applications. Kendrick (66 and 67) by-passes the population problem by referring to historical production figures. By assuming that all the parts produced in a given period would fail according to a given life distribution and would then require replacement, it would be possible to predict future usage. The failure characteristics of the parts concerned were obtained from service return data, since the parts were date stamped at the time of manufacture. He showed that the approach was quite successful when applied to a range of automotive spares, but the occurrence of sufficiently well documented parts history is rare in industry.

An investigation into circumstances apparently very similar to the CompAir situation was reported by Ekanayake et al (39). The team was faced with the problem of designing an inventory control system for a manufacturer of (unspecified) machines for industrial and domestic applications. Although they eventually recommended quite conventional techniques to the company, there are two aspects worth noting. Firstly, they investigated the possibility of developing the monthly demand forecast in a similar manner to Kendrick - i.e. they assumed that each part was subject to random failure at a certain mean rate from the time it was first used, and that on failure, the customer would decide with a certain probability to replace the part. By referring to historical despatch data, and determining the time interval from despatch to commencement of operation, a forecast could be prepared. They claimed to have achieved encouraging results on certain parts, but problems of commonality and interchangeability often confused the issue. They also commented on the difficulty of determining the three parameters (failure rate, replacement probability, and time between manufacture and commencement of operation) for each part. This probably explains why they recommended the use of exponential smoothing for forecasting. The second point of interest concerns the implications of declining demand on batch sizes. Having recommended the traditional E.O.Q. formula for replenishment orders, they investigated whether "all time" batches would be more economic for those items with a negative trend in demand but concluded that such batches were only justified if they were less than 80% of the normal batch quantity.

This question of parts with decreasing demands is a characteristic of the spares supply problem and has been examined by Moore (82), again the automotive industry. He discovered the decline in demand for obsolescent parts (i.e. parts no longer used in current production vehicles) followed one of a family of characteristic curves and that once sufficient data for any given part was available to identify the particular curve, the future demand for that part could be predicted. Unfortunately he mentions that the exceptions were invariably spare parts for commercial or agricultural vehicles, which intuitively would seem to have more in common with the CompAir range than automobile spares would.

The final stage in assessing the current thinking on spares provisioning was to compare practice with theory. To this end, a series of visits was made to a number of leading U.K. manufacturers to whom spares are an important section of their business. These visits are described in Appendix 1, but to summarise, they confirm the impressions made by the popular technical press and tend to concentrate on the rapid processing of data with the intention of achieving a fast order turnround and rely on extremely naive decision rules to maintain their level of service.

4.2. The Relevance of Current Practice

In assessing the relevance of the foregoing papers, it is important to bear in mind the objectives of the spares division at CompAir and the success with which it meets these objectives.

They may be summarised as "to supply a specified proportion of line items ordered on a given class of order within a specified interval from receipt of the order, while incurring a minimum level of expenditure".

Thus the company endeavours to despatch 95% of line items within 24 hours for breakdown orders,and within 20 days for bulk orders. These figures, which are company policy, are somewhat arbitrary and are thought to reflect what the market expects, but there is no evidence to confirm or deny this.

The previous chapter demonstrated that, like many other aspects of the systems behaviour, the company's success in meeting these objectives varied in a cyclical fashion. It was suspected that as well as being undesirable in itself, the cyclical behaviour was generating or aggravating many of the problems. A superficial consideration of the spares demand forecasting procedure (which is based on a twelve month moving average) suggested that the replenishment system would always lag the orders received by six months, thus generating excess stock in conditions of declining demand and stock shortages in periods of increasing demand. It was also the common experience of members of the project team that as activity increased, lead times also increased - a view supported to some degree by the evidence (see Figs 19-21). This would obviously exacerbate the relative stock holding position.

These arguments suggested that an understanding of the cyclic behaviour and its source was essential before any recommendations could be made concerning the spares system. Once such an understanding had been obtained, it could be decided to what extent the cyclic behaviour was inevitable and whether the better option would be to endeavour to suppress it, or to accommodate it by responding to it more quickly.

Having stated the problem in this manner, the literature available on spare parts has little relevance. However, before addressing itself to this problem and initiating an investigation which could well have fundamental and expensive implications, it seemed sensible for the team to establish for how long the problem was expected to persist.

The predicted decline in sales of reciprocating compressors has already been mentioned as one of the circumstances instigating the project. Clearly, there would be no point in determining a better method of servicing the spares market if that market no longer existed, or had only a limited life.

Thus, the next phase of the project was to investigate the rate and timing of the decline in demand for reciprocating compressor spares and here the work of Kendrick, of Moore and of Ekanayake et al have a contribution to make.

CHAPTER 5

LONG TERM DEMAND

The principal reasons for wishing to determine the long term sales pattern for spare parts have already been given, but such information, once available, would be useful in many ways.

In particular, the company was approaching a period during which decisions would have to be made on the continuation of spares support for models which had been withdrawn from production many years previously. The normal company policy was to guarantee spares support for a minimum period between five and fifteen years according to the product. However, these figures had been chosen somewhat arbitrarily and it was clearly sensible to extend these periods wherever it was profitable to do so. Furthermore, since the company was also reviewing the physical storage facilities and order picking operation in the spares warehouse, estimates on the future size of the total spares range and the likely level of business were an essential requirement. Finally, information on a given spare parts long term requirement would be of great advantage in making tactical provisioning decisions concerning the method of manufacture and batch quantities.

To answer this question on the actual pattern of decline that the demand for a spare part follows, the approaches outlined in the previous chapter were studied and modified where necessary to suit the data available at CompAir.

5.1. The Component Population Approach

Since estimates of the field population of the various machines were not available within the company, it was decided to investigate whether historical machine sales data, coupled with estimates on machine life, would yield the required results.

Several sources of sales history were located, but a major problem was the length of time which was pertinent. For those components which were about to be withdrawn from the spares stock list, the parent machines had been withdrawn from production some fifteen years previously - in some cases having been in production for over a decade before that. In order to test the hypothesis that sales of spare parts could be related to the machine population, it was decided to concentrate initially on two types of machine. The first was one which had been introduced in the previous twelve years (the "Vee Compact") and which therefore had a determinable population. The second was a small machine which had been in production for many years but had a comparatively short design life. In this case, it was considered impossible to determine the actual field population of machines, but it was postulated that the trend in machine sales would, after a delay, create a similar trend in sales of spare parts, i.e. it should be possible to calculate the change in population even if the actual size could not be established, and relate this change to a change in spares demand. To minimise the computational aspects, which were already assuming formidable dimensions, for the exploratory stage it was decided to concentrate only on a small selection of wearing items such as pistons and various valve components. In the case of both the Vee Compact and the smaller machine, there arose problems of commonality of parts within and across the ranges - the Vee Compact, for example, including high and low pressure versions of various outputs. Thus the establishment of the population of any given part became extremely complex and required precise well-defined sales data. When finally an estimate had been made, the issue was further complicated by the fact that only seven years spares demand (i.e. orders received) data was available.

In the case of the Vee Compact components, it was expected that the sales of spare parts would follow a similar pattern to the curve of cumulative sales, since the machines were too "young" to have reached the stage where significant numbers were being scrapped. In fact, the demand figures available defied any attempts to fit them to any sort of pattern.

In the case of the smaller machine the sales figures for machines for twelve years were noted and attempts made to relate the trend in original equipment sales to the trend in demand for the relevant spare parts. Even after trying various delay periods of up to two years, no discernable relationship emerged.

These attempts were neither exhaustive nor rigorous and it is possible that further work, concentrating on specific parts and possibly including a field survey to establish more reliable population data, would produce more positive results, but this degree of effort could not be justified for what was felt to be only a subsidiary problem.

5.2. Decay Curves

Although only seven years demand history for spare parts was available, this was considered sufficient to establish whether a clear pattern of decay existed. It was hoped to establish that a common pattern existed among groups of components, so that once the pattern had been identified, extrapolation would be straightforward. The first stage was to identify all those parts which had become non-current or obsolescent in the period for which demand data was available. This produced a very small list of parts (less than 200 items) for which it was possible to compare the demand in each successive year with the demand in the last full year of parent machine production. The results were totally random. Not only did no clear pattern emerge, but many components showed either sustained or sporadic growth in demand, sometimes after periods of decline or stability. These could often be explained by extraneous factors such as product rationalisation, but occurred so frequently as to render the data useless.

The second approach was to relate the year on year decline to the year of obsolescence. By including all non-current parts, rather than the most recent ones, the total sample size was greatly increased, although the list would include certain parts which had been non-current for up to eight years at the beginning of the period covered by the demand data. However, it was hoped that by comparing both the annual and cumulative decline in demand with the number of years that the parent machine had been obsolete, a pattern would be discernable. The results however, were as disappointing as the previous set.

The final approach was to identify certain component types which would be expected to have similar life cycles and demand decay patterns. For exploratory investigations, groups of pistons and valve components were selected and the demand data for samples of these components were analysed in detail. Although some components did show a consistent demand pattern (not always a decline), the range of results varied too widely for any general statement to be made.

5.3. Financial Information

For their own purposes, the spares division analysed the revenue generated in the financial year 1975-76 by spare parts relating to machines withdrawn up to fifteen years previously. Although these figures did not provide any information on individual piece parts, the size of the sums suggested that even after fifteen years sufficient machines remained operational to generate a significant level of business.

5.4. Conclusion

In the previous chapter some successful applications of long demand forecasting techniques were described, but it is probably significant that they all occurred in the automotive industry. Ekanayake et al (op cit), under similar circumstances to those at CompAir, implied that problems such as commonality of parts, compounded with the computational efforts required, rendered their technique impractical.

Possible reasons for the lack of success compared with automotive applications are:-

i. The demand for any given part is relatively low and more variable, thus masking any underlying patterns.

ii. The life of parent machines is often longer and again more variable. This complicates attempts to establish the parts' populations.

iii. The lack of a longer demand history was a significant handicap. A recommendation has been put to the company to retain the relevant demand information for longer periods.

iv. The level of complexity of commonality and interchangeability which occurred, combined with the sometimes chequered technical history of certain parts, meant that a detailed knowledge of the history and application of each part was essential.

v. The existence of a cyclical demand pattern tended to mask or distort underlying demand patterns.

Nevertheless, the exercise suggested that estimates of lives of fifteen years for the large machines were, if anything, conservative and that the spares division level of activity was unlikely to decline significantly for at least this period.

CHAPTER 6

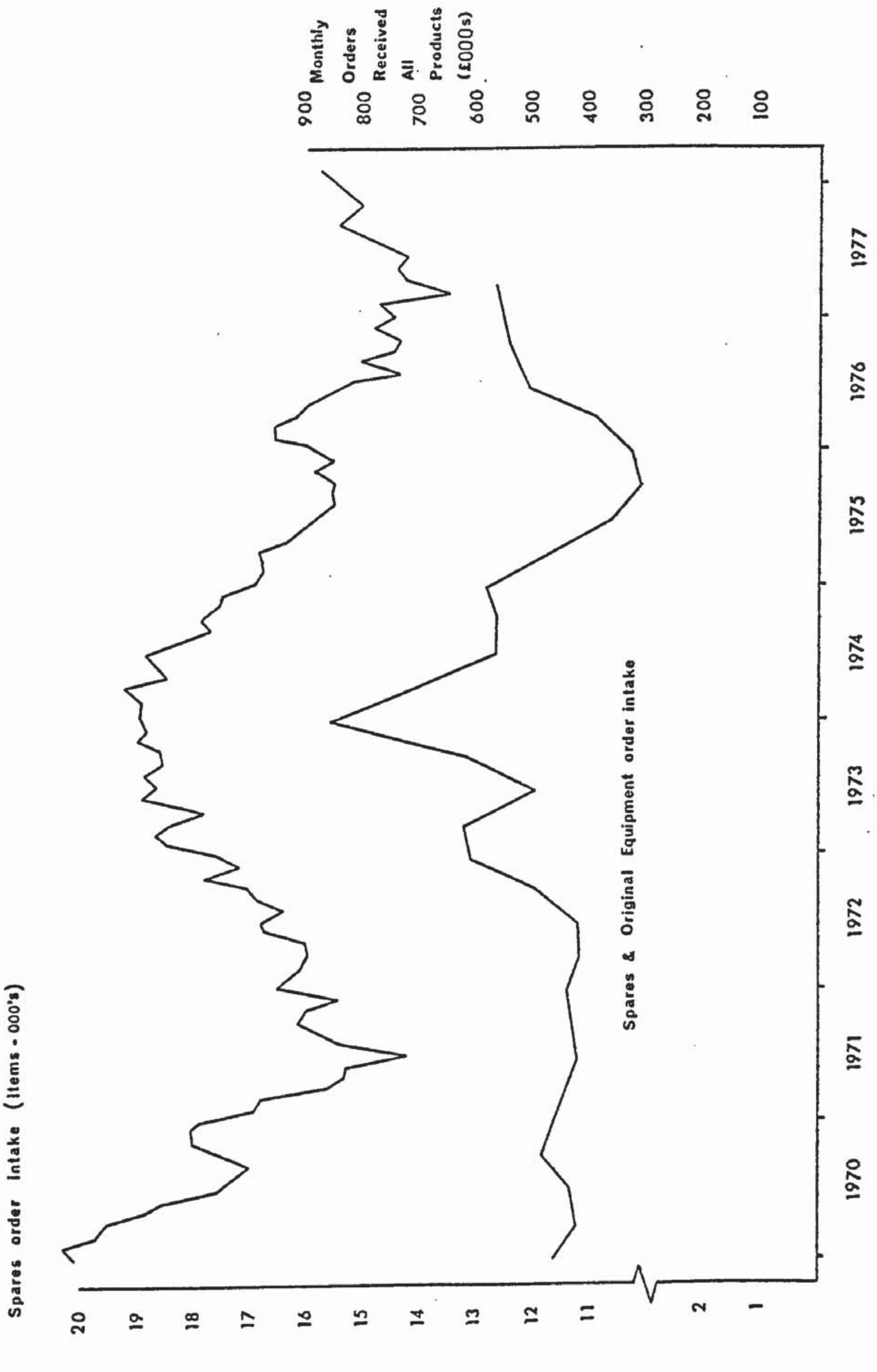
ANALYSIS OF PERFORMANCE

6.1. Possible Explanations of System Behaviour

It had long been recognised within the company that demand for spares fluctuated in the long term, but this was commonly believed to be in direct opposition to the demand for new machines. It was well known that the various original equipment markets (heavy machines, light machines and power tools) followed the national trade cycle with varying degrees of lag and amplitude, and the spares demand was popularly believed to be 180° out of phase, on the assumption that in times of recession the constraints on investment encouraged the refurbishment of old machines rather than their replacement.

Comparison of the demand for original equipment with the demand for spares shows this argument to be false (see Fig 24).

It can be argued that the trade cycle operates through the system in the following manner:- In response to a small increase in demand, the distributors pass on an increase in orders to High Wycombe, often inflated by the intuitive content of most distributors' stock



Comparison of order Intake for spares and original equipment

(6 month moving average)

Fig. 24

control systems. (For the simple policy which most claimed to operate, in which the forward order cover is a fixed ratio to the average demand, a degree of inflation is inherent). In response to this slightly larger increase in demand, CompAir spares division would marginally extend the lead times it was offering on spares and pass on a further amplified demand to its suppliers, the amplification again being due to the stock control policy. Reacting to the increased demand and the generally higher level of activity, the lead time on supplies would also extend, thus creating a higher frequency of stock-outs at CompAir. This, coupled with the increasing turnround times on incoming spares orders, would create even greater stock deficiencies at the distributor, thus stimulating a further rise in the distributors' orders. Under conditions of falling demand, the process operates in reverse.

In such a feed-back loop, it is difficult to differentiate between cause and effect. For example, the actual consumption of spares by the customer could be stable, the cycle being generated by the variations in lead time in response to the general increase in the level of industrial activity. If this were the case, then control of the lead times would remove the cyclical pattern in spares demand.

It will be noted, however, that the effects of the trade cycle are felt in all types of components at the same time. The curves for shortages in bought-out components, and components from each of the factory departments are highly correlated with no discernable lead or lag, suggesting a more direct cause (see Figs 14 and 15). This argument is substantiated by comparing the demand for spare parts with the level of industrial activity, as measured by the D.o.I. "Index of Industrial Hours Worked" (Fig. 25).

A possible explanation is that as general activity is increased, so compressors are worked harder and longer, not only increasing the wear on parts, but also running through their service intervals (in running hours) in a shorter period of elapsed time, due to greater overtime etc.,

6.2. Industrial Dynamics

A method was required to test the various hypotheses on how the trade cycle affected the spares division.

Such a problem represents an ideal application of Industrial Dynamics - a simulation technique developed at M.I.T. in the 1950's by a team led by J.W. Forrester. The technique operates by extracting a number of variables from the system under study and considering how these variables accumulate at

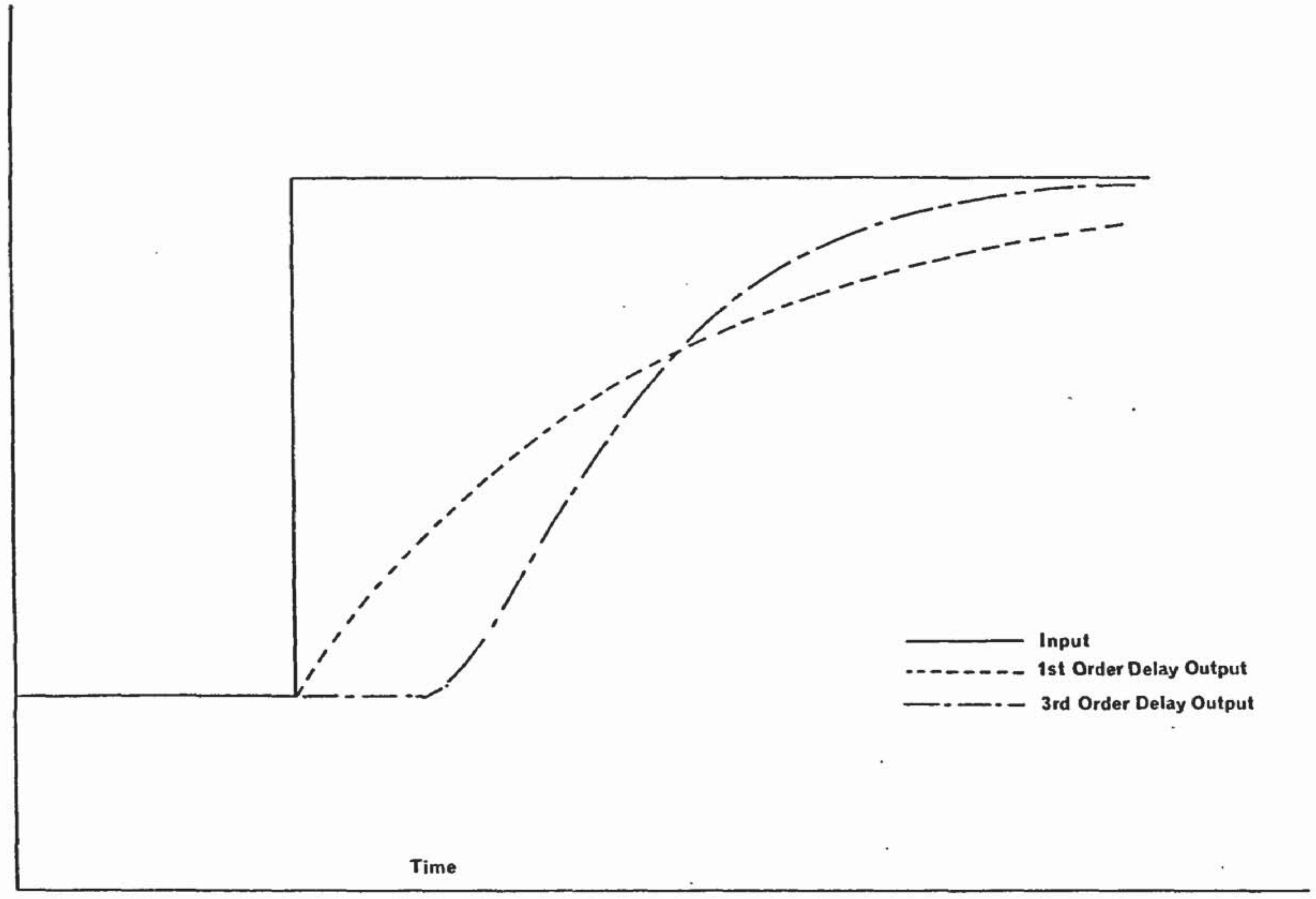
COMPARISON OF SPARES ORDER INTAKE WITH THE LEVEL OF INDUSTRIAL ACTIVITY

Fig. 25

different points to form "levels" and how the rate of flow varies between "levels".

It considers any system, including industrial systems, to be a series of feed-back loops with either positive or negative feed-back of the value of one level having a direct influence on the rate of flow of the variable(s) concerned which contribute(s) to that level. The feed-back loops themselves are subject to time delays which are simplified to two basic kinds; a first order delay, and a third order delay, which are chosen according to the response of the delay to a step input (see Fig 26). The third order delay is calculated from three sequential first order delays, each having a time constant of 1/3 x total delay.

Contrary to conventional simulation practice, the technique operates with additive transfer functions rather than differential, which Forrester claims is a more natural extraction from the real world(49). Many of the transfer functions, which operate on the rates of flow of the variables, have inputs from more than one feed-back loop. The simulation operates on discrete time intervals, which are constant, and have to be set sufficiently small that for the smallest delay factor concerned the output approximates to a continuous output.



EFFECT OF Ist & 3rd ORDER DELAYS ON A STEP INPUT

Fig. 26

In modelling the decision processes, Forrester argues that all the factors which enter in the decision process should be modelled and, where these factors are difficult to quantify, an approximation should be made, as this is more accurate than totally ignoring them. If subsequent testing of the model shows the function in question to be sensitive to variations in the factor concerned, then it indicates a need for further investigation and refinement. It thus provides a method of modelling many of the intangibles that exist in a system.

The variables considered are gross abstractions from the real world, so the model cannot be used for detail predictive purposes. However, as a means of observing general system behaviour and its sensitivity and response to particular control parameters, the technique has many advantages. Not least of these is efficiency. In observing gross behaviour in this fashion, it is necessary to consider extended time scales, of the order of at least five years.

Industrial Dynamics can accomplish this very easily with only modest requirements for computer processing and storage capacity. However, like any other simulation, it is essential that the structure and control parameters are modelled very closely on the system under study, and this is normally a time consuming operation. In this particular case the author was intimately familiar with the spares operation at CompAir, which considerably reduced the time required to arrive at a satisfactory model.

6.3. History of the Technique

Industrial Dynamics (or I.D.) was developed during the 1950's at M.I.T., and the concept received wide circulation in a number of articles by Forrester and his colleagues, e.g. (44,45,46,48,98,99) and through the publication of his book (47) in 1961.

The general theme running through them all is that I.D. is a technique which when properly applied will revolutionise the art of management and turn it into a science. It was submitted that I.D. is of more potential benefit than any or all of the other O.R. techniques then available. In spite of (or perhaps because of) these claims, the technique received a cautious reception from both the business and academic worlds. Wagner (121) and Ansoff & Slevin (9) summarise these reservations which centre on two aspects of the technique.

The first concerns the objectivity of the technique, particularly when dealing with the more abstract variables such as "pressure to expand" or "customer satisfaction". The second strong reservation concerns validation. These two are linked. In the simpler, more clearly structured problems, it is usually possible to examine historical behaviour and compare it with the model - thus providing a means of validation which will either support or contradict the model structure and the quantification of the abstract variables. This is a lot more difficult when considering such cases as the effect of R & D on the long term growth of a company. Nevertheless, it should be remembered that even with these reservations the technique does provide a method of examining such problems, which is considerably more objective than the usual treatment they receive.

A third area of concern, voiced in particular by Ansoff & Slevin, was the uses to which the model should be put, how "ideal" behaviour could be defined and whether it could be achieved in fact by translating favourable model adjustments to the real world. The answer to the last question must obviously depend on how realistic the model is, while the answer to the first two would depend on the results of the model runs. While it is difficult to define ideal behaviour, there are clearly certain undesirable behaviour characteristics which a well constructed model can highlight.

In America, a number of applications have been published and seem to fall into two groups. The first group consists of applications where the technique has been selected to solve a specific problem. The list includes one of the very first applications, where a manufacturing company used the technique to modify its production and inventory policies to alleviate the effects of a cyclical demand pattern (98) and (108). In another case, the technique was used to assess the effect of linking process control computers to a large central management information system, to achieve D.N.C. in effect, and to assess the effect of continuous or batched information exchanges (79). A third example (94) in which the transfer pricing and ordering policies in a food company were examined, provides an interesting example of where highly abstract variables (such as "willingness to over order") have been quantified with some success. It is interesting to note that validation in all the above cases seems to be limited to subjective assessment by company personnel on whether the model behaviour was realistic or not.

The second group of applications is where an Industrial Dynamics Model has been constructed purely to increase management's understanding of the system. Schlager (99) describes three such cases and, interestingly, describes how tangible benefits were realised as a direct result in one instance. It may be significant that Schlager's attitude to validation, which is more rigorous than in any of the other cases, seems to be accompanied by a readier acceptance by the companies of the results and conclusions of the model tests. Another example of similar "educational" exercises is Manetsch's study of the U.S. Plywood Industry (75) whose validation and objectives seemed vague.

In comparing the results of the two types of exercise, the conclusion is reached that in spite of their different objectives, the outcome is usually the same, that the management's understanding of the system is greatly increased and, as a result, profitability improves.

In the U.K. most of the published work has been associated with Professor Coyle of the University of Bradford (see e.g. 31 and 101) and J.A. Sharp describes some of the applications in his article (100). A more detailed description of one of these studies is given in (101) where some of the pitfalls of an industrial application are described. This example concerns a "growth" type model rather than a "cyclical" one and demonstrates that, provided the validation is sufficiently rigorous, a degree of direct prediction of actual levels is possible. This article also introduces the topic of forecasting and its effect on system behaviour, which is developed elsewhere by Coyle (see 31) and Winch (127).

In (31), Coyle convincingly demonstrates the need to examine the purpose and scope of forecasting in the context of total system behaviour, although his fictitious example would probably give different results if more closely based on reality.

6.4. The Spares System Model

Ansoff and Sleven (9) warn that "one would expect that better structured functional areas would be the most likely candidates for simulation...", and, although Forrester disagrees, he concedes that such areas are more easily studied (49).

With this in mind, and also considering the valid reservations on the quantification of abstract variables and on validation, it was decided to confine the model - at least in the initial stages - to the study of three variables:- orders, goods and information. The benefits were considered to be:-

(i) The system boundaries could be clearly defined, embracing the distributors at one end and the supply source or factory at the other.

(ii) Many parallels could be drawn between model variables and control data within the spares system, thus simplifying validation.

(iii) The decision rules in general were simple and not subject to a large number of inputs.

(iv) There were no highly abstract variables.

A schematic diagram of the Industrial Dynamics model of the spares system is shown in Fig. 27.

6.4.1. The Distribution Section

6.4.1.1. Model Structure

The stimulus for the model is the flow of orders into the distributor, who in this case is also the retailer. The orders flow directly into a pool of unfilled orders (Unfilled Orders at Retail = UOR) which is updated every time increment by taking into account the rate of orders received (Requisitions Received at Retail = RRR) and time increment (DT), and the rate at which orders are cleared, or shipped out (Shipments Sent from Retail = SSR),

i.e. $UOR_T = UOR_{(T-1)} + DT(RRR_{(T-1)} - SSR_{(T-1)})$

The shipping rate is determined by the shipping delay factor (Delay in Filling orders at Retail = DFR) and the level of unfilled orders, provided there is sufficient stock to satisfy the required shipping rate for the time increment,

i.e. $SSR_T = \frac{UOR_T}{DFR_T}$

If the stock level is insufficient to maintain this rate of shipment for the whole time

SCHEMATIC DIAGRAM of the SPARES SYSTEM INDUSTRIAL DYNAMICS MODEL

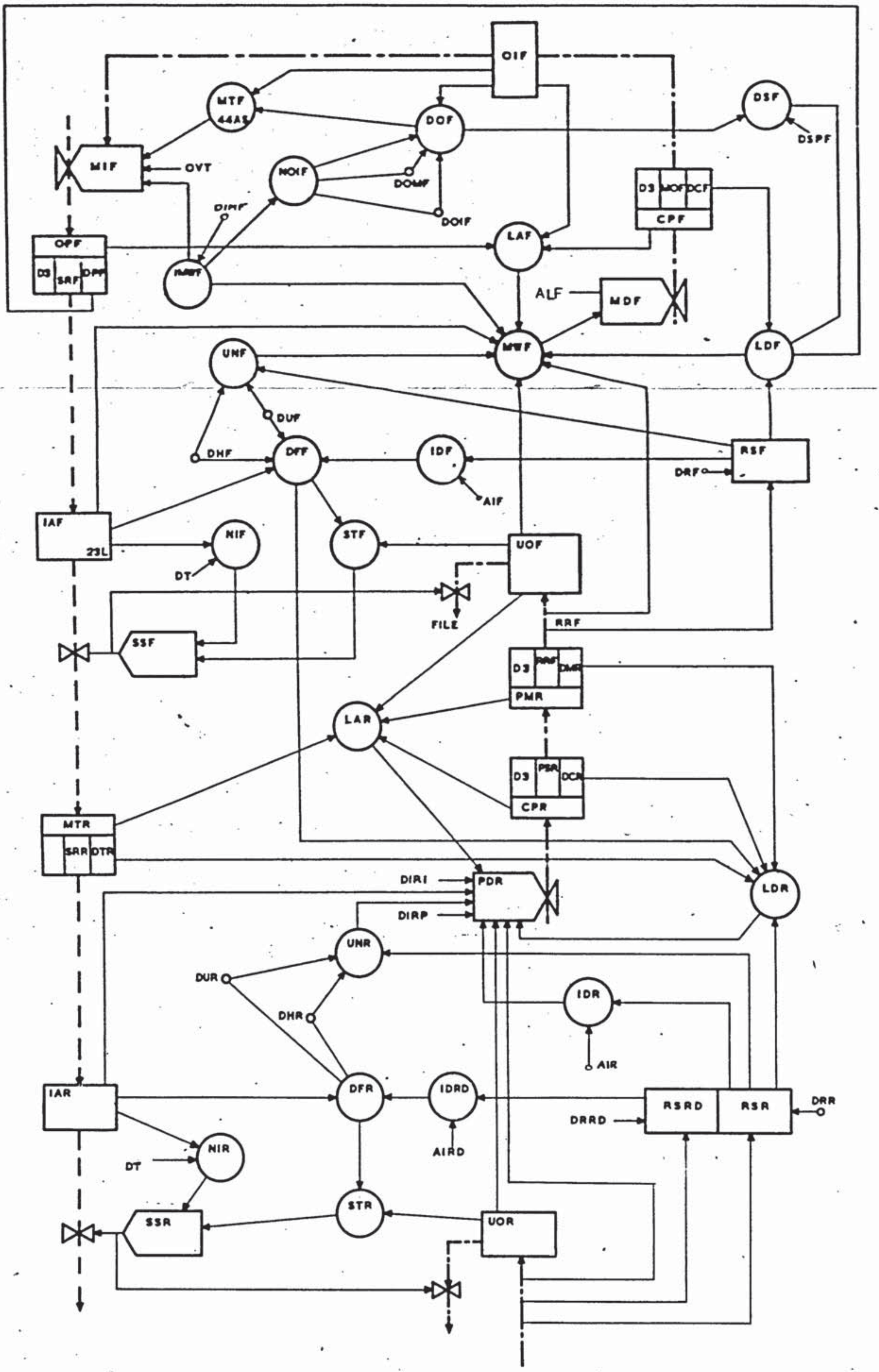


FIGURE 27

FIG 27. THE SPARES SYSTEM MODEL

Key to Initials

Distributor Section

RRR = Order receipt rate at distributors
UOR = Unfilled order level
RSRI = Smoothed order receipt rate (for re-ordering)
RSRD = Smoothed order receipt rate (for meeting service target)
IDR = Policy stock level (for re-ordering)
IDRD = Policy stock level (for meeting service target)
STR = Desired despatch rate
NIR = Maximum possible despatch rate
SSR = Actual despatch rate
DFR = Order turn-round delay
DHR = Handling component of DFR
DUR = Shortaged component of DFR
UNR = Normal level of unfilled orders
AIR = Stock holding policy level (for re-ordering)
AIRD = Stock holding policy (for meeting despatch targets)
DRR = Smoothing co-efficient
DRRD = Smoothing co-efficient
DIRI = Lag in correcting inventory levels
DIRP = Lag in allowing for lead time variations
LDR = Desired level of outstanding suppliers orders
LAR = Actual level of outstanding suppliers orders
PDR = Purchasing decision rate
CPR = Orders awaiting typing etc.
DCR = Delay in typing etc. orders
PSR = Despatch rate of purchasing orders from retail

Convention

Boxes represent levels
Large circles represent subsidiary or auxiliary equations
Small circles represent externally set parameters

Warehouse Section

PMR = Orders in the post to the warehouse
DMR = Postal delays
RRF = Order receipt rate at warehouse
UOF = Unfilled orders at factory warehouse
RSF = Smoothed order receipt rate
DRF = Smoothing coefficient
IDF = Policy stock level
AIF = Stock holding policy
STF = Desired despatch rate of satisfied orders
NIF = Maximum possible despatch rate
SSF = Actual despatch rate
IAF = Actual inventory level
DFF = Order turn round delay
DUF = Shortaged component of DFF
DHF = Handling component of DFF
UNF = Normal level of unfilled orders
LDF = Desired level of work in progress
LAF = Actual level of work in progress
MWF = Required supply rate
DIF = Stock review and order generating delay
ALF = Absolute limit to supply factory capacity
MDF = Actual rate of issuing factory orders

Supply Section

CPF = Orders awaiting release to the production facilities
DCF = Delay in releasing orders
MOF = Rate of releasing orders for manufacture
DOF = Total queuing time in factory
DOMF = Minimum possible queuing time = fixed component of DOF
DOIF = Load dependent component of DOF
DSF = Smoothed average queuing time
DSPF = Smoothing factor
OIF = Orders in queue at factory
NOIF = Normal level of order in queue
IMWF = Short term limit to factory capacity
DIMF = Rate of adjusting capacity to meet requirements
MTF = Manufacturing rate required at shop floor level
MIF = Manufacturing rate implemented at factory
OVT = Maximum permissible overtime proportion
OPF = Orders being processed
DPF = Actual process time
SRF = Factory output

increment, then the shipping rate is constrained to the maximum achievable for that stock level

$$SSR_T = \frac{IAR_T}{DT}$$

where IAR is the Inventory (Actual) at Retail.

This stock level is updated in a precisely similar manner to the level of unfilled orders, only in this case the inflow is Shipments Received at Retail, and the outflow is the shipping rate (SSR)

i.e. $IAR_T = IAR_{(T-1)} + DT\ (SRR_{(T-1)} - SSR_{(T-1)})$

The delay factor used to calculate the shipping rate represents the average time taken to meet an order, and this has two constituents :-

i. the handling delay (Delay for Handling at Retail (DHR)

ii. the service delay (Delay for Unfilled orders at Retail (DUR).

The handling delay is an external parameter, which can be measured in the real system, while the service delay is a variable.

Working from the premise that when actual stock (IAR) is equal to the ideal stock (Inventory Desired at Retail for Demand = IDRD) then a given delay will occur, it follows that if the stock is higher the delay will be smaller,

i.e. $DFR_T = DHR_T + DUR_T \left(\frac{IDRD_T}{IAR_T}\right)$

This"ideal" stock figure is calculated from an external constant (AIRD) and the order receipt rate suitably smoothed (Requisitions Smoothed at Retail for Demand response)

$$IDRD_T = AIRD \times RSRD_T$$

and

$$RSRD_T = RSRD_{(T-1)} + \left(\frac{DT}{DRRD}\right) \times \left(RRR_{(T-1)} - RSRD_{(T-1)}\right)$$

where DRRD is the smoothing delay.

The principal decision point in this section of the system is the purchasing decision, which is the control set by the distributor on the rate at which his stock should be replenished.

There are four separate factors which make up this rate:-

i. The current order receipt rate. The prime requirement on the distributor is to meet existing orders, therefore the stock replenishment rate must be matched to the stock depletion rate (RRR).

ii. Stock Correction. A second requirement is to restore the actual stock level to the policy level (Inventory Desired at Retail = IDR). This policy level is set from multiplying the smoothed order receipt rate by the policy constant. This smoothed order receipt rate uses a different smoothing constant from that used for determining the demand response. In this case, Requisitions Smoothed at Retail (RSR) is determined by

$$RSR_T = RSR_{(T-1)} + (\frac{DT}{DRR} \times (RRR_{(T-1)} - RSR_{(T-1)})$$

and as before $IDR_T = AIR \times RSR_T$

When making the purchasing rate decision, the information available is never up to date, as the actual stock level figure is only as recent as the last review period. Consequently a delay must be applied to the information before including it in the purchasing equation, the Delay In Retail Inventory correction (DIRI). The total stock correction factor is thus

$$\frac{1}{DIRI} (IDR_T - IAR_T)$$

iii. Unfilled Order Level Correction. As with the stock level, the distributor will also seek to restore the unfilled order level to a figure which is appropriate for the current level of business. Thus, Unfilled orders (Normal) at Retail (UNR) is derived from the inevitable handling and service delays (DHR and DUR) applied to the smoothed order receipt rate. Again, as with the stock level, the information is dated when it is actually used, so that the unfilled order correction factor is:-

$$\frac{1}{DIRI}\ (UOR_T - UNR_T\ )$$

iv. Work-In-Progress. The final factor which affects the distributors' replenishment decision is the work-in-progress which exists compared with what he feels is necessary, according to his perception of the turn round time the warehouse is offering and the current order receipt rate.

The actual work-in-progress (or pipeLine content Actual for Retail (LAR) is obtained by summing the content of all the levels in the Warehouse Loop, including the orders in transit to (and the goods in transit from) the warehouse.

$$LAR_T = CPR_T + PMR_T + UOF_T + MTR_T$$

when CPR = Clerical in-Process orders at Retail

PMR = Purchase orders in Mail from Retail

UOF = Unfilled Orders at Factory warehouse

MTR = Material in Transit to Retail

The required work-in-progress (pipeLine content Desired at Retail = LDR) is calculated from the distributor's perception of the delays at the warehouse and current receipt rate. The relevant delays are:-

Delay (Clerical) at Retail = DCR
Delay (Mailing) from Retail = DMR
Delay in Filling orders at Factory Warehouse = DFF
Delay in Transporting goods to Retail = DTR

The desired line content is thus:-

$$LDR_T = RSR_T\ (DCR + DMR + DFF + DTR)$$

The distributor is normally only in a position to assess the delays after a delivery, and it probably takes at least two deliveries for a definite change to register. The delay to be applied to the work-in-progress factor (Delay In Retail Pipeline correction = DIRP) is thus different from (and probably greater than) that applied to the inventory and unfilled order correction factors. The total work-in-progress correction factor must be:-

$$\frac{1}{\text{DIRP}} \text{ x } (\text{LDR}_{\text{T}} - \text{LAR}_{\text{T}})$$

Aggregating these four factors makes the total purchasing decision equation:-

$$\text{PDR}_{\text{T}} = \text{RRR}_{\text{T}} + \frac{1}{\text{DIRI}} \left[(\text{IDR}_{\text{T}} - \text{IAR}_{\text{T}}) + (\text{UOR}_{\text{T}} - \text{UNR}_{\text{T}}) \right] + \frac{1}{\text{DIRP}} (\text{LDR}_{\text{T}} - \text{LAR}_{\text{T}})$$

Once the order rate is generated, there are two further stages before it reaches the central warehouse. Firstly, the orders have to be processed at the distributor (i.e. typed, sanctioned, etc.) and then mailed or transported to the warehouse.

In both cases, a third order delay is appropriate. The equations for the clerical processing calculate the Purchasing requisitions Sent from Retail (PSR) and the Clerical in Process orders at Retail (CPR) from the Delay in Clerical processing at Retail (DCR) as shown.

$$PSR_T = \text{Delay } 3\ (PDR_{(T-1)} \cdot DCR)$$

$$CPR_T = CPR_{(T-1)} + DT \times (PDR_{(T-1)} - PSR_{(T-1)})$$

Similarly, the Delay in Mail from Retail (DMR) is used to calculate the Requisitions Received at Factory warehouse (RRF) from the Purchasing Requisitions Sent from Retail.

i.e. $RRF_T = \text{Delay } 3\ (PSR_{(T-1)} \cdot DMR)$

and the level of Purchasing orders in the Mail from Retail (PMR) is updated accordingly:-

$$PMR_T = PMR_{(T-1)} + DT \times (PSR_{(T-1)} - RRF_{(T-1)})$$

These nineteen equations define the distributor system for the three variables considered.

6.4.1.2. Reservations Concerning the Distributor Model

Since the distributor section of the model represents an amalgam of all the CompAir spares distributors, there are some inevitable approximations, especially since the distributors themselves tended to be highly informal in their methods of operation.

The principal reservation concerns the calculation of the service delay (DUR) and hence the level of service offered. The assumptions imply that provided a certain level of stock is present, then a given level of service is achieved, ignoring the fact that service depends on other characteristics of demand, such as variability. However, this is only true at a piece-part level and, as a generalisation, the relationship that "as stock increases so does service" is undoubtedly true. A secondary and related reservation concerns the response to changes in demand. The model indicates that an instantaneous increase in demand initially generates a steady deterioration in service, due to the following sequence:-

IAR (the actual inventory) decreases
RSRD (smoothed requisition receipt rate) increases, causing
IDFD to increase, thus the ratio IDFD : IAR increases

which in turn increases the unfilled order delay, reducing the shipping rate. Because it was believed that this rate of increase in IDFD was independent of the conscious response in setting the policy stock level (IDF), two versions of smoothed orders (RSR and RSRD) were generated - the latter having a faster response.

6.4.1.3. Constants used in the Distributor Model

AIR = Policy stock level. Discussions with a number of distributors indicated that four months (16 weeks) was a typical value.

AIRD = Stock level required to maintain specified service. Again discussions with distributors indicated that if four months' stock were available, they expected to achieve a 90% service level.

DRR = Demand Smoothing Factor for Policy Decisions. Few of the distributors formally monitored demand, but a typical distributor would examine the demand for the most recent two to three months. DRR was thus set at ten weeks.

DRRD = Demand Smoothing for Setting Demand Response. Intuitively, this smoothing factor was thought to be at least three times as responsive as the former, so a figure of 3.3 weeks was used initially.

DHR = Handling delay at Retailers. To all intents and purposes, this is normally zero at a distributor for counter sales. Since it is only used in conjunction with DUR, the only risk is if $\frac{IDRD}{IAR}$ gets very small, and this is most unlikely so DHR was set at zero.

DUR = Delay for unfilled orders. If a distributor offers a 90% service level, then 10% of all items will be out of stock. The average procurement time for these items will be five weeks (four week review period = two weeks average + three weeks nominal lead time ex warehouse). However, if the warehouse is also offering a 90% service level, then 1% of the items will be subject to the factory lead time - typically twelve weeks. The delay for unfilled orders can thus be built up:-

90% have zero delay

9% have five week delay = 45% weeks

1% have seventeen weeks delay = 17% weeks

Averaged over the total throughput, this gives a figure of 0.6 weeks.

DIRI = Delay in correcting stock and unfilled order level. With a minimum stock review period of one month, it was felt that four weeks represented the response time of a typical distributor to low stock figures or an excessive level of unfilled orders.

DIRP = Delay in correcting work-in-progress. Since a single deviation from the typical lead time would not be significant, at least two order-delivery cycles would be necessary before a change in the warehouse response time was noticed. Under normal conditions this would take approximately eight weeks.

DCR = Clerical delays. The average delay between reviewing the stock and despatching the order is approximately one week.

DMR = Postal Delays. Since second-class post was the normal method of despatching orders, a figure of four days (0.6 weeks) was used in the initial model.

DTR = Transport delay for goods. Including the time for packing and despatch, a typical figure would be two weeks.

6.4.2. The Factory Warehouse System

6.4.2.1. Systems Structure

The structure of the factory warehouse system is more clearly defined, but otherwise very similar to the distributor system and this is reflected in the model.

The incoming orders (from the distributors) again flow into a level of unfilled orders (Unfilled Orders at Factory warehouse = UOF), which is depleted by the shipping rate (Shipments Sent from Factory warehouse = SSF):-

$$UOF_T = UOF_{(T-1)} + DT\ (RRF_{(T-1)} - SSF_{(T-1)})$$

As in the distributor system, the shipping rate is calculated from the delay factor (Delay in Filling orders at Factory warehouse = DFF), again subject to the constraints that sufficient stock is available, i.e. normally

$$SSF_T = UOF_T \div DFF_T$$

but exceptionally:-

$$SSF_T = \frac{IAF_T}{DT}$$

where IAF is the total stock (Inventory Actual at Factory warehouse).

The shipping delay again has two components - the handling delay and the unfilled order delay - which are calculated in the same way as for distributors:-

$$DFF_T = DHF_T + DUF_T \left(\frac{IDF_T}{IAF_T}\right)$$

In this instance, however, IDF (the Inventory Desired at the Factory warehouse) is calculated from the same value of smoothed order receipts (Requisitions Smoothed at the Factory warehouse = RSF) as that used for calculating the re-order rate, thus:-

$$IDF_T = AIF \times RSF_T$$

(AIF being the stocking policy level)

Although the reservations concerning the calculation of DUR in the retail section also apply to DUF, the effects were thought to be less critical, as the incoming orders have been previously smoothed by the distributor system.

This value of RSF is calculated as before, using an appropriate smoothing factor:-

$$RSF_T = RSF_{(T-1)} + \frac{DT}{DRF} (RRF_{(T-1)} - RSF_{(T-1)})$$

Again as in the distributor system, the total stock level (Inventory Actual at Factory warehouse = IAF) is updated from the goods received (Shipments Received at Factory warehouse) and the shipping rate (Shipments Sent from Factory warehouse = SSF):-

$$IAF_T = IAF_{(T-1)} + DT \ (SRF_{(T-1)} - SSF_{(T-1)})$$

Because of the factory involvement, what was called the purchasing rate decision at the distributors is called the manufacturing decision in this case, but is calculated in exactly the same way so that the Manufacturing rate Wanted at the Factory (MWF) contains components to supply the existing order receipts, and to correct the levels of stock, work-in-progress and unfilled orders thus:-

$$MWF_T = RRF_T + \frac{1}{DIF} \left[(IDF_T - IAF_T) + (LDF_T - LAF_T) + (UOF_T - UNF_T) \right]$$

In this instance it is possible to use only one delay factor, as the overall manufacturing rate is a result of computer processing up-to-date information on all the relevant levels. Of course the work-in-progress levels (LDF and LAF) are made up slightly differently on this occasion, as they refer to Factory work-in-progress and delays, but the principle is identical. As before, the "normal" level of unfilled orders (UNF) is calculated from the smoothed order receipt rate and the "normal" value of order turn-round delay. i.e.

$$UNF_T = RSF_T \times (DHR + DUF)$$

Although initially the model was constructed to represent the total system, it was noted that by adjusting the relevant parameters, it could be made to represent either the "bought out" system or the "made in" system. In the case of the latter, the factory scheduling procedure at CompAir is based on the concept of "infinite capacity", so that MWF represents the real order issue rate. However, the possibility of requiring to test alternative systems in which real factory capacity was recognised at this point was foreseen, in which case there would be a need to modify this rate.

Thus if ALF represents the Actual Limit to Factory capacity, then the Manufacturing Rate Desired (MDF) at the Factory will be calculated thus:-

$$MDF = MWF \text{ if } MWF \leqslant ALF$$

$$MDF = ALF \text{ if } MWF \geqslant ALF$$

To remove the effects of this test, it is only necessary to set ALF at a value much higher than the normal value of MWF.

6.4.2.2. Reservations Concerning the Warehouse Section

As the CompAir spares stock control system is well defined and documented, it was relatively easy to create a model which is a close analogy. The principal reservation, as in the previous section, concerns the calculation and application of the unfilled order delay (DUF). The other major problem in constructing this section of the model was to set the control parameters so that they represented the total system, rather than either of the separate systems for "bought out" or "made in" components.

6.4.2.3. Constants used in the Factory Warehouse Model

AIF = Stock Policy. For a typical mix of orders, the overall stock objective works out at 2.8 months (11 weeks) on average (see

Appendix 3). However, reference to figure 12 confirms that in practice, the stock varies between three and eight months, the actual average being 5.13 months. The reason for this discrepancy cannot be fully explained, but is thought to be due to the following factors:-

1. S.D. notes are automatically raised one month in advance of actual requirement in order to allow time for the physical transaction to take place. Where parts are readily available within a production department, this transaction takes only a matter of days - thus transferring stock some three weeks in advance of requirement.

ii. Manual intervention overriding the set stock or reorder quantity parameters. This applies mainly to low usage items, where the spares division often have to order larger quantities than the objective in order to obtain any supply at all. These, however, would only represent a small proportion of the excess stock.

iii. Over-delivery, especially by the production factories. This is especially true of obsolescent parts which tend to be sent automatically to the spares' stores when production have no further requirement for them.

iv. Class mobility. Although the system ignores changes in average monthly usage of less than 10%, analysis has shown that the demand pattern for individual piece parts is highly variable (see Chapter 8). However, only approximately 20% of the active range changes average monthly usage each month (approximately 10% in each direction), so the effect of components changing value category each month is not likely to account for a significant proportion of the discrepancy.

Since there seemed to be factors operating which consistently held the stock balance at an inflated level, it was decided to recognise the fact and set AIF at twenty weeks for the purposes of validation.

<u>DUF</u> = Delay for Unfilled Orders at warehouse. Although a proportion of the unfilled orders will be due to late delivery from source of standard items, since only 50% of the CompAir spares range has a monthly usage greater than zero, the majority of unfilled orders is likely to be for these items. Since these items are not normally stocked, the delay is likely to be a complete lead time. The calculations are:-

Source 1 components:-

Lead time (high activity period)	23 weeks
Lead time (low activity period)	14 weeks
Average lead time	18½ weeks

Source 2 components:-

Lead time (high activity period)	18 weeks
Lead time (low activity period)	6 weeks
Average lead time	12 weeks

Assemblies:-

Average lead time	4 weeks

The normal ratio of source 1, source 2 and assemblies throughput is 64%, 26% and 10% respectively, so a weighted average of the above figures gives a total average lead time of 16.33 weeks.

During a complete cycle (Oct.1970 to Jan 1975) the average first-pick achievement was 82.6%. Therefore the full average lead time would apply to 17.4% of the throughput. DUF = .174 x 16.33 = 2.7 weeks.

<u>DHF</u> = Handling and picking delay. The average delay of items in the picking queue is .21 months (see Fig.17) = .85 weeks. The time

taken to register the incoming orders for clearance through credit control and for the E.D.P. department to raise the picking documents is typically eight days, so DHF is typically 2.9 weeks, allowing for picking.

DIF = Delay in correcting work-in-progress, unfilled order level and stock. The computer issues updated spares' requirements on the factory monthly, and source 2 requirements weekly. This corresponds to an average delay of two weeks and a half week respectively. After weighting according to the proportional turnover (approximately 2:1, Source 1 to Source 2), the overall average delay is 1.5 weeks.With a three day allowance for clerical input time on each of the above levels, the total delay factor is approximately 2.1 weeks.

ALF = Factory Capacity limit at Planning Stage. Since CompAir plans for infinite capacity, and sheds excess load by means of sub-contract, this limit was set at a factor of ten times the normal throughput rate.

DRF = The order smoothing constant. CompAir use a twelve month moving average to smooth orders for forecasting and hence factory (or purchasing) order decisions. To achieve the same degree of smoothing with an exponentially weighted moving average, the following formula is used:-

$$\frac{n - 1}{2} = \frac{1 - \alpha}{\alpha}$$

where "n" is the number of time periods in the plain moving average, and "α" is the smoothing coefficient. Since n = 48 weeks, $\alpha = \frac{1}{24.5}$ but since DRF $= \frac{1}{\alpha}$, DRF = 24.5

6.4.3. The Factory (or Supply) System

6.4.3.1. The System Structure

After the order rate has been generated by the computer, it is necessary to distribute the orders to the personnel responsible for implementation and for them to take the necessary action before releasing the order. This is represented in the model as a third order delay, in which the Clerical orders in Progress in the Factory (CPF) is calculated after each time increment from its previous value, and the difference between the order release rate (Manufacturing Order rate on the Factory (MOF) and the order issue rate (MDF)

$$CPF_T = CPF_{(T-1)} + DT\ (MDF_{(T-1)} - MOF_{(T-1)})$$

The MOF is generated from the third order delay equation using the factor Delay in Clerical issue at Factory (DCF) and MDF.

$$MOF_T = \text{Delay 3}\ (MDF_T\ DCF)$$

Once the orders have been released, they enter the manufacturing (or procurement) process. This can be broken down into two stages. Firstly, there is the actual processing time, which is the time the part is being manufactured. There is also the waiting time, including the inter-operational waiting time and so forth, until the component is available in the warehouse. For the sake of simplicity, this waiting time has all been collected together in the model into the Delay in Order actioning at the Factory (DOF) and the resulting queue is called the Orders awaiting Implementation at the Factory (OIF).

The required implementation rate can be calculated from these two figures, but this does not represent the actual implementation rate, as the latter normally is adjusted to suit the capacity available, so that the Manufacturing rate Tried at the Factory (MTF) is given by:-

$$\mathrm{MTF} = \frac{\mathrm{OIF}}{\mathrm{DOF}}$$

The capacity of the shop represents the Ideal Manufacturing rate Wanted for the Factory (IMWF) and is calculated from the recent this can be represented by taking the delay when the factory is loaded to its optimum (DOIF), and multiplying this factor by the ratio of the actual load to the ideal load. If the actual load is represented by the queue of orders awaiting implementation, (i.e. OIF) then the "normal" load (Normal Orders awaiting Implementation at Factory = NOIF) can be derived from the Ideal manufacturing rate. The equations are thus:-

$$\text{DOF} = \text{DOMF} + \text{DOIF} \left(\frac{\text{OIF}}{\text{NOIF}} \right) *$$

where

$$\text{NOIF} = \text{IMWF} \ (\text{DOIF} + \text{DOMF})$$

The actual manufacturing process is treated as a third order delay, acting upon the implemented orders (MIF) and transforming it into finished goods (Shipments Received from Factory = SRF). The work-in-progress at this stage is called the Orders in Progress at the Factory (OPF) and is calculated in the usual way

$$\text{OPF}_T = \text{OPF}_{(T-1)} + \text{DT} \ (\text{MIF}_{(T-1)} - \text{SRF}_{(T-1)})$$

and $\text{SRF}_T = \text{Delay 3} \ (\text{MIF}_{(T-1)} . \text{DPF})$

* Note the resemblance to the queuing theory formula for mean waiting time.

where DPF = Delay in Processing at Factory.

The actual and ideal work-in-progress levels are calculated as before, the actual level (Level of Actual work-in-progress at Factory = LAF) being the sum of all the levels in the factory loop.

$$LAF_T = CPF_T + OIF_T + OPF_T$$

The desired level is the sum of the perceived delays, multiplied by the average (or smoothed) order receipt rate. The perceived delays in fact represent the lead time monitoring of the re-ordering system, so that before these delays can be recognised in the decision, the system itself needs time to measure and assess what they are. Since the variations occur only in DOF (the queuing delay), the reaction time can be emulated by applying a further delay to DOF before summing it with the other delays, thus DSF (Delay (Smoothed) in Factory) is calculated from DSPF (the smoothing factor)

$$DSF_T = \frac{DT}{DSPF} (DOF_T)$$

The total required level of work-in-progress (Level of work-in-progress Desired at Factory = LDF) can now be calculated from the anticipated throughput (RSF) and the total expected delay:

$$LDF_T = RSF_T \times (DCF + DSF_T + DPF)$$

6.4.3.2. Reservations Concerning the Factory Structure

Although throughout this section there is reference to the factory, the structure is applicable to virtually any source where queuing is involved, since even when sourced from a warehouse, the lead time can be split into processing (i.e. clerical work, picking and packing) and waiting or queuing. The relative length of queues may vary between bought-out, made-in and sub-contract components and the variation of the lead time may also have a different characteristic, but variations as great or greater may occur within the range of components from any one source. Provided that the parameters chosen are representative of the class or classes of goods being studied, the structure should provide a satisfactory model.

A bigger problem arises when considering the effects of increased throughput in this section. The model treats the factory or manufacturing source as "dedicated", with the orders generated by the spares warehouse as the sole throughput. However, at CompAir the spares are sourced either on the original equipment factories (where spares demand is a relatively small proportion of the total) or from outside suppliers (where, of course, the spares demand is often insignificant). However, for the particular purposes of this exercise, i.e. the investigation of the effects of cyclical demand, cyclical variations occur in both the general level of trade and in the requirement for original equipment which are in phase with the spares cycle. Consequently, the proportion of capacity which is available to spares is likely to remain substantially the same. In any case, providing the parameters controlling this section - particularly the variability of lead time with load - reflect the observed variations, then the actual interactions between these three demands will have been taken into account. A detailed investigation of these interactions is discussed in the thesis by Mr. Love (72), who developed an Industrial Dynamics model with multiple sources specifically for the purpose.

6.4.3.3. Parameters Used in the Factory Section

DCF = The clerical delay in issuing orders. The computer-generated order list is distributed within 24 hours of issue, but for bought-out components there is an additional mailing delay, while for factory sourced parts some delay occurs while material is issued and shop supervision is instructed. Taking these factors into account, the total issue delay was assessed at one week. This ignores any queuing time, which is considered in DOIF.

<u>DPF</u> = The process delay. An analysis of the actual machining and setting times for sixteen of the most popular items gave a mean process time of 4.8 weeks for parts made on the factory. Since CompAir tended to concentrate on the higher volume or more complex components, this figure was thought to be higher than the average for all parts. Of the bought-out components, some would be available ex-stock, where the only "processing" would be clerical operations or picking, packing and transporting which, including other incidentals, would not exceed three weeks. For bought-out items made to order and for sub-contract items, the actual process times would be similar to those for made-in components. A figure of four weeks was chosen as representative.

<u>DOMF</u> = Minimum Queuing Delay. Consideration of the machine shop as a queuing model suggests that the minimum queuing delay possible is zero.

However, due to the structure of the machine shop equations, it is necessary to allocate a value. Since the significant figure is the ratio between fixed and variable delays, the same effect can be achieved by setting DOMF at a very low value, such as 0.2 weeks.

DOIF = The variable queuing delay. If the fixed portion of the lead time is 4.2 weeks, then for an average lead time of 16½ weeks (see DUF in warehouse section), the variable portion, or queuing time, would average 11.3 weeks under steady state conditions.

DSPF = Reaction time to lead time variations. For made-in components, there is no mechanism for updating the nominal lead times which the computer holds for calculating re-order levels. For bought-out components, the lead times are updated bi-annually from statistics published by the purchasing department. However, the purchasing department are often only aware of changes in lead time after the event, so that the reaction time is probably of the order of six months. A figure of 24 weeks was used in the model.

DIMF = Delay in adjusting factory capacity. With the extensive use of sub-contracting, CompAir can expand its effective capacity relatively quickly for many components.

Under favourable conditions the time required to recognise the increased requirement, to arrange for sub contracting, and to actually receive the benefit, is probably of the order of four months. On the other hand, under conditions of increased activity (when sub-contracting is most necessary) the lead times quoted often extend to four months and greater, in addition to the reaction time of two to three months. However, for many components requiring special operations, or those components from outside suppliers, the capacity is often limited and fixed, in which case the shortest reaction time possible would be the time required to acquire and commission new plant - a course of action not always economically practical. Even when practical, the total time taken from identifying the need for a piece of plant, through the justification and approval stages to actual commissioning could well exceed two years if it coincided with the height of the activity cycle. For those cases where the need is never actually recognised, the capacity of course remains fixed and the delay is effectively infinite. From these considerations, the delay for the provisioning sources as a whole was tentatively set at fifty weeks.

6.4.4. Model Input

Facilities in the model programme were provided for changing the value of any of the parameters described prior to a run. Since the model equations are deterministic and linear, the effects of these changes under steady state conditions could easily be calculated without running the model. Since the objective of building the model was to study the dynamic behaviour of the system, it was necessary to superimpose dynamic variations on the model input in order to stimulate any reaction. The model input was the order receipt rate at the distributors, and this was normally set at 100 under steady state conditions, for convenience. In addition, the following dynamic inputs could be superimposed:-

i. A step. Two parameters, controlling the size (expressed as a percentage of the starting conditions) and the timing of a step change to the input value were required.

ii. A ramp. Three parameters, controlling the total height (as a percentage of the initial conditions) the timing of the start and the timing of the finish of the ramp change were required.

iii. A sine wave This also required three parameters to control the start, the amplitude (as a percentage of the steady stage) and the period of the sine wave.

iv. Noise. Random normal deviations could be superimposed on the input. The control parameter was the standard deviation of the "noise" (expressed as a percentage of the "un-corrupted" input value).

If required, all four patterns could be used, thus a "transient" change in input could be obtained by following a step input with a negative ramp of the same amplitude and very short duration.

6.4.5. Model Output

The program could, if required, list the value of every variable at predetermined intervals. The intervals were controlled by an input parameter which for most runs was set at four weeks, to correspond with the data available at CompAir. In addition, fifteen key variables had their means and standard deviations calculated at the end of each run.

A further option was to present the value of selected variables on a graph, expressed as a percentage of their respective initial conditions. Examples of typical graphical outputs are given in Figs. 28 & 31 to 36.

6.5. Validation of the Model

6.5.1. Comments on Validation

In spite of its importance, relatively little has been written on the subject of model validation. Even the Ph.D. thesis which was devoted to the topic (69) concentrated on the verification of the computer code rather than testing the realism of the basic model. It was noted in a previous section that many of the Industrial Dynamics applications relied on comments by experts from the modelled system on how well the model emulated the real system.

As most authors point out, there is no definitive test of validity, it is a question of building up confidence in the ability of the model to simulate the relevant system behaviour. This being the case, it is not unreasonable that if informed and impartial comment indicates that the model is mimicking the system closely, then confidence is reinforced. Van Horn (120) develops this approach further and suggests the application of "Turing" tests, so that the "informed opinion" can be statistically tested for consistency.

Most validity tests are concerned with the statistical comparison of model output with the real system variables. Hermann (62) suggests five "validity criteria" and statistical analysis play an important part in all but one of them. They are:-

i. Internal Validity, or the sensitivity of the model to extraneous factors. This compares the inherent "randomness" of the model with that of the system under study when running under identical conditions.

ii. Face Validity or a subjective impression of the model's realism. He does not clarify whether this applies to the structure or behaviour of the model, or a general overall impression.

iii. Variable Parameter validity in which parallels are drawn between corresponding parameters in the real and modelled systems and their influence on system behaviour.

iv. Event Validity which compares the behaviour of internal model variables with the corresponding variable of the system under study.

v. Hypothesis Validity which tests the consistency of internal relationships between different variables.

Although Hermann developed these criteria for testing polical models and games, they are also relevant to industrial systems.

Fishman and Kiviat (42) divide the process of developing confidence into two stages, verification and validation. The verification stage consists of ensuring that the model structure is correct and that all the internal processes are as the model builder intended, while the validation process compares model behaviour with system behaviour. Mihram describes techniques for use in these two stages (78). He also comments that the required level of confidence is a subjective matter, where critics will require more "proof" than adherents. This emphasises the need to meet Hermann's "face validity" criterion, especially if the model results are to be used to affect subsequent policy.

A more mathematically orientated approach is suggested by Wigan (121) in which the desired objective seems to be to match the input and output of the model and real system as closely as possible, ignoring (or at least placing less emphasis) on structural and parametric similarities. He suggests four stages of validation (quote)

"1. Postulates. The selection of basic assumptions of form and interaction on which the remaining stages are based.

2. Fitting. Having selected a set of parameterised functions based on postulates, fit "best" values to

these functions according to defined criteria of "best fit".

3. Calibration. Given a set of fitted functions (or sub-models) calibrate their inter-relationship with direct reference to the overall behaviour of the model and the data which the model aims to produce.

4. Identification. Ensure that the detail of the calibrated model is justified by the available data (and find the best reduced form if required)."

(unquote).

This approach seems dangerous, since in theory there could be many transfer functions of very different forms, each capable of producing similar output from a given input for a limited period. Not attempting to limit the range by specifying similarity of parameters and structure would appear to be risky. Indeed, much of the confidence of a model synthesised from its individual elements is gained from obtaining realistic output without recourse to "fitting" or "calibration".

With the exception of Wigan, all the authors make the point that the validation process cannot be divorced from the purpose of the model, or as Van Horn puts it "Validation is problem dependent".

In many cases, part of the problem is to convince the policy makers that the model results are reliable. Since such people are often unversed in statistical techniques, this places a high premium on "face validity" and will often require minor alterations to the model which are, to the model builders, irrelevant.

6.5.2. Requirements of the Spares Model

Most of the problems with model verification and validation arise due to the stochastic nature of the processes being modelled. However, the Industrial Dynamics technique in its basic form uses deterministic processes, although there is provision for introducing "noise" at decision points. This approach is justified on the principle that by modelling "gross" behaviour, a very large sample is being taken in which the sample variance is negligibly small.

To adopt Fishman and Kiviat's approach, the "verification" of the spares model could be carried out with ease, as the equations were all deterministic. Two methods were used:-

i. To calculate the value of all the variables, starting from a given set of values. This confirmed that the model program was using the correct equations in the correct sequence.

ii. To run the model under steady state conditions, when all the variables should assume a fixed value which can be easily confirmed by referring to the relevant equation and control parameters.

These checks were carried out as part of the normal "program debugging" process.

The actual validation process has to confirm that the model represents reality sufficiently well for the purpose in hand. In this instance, that purpose was to examine the dynamic behaviour of the system. Consequently, while conventional validation concentrates on the mean value of variables, and their variation about the mean, with industrial dynamics the emphasis is on the time related response of variables, examining their periodicity, the duration of "lags" and "leads", and noting the presence and gain of any amplification in the system.

6.5.3. Sensitivity Tests

A complete model consists of two kinds of mathematical statement - the equations (which define the model structure) and the control parameters (which quantify the relationship between the system variables). The validation process has to establish user confidence in the correctness of each of these two aspects. The model structure is validated to an extent while in the course of construction, since the frequent interviews with the participants in the real system confirm the relationships being modelled, and the factors being considered at each point. This is not always true of the control variables, as it is often difficult to assign a weighting to a factor in an equation, although recognising that the factor is certainly significant. In order to reduce the uncertainty in this area, it was decided to run a series of sensitivity tests, which would fulfil the dual purpose of constituting a valdity test in its own right, while also dividing those parameters which had a significant effect on the total system behaviour from those which were relatively robust.

The sensitivity tests were performed by completing a series of runs, in each of which one parameter was sequentially assigned two values equal to one half and double the normal value. For many key parameters (such as lead time or stock objective) an extreme value was also assigned. The effects of this variation were assessed by examining the mean and standard deviation of fifteen principal variables selected from the three sections of the model.

To assist with the interpretation of the results, a program was written which took this output and printed two "sensitivity" tables. The first table listed on each line the identity number of the parameter being varied, its value and its normal or standard value, and the value of the mean and standard deviation of each of the fifteen variables. The first run in any series always used the model with "standard" parameters, i.e. with the values as assessed in the preceeding section. Thus comparison with the first line of the table indicated what the effects of the parameter change were. To facilitate this comparison, the program printed a second table but instead of using the absolute values as in the first, the program calculated the ratio of the value to the standard value. Thus any variable totally unaffected by a particular parameter change would show 1.0 in the relevant places in the matrix. (Appendix 4).

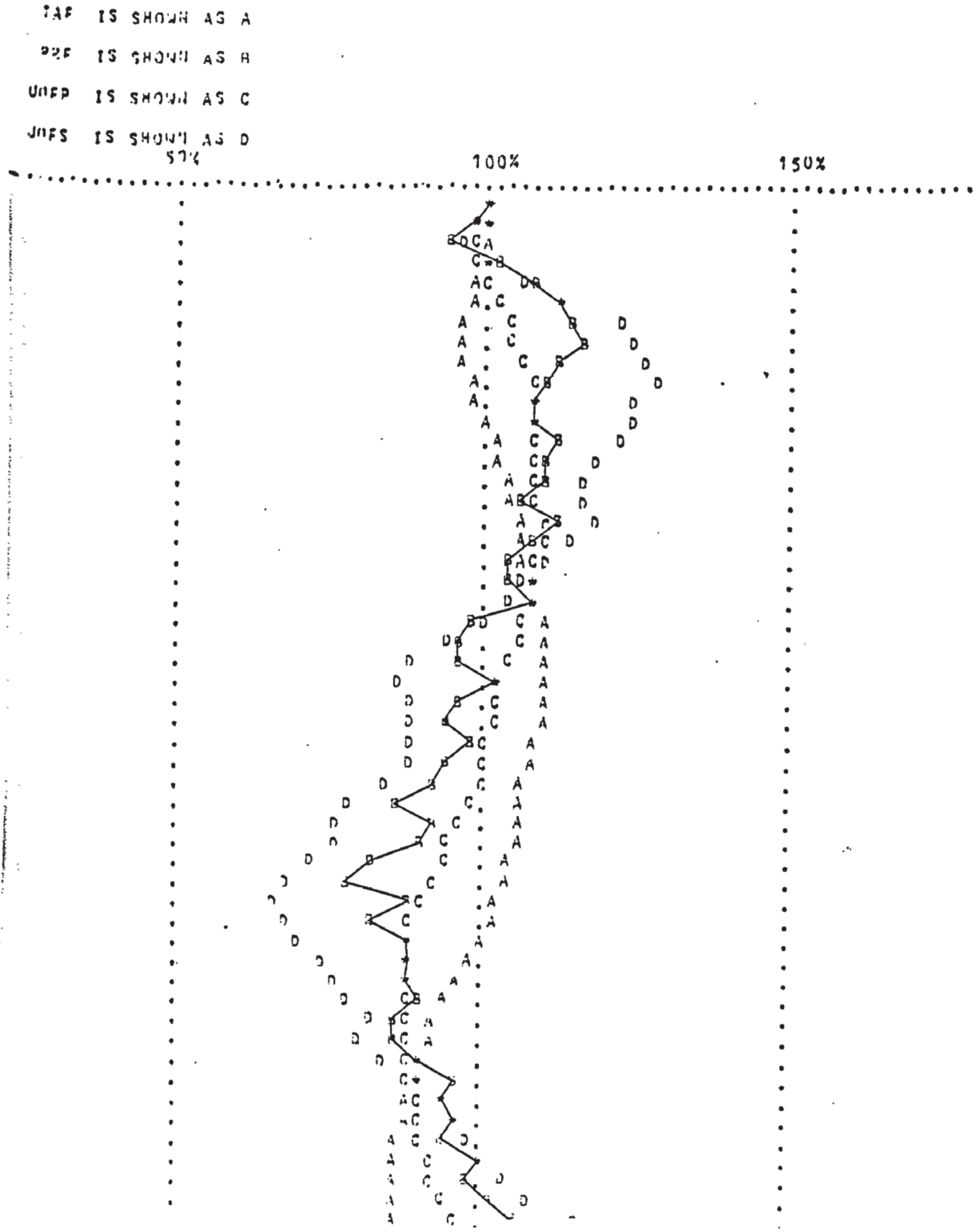
The sensitivity tests were performed with two types of input. The first was a step input of 10% and the run was for a period equivalent to one year. Although never encountered in reality, the step input was chosen to stimulate any tendency to self excitation or resonance, and to reveal any natural frequencies of the model. A short run, as well as being economical, was necessary since a long run would dilute the effects of the step input on the variable's means and standard deviations. On the other hand, a period of some thirty weeks was required before any significant effects could be detected in the provisioning section of the model.

In the second series of runs, the input was made to approximiate to the real system input (after smoothing) by superimposing "noise" with a standard deviation of 3% onto a 4¼ year (220 week) sine wave with an amplitude of ± 10%. Figure 28 shows a graphical output from the standard model using this input and the similarity between the resulting order receipt rate at the warehouse (RRF) and the actual six month smoothed order receipt rate (Fig. 10) can be seen. Consideration was given to the feasibility of simulating the unsmoothed order data, but this was decided against for several reasons:-

i. That the very high "noise" would make detection of underlying patterns very difficult.

ii. That such input was unlikely to provide any more information about the system.

iii. That smoothed input, and the resulting output would be in a form more familiar to observers,



EXAMPLE OF MODEL GRAPH OUTPUT—CYCLICAL INPUT WITH NOISE

Fig. 28

thus assisting in the "face validation" of the model.

This reasoning, plus the additional computer storage requirements, also justified the decision not to expend any effort in trying to input real data on distributors' sales.

For this series of runs, the run length was fixed at one complete cycle of input, and the results analysed as before.

6.5.4. Sensitivity Test Results

Appendix 4. shows copies of the two complete sensitivity tables. Reference to the second part of each set (headed "Ratio Values") shows how the table could be used to assess the size and extent of changes in the pattern of model behaviour caused by altering each parameter. Summaries from these tables are shown in Figs. 29 and 30. It demonstrates how certain parameters, such as the clerical delay in processing factory orders (DCF) have very little effect at all, while others, such as the production process time (DPF) have a significant effect in a limited area, while yet others, such as the stock objectives, have a significant effect throughout the model. The three areas which emerge as being highly critical are the

FIG. 29. SENSITIVITY RESULTS SUMMARY - STANDARD DEVIATIONS OF VARIABLES - STEP INPUT

PARAMETER	VALUE	WAREHOUSE UNFILLED ORDER LEVEL	WAREHOUSE STOCK LEVEL	FACTORY OUTPUT RATE	REQUIRED RATE OF PRODUCTION	WAREHOUSE DESPATCH RATE	FACTORY QUEUING TIME	FACTORY W.I.P.	WAREHOUSE ORDER RECEIPT RATE	DISTRIBUTORS STOCK LEVEL	DISTRIBUTORS UNFILLED ORDER LEVEL
WAREHOUSE DEMAND SMOOTHING COEFFICIENT (DRF)	x 0.25	+	-	+	+++	+	+	+	+	+	+
	x 0.5	+		+	++	+		+	+	+	+
	x 2.0	-	+	-	--			-	-		
WAREHOUSE STOCK OBJECTIVE (AIF)	x 0.10	+++	--	+	++	+	+	+	+++	+	+
	x 0.50	+			-				+		
	x 2.0	-	+	+	+		+	+			
MEAN DELAY DUE TO SHORTAGES AT WAREHOUSE (DUF)	x 0.04	----	+	-	--		-	-	--	-	-
	x 0.5	--	+	-	-		-	-	-	-	-
	x 2.0	++	-	+	+		+	+	+	+	+
MEAN ORDER HANDLING DELAY AT WAREHOUSE (DHF)	x 0.1	--	+		-				-	-	-
	x 0.5	-							-		-
	x 2.0	+	-						+		
WAREHOUSE STOCK CORRECTION DELAY (DIF)	x 0.6										
	x 2.0				-						
	x 7.5		+	-	--		-	-			
CLERICAL DELAY IN PROCESSING FACTORY ORDERS (DCF)	x 0.5										
	x 2.0										
	x10.0			-	-		-	-			
DELAY IN ADJUSTING FACTORY CAPACITY (DIMF)	x 0.25	-	++	++	-	+	---	++			
	x 0.5		+	+			---	+			
	x 2.0		+	--	-		++	-			
MEAN PROCESS DELAY (DPF)	x 0.5		-	-				---			
	x 2.0		+	+	+			+++			
	x 5.0	+	++	+	++	-	+	+++			
MINIMUM QUEUING DELAY (DOMF)	x 6.0		+	+			--	+			
	x25.0		+	+	+		---	+			
	x50.0		+	+	+		---	+			
VARIABLE QUEUING DELAY FACTOR (DOIF)	x 0.5				-						
	x 2.0				+		--				
	x 4.0		-		++		---				
DISTRIBUTORS STOCK OBJECTIVE (AIR)	x 0.12	++	+++	+	+++	++		+	+++		+++
	x 0.5	-	-	-	-	--	-	-	--	--	+++
	x 2.0	++	++	+	++	+	+	+	++	++	---

KEY: "+" = + 10% to + 50%, "++" = + 50% to + 100%, "+++" = MORE THAN + 100%
"-" = - 10% to - 30%, "--" = - 30% to - 50%, "---" = MORE THAN - 50%

FIG.30. SENSITIVITY RESULTS SUMMARY - STANDARD DEVIATIONS OF VARIABLES - REALISTIC INPUT

PARAMETER	VALUE	WAREHOUSE UNFILLED ORDER LEVEL	WAREHOUSE STOCK LEVEL	FACTORY OUTPUT RATE	REQUIRED RATE OF PRODUCTION	WAREHOUSE DESPATCH RATE	FACTORY QUEUING TIME	FACTORY W.I.P.	WAREHOUSE ORDER RECEIPT RATE	DISTRIBUTORS STOCK LEVEL	DISTRIBUTORS UNFILLED ORDER LEVEL
WAREHOUSE DEMAND SMOOTHING COEFFICIENT (DRF)	x 0.25	-	-	-			-	-			
	x 0.5		-								
	x 2.0				-						
WAREHOUSE STOCK OBJECTIVE (AIF)	x 0.10	+++	--	-		+	-	-	+	+	
	x 0.50	+	-	-	-		-	-			
	x 2.0	-	++	+	+		+	+			
MEAN DELAY DUE TO SHORTAGES AT WAREHOUSE (DUF)	x 0.04	---	+		-				-	-	-
	x 0.5	--									
	x 2.0	++	-								
MEAN ORDER HANDLING DELAY AT WAREHOUSE (DHF)	x 0.1	--									-
	x 0.5	-									
	x 2.0	+							+		+
WAREHOUSE STOCK CORRECTION DELAY (DIF)	x 0.6										
	x 2.0										
	x 7.5	+	+		-						
CLERICAL DELAY IN PROCESSING FACTORY ORDERS (DCF)	x 0.5										
	x 2.0										
	x10.0	+	-	-	-		-	-			
DELAY IN ADJUSTING FACTORY CAPACITY (DIMF)	x 0.25	--	--	-	--		---	-			
	x 0.5	-	-	-	--		---	-			
	x 2.0	+	+		+		++		+		
MEAN PROCESS DELAY (DPF)	x 0.5		-					---			
	x 2.0	+	+		+			+++			
	x 5.0	+	+	+	+		+	+++			
MINIMUM QUEUING DELAY (DOMF)	x 6.0	-			-		--				
	x25.0	-	-	-	--		---	-			
	x50.0	-	--	-	--		---	-			
VARIABLE QUEUING DELAY FACTOR (DOIF)	x 0.5	-			-		--				
	x 2.0		-	-			-	-			
	x 4.0	-	---	-	-		---	-			
DISTRIBUTORS STOCK OBJECTIVE (AIR)	x 0.12	+	-		+	+			++	---	+++
	x 0.5	-	-	-	-	-	-	-	-	--	++
	x 2.0	+	+	+	+	+		+	+	++	---

KEY: "+" = + 10% to + 50%, "++" = + 50% to + 100%, "+++" = MORE THAN + 100%
"-" = - 10% to - 30%, "--" = - 30% to - 50%, "---" = MORE THAN - 50%

stock control and re-ordering decision at the distributors, the stock control and re-ordering decision at the warehouse, and the response of the factory or supply source.

6.5.5. Discussion of Sensitivity Test Results

The most encouraging point to emerge from these tests was that, considering the scale of the parameter changes, (which was always by a factor of at least two) the model seemed to be acceptably robust. Consequently, reservations about many of the parameter values - some of which were uncertain - could be discounted, although they could marginally affect relative phasing.

A more disturbing feature concerned the interpretation of certain parameter changes. In the real system, some pairs of parameters are mutually dependent. For example, it was estimated that distributors typically hold 16 weeks stock, and at this stock level, are able to achieve a 90% service level. The model sensitivity tests implied that if distributors decided to reduce their stocks by half (i.e. setting AIR to eight weeks) while leaving other parameters unchanged there would be few drawbacks and many benefits - ignoring the fact that in practice such a change would certainly bring a corresponding deterioration in the service level. This emphasised that the approximations inherent in the Industrial Dynamics approach are only valid when the model is operating with parameter values close to those observed in the real system. It also means that the extrapolation of parameter changes into the real system must be carefully considered before implementation.

In general, the sensitivity tests confirmed that the model represented a sufficiently close emulation of the real system for the purpose, viz. to examine the inter-relation of the various parts of the system to assess where the cyclic pattern was originating and what its effects were. All the reactions implied in the results as a consequence of the various parameter changes appeared to represent a reasonable estimate of what the real system response would have been, had the parameter changes been put into practice. (Thus meeting Hermann's third criterion, the "Variable Parameter" Test).

The sensitivity tables also highlighted a number of parameters which were particularly significant in their effects on model behaviour, e.g. the two stock objectives (at the distributor and at the warehouse) and the manufacturing parameters. As a result, these parameters and the equations in the model, where they exerted their influence, were critically re-appraised prior to subjecting the model to further validation tests.

6.5.6. Other Validation Tests

One of the major problems concerning the validation of the total model was the scarcity of information regarding either the performance of the factory or supply sources, or of the distributors, over a sufficiently long period. In both cases the reasons were similar. Firstly, while both areas generated a lot of useful data, it was usually destroyed after use. Secondly, where long term records did exist, they referred to overall figures in which the CompAir spares information was a relatively insignificant proportion. Validation of these areas was thus only possible at a general level, since information on the corresponding real variables was not available.

6.5.6.1. Distributors

The only figures available from the distributors at all relevant to the validation exercise were those used for comparing distributor's sales with CompAir sales (see Fig. 22). Even though these figures are highly processed and only represent a sample (albeit a significant one) they do demonstrate how a cyclic variation of 7% about the mean in distributor's sales is amplified to a 12% variation about the mean in CompAir's sales. It was considered that, with their normally high service levels, the distributors' sales would closely follow their orders, and that the High Wycombe sales would not be significantly different from the orders. Thus, a close correspondence between the behaviour of these figures and the model variables SSF and SSR would confirm that the distributors's stock control and purchasing decisions were being adequately represented by the model. Fig. 31 shows the model output, and comparison with Fig 22, supports the claim, both displaying a small degree of amplification.

6.5.6.2. The factory and other suppliers

While the operating data generated for the factory management was extremely comprehensive, it was universally discarded on release of the updated issues the following month. Even the lead time data referred to in the last section was available only by chance. Consequently, the validation of this area had to be based on figures generated within the spares division. Although no figures are

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ST OF GRAPHED OUTPUT
T WITH UOF SPLIT INTO UOFS & UOFP                    -05.10.78.

SSR  IS SHOWN AS A

SSF  IS SHOWN AS B
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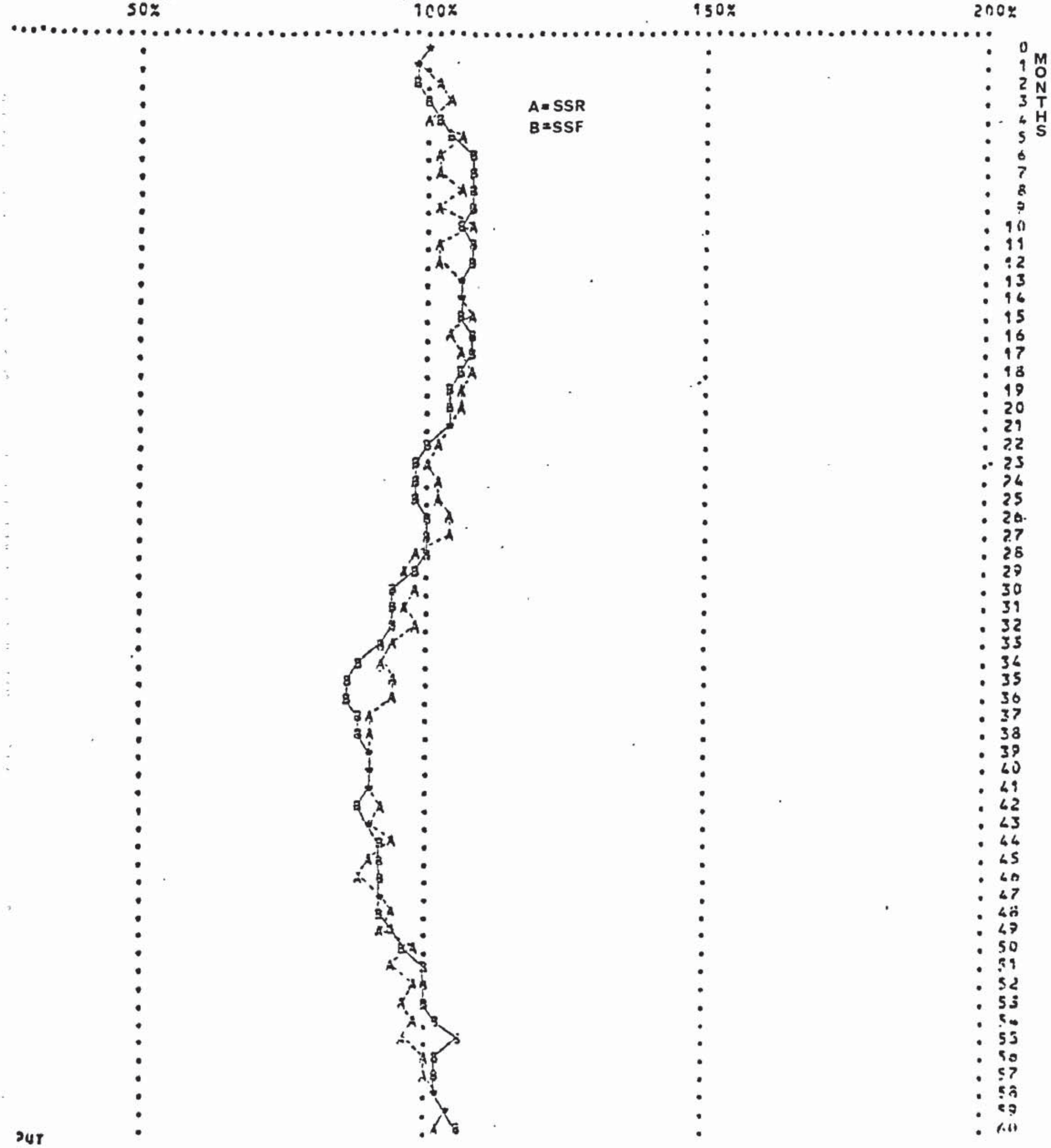

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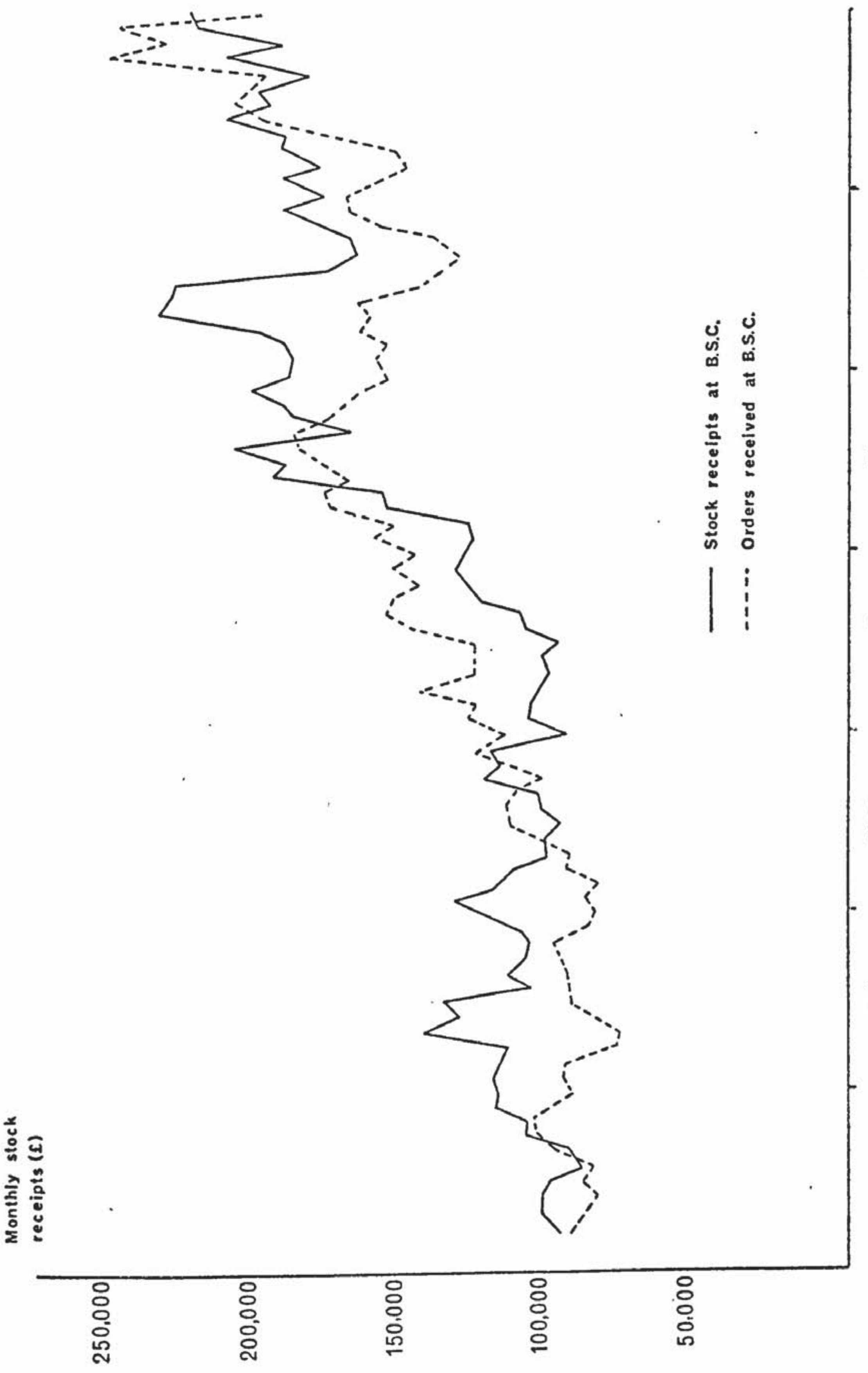
MODEL OUTPUT—SSR & SSF— CYCLICAL INPUT WITH NOISE

Fig. 31

available of the orders generated on the spares suppliers, there were records of the goods received. It was reasoned that comparison between the modelled warehouse order receipts and goods received (RRF and SRF) and the actual order receipt rate and goods received rate would assess the transfer functions of both the warehouse stock control and the factory. Since the warehouse stock control and re-order decision rules were clearly defined and accurately followed by computer, correspondence between these variables would establish confidence in the suppliers' model equations.

The illustration in Fig. 32 shows how the actual goods receipt rate lagged the actual order receipt rate over the period 1970 to 1975. The upward trend discernable in both cases is due to inflation, since the figures are in cash terms. An exercise was conducted by creating an input (RRR) which would cause RRF (the model order receipt rate) to follow a pattern similar to the actual order receipt rate. Observations of how closely the response of SRF (the model goods receipt rate) matched the behaviour of the actual goods received rate would indicate how accurate the model was



STOCK RECEIPTS AND ORDER INTAKE
(3 MONTH MOVING AVERAGES)

Fig. 32

in representing the sources of supply. The input signal consisted of a 4¼ year sine wave with noise superimposed. At the relevant point, a ramp signal was also added, to represent inflation. The resulting graphical output is shown in Fig. 33 and confirms the similarity between the model behaviour and that of the real system.

6.5.6.3. The Warehouse

A considerable amount of data was available concerning the warehouse performance, and most of the variables were a result of the interaction between the factory and the distributors. Correspondence between model and system behaviour in these variables would encourage confidence in the model as a whole. For example, under cyclical conditions, the shortage level varies as a result of the factory (or suppliers) response lagging the order receipt rate. Thus the behaviour of this variable is particularly sensitive to inaccuracies in the model, and correspondence between such variables greatly increases the probability that the model is "correct".

The graphical output from a series of runs with a realistic input (i.e. a 4¼ year sine

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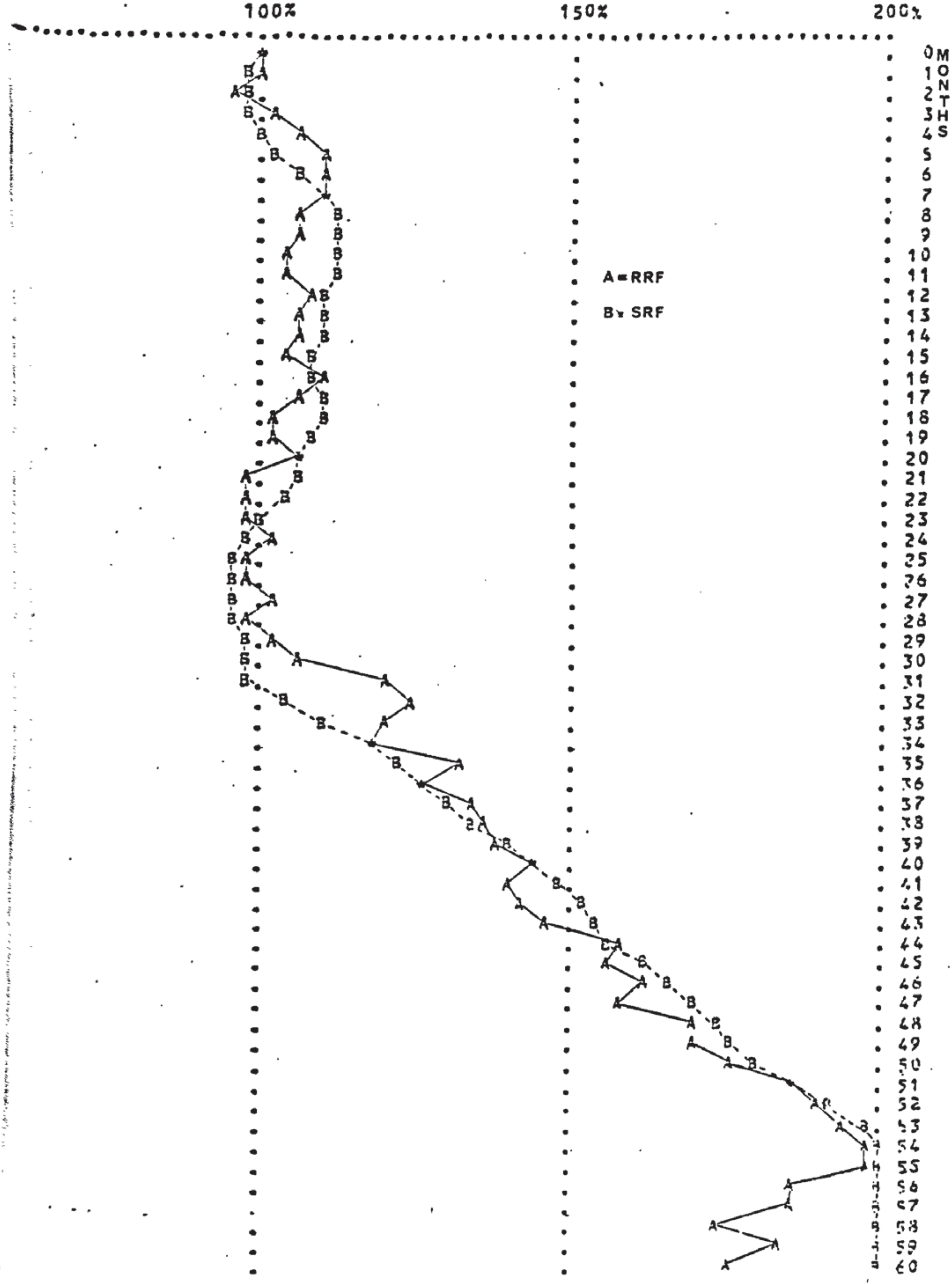


MODEL OUTPUT—RRF & SRF—CYCLICAL AND RAMP INPUT WITH NOISE

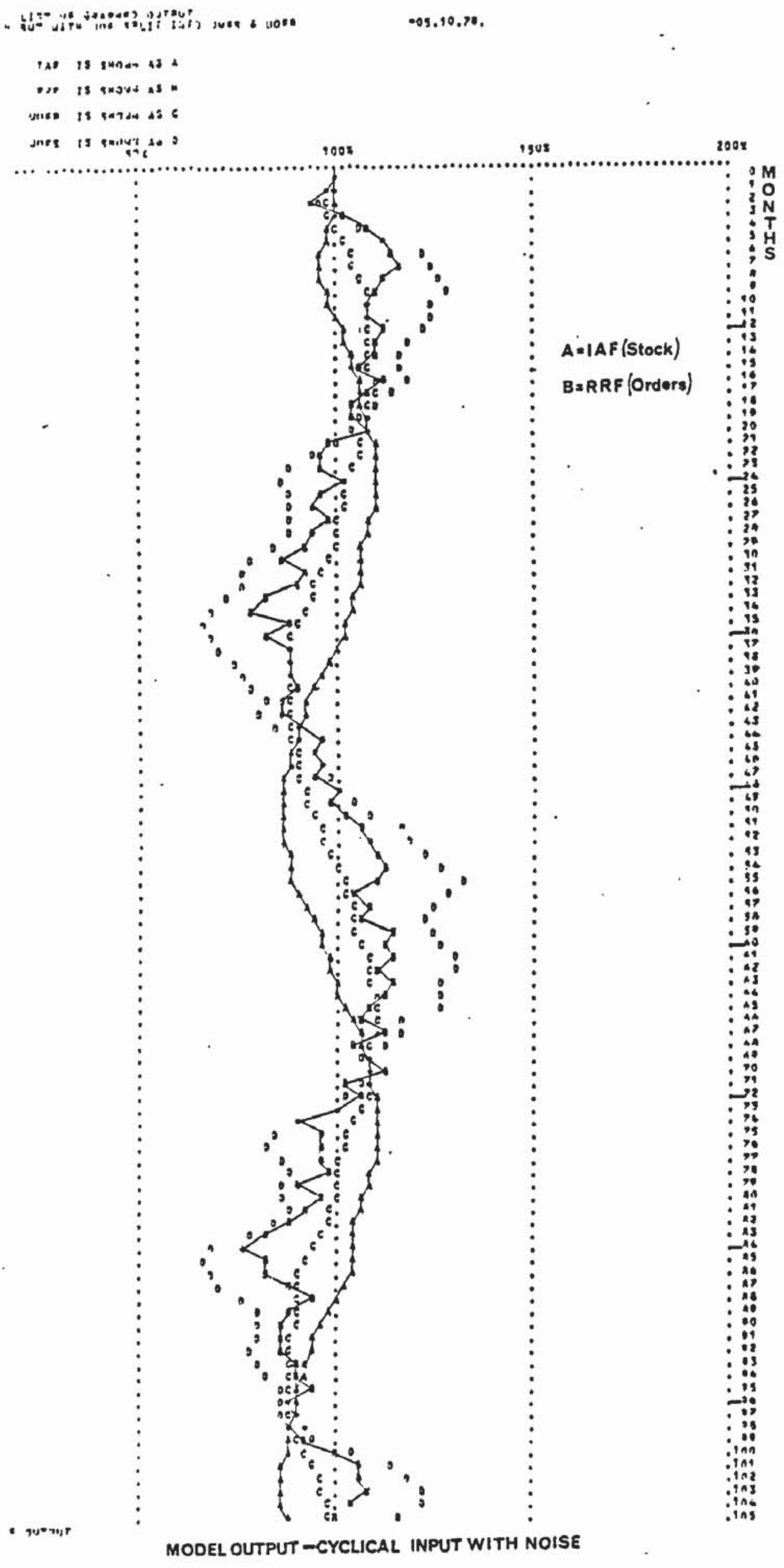
Fig. 33

wave with superimposed noise) is shown in Figs. 34,35, and 36. This may be compared with the illustrations of real system performance in Figs. 12,13, and 16. When the results were discussed with management of the CompAir spares division, they confirmed the close resemblance of the model output to reality.

6.6. Discussion of Model Test Results

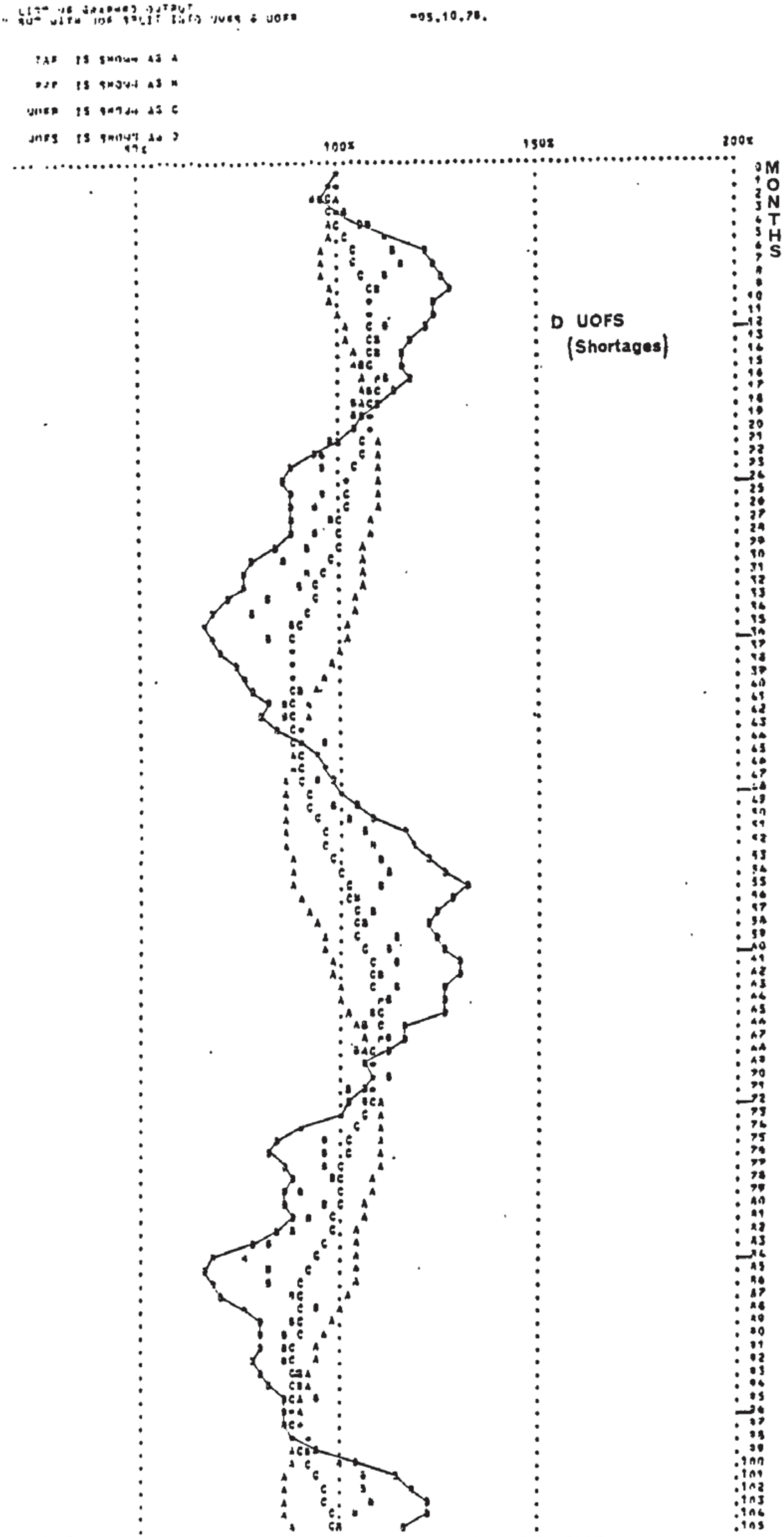
There is no doubt that the Industrial Dynamics technique is a coarser approximation than most simulations. However, the validation tests showed that the behaviour of the spares model closely resembled the system behaviour and gave confidence in the belief that the structure was substantially correct, when combined with the correct control parameters. However, the sensitivity tests showed that because the structure ignores the implicit interdependence of certain parameters, their manipulation could give misleading results. Nevertheless, the model demonstrated its adequacy to fulfil its original purpose, namely to explain the origin of the cyclical behaviour and its effect on the system.

In the event, this objective was met in the course of the validity tests. The sensitivity tests demonstrated that, although altering the factory parameters had a



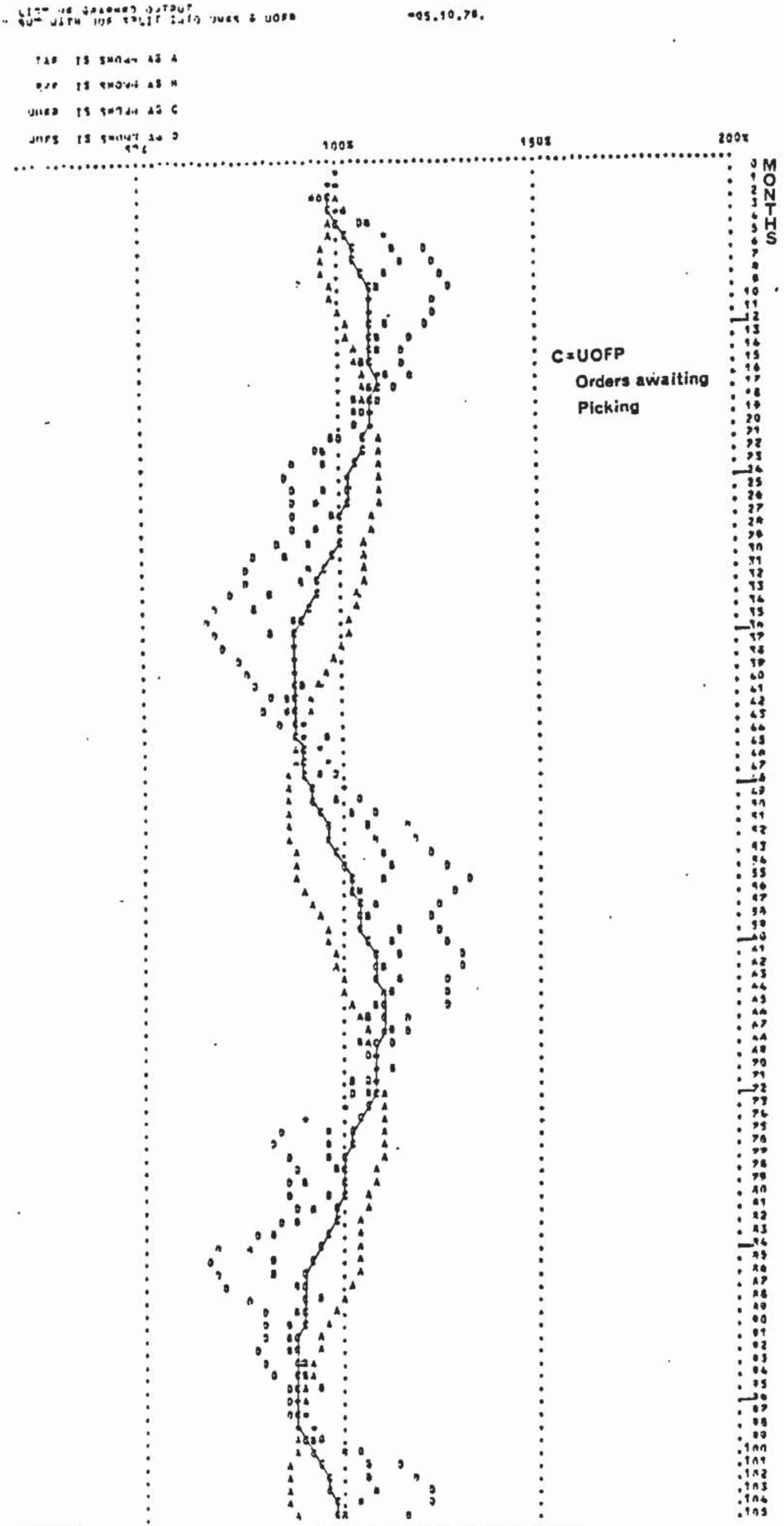
MODEL OUTPUT —CYCLICAL INPUT WITH NOISE

Fig. 34



MODEL OUTPUT—CYCLICAL INPUT WITH NOISE

Fig. 35



MODEL OUTPUT—CYCLICAL INPUT WITH NOISE

Fig. 36

marked effect on the behaviour of the warehouse, the effects on the distributor were negligible. On the other hand, the effects of a cyclical demand pattern were amplified by the system, which is confirmed by experience. It thus appears highly unlikely that the cyclical pattern is generated by variations in supply capacity, but tends to confirm that the variations occur in the actual customer demand. (Subsequent experiments by Mr. D. Love added further weight to this argument - see ref. 72).

The sensitivity tests also showed that the amplification of the cyclical pattern was principally due to three causes:-

i. The effects of the distributors' stock control system.
ii. The effects of the warehouse stock control system.
iii. The response of the suppliers to a change in load.

Because of the reservations which were held concerning the structure of the model in these areas, it was deemed unwise to draw more specific conclusions on how the amplification, or gain factor, could be adjusted, although reduction in this was thought to be highly desirable.

A point of general interest to the company management was the robustness of the distributors' service level (as measured by UOR) to changes in the warehouse service level. This suggested that throughout the trade cycle, the end customer remained largely unaffected by the problems of supply experienced at the warehouse. Nevertheless, it was still in the company's interest to maintain a high level of service to the distributors, since any deterioration generated a compensating tendency in the distributors' order rate.

It was not only the sensitive areas which were of interest. The relative insensitivity of the model to changes in the order picking delay and the order processing delay (DHF) suggested that the company's intention to revise the warehouse order processing system and to introduce more mechanical handling, although bringing benefits of higher productivity, would do little to stabilise the overall performance of the system in the long term.

6.7. Proposed Action

These findings were submitted to the company in December, 1976 (ref. 73) when it was proposed that the performance of the spares division was limited by the extent to which it could contain and respond to the cyclic demand pattern. To achieve any improvement it would be necessary to concentrate attention on the three areas identified by the sensitivity tests.

The company accepted these proposals, and the following courses of action were agreed.

6.7.1. Action Concerning the Distributors' Stock Control

Since the distributors were all independent companies, change would have to be achieved by diplomacy rather than directive. The question of company-owned outlets was raised, but despite the attractions, the scale of organisational effort and investment made the proposal impractical. It was decided that the adoption of a stock holding policy by the distributors giving a more consistent ordering pattern more closely related to real customer demand would be the most cost effective action for both the company and the distributors. The company therefore decided to appoint a consultant to investigate this area, to assess the likely reaction from the distributors and gauge the potential benefits to the company.

Since the variations in customer demand are so central to the spares problem, the provision of an efficient service by the company would be greatly facilitated by timely and accurate information on the level of customer demand - information which only the distributors can provide. An important aspect of the consultant's task was therefore to assess whether the distributors were prepared to provide for CompAir regular information on their spares sales, stocks, and service.

6.7.2. Action Concerning the Spares Warehouse

An improved level of service at the spares warehouse could easily be achieved in the short term by increasing the objective stock holding figures used in the re-order rules. However, it was suggested that the level of stock already seemed excessive for the service level provided, and that such a policy would also increase the amplification factor, thus aggravating the problem for the suppliers. The company therefore agreed that the author should concentrate on investigating the warehouse stock control and re-ordering systems with the objective of designing a more responsive system capable of offering a more consistent level of service from a lower level of stock. It was also agreed that the author should assess whether the benefits of the more comprehensive information which could be made available by the distributors would repay the effort and expense of its collection and preparation.

6.7.3. Action Concerning the Provisioning System

The majority of spare parts were obtained from outside suppliers - either directly or through the factory - while the remainder were manufactured within the factory, which was strongly orientated towards the manufacture of original equipment. In neither case did the spares division exercise any direct control over the provisioning process. It was proposed that placing more control over the sourcing of parts within the spares division would allow the adoption of more flexible policies which could be closely matched to the requirements of the spares market. In addition, there appeared to be a strong case for establishing an independent spares manufacturing unit which would be designed to provide a fast response rather than minimum unit costs. This case was supported by the impending withdrawal from production of a number of models, which would subsequently require a new source for spares. Mr.D. Love,who had worked with the author on the investigations to date, was assigned to the task of investigating the provisioning system of the spares division, with emphasis on the potential benefits of an independent spares manufacturing unit. This work, and his conclusions, are described in his Thesis (ref. 72).

CHAPTER 7

STOCK CONTROL CONSIDERATIONS

The sensitivity tests described in the last chapter indicated that the system behaviour was influenced by the inter-actions between stock and service. In the industrial dynamics model, this relationship is approximated by a series of equations which consider such factors as demand level, unfilled orders, absolute stock level and "desired" stock level. In particular, the technique sets the "desired" stock level as a function of the average demand level, and postulates that the service is a function of the ratio between actual and "desired" stock.

Although many stock control policies do set their stock objectives in terms of average demand, the ratio of actual to objective stock does not uniquely determine the service level. Consideration of elementary stock control theory emphasises that a vital factor in the equation must be the variability of demand at piece-part level. It is this factor which dictates what a stock level should be to achieve a given service level for a given set of supply conditions. Unfortunately, because the industrial dynamics technique operates in terms of gross demand, it cannot be used to investigate this aspect of stock control. On the other hand, because it is the variability of demand which controls the stock/service relationship, the introduction of a stock control system which recognises this would also remove one of the principal amplification factors in the system.

The other factor to be considered is the supply pattern. Although the industrial dynamics technique does recognise this factor at a gross level, again it cannot operate at a piece-part level. Consequently, it was impossible to assess what effect the ability of the CompAir system to reschedule urgent parts was having on system behaviour.

The above considerations led to the following approach to the problem:-

i. To investigate the variability of demand of the CompAir spares range at a piece-part level in order to assess its significance.

ii. To select a number of alternative stock control rules, and assess their intrinsic merits compared with each other and the existing CompAir rules when operating on the CompAir spares range.

iii. To determine how the most attractive stock control rules would react with the CompAir production control system, and to evaluate the effects on total system behaviour compared with the existing rules.

iv. To assess whether making available at the warehouse information on true customer demand (thus theoretically by-passing one stage of amplification) would be of any benefit to the company in maintaining its service objectives.

CHAPTER 8

DEMAND PATTERN OF THE COMPAIR SPARE PARTS RANGE

8.1. Demand Variability

The data for the analysis of the pattern of spares demand was obtained from a copy of the "Spares Demand History File". This was a computer generated magnetic tape file which held the monthly demand figures for each spare part for the period May 1969 to March 1976. Because of the volume of data (the file contained information on over 15,000 part numbers), it was necessary to write a computer program to perform the necessary analysis.

Due to operating constraints, it was only practical to process the first 12,000 or so part numbers, and these were analysed in groups of 1,000 at a time.

In the first analysis, the program calculated the mean and standard deviation of demand for each part number for a period covering the available history of the part. For stock control purposes, a most important parameter is the coefficient of variation, or the ratio of the standard deviation to the mean demand, and this figure was also calculated. A preliminary examination of some parts had indicated that the maximum mean demand was likely to be less than 5,000, but the coefficient of variation could exceed ten for items with very erratic demand. These figures were used to set the upper limits of logarithmic scales divided into twenty classifications.

As the analysis program calculated the mean demand, the standard deviation and the coefficient of variation, it classified the results, using the same scale for the mean demand and standard deviation. The length of the available history for each part number was classified on a twenty division arithmetic scale, from 0 to 120 months. After examining 1,000 part numbers, the program printed a table showing the class boundaries of each of the four scales and the distribution of the 1,000 components within the classes. Items with zero mean demand were counted separately. Figure 37 shows a summary of the eleven tables it was possible to obtain from this analysis. The layout of this table is similar to the computer output.

This first analysis demonstrated that the variability of demand, as measured by the coefficient of variation, is highly significant for the CompAir spare parts range. The average coefficient of variation for these 11,000 parts was 3.48. This implies a range of demand much greater than the mean level of demand.

Fig. 37

CLASS NO:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Largest Coefficient of Variation:- 110.62																				
Upper Class Boundaries	.127	.163	.208	.265	.338	.431	.550	.701	.894	1.14	1.46	1.86	2.37	3.02	3.85	4.92	6.27	8.00	10.2	OVER
Distribution	1129	0	0	0	1	45	152	380	547	682	763	919	940	1062	990	922	740	827	772	129
Largest Average Demand																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	6801	652	609	566	504	403	355	299	228	185	137	108	50	45	30	11	11	4	1	1
Largest Standard Deviation of Demand																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	4985	953	941	873	775	660	591	400	296	216	110	72	57	36	17	6	4	6	1	1
Longest History																				
Upper Class Boundaries	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
Distribution	1105	59	127	148	77	113	216	246	143	331	202	198	198	171	174	7492	0	0	0	0

PART NUMBER: AS10 000000000

TO

PART NUMBER: PP40 C11158/590

OVERALL DEMAND PATTERN ANALYSIS

DISTRIBUTION OF PARAMETERS THROUGH TOTAL RANGE

COMPONENTS WITH AVERAGE SALES BETWEEN 0 AND 15,000 ONLY

837 LINES WITH ZERO SALES
11,000 COMPONENTS INSPECTED

Intuitively, one would expect that higher demand levels would be relatively more stable, and some authors have suggested that there is an empirical law relating the mean and standard deviation of demand in many cases (see for example Burgin and Wilde (20), or Van Hees and Monhemius (119, Page 156).

The first analysis could not reveal if such a relationship existed at CompAir, and to do so, it was necessary to examine the pattern of demand variability within specific ranges of mean demand.

Five ranges of demand were defined, as follows:-

i. Average demand between 1 and 5 per month
ii. Average demand between 5 and 25 per month
iii. Average demand between 25 and 125 per month
iv. Average demand between 125 and 625 per month
v. Average demand between 625 and 5,000 per month

The second analysis consisted of five runs, each performed precisely as in the first analysis, with the exception that those items with a mean demand outside the specific range being considered were excluded from the output table. Copies of the five resulting tables are given at Appendix 5. Fig. 38 shows a summary of the results, and the curve of mean coefficient of variation against mean demand (on a logarithmic scale). Performing a linear regression on the

PATTERN of DEMAND VARIABILITY

Class	1	2	3	4	5
Sample Size	12321	12385	11828	12290	13874
Nº of Compts in Class	2926	1745	789	253	51
Average Demand	2·34	11·43	55·06	247·43	1146
Actual C_v	2366	1·447	0·959	0 793	0·699
Predicted C_v	2·085	1·52	111	0 832	0 651

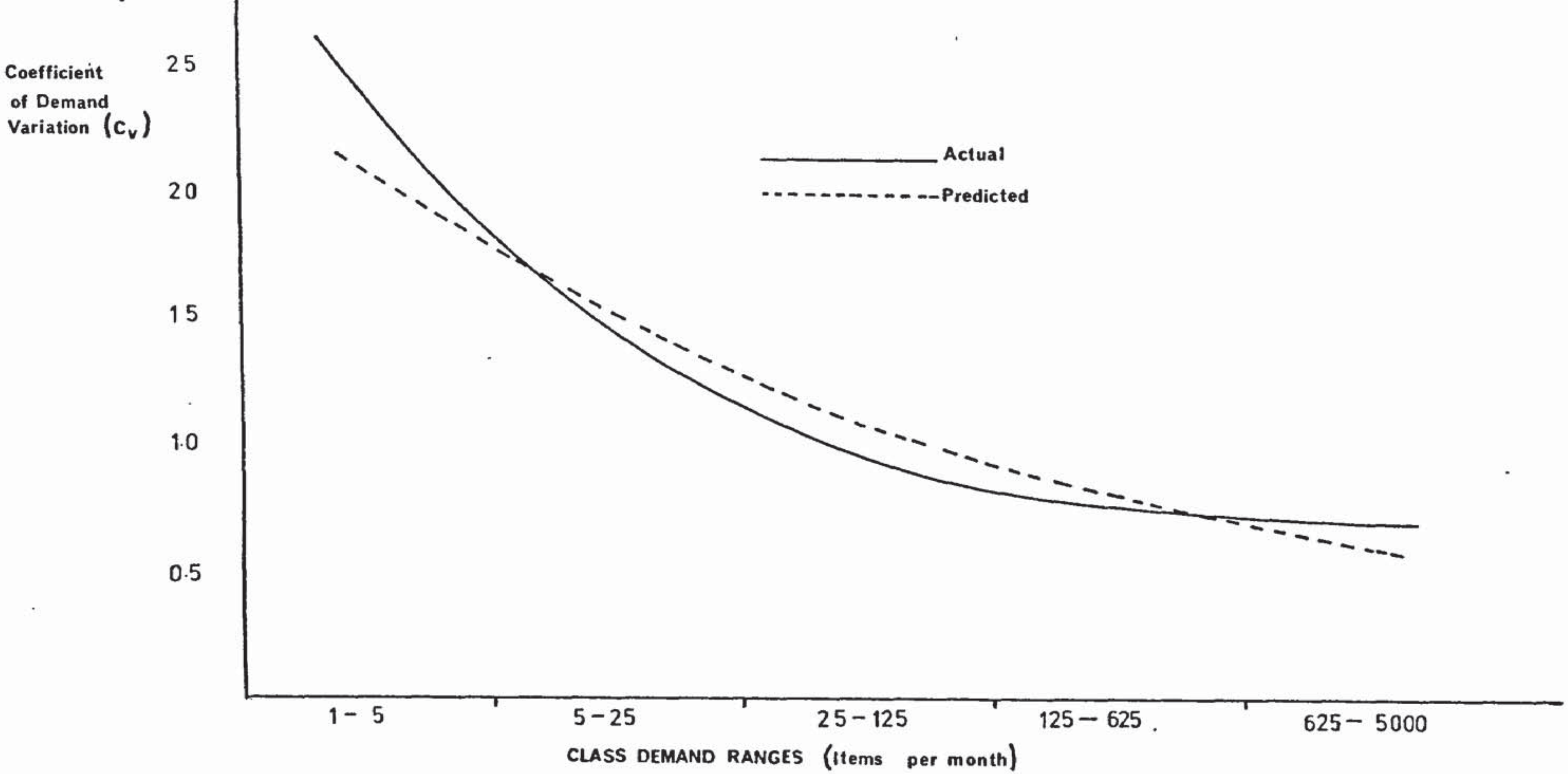


Fig. 38

logs of these figures gives a correlation coefficient of 0.969 against the law

$$C_v = 2.46526 \times (\bar{D})^{(-0.1971)}$$

where $\bar{D}$ = mean demand

and C_v = coefficient of variation

This demonstrates that a general relationship does exist between the mean demand and the standard deviation of demand for the CompAir spare parts range.

However, examination of the distribution of coefficients of variations within each of the five classes (see Appendix 5, Figs. 1 to 5) shows that although such a law may apply for a class of parts, it can only be applied to individual piece-parts with a severely limited degree of confidence.

Tests on a small sample of components (see Appendix 6) indicated that the demand standard deviation fluctuates in an unpredictable manner from component to component, and no clear time based pattern emerges, but further work is necessary to confirm this.

8.2. Individual Piece-Part Demand Patterns

With over 12,000 part numbers to consider, it was impractical to examine the demand distribution of even a significant proportion. However, the demand patterns for some thirty components were plotted, and a dozen of these were selected for detailed analysis.

The sample contained distributions which,on inspection, appeared to conform to the shape of either normal, Poisson, or negative exponential distributions, as well as one or two cases which showed no pattern at all.

When subjected to the Kolmogorov - Smirnoff goodness of fit tests, the best fit was obtained in nearly every case with a normal distribution.

Certain of the demand patterns were also subjected to the "chi squared" test against the same distributions, and again the normal curve usually provided the best fit, although in very few cases did this test suggest a very close fit. An example of a distribution which appears exponential, and the calculations which suggest otherwise is given at Appendix 7, together with other examples of typical demand patterns.

8.3. Demand within Value Categories

As explained in Chapter 2, the company classifies all parts according to the value of their mean monthly demand, and sets the stock control parameters according to these categories. Therefore, the distribution and variability of demand figures within these categories is of interest.

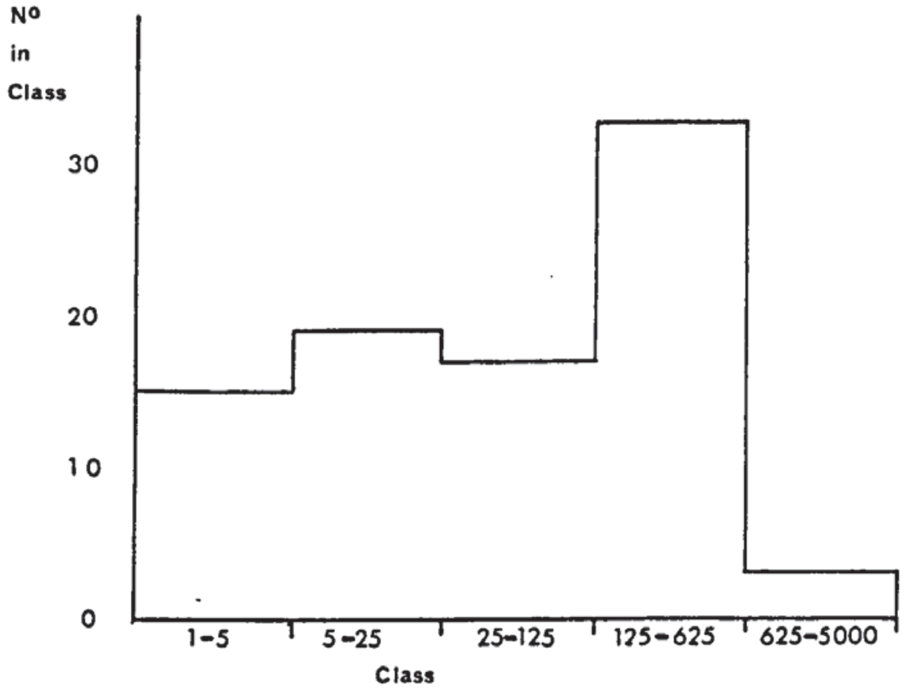
An analysis of the top category (VC1), containing over 60% of the turnover, for both bought-out and production-sourced items, gave the distributions shown in Fig. 40. It should be noted that a significant proportion in each case have demands both higher and lower than the mean, implying that the safety stocks for these items are far from optimal under the existing system, if their variability of demand follows the observed rule. Fig. 39 shows the mean demand for each value category for each of the supply options.

Value Category	Mean Monthly Demand Per Item	
	Production Sourced	Bought-Out
VC1 (monthly usage value £150 +)	167.2	133.2
VC2 (monthly usage value £35-£150)	55.4	49.5
VC3 (monthly usage value £10-£35)	56.4	43.8
VC4 (monthly usage value £3-£10)	36.8	39.8
VC5 (monthly usage value £3 and under)	11.8	9.6

FIG. 39

SOURCE COMPAIR HVC 14.6.77

Distribution of Mean Demand in Value Category One — Bought out Items



Distribution of Mean Demand in Value Category One — Made in Items

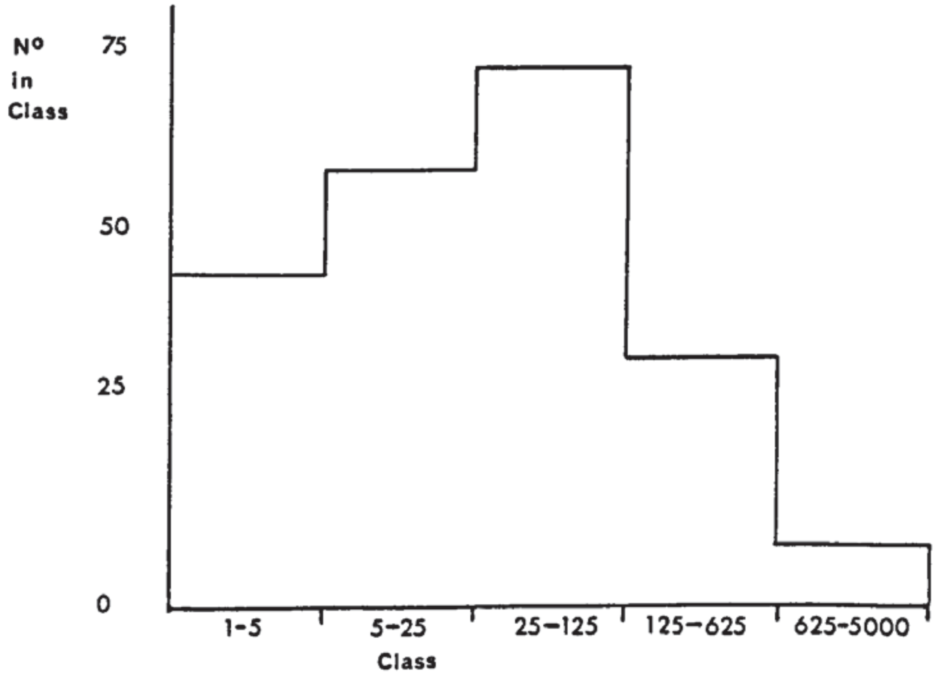


Fig. 40

CHAPTER 9

THE REQUIRED ATTRIBUTES OF A SOLUTION

The range of variability of demand of individual spare parts revealed by the analysis just described suggested that the simple stock control rules which CompAir operated for its spares inventory were inadequate to meet their service objectives. The industrial dynamics model had indicated that increasing the stock objectives would increase the amplification at this point in the system, as well as committing more capital to inventory. An approach suggested by Stevens (111) to classify each part by its mean demand, and hence estimate its demand variability, using either the exponential rule already used, or Burgin and Wild's quadratic rule (20) could possibly have provided some improvement, but the range of variability within each class indicated otherwise.

There was thus a need to seek an alternative set of rules which would meet the following objectives:-

i. To improve the stock/service balance of the spares inventory.

ii. To reduce or eliminate any demand trend amplification.

iii. To interface with the company's existing production control and original equipment stock control systems.

iv. To require computing capacity not significantly greater than the existing rules. As the company ICL 1902S was nearing the limits of its capacity, the marginal cost of increased requirements would have been substantial.

v. To be acceptable to company management and the operating personnel alike. This implied rules whose logic was clear and assumptions self-evident.

9.1. Possible Solutions

The field of inventory control is one which has attracted a considerable amount of attention for many years, and there have been innumerable papers written on many aspects. Some of the more recent have been reviewed by Aggarwal (6) and Fortuin (50). Aggarwal is principally concerned with the mathematical models used and proposed a system for classifying the eleven principal types which he identified. Fortuin concentrates on those aspects relevant to production inventories and divides the field into theory based on "Materials Requirements Planning" and "Statistical Inventory Control", the latter being more relevant to spares. Some idea of the number and variety of models possible can be obtained from the complexity of the code proposed by Hollier and Vrat (63) for classifying inventory models. This code can include up to 14 terms.

The problem of inventory control cannot be divorced from production control, since the one either constrains or is constrained by the other, and a whole body of work has been devoted to the question of production scheduling, in which inventories serve principally to smooth the production load (see for example, ref 65 chapters 7 and 8). This approach is usually at the gross level and does not consider the implications of maintaining a specific level of service on every member of a whole range of components. On the other hand, in general, inventory control theory does not consider the interaction between production and inventory control rules, except by recognising order costs, although some authors are concerned with the short term interactions between the inventory system and the production system. This is often represented by a single server queuing system, as in the case of Fairhurst and Livingston (41) and Dzielinski and Manne (37). In both cases, simulation is used, but only extremely limited parts ranges are considered. Consequently, the overall conditions are extremely artificial and the results not directly applicable to CompAir. Chestnut, Kavanagh and Mulligan (23) describe a model capable of simulating the total production process and inventory control system, which they use to test various forecasting methods for demand and lead time. Because of the comprehensive machine shop model, this technique would he highly expensive to use for large ranges of parts over extended simulation runs.

The major concern of most investigations is how much to order and when. Much of the literature is concerned with the joint calculation of both the re-order level and the order quantity for continuous review systems or the lower and upper stock levels for periodic review systems, thus recognising the effect of the order quantity on the frequency of opportunity for stock-outs to occur. Due to the large number of assumptions and their variety, the range of models of either basic sort is extensive (see for example 58, chapters 4,5 and 6). The approach in both cases is generally consistent, in that an expression is derived for the total cost of operating the system for the part concerned. This expression contains terms for the expected demand and expected lead times (and hence the likelihood of a stock-out) usually as cumulative probability distribution functions. Terms are also included representing the cost of holding stock, the cost of a stock-out, and the cost of raising an order. The resulting expression is then usually dealt with in one or two ways. Some approaches apply a computer search routine, and using various combinations of re-order point (S) and re-order quantity (Q), determine which combination gives a minimum value for the total cost expression. Problems occasionally arise in ensuring that a true global minimum is found. The second approach is to partially differentiate the cost expression twice, once with respect to S and once with respect to Q. Equating the resulting expressions to zero determines the point of minimum cost, but the resulting expressions are not explicit for either Q or S. Consequently an iterative approach is necessary, using an initial estimate of Q to evaluate S, and using the result to re-evaluate Q, continuing until successive terms converge to a sufficient degree of accuracy. Unfortunately, under certain circumstances, they don't.

The factors which create such a wide variety of such models are:-

i. The optimising function used, e.g. a similar procedure could be adopted for rate of return rather than total cost.
ii. The existence of tangible lead times.
iii. The distribution function of lead times.
iv. The distribution function of demands.
v. The permissibility of back ordering.
vi. Since the total cost expression contains terms with cumulative distribution functions, their evaluation can often require some degree of approximation. The nature and degree of approximation introduces a further source of variation.

Because of the complexity of the calculations, many authors suggest or imply that the exercise is carried out once for a range of conditions which are relevant to the particular parts concerned, and that a set of tables is produced. By referring to the lead time and average demand for a given component, and taking into account other significant features, the relevant stock control parameters (i.e. re-order point and quantity) may be determined. This approach is followed by Burgin and Wild (20) and Boothroyd and Tomlinson (16). This is only effective for a stationary demand pattern and as Barrington-Taylor and Oke (12) point out, raises problems of compromising between comprehensiveness and utility. To overcome these problems, Eilon and Elmaleh (38) investigated the effects and problems of re-calculating the re-order point and quantity on a regular basis, using updated demand information, a procedure which was also adopted by Gross, Harris and Robers (54) in what must be one of the few practical applications of the approach.

The whole question of an economic order quantity is disputed by certain writers, notably Burbidge, who points out that however it is formulated, it disregards the interactions between factory efficiency, production scheduling and order quantities (see 18 and 19, chapters 21-23). In spite of these objections, the basic formula is still widely employed in industry and continues to receive attention in both deterministic and probabilistic forms (see Snyder 106).

Its most usual variation is where it has to operate within a constraint of one kind or another, when a summing equation for the total range of components is formed and solved using a Lagrangian Multiplier and adopting an iterative routine. Examples of this technique are given by Parsons (89), Page and Paul (88), Wiersma (124) and Garmann (51). This technique was also employed by Burgin and Wild (20).

Most spare parts ranges contain some items with low intermittent demands, and Croston (32 and 33) suggests that a better service/stock holding balance can be achieved for these items by separately estimating the demand interval and size of demand, only updating the latter when demands occur. Mitchell (80) also considers the problem of slow moving spares, but uses a graphical method to solve the total cost equation he constructs, assuming a Poisson demand in the lead time, non captive demand, and unit order size. However, Mitchell's definition of "slow moving" is extremely stringent, referring to usages of less than one per annum.

In view of CompAir's changing product range, and the subsequent decline in sales of certain spare parts, it is possible that excessive stocks of certain items may occur.

Simpson (104) proposes a formula which determines the period for which the retention of stock subject to a known rate of deterioration is balanced by the overall cost of immediate disposal with subsequent procurement, thus identifying the optimum amount of stock to retain. Hart (61) adopts a procedure whereby the total cost of retention and subsequent procurement (according to a given schedule) is calculated for the planning horizon considered and is evaluated for a number of different retention quantities, using a search procedure to select the optimum. Either of these procedures could only be applied on an "ad hoc" basis within CompAir, but would add an element of objectivity to the decision in spite of the approximations necessary in evaluating some of the parameters.

The CompAir spares distribution system may also be considered as an example of a multi echelon system, in which case the problems are complicated by the question of optimal disposition of stock within the system. A significant proportion of the studies in this field have a military basis, as this is one of the few areas where more than two echelons are under the control of one central authority. Clark (26) examines some of the work done in this area, but mentions only one reference which concerns itself with the dynamic interactions within such a system. Because of the complexities of the problem, simulation is frequently used, although Roseman (96) offers an analytic approach to what he admits is a simplified problem, in which he examines the effect of differing lead times and stock disposition policies. Even so, his approach requires a large number of calculations since, for each different set of lead times, he considers the cost of holding various quantities in stock at all possible dispositions, and calculates the total cost. Examples of the simulation approach are given by Haber (56 and 57) and Clark (25). Both authors deal with the problem of maintaining submarines in a state of operational readiness, but, whereas Clark is concerned with only one part (with rather specialised manufacturing and provisioning constraints), Haber deals with a more general case of a multi-item inventory containing 35,000 different parts. Even after sampling from the range, the computer capacity requirements were extremely large. The study by Eilon and Elmaleh (38) is an example of a commercial problem concerning three echelons:- finished goods, work-in-progress, and raw material. Aggarwal and Dhavale (8) examined the inter relationships between lead time, demand patterns and costs in two levels of a four echelon system, and assessed the effects of varying these parameters on some of the standard management criteria (e.g. average stock holding).

In applying these techniques to the CompAir system, the problem arises of modelling the different stocking policies at each of the various distributors. Conners et al (29) have developed a suitable program generator which is capable of creating simulation programs for multi-echelon provisioning systems, which also examine the effect of transport policies as well as inventory control. However, it suffers from the disadvantage that its treatment of the manufacturing source is not appropriate, regarding it as an infinite source with instantaneous response (see Aggarwal 7).

Stock control is an obvious application for simulation which is widely used. Not only is it a fundamental feature of some of the techniques for jointly calculating re-order points and quantities (34), but is frequently used to confirm results obtained by analytical methods (e.g. Chern 22). As a technique, simulation is better suited to assessing the performance of a given set of rules under closely specified conditions rather than actually formulating those rules, and many examples of its use in this way can be found (86, 102 and 126). However, few of the examples deal with more than one item at a time, so it is impossible to assess the gross effect of implementing any given set of rules. Exceptions to this are given by Packer (87), Haber (56) and Connors (29). K.J. Cohen (28) describes the most relevant application for CompAir in which simulation is used to set stock control parameters in an automotive spares distribution system. However, some of the assumptions are so inadequate for the CompAir parts range that the technique would have to be applied to each part in turn to achieve maximum benefit.

A significant point is that none of the studies mentioned consider the long term dynamic effects as described by Forrester (see 47, chapter 6.2) that any given stock control policy may cause.

Any stock control policy depends upon certain assumptions about future demand patterns. In the very simplest systems, these assumptions are implicit, but a whole range of techniques has been developed on the explicit assumption that the best guide to future demand patterns is the demand history. At its simplest level, a forecast is obtained by taking an arithmetic average of recent demands, and this technique is widely used throughout the industrial and commercial world. The use of exponential smoothing is not, in the author's experience nearly so widespread, but does offer distinct advantages:-

i. It is more economical of computer capacity, requiring less data to be carried over from one review to the next, and fewer calculations.

ii. More weight is given to recent data than older data.

However, the question arises of determining the optimum rate for discounting older data. A number of authors have considered this problem (e.g. 14, 112 and 117) but the techniques they describe are best suited to single forecasting exercises, requiring excessive time and computation for most commercial applications, where frequent updating across large ranges of components is required. This highlights the wide variety of uses to which forecasting may be put. On the one hand, there are major exercises such as long range strategic planning which perhaps justify the more sophisticated techniques. This category would include the Box-Jenkins method (see 17). Successful applications in this type of exercise have been reported by Uri (118) and Tomasek (114) although Chatfield and Prothero (21) indicate that even in this field simpler methods may sometimes be as effective. One of the features of the Box Jenkins approach is the discretion it leaves to the forecaster in determining the nature of the forecasting model. In contrast, the approach by Eilon and Elmaleh (38) is almost automatic once the computer has been programmed. These programs determine the smoothing parameters which would minimise the forecasting error for the data available, and then uses these parameters to make the next forecast. Although the authors propose the technique for use in a routine stock control system,it requires the calculation of the forecast error for every combination of values of three parameters, each adopting values between zero and one, at 0.1 intervals. This requires 0.8 minutes of computer time per component, which makes it impractical for many routine applications.

The same charge can be made against the technique of adaptive filtering (123) which uses an iterative algorithm to modify the individual weights allocated to each item of historical data, such that the mean squared error is minimised. Here again it seems that a high level of expertise is necessary to judge how many previous data points to include and the rate at which the iterations converge on a solution. The effectiveness of the technique has been questioned elsewhere (40).

The other category of forecasting techniques includes those suitable for applying on a regular and frequent basis to large ranges of parts. Most of these techniques are variations of simple exponential smoothing. Winters (124) describes versions which include factors for allowing for trend and seasonal variations, and suggests how these factors can be computed.

A problem with automatic systems is to monitor the accuracy of individual forecasts. Harrison and Davies

(60) describe how this can be done using the cumulative sum of previous and current forecast errors, and comparing the figures with pre-set control limits. However, the amount of data to be carried forward for each component can be prohibitive. Trigg (115) developed a method based on a "tracking signal" which is the ratio of the smoothed error to the smoothed absolute error, and showed that confidence limits could be assigned to various values of the tracking signal. In a later paper (116),he and Leach describe how the modulus of this tracking signal can be smoothed and used as the forecast smoothing constant. This has the effect of changing the rate at which the forecast responds to changes in demand pattern, i.e. increasing the discounting factor when required. Shone (103) suggested a method by which the sensitivity of the model to random extreme values could be improved.

A further improvement on the technique is claimed by Smith (105), who suggests that adaptively modifying the rate at which the smoothing constant changes improves the accuracy of the forecasts.

An alternative method of modifying the smoothing rate is described by Chow (24). In this method, the forecast is made in the usual way, using a selected value for the smoothing constant. However, two additional forecasts are made, using constants greater and smaller than the selected value by a given amount. If either of these "alternative" forecasts generates a smaller forecast error by the next review, then that value is used to make the "proper" forecast, and two new alternative forecasts are generated.

D'amico (35) also suggests multiple forecasts, but in this instance two alternative values of the smoothing constant are computed from the smoothed absolute deviation of the forecast, and which of these values to be used is determined by referring to its associated smoothed absolute deviation.

A number of comparison tests have been made between some of the forecasting methods available. Gross and Craig (53) performed a series of simulations on a period review "order up to" inventory system, and concluded that for the circumstances they studied, exponential smoothing offered better all round performance than either maximum likelihood or two Bayesian methods. Markland (76) tested single, double and triple exponential smoothing against more intuitive techniques in a military context, and found that for the parts in question (helicopter spares) the triple smoothing provided the most accurate forecasts. However, the demand pattern showed a significant and increasing trend which from theoretical considerations is best monitored by triple smoothing, so that the result is not universally applicable.

Although most authors assess the efficacy of any forecasting method by its accuracy, from a commercial viewpoint a better criterion is its cost of operation, and this aspect was considered by Roberts and Whybark (95). They assessed the performance of four different methods by simulating a single item inventory system, in which a uniformly distributed demand pattern was subjected to two step changes, one positive, and another smaller and negative. Under these conditions, the Trigg Leach method proved most effective, but the total difference in cost between the best and worst was only 3½%.

The question which concerned Newbold and Granger (84) was whether simple automatic procedures were significantly inferior to the Box-Jenkins method, or to an autoregressive method they had developed. In a series of tests on a wide range of time series, they found that the Box-Jenkins method did produce significantly more accurate forecasts, particularly for more than one period ahead. A surprising further conclusion was that, contrary to their expectations, combined forecasts often performed better still. In another paper (83), Newbold discussed how a forecast could be produced from both historical data and a leading indicator. A similar theme was developed by G.D.

Cohen (27), who suggests combining forecasts and weighting them according to their expected error.

The relationship between many of the models discussed was investigated by Ward (122) who demonstrated that the Box Jenkins model is a general form of Winter's seasonal model, which in turn is a more general form of the basic exponential smoothing formula.

9.2. Practical Considerations

With a parts range containing over 12,000 part numbers the more computationally cumbersome methods of controlling stocks were not acceptable to CompAir. This applied not only to methods of deciding on re-order levels and order quantities, but also to methods of forecasting future demand. In this respect, the comments of Stern (110) are especially pertinent.

This consideration eliminated from the range of practical possibilities the joint calculation of re-order level and order quantity, but in any case, the question of an economical order quantity is most complex in the context of the CompAir spares operation. For the relatively small proportion (approximately 25%) of parts bought directly by the spares division, it is questionable how sensitive the company's total purchasing costs were to order quantities, and the task of identifying specific attributable costs was complicated by the fact that many of the processes were carried out by cost centres attached to the Original Equipment factory. Nevertheless, for bought-out components, the structure of the basic inventory cost equation suggests that the order quantity should be a function of the square root of the demand, even if the exact relationship cannot be precisely quantified, and in any event, the shape of the cost/batch quantity curve is relatively flat near the optimum. Consequently, it was considered that estimates of the various cost parameters would at least ensure consistency of the batch sizes within the parts range and that although the total costs may not be minimised, they would be expended among the individual items to the best effect.

For those items sourced from the original equipment factory, which constituted the majority of the range, the spares requirements programme was carried across and merged with the original equipment programme before deciding on batch quantities to be purchased or loaded on the factory. Consequently, the spares order quantity for these items is merely a transfer quantity, based as much on original equipment provisioning considerations as the spares system requirements. Any proposal to alter these quantities would have to recognise the consequences for the Original Equipment factory, and such an investigation was beyond the scope of the project. For this reason, it was decided that for spare parts sourced from the factory, the existing transfer quantities should stand.

The rules for setting the re-order level in a system such as CompAir's can be simply derived from statistical considerations. The objective is to hold sufficient stock to last until the next replenishment delivery, i.e. the re-order point should be a function of the expected demand within the expected lead time. Because both the lead time and the demand are random variables, it is impossible to predict the lead time demand precisely, so that to maintain a specified level of service, it is necessary to hold safety stock, the level of which is a function of the variability of the demand and lead time. If the lead time variability is not significant, it can be ignored, and assuming a normal distribution, the maximum likely demand in a given lead time can be calculated, with a known risk that this demand will be exceeded, i.e.

$$E = \hat{D}\hat{L} + K \hat{\sigma}_D \sqrt{\hat{L}}$$

where E = Maximum expected demand

$\hat{D}$ = Most likely demand rate

$\hat{L}$ = Most likely lead time

$\hat{\sigma}_D$ = Most likely demand population standard deviation

K = Safety factor, obtained from reference to tables of cumulative normal distribution function, for a given level of service.

These considerations ignore the effect of batch size, in as much as smaller batches increase the number of occasions on which a stock-out could occur. However, there are many other approximations in the technique, such as the normality of the demand distribution, so that an imprecise result is inevitable. In operation, it would be within the discretion of the system managers to adjust the operation controls to achieve the desired result. For example, a system which consistently provided a higher level of service than the company objective could achieve savings in stock by progressively reducing the value of "K".

Where the lead time also varies significantly in a random fashion, the lead time demand is even less predictable, and additional safety stocks are required for a given degree of risk. If both the demand and the lead time are normally distributed, then it can be shown that the lead time demand is also normally distributed with a standard deviation given by:-

$$\sqrt{\hat{\sigma}_D^2 \hat{L} + \hat{\sigma}_L^2 \hat{D}^2}$$

Thus, using the previous line of argument, the maximum likely demand can be derived

$$E = \hat{D}\hat{L} + K \sqrt{\hat{\sigma}_D^2 \hat{L} + \hat{\sigma}_L^2 \hat{D}^2}$$

2

This equation requires forecasts to be made of four parameters.

i. The most likely demand rate.

ii. The probable lead time

iii. The standard deviation of the population of possible demand rates.

iv. The standard deviation of the population of possible lead times.

Strictly speaking, items iii. and iv. are no less a forecasting exercise than items i. and ii. but because they are more stable, it is considered sufficient to estimate their future values from an exponentially smoothed average of historical values of the mean absolute deviation of the relevant variable.

It is usual to treat the lead time in a similar manner. Although there is no real justification for assuming that lead times are less susceptible to time dependent disturbances than demand patterns, it is not usual to incorporate seasonal or trend terms in a lead time forecast. Certainly under the cyclic circumstances observed at CompAir, it is possible that the inclusion of a trend term could be more accurate. However, it was felt that such investigations would lead to unacceptably complex re-order rules, whereas the conventional approach of using a simple single exponentially smoothed average would still achieve the primary objective of reducing the effects of the trade cycle.

In the previous section (9.1) many methods of deriving a demand forecast were examined, and a high proportion eliminated from further consideration for application at CompAir for one or more of the following reasons:-

i. A high degree of skill and personal intervention required to develop the forecasting model, making the technique impractical at a piece part level.

ii. Excessively demanding of computing facilities. This includes those techniques based on a simple model such as exponential smoothing, but where updating of the smoothing constants is expensive, e.g. the approach described by Eilon and Elmalah (38).

iii. Inflexibility of the method to adapt to changing circumstances.

What was required at CompAir was a relatively simple system which could be applied to a whole range of parts and produce "automatic" forecasts, yet be easily adjusted by the system managers to suit changing circumstances or objectives.

This restricted the selection to either simple exponential smoothing (with and without seasonal and trend terms), higher orders of exponential smoothing, or one of the various adaptive forecasting techniques. Of the latter, the Trigg-Leach method, and Shone's modified version appeared to be both simple and effective (95). Its sensitivity to changes in the underlying demand pattern should theoretically make separate consideration of trend and seasonal variations superfluous, while avoiding the additional data and calculating capacity such techniques require. Consequently, only two forecasting systems were selected for further considerations:-

i. Simple exponential smoothing, without any trend or seasonal terms, representing the most basic alternative to the existing twelve month average.
ii. Modified Trigg-Leach, representing the most complex which could be considered for CompAir.

The two re-order level rules discussed earlier both represented a theoretical advance over the existing CompAir rules, but it was necessary to establish whether the financial benefits justified the costs of implementation, and whether there was any significant material difference between these alternatives.

These arguments were put to the company in September 1977 (ref. 73) and it was agreed that tests should proceed on the two alternative re-order level rules, and on the two alternative methods of forecasting demand.

Three complete sets of stock control rules were constructed for comparison with the existing set:-

Option 1. In which the re-order level is based upon consideration of the forecast demand and its variability and the forecast lead time only:-

$$ROL_{(T)} = \hat{D}_{(T)} \hat{L}_{(T)} + K\sigma_{D(T)} \sqrt{\hat{L}\ (T)}$$

The forecast demand is a simple exponentially smoothed average of historical demand, updated every period.

$$\hat{D}_{(T)} = \alpha \times D_{(T)} \quad + (1 - \alpha) \times \hat{D}_{(T-1)}$$

α = Smoothing constant

D_T = Actual demand in period

$\hat{D}_{(T-1)}$ = Forecast made one period previously.

The standard deviation of demand is estimated from the mean absolute deviation of demand, and is updated each period:-

$$\sigma D(T) = 1.25 \times (MAD_D)_{(T)} = 1.25 \,[\beta \times \left| D_{(T-1)} - D_{(T)} \right| + (1-\beta)(MAD_D)_{(T-1)}$$

β = Smoothing constant

The lead time forecast is calculated in a similar manner to the demand forecast, but is updated only when an incoming delivery is received:-

$$\hat{L}_{(T)} = \gamma \times (L_{(T)}) + (1 - \gamma)\ (\hat{L}_{(T-1)})$$

γ = Smoothing constant

Option 2. These rules were precisely as for Option 1. with the sole exception that the re-order level also recognised the additional uncertainty of a varying lead time:-

$$ROL_{(T)} = \hat{D}_{(T)} \hat{L}_{(T)} + K \sqrt{(\sigma_D^2 \hat{L} + \sigma_L^2 \hat{D}^2)}$$

As with the demand, the likely value of the lead time standard deviation is estimated from the mean absolute deviation of the lead time, but is updated with each delivery:-

$$\sigma L(T) = 1.25\ (MAD_L)_{(T)} = 1.25[\delta \times |L_{(T-1)} - L_T| + (1-\delta)(MAD_L)_{(T-1)}]$$

δ = Smoothing constant

Option 3. As for Option 2, except for the demand forecast.

$$\hat{D}_T = \mu\ D_T + (1 - \mu)\ \hat{D}_{(T-1)}$$

where $\mu = \left| (SMERR_D)_{(T-1)} \div (MAD_D)_{(T-1)} \right|$

SMERR(D) being the smoothed error of demand, calculated precisely as the mean absolute deviation (MAD) except that the sign of the error is recognised:-

$$\mathrm{SMERR}(D)_T = \beta(D_T - \hat{D}_{(T-1)}) + (1 - \beta)(\mathrm{SMERR}_D)_{(T-1)}$$

It can be seen that comparison of Option 1 with the existing rules would indicate the benefits of monitoring the demand varability and also afford the opportunity of assessing the effects of different smoothing constants. Comparison between the first and second Options would indicate what advantages would accrue from monitoring the variability of the lead time. Finally, comparison between the third option and the second would demonstrate the difference in the effects of adaptive smoothing and simple exponential smoothing.

CHAPTER 10

THE SELECTION OF ALTERNATIVE CONTROL RULES

10.1. Methods of Comparison

As mentioned in Chapter 8, simulation can be a most effective tool for assessing the performance of any given policy under operating conditions, and many examples of such applications were cited. However, none of the studies described met the essential criteria for the purpose in hand:-

i. To consider several levels of a multi-echelon system, with independent policies at each level.

ii. To deal with the dynamic interactions of the various levels, including the effects of and upon the manufacturing lead time.

iii. To examine specific stock control policies applied to a range of components.

iv. To examine specific production control policies as applied to a range of components.

v. To run for an appreciable period of simulated time (eight years minimum) without using excessive computer capacity.

The need to include the production control system arose from the philosophical differences between the existing system and the proposed alternatives. In the existing system, the stock level parameters (reorder levels and quantities) were fixed without reference to demand variability. This sytem operated by constantly monitoring component stock levels, and passing on the effects of demand variations to the production facilities, in the form of revised priorities. Thus an item which had experienced a period of higher-than-average demand would cause the"due date" on the next delivery of components to be brought forward.

On the other hand, all the proposed alternatives were designed to monitor demand variability and accommodate it within their safety stocks, using the rescheduling ability of the production control system only as an added precaution.

Apart from practical questions concerning the ability of the production sources to respond to changing priorities, and the effects such changes have on factory efficiency, there was a need to test whether such a system could respond better to a volatile and cyclical demand pattern under idealised conditions.

The industrial dynamics model had already shown itself capable of meeting criteria i. ii. and v, the program requiring less than 12K words of memory and less than 36 seconds of processor time on an ICL 1904S to simulate eight years of operation. However, the method did not meet the other two requirements, being incapable of operating at the detailed part level. Since this degree of detail was only required at one level (the factory warehouse) it was decided to construct a composite model, in which a detailed simulation of a stock and production control system would be substituted for the usual industrial dynamics equations at this one level.

Although the program would be bigger (to accommodate individual component attributes for each member of the parts range) and would undoubtedly take longer to execute, it still promised to be a highly efficient method of simulating the necessary conditions.

The exercise was divided into four stages:-

i. To select or construct a suitable parts range.

ii. To construct a detailed inventory system model, to be used to test various control policies. This model would be used on its own to perform a preliminary assessment of the options selected thus reducing the variety to be tested on the composite model.

iii. To combine the industrial dynamics model and the detailed inventory system model.

iv. To test the effects of various control policies and compare them with the existing system. The composite model could also be used to test the effect of different system structures e.g.direct feed back to the factory warehouse on the level of distributors' sales.

10.2. The Simulation Parts Range

In the interests of program efficiency, it was desirable that the parts range should be as small as possible while representing the CompAir range with respect to demand, supply and value characteristics. These characteristics were functions of five component characteristics:-

Mean demand
Variability of demand
Mean lead time
Variability of lead time
Unit cost of each component

The inclusion of the cost parameter was necessary to enable comparisons with the existing system to be made, since it controlled component stocks according to the value of their average monthly demand. It was thought desirable to include at least three values of each of these variables (a typical or mean value, and a high and low value). This set the range at 243 (=3^5) components. However, the inclusion of the cost factor had introduced a further degree of complication. To achieve correspondence with the effects of the existing system on the real parts range, it was necessary to ensure that each value category should contain similar proportions of the range, both by value and by volume in the simulation and the real world. Furthermore, since the alternative rules reacted to demand variability, it was also necessary to ensure that the simulated range and the real parts range were similar in this respect.

Reconciling all these requirements within a limited sample of actual components seemed impossible, so it was decided to construct a pseudo or artificial parts range, using hypothetical but representative values for the demand and lead time parameters. By utilising the relationship between the mean demand and demand variablity, (see Chapter 8.1) it would be possible to eliminate one of the variables, yet ensure compatability with the real parts range. The cost parameter values would not be representative, since it was this variable which would be manipulated to ensure that the correct proportion of the range fell into the various value categories, while ensuring that the mean demand of each category (especially value category 1) was of the right order.

Details of the constitution of this first artificial parts range are given at Appendix 8, but Fig. 41 shows how the distribution of this range differed from the CompAir parts range.

CompAir Value Category (V.C.)	% of Range		% of Turnover	
	Dummy Range	CompAir Range	Dummy Range	CompAir Range
V.C.1. (Monthly usage £150 +)	10	5	63.4	65.6
V.C.2. (Monthly usage between £35 and £150)	10	10.4	25.4	22.4
V.C.3. (Monthly usage between £10 and £35)	15	14.2	7.4	8.1
V.C.4. (Monthly usage between £3 and £10)	15	16.5	2.6	2.8
V.C.5. (Monthly usage less than £3)	50	53.9	1.2	1.1

Fig. 41

Comparison between Compair & Dummy Parts Range

The correspondence is in general very good, the exception being the number of lines in Value Category 1, the dummy range containing twice the proportion found in the real range.However,the proportions of value agree very closely, and the mean demand of the two ranges agree very closely (150 units per month for the artificial range and 167 for the real range).

Thus the parts range consisted of the members of a four dimensional matrix, with the following dimensions:-

Three values of mean lead time

Three values of lead time co-efficient of variation

Three values of mean demand
Four values of unit cost

In order to achieve the parts range characteristics described, certain combinations of values could not be used, reducing the size of the parts range to 90 243
items.

10.3. The Purpose of the Basic Inventory Control Model

It was decided that the basic simulation models should be as simple as possible, representing a crude approximation to the real world, and designed only to reduce the range of options to one or two alternatives to the existing system. A more realistic comparison would subsequently be made using the composite model. The major deficiencies of these basic models were recognised as their failure to incorporate the interaction of the stock control system with the distributors and with the supply sources. However, in the case of bought-out parts, this latter problem could be overcome. Firstly, the variations in lead time were less significant than with production sourced items, and were at least partly due to the general effects of the trade cycle rather than the specific increase in demand for CompAir parts. Secondly, although the production control system rescheduled parts according to the latest priorities (as with production sourced parts), it was believed that the scope for achieving any change in delivery was more restricted when dealing with outside suppliers. By artificially inducing the lead times to vary cyclically in sympathy with the demand cycle, the basic model could provide an approximation to the system as applied to bought-out parts. Thus the basic model would not only be used to preselect systems for subsequent assessment using the composite model, but could also be used to provide some direct results for application to the bought-out system.

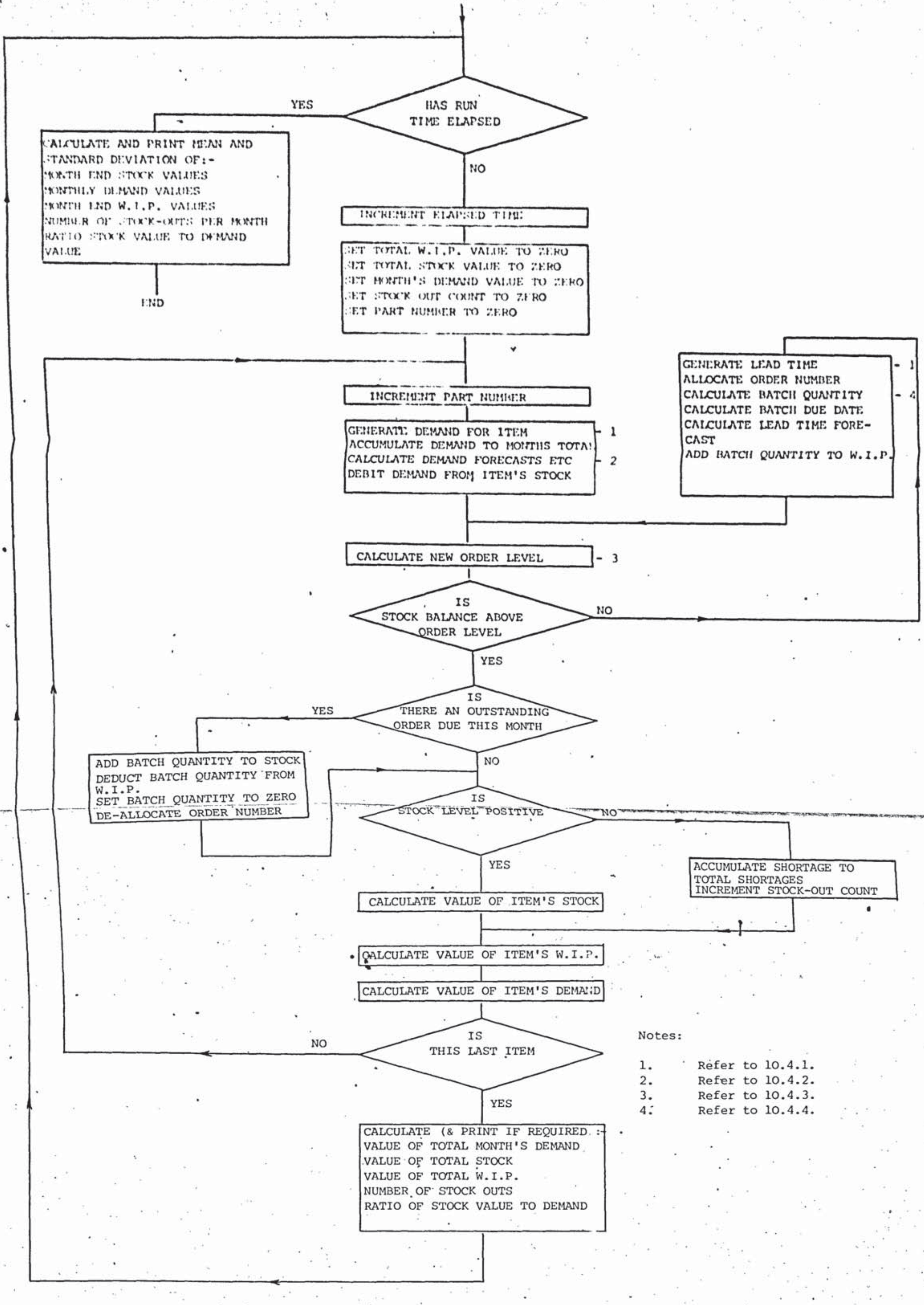
10.4. Model Structure

The time increment of the model was set at one month, as this represented the effective review period of the existing system, and all the operating data and statistics referred to this period.

The basic logic for each of the several models is shown in Fig. 42. The models were written in ICL Extended Fortran, and an example is given of a typical source program at Appendix 9.

10.4.1. Demands and Lead Times

For each component these were generated by the Monte Carlo technique. Demands with a mean of less than five units per month follow a Poisson distribution, whereas all other demands and the lead times follow a normal distribution, accor-



Notes:

1. Refer to 10.4.1.
2. Refer to 10.4.2.
3. Refer to 10.4.3.
4. Refer to 10.4.4.

SCHEMATIC DIAGRAM OF BASIC INVENTORY MODEL

FIG. 42

ding to the specified demand parameters.

In the demand and lead time generator, only ten possible values were allowed from each normal distribution, and the distribution was truncated at 1.65 standard deviations either side of the mean. Any values less than zero were equated to zero. (Surprisingly, this closely resembled the distributions of demand observed on a significant number of CompAir components. When subjecting these distributions to a "chi squared" test, a better fit was obtained if the sub zero figures of the theoretical normal distribution were aggregated with the zero figures than if they were ignored).

The fortran code for the subroutine ('Rand') including the pseudo random number generator is also given at Appendix 9. Because a new demand was required each month by each component, one seed would uniquely define a series of demands which could be repeated consistently. However, the precaution was taken of separately generating a series of seeds for each part number (using a similar generator) and then identifying each part number with its own series of random numbers, but the effect of generating a repeatable sequence of random demands was the same. Because the demands thus generated were independent the total demand value each month was also a random variable, constrained only by the means and standard deviations of its constituents. In order to emulate the conditions at CompAir the facility for superimposing a cyclical pattern was provided. (The effect of the cyclical pattern was superimposed on the randomised demand figure, so that the variability of the demand also varied in sympathy with the cycle).

The lead time generator operated in a precisely similar fashion, only in this case, the provision of a repeatable sequence of random numbers for each part was essential. Since the requirement for a lead time is itself a more random event, this technique ensured that the same part number experienced the same sequence and values of lead times when the system is operating under different rules, even though the lead times would not necessarily apply at precisely the same times.

10.4.2. Calculation of Forecasts (see Fig 42)

This refers to those activities which require the latest demand information, and varied from model to model. At its simplest, the model used the information to calculate a new forecast, whereas more sophisticated versions would also monitor the forecast error, and in the case of the version using Trigg-Leach forecasting, calculate the new smoothing coefficient.

10.4.3. Order Level Calculation

The batch sizes selected by the CompAir system were such that in most cases there was more than one batch outstanding for any given part number, so that the re-order level had to recognise the total outstanding work-in-progress. Where the batch size is as low as one month, it is possible that in some cases increasing the work-in-progress level by one month's demand would be insufficient. It was therefore necessary to recheck after raising one order, and raise another if required.

10.4.4. Batch Quantities

The model of the existing system applied the value classification technique to each item and is directly comparable with the existing system.

As mentioned in the previous chapter, it was impractical to identify the cost of placing a purchasing order. However, it was considered that for bought-out parts, some attempt should be made to relate the order quantity to the stock holding and marginal purchasing cost. After consideration of some of the costs involved (stationery, postage, telephones, transport and certain inspection costs) the marginal cost of each order was estimated to be approximately £6 and this figure was used in the basic economic order quantity calculation, used by all the alternative stock control systems being considered. The other assumption in this formula was that the cost of holding stock was 20% p.a. The batch quantity was calculated thus:-

$$QR = \sqrt{\frac{2 \times C_o \times 12}{M \times i \times C_u}}$$

QR = Batch size (in terms of months of demand

C_o = Marginal cost of raising and procuring an order (£6)

M = Average Monthly demand

C_u = Unit cost of item

i = Stock holding cost rate (20%)

10.4.5. Additional Activities

For the sake of clarity, the logic diagram does not show the activities required to monitor performance and obtain the means and standard deviations of the various measures. This monitoring only commenced after an initial period of stabilisation, which after trials was set at 50 months.

10.4.6. Output

As shown on the diagram, the simulation could produce monthly figures for the principal measures of effectiveness, but these figures were mainly for use in verifying the models, and could be suppressed. Another option available, solely for use in verifying the models, was to produce a table of the stock level, work-in-progress, and number of stock-outs to date for each part number. However, once the models were satisfactorily verified, most attention concentrated on the summaries produced at the end of the run, and in particular, the stock level and the two measures of service. These are described in detail in the section on experimental design.

10.4.7. Input

In addition to the three sets of data required to specify the parts range characteristics, data was also required to set the stock control parameters, the random number generator seeds, the run length, etc. This data was read in from a data file prior to setting the initial conditions. To ensure consistency of input, one data file was used for all models in any given experiment. This file also specified the demand pattern, i.e. steady state (or stationary), or cyclical and, if the latter, the amplitude and period of the disturbances.

10.5. Initial Conditions

Conway (30) puts forward a most convincing argument for ensuring that in simulation experiments of comparison, the starting conditions should be identical for each simulation for the comparison to be valid. He also points out that the common practice of starting with the system "empty and idle" can be most inefficient. This is very true of stock control models, where the smoothing effect of the various forecasting systems exacerbate the problem. Conway suggests using a set of initial conditions which are a compromise between the expected "steady states" of the system under examination. In this instance however, whatever option was to be implemented, it would have to take over from the existing system. It would thus not be unreasonable to establish the initial conditions for all experiments as an idealised version of the expected steady state of the existing system.

Each component was assumed to have a stock level with an evenly distributed probability of being between the minimum stock objective and one batch size greater, and zero probability of taking any other value. The actual value was determined by a pseudo random number generator, similar in principal to that used in the demand generator. This stock level, when compared with the average demand, indicated the timing of the next replenishment. The size of this replenishment, and the relevant lead time then dictated the number and timing of subsequent replenishments. The initial conditions thus established a stock level, a work-in-progress level, and an order list with due dates for each component. The value of the stock and work-in-progress levels, together with the distribution of parts in the value categories were displayed as part of the standard print out (see Fig. 43). *

10.6. Verification of the Model

The purpose of the basic inventory control model was to provide an environment which would distinguish which of the options available (including the existing rules) intrinsically performed more effectively. The rules were explicit and clearly defined, while the correspondence between the real and simulated parts range and demand patterns was ensured by the selection of suitable input data (as discussed in 10.2). The verification exercise could therefore concentrate on ensuring that the model was behaving precisely according to the intended logic. A number of tests were applied which confirmed that this was so.

```
----------------------------------DET INV MODEL2,(BAW H.0),DIP.09.08.78.

            INPUT PARAMETERS

LEAD TIME AVERAGES      2.0      3.0      4.0

DEMAND AVERAGES        1.00   150.00    50.00

LEAD TM VARN RATIO     0.10     0.15     0.40

UNIT COSTS     0.05    0.20     0.80     2.00

CYCLIC PARAMETERS-PERIOD= 52.0  START=50  HEIGHT= 0.1
SMOOTHING PARAMETERS:-  DEMU.20  ADAPTU.05  LEADU.20  H.A0.2  N.A1.0  N.A0.0  QR1.00  N.A0.0

RUN LENGTH 355MONTHS

VALUE CATEGORIES LIMITS: 150.   35.    10.     3.
 NO OF STOCK    VAL OF MONTHS     MONTH-END      WIP      STOCK     MONTH  VC1  VC2  VC3  VC4  VC5
  -OUTS             SALES         STOCK-VAL      VAL    HELD(AV)     NO

                                   19114.7     14713.0               0          9    9    9   13   45
  AVERAGE & STD DEVN VALUES OVER LAST 305  PERIODS

      9.28          4596.3         10482.3     12047.2      2.3

      7.36           785.8          3828.1      5542.7      2.3

 TOTAL MONTHS/ITEMS WITH ZERO STOCK:*54101926.

 SERVICE(2)= 83.0202
```

BASIC MODEL TABULAR OUTPUT

Fig. 43

Since the pseudo random number generators were all based on a simple mathematical expression, using specified seeds, it was easy to calculate manually the initial conditions and the results of the first and second months simulation. The time consumed made manual verification impractical over longer periods.

A second test was made to ensure that the re-ordering and stock balancing routines were operating correctly. Two runs were performed, identical except for their durations, which differed by one month. The optional print of individual terminal stock and work-in-progress figures was obtained for each run, and comparison of two corresponding sets of figures for each part confirmed that the correct rules were being applied.

In the case of the model of the existing system, further confirmation was provided by observing the distribution of the component range in the value categories and also by comparing the average stock holding predicted by the model (with a stationary demand) with the theoretical stock holding (see Appendix 3).

The lack of any bias in the pseudo random number generators was confirmed by monitoring the monthly demand figures, but the comparative nature of the experiments, with exact correspondence of demands from model to model were thought sufficient to eliminate any chance of the random numbers affecting the result.

10.7. Experimental Design

In order to provide a common basis for comparison, it was considered that the performance of each set of stock control rules could be described by a plot of the service level against the stock level. To obtain one curve, it was necessary to perform a series of runs, in which the objective stock level was altered, and to observe the resulting service level. In the case of the model of the existing rules, this effect was achieved by altering the "minimum stock" objective figure by a constant ratio for each component for the duration of each run. For the other options the safety stock factor (K) was altered in the re-order level calculations.

In view of the limited objectives set for the basic model, only three sets of experiments were necessary:-

i. To assess the effects of different "seeds" for the random number generators, and to establish the minimum duration for these effects to disappear.

ii. To compare the performance of the different stock control rules under stationary demand and lead time conditions.

iii. To compare the performance of the options with cyclically varying demands and lead times.

For these experiments, the exponential smoothing constant was set at a value of 0.2 in line with common practice, whereas the smoothing constants used in the adaptive smoothing model were set at 0.02, as recommended in the original artical by Trigg and Leach.

The first series of experiments was necessary to ensure consistency of results, and reduce the probability that any given result was the effect of chance. The standard tests of significance were of dubious value, since they assume a population with a normal distribution. With the serial correlation which existed in the monthly stock figures, and the effects of the cyclically varying demands and lead times, such assumptions were not valid. It was considered to be more satisfactory to determine empirically the minimum run length necessary to establish the stock levels consistent within 0.1 month's demand for various seeds.

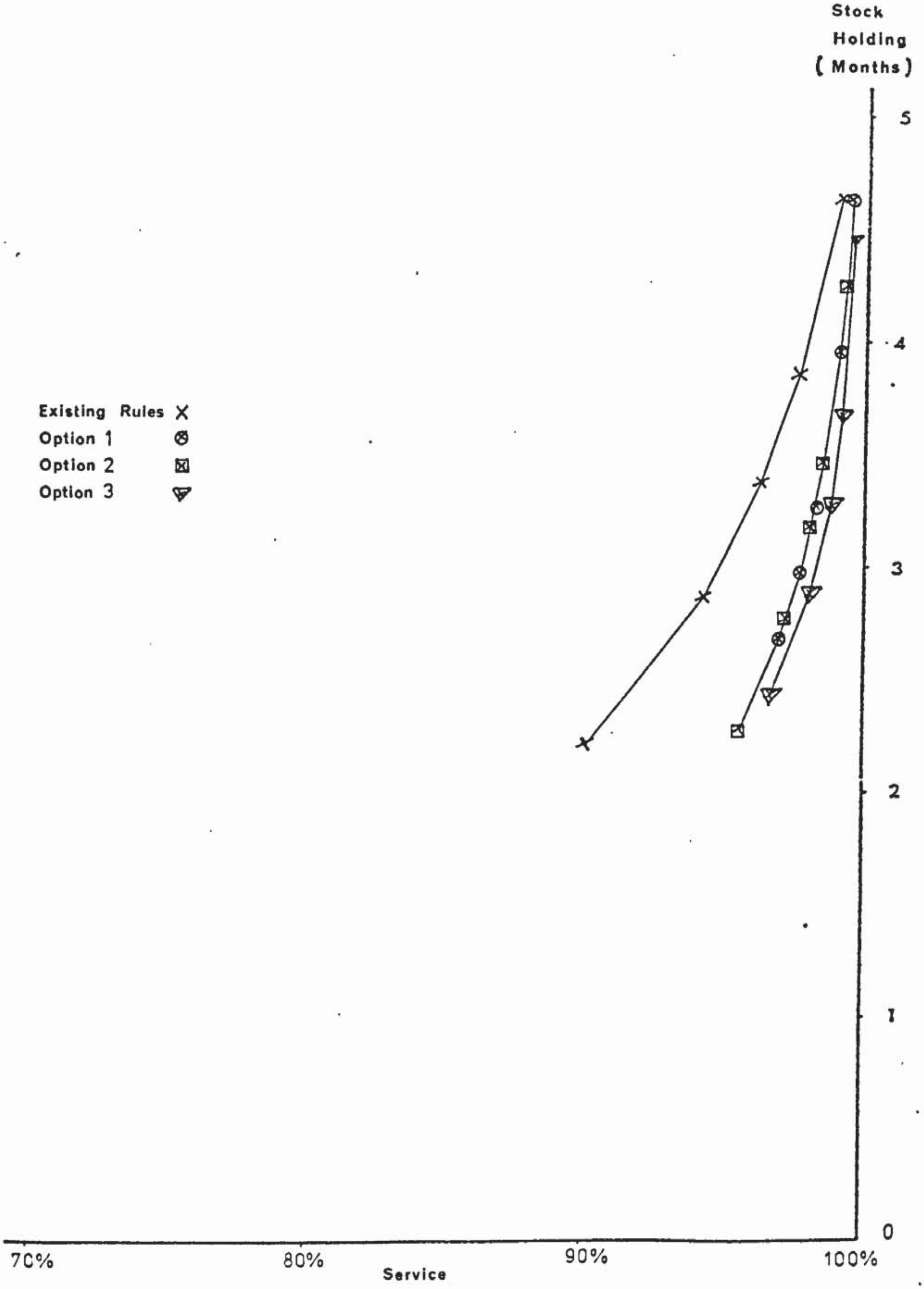
In the subsequent experiments, the performance of the system was assessed using two measures of service.

The first registered the number of stock-outs which occured each month, expressed as a percentage of the parts range. Thus a stock-out on four items out of the range of 90 items gives a service level of 95.56%. This measure monitors what proportion of the parts range is being adequately controlled, but ignores the size of the stock-out and its duration. These two factors are most significant from the customers' point of view, especially when relating to spare parts. The second measure of service monitors these variables, and expresses the result as a percentage of the total potential shortage duration for the simulation run (i.e. the total accumulated demand each month multiplied by the period to the end of the run). This figure is shown as "SERVICE (2)" in the computer prints.

Appendix 10 shows the tabulated results for the two comparison experiments, from which the performance curves shown in Figs. 44 to 46 were plotted. In the final experiment, with cyclical variation of both demand and lead time, the sequence of runs was repeated with different seeds for the random number generators, to create further confidence in the results.

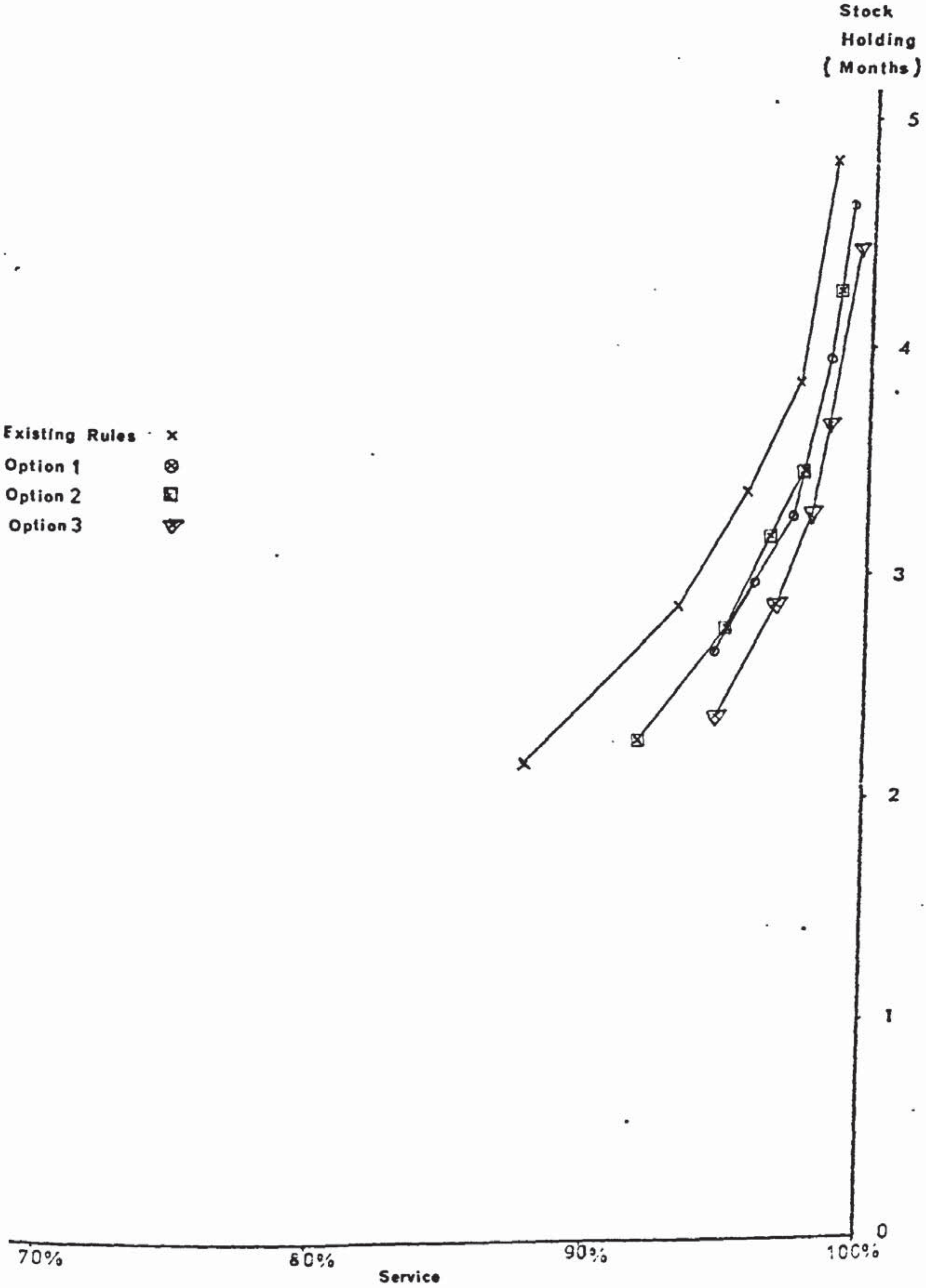
10.8. Results from the Basic Inventory Model

Figs. 44 and 45 show the operating characteristic



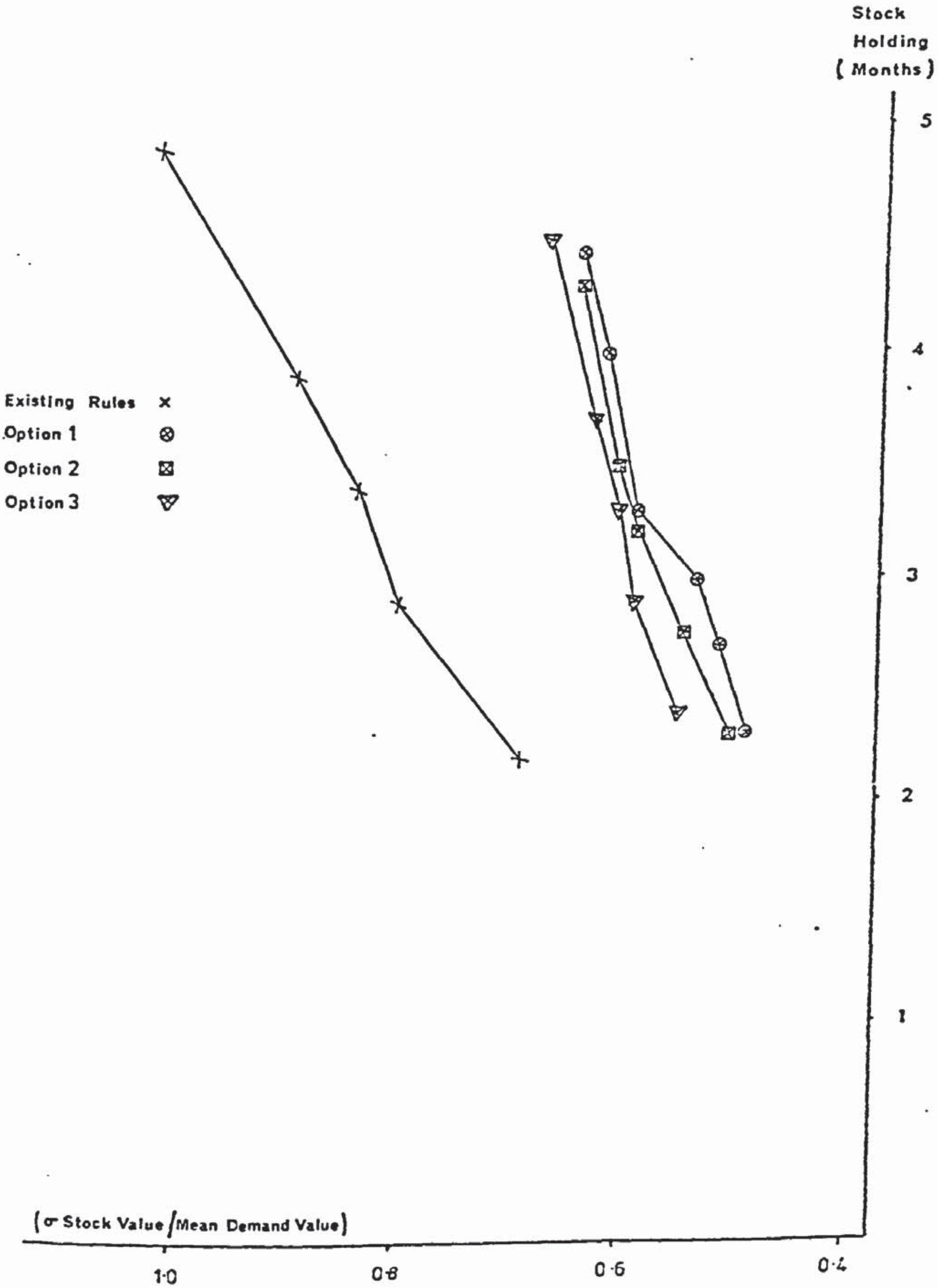
BASIC MODEL PERFORMANCE — STEADY CONDITIONS — SERVICE LEVEL 1
(NUMBER OF STOCK—OUTS)

Fig. 44



BASIC MODEL PERFORMANCE – STEADY CONDITIONS – SERVICE LEVEL 2
(SIZE & DURATION OF STOCK-OUTS)

Fig. 45



BASIC MODEL PERFORMANCE — STEADY CONDITIONS — STOCK STABILITY

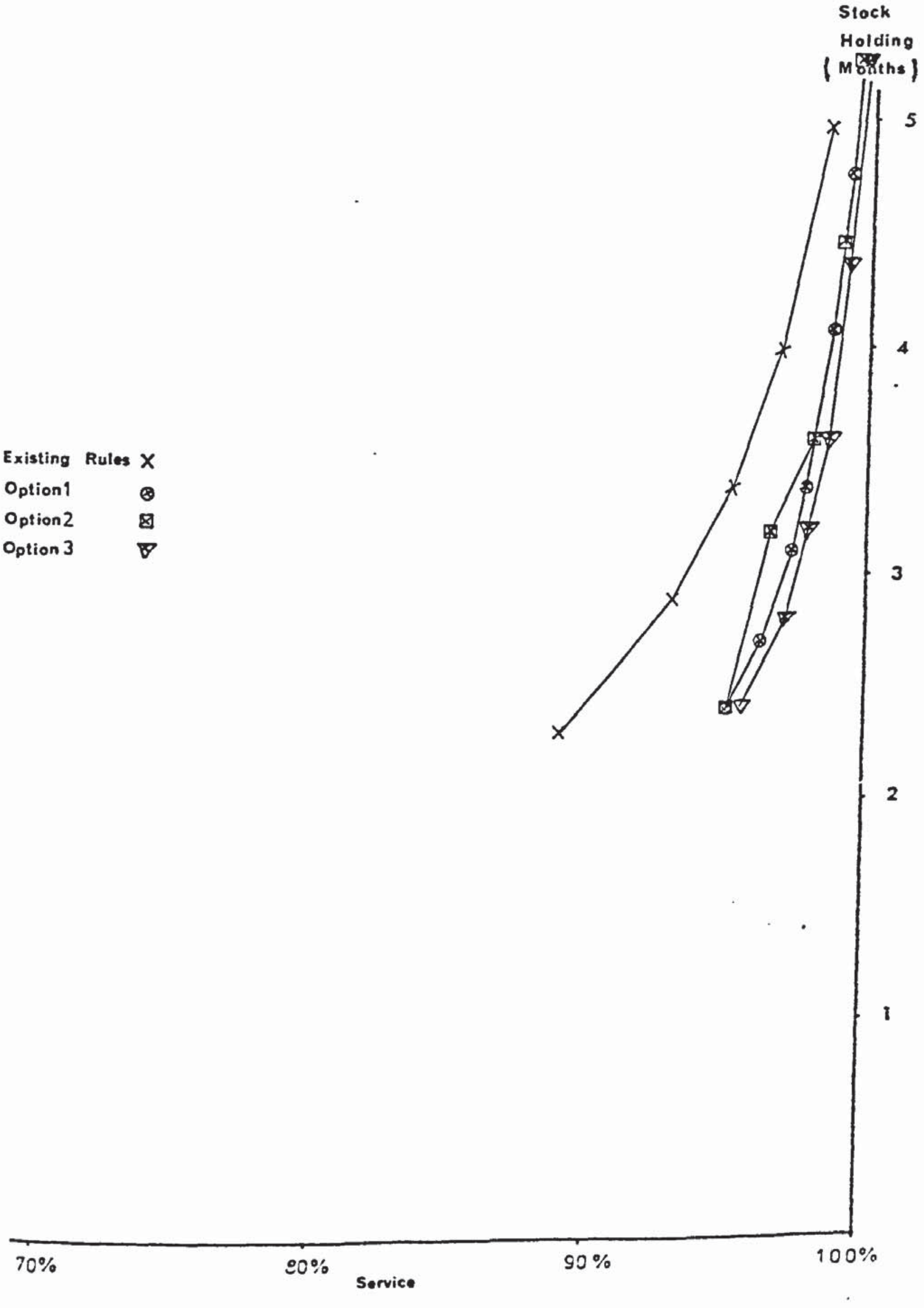
Fig. 46

curves for the existing rules and the three potential alternatives under steady state (stationary means for the lead time and monthly demand figures). The most significant point is the clearly inferior performance of the existing rules, which consistently provide a lower level of service for any given level of stock. Between the different options, the difference in performance is smaller, and the results suggest that there is no benefit in monitoring the lead time variability, and adjusting the safety stocks to suit, as the curves for options 1 and 2 appear to be co-incident whereas the further refinement of using adaptive forecasting does effect some improvement. The relative merits of the systems are supported by both measures of effectiveness, and comparison between the two sets of curves shows that the more effective rules not only reduce the number of stock-outs under any given circumstances (Fig. 44) but the stock-outs are less severe (Fig. 45).

Fig. 46 shows the standard deviation of the stock level (expressed as a percentage of the monthly demand), plotted against the stock holding, and indicates the stability of the stock holding under each of the options. Once again, the existing rules are the least satisfactory, but of the alternatives, the simplest set of rules give the most stable stocks.

When operating under cyclical conditions, all the options provide a lower level of performance, but the relative positions are maintained. Once again there is no apparent benefit in monitoring the variability of the lead time, since the characteristic performance curves for options 1 and 2 are nearly identical whichever measure of service is used. The measure which recognises the size and duration of stock-outs (Fig. 48) again proves the more discriminating and emphasises the differences in performance measured by counting the number of stock-outs (Fig. 47).

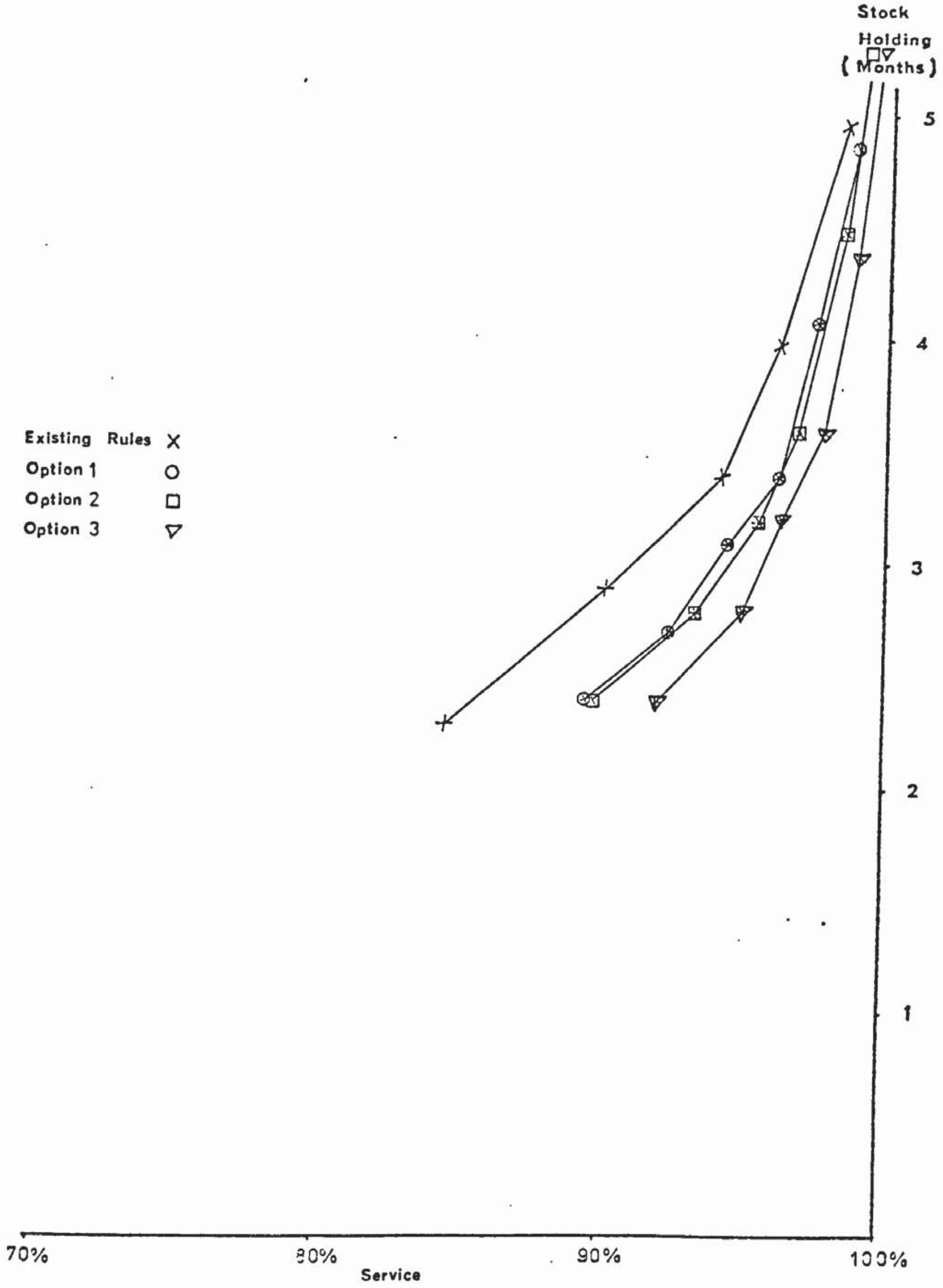
Unfortunately, because of the simple nature of the model, it was impossible to draw any direct parallels between the historical performance of the existing rules, and the performance predicted by the simulation runs. Furthermore, it was understood that, in practice, the rules were not being followed exactly (see Chapter 6. paragraph 4.2.3.) and that there was a wide discrepancy between the theoretical stock holding and the actual. Nevertheless, there was evidence that adoption of any of the proposed alternatives would enable the company to maintain a 95% service level (as measured by the number of stock-outs) with approximately one month's stock less than that necessary using the existing rules, assuming that the cyclical variation in demand and lead times



BASIC MODEL PERFORMANCE – CYCLICAL CONDITIONS – SERVICE LEVEL 1

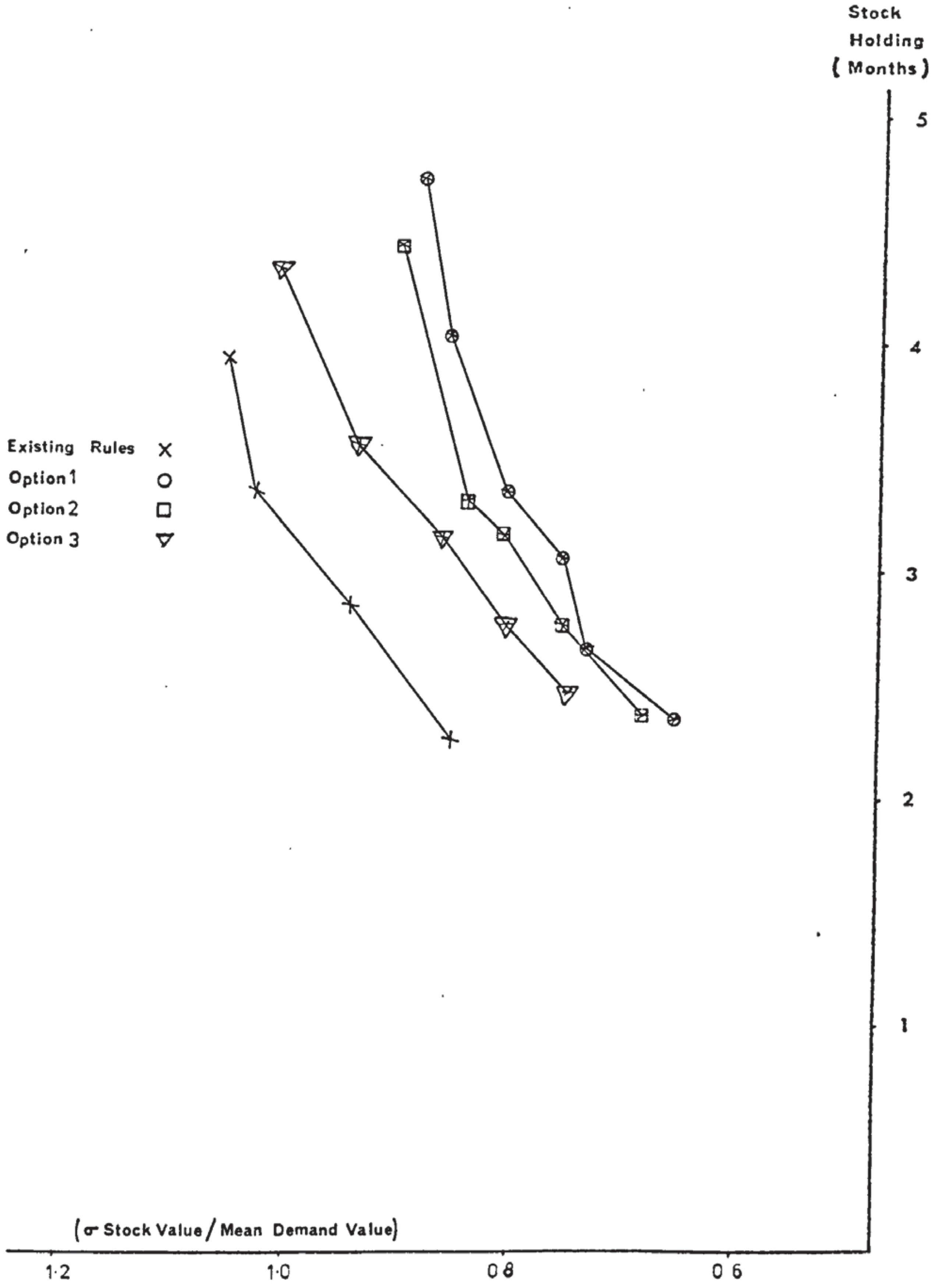
(NUMBER OF STOCK-OUTS)

Fig. 47



BASIC MODEL PERFORMANCE – CYCLICAL CONDITIONS – SERVICE LEVEL 2

Fig. 48



BASIC MODEL PERFORMANCE — CYCLICAL CONDITIONS — STOCK STABILITY

Fig. 49

observed in the past continue to follow similar patterns.

In selecting which of the options to implement, the criteria were:-

i. Efficiency
ii. Simplicity, so that the rules could be understood and accepted by the operating personnel.
iii. Stability, so that fluctuations in stock were kept to a minimum. By selecting a set of rules which give stable stocks under cyclical conditions, it would be easier for management to exercise its discretion to alter stock and service objectives to suit changing financial and operating conditions.

Examination of the various curves shows that, although Option 3 is the most efficient of the rules, (i.e. it provides the best service for any given stock holding), it is also the least stable of the alternatives. Furthermore, the complexities of the adaptive forecasting technique would not only require greater computer time than Option 1. but would also be difficult to explain to the spares personnel. Consequently, an interim report was submitted to CompAir management, recommending that the rules described as "Option 1" should be used to control the stocks of parts sourced from outside suppliers (ref.

74). It was also decided that these rules should be subject to further tests to assess their suitability for controlling made-in parts.

CHAPTER 11

THE COMPOSITE MODEL

11.1. Model Structure

Fig.50 shows the general model structure, and it can be seen that both the factory and the distributor network are represented exactly as in the original industrial dynamics model. However, to accommodate the detailed inventory model, some additional equations of the industrial dynamics type have been added, while others which formerly dealt with aspects of inventory, are now redundant.

The input to the inventory model is RRF (Requisitions Received at the Factory) and is unaltered. The level UOF (Unfilled Orders at the Factory warehouse) is retained to provide an input to the variable LAR, which monitors the distributors' actual level of outstanding work-in-progress.

The input to the factory is again MWF (Manufacturing rate Wanted at the Factory) but it is dependent solely upon one input (OIC) which in turn is calculated from OPC. As in the real system, the inventory model reviews stock at each transaction (or every time increment) and raises an order when re-

SCHEMATIC DIAGRAM of the COMPOSITE MODEL

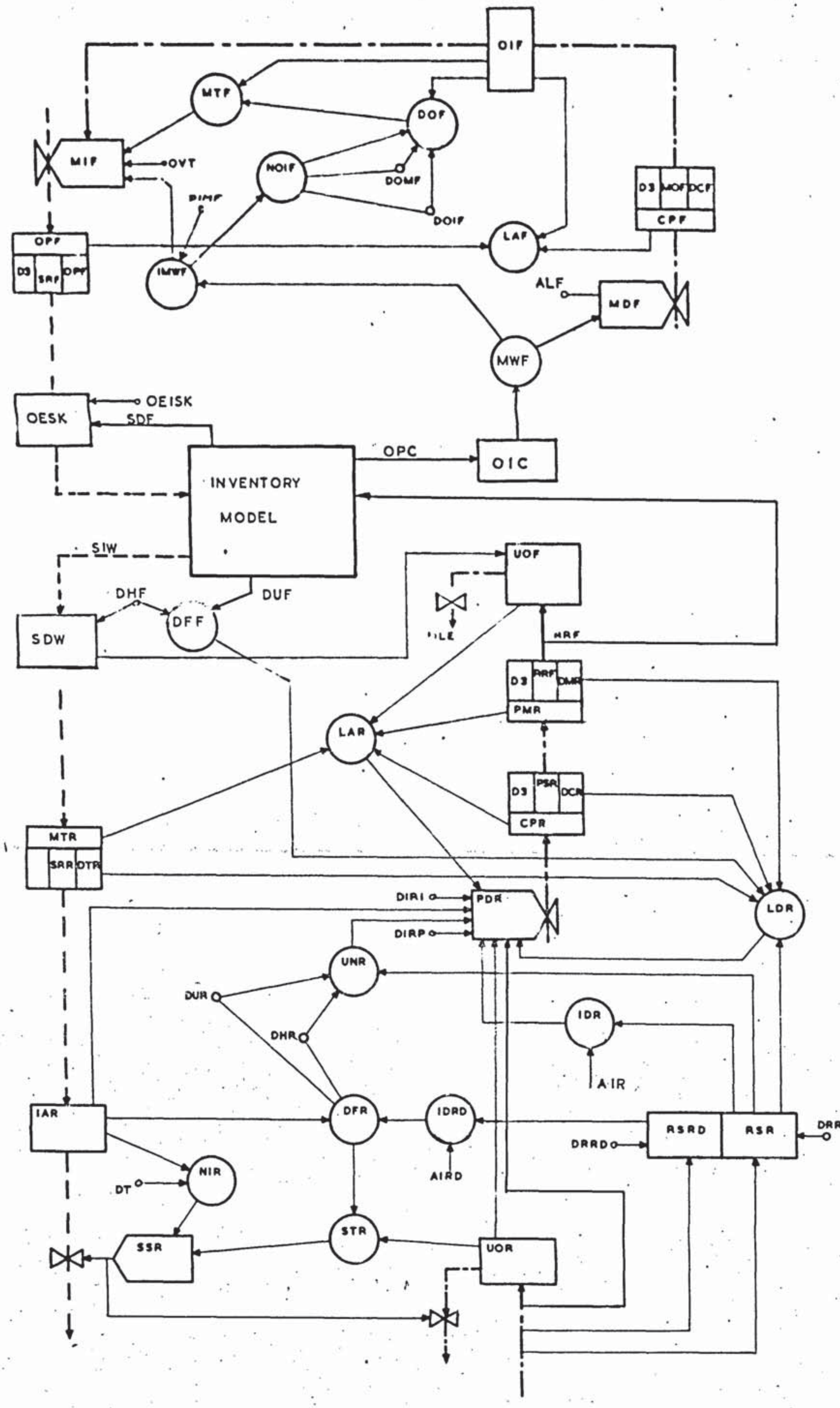


FIGURE 50

quired. These are accumulated in a level, Orders to be Processed by Computer (OPC) and these orders are released, as a batch once every month, to another level, Orders to be Issued from Computer (OIC). This level is decayed exponentially with a time constant of one week, thus representing the flurry of ordering activity at the beginning of each month. The equations are:-

(a) Once every month

$$OIC_T = OIC_{T-1} + OPC$$

(b) and every time increment

$$MWF = OIC_T / DIC$$

(DIC = Delay in Issuing from Computer)

$$OIC_{T+1} = OIC_T - (MWF \times DT)$$

Because the fluctuating value of MWF was difficult to interpret it was necessary to calculate an average value each month (AMWF) for monitoring purposes only.

The warehouse receipts are controlled by the level OESK (Original Equipment StocK level). The factory is geared to the manufacture of original equipment, and although provision is made in the factory production control for the spares requirements, these requirements are only satisfied if the factory requirements have already been met. Thus the ability to satisfy spares requirements is a function of the ratio of the ideal original equipment stock level

(OEISK) to the actual (OESK). The ideal rate of receipt is calculated within the inventory control model from the register of outstanding orders which are due for imminent delivery (Shipping Rate Due at the Factory warehouse: SDF), and the actual rate of receipt (Delivery rate To Stores: DTS) is calculated from these three factors:

$$OESK_T = OESK_{T-1} + DT(SRF - DTS)$$

and either:

$$DTS = OESK/OEISK \times SDF$$

or

$DTS = OESK/DT$ when OESK is too low to support the former value.

When dealing with the warehouse despatch rate, the total throughput delay is split into two, as in the original industrial dynamics model. The delay due to unfilled orders (DUF) is calculated in the inventory model directly from the value of the shortages, expressed in terms of the current level of demand. The handling delay (DHF) is meant to represent all the handling, including order processing, picking and packing, but for convenience is applied at one stage, represented by the despatch process. Thus all orders received in any time increment which the inventory can satisfy are issued during that time increment to the Despatch Department (SIW = Shipments Issued by Warehouse). Here they are subject to the total handling delay which operates on the level SDW (Shipments for Despatch from the Warehouse), and after the delay, are sent to the distributor as SSF, as in the original model. The relevant equations are:-

$$SDW_T = SDW_{T-1} + DT(SIW-SSF)$$

$$SSF_T = SDW_T \,/\, DHF$$

11.2. Reservations concerning the structure

The general structure of the Industrial Dynamics model where it interfaced with the detailed model was thought to be a reasonably good representation of the real system, except where the factory output provided the supply source to the inventory model. For the situation where a factory is devoting its entire effort to satisfying the requirements generated by the inventory system, the model is satisfactory, and could operate without the level OESK. However, at CompAir, the factory in total had many times the capacity required to satisfy the spares demand, and could under favourable conditions, devote a large proportion of this capacity to supplying spares. Conversely, when the level of activity was high, it was clear that spares requirements were allocated a low priority. These remarks apply even more at the detailed component level, where there is the additional complication that the ratio of original equipment to spares requirements varies from component to component. Where the spares requirement is relatively low, then the factory can satisfy large fluctuations in spares requirements easily, as the fluctuations are insignificant compared with the total. However, where the spares requirement approaches the original equipment requirement (as with valves) or exceeds it (as with non-current components) then the factory response is correspondingly worse.

The introduction of the original equipment stock level (OESK) provided a means by which the inventory model could exceed its average rate of drawing supplies in the short term, thus representing the ability of the factory to satisfy high short term spares requirements. It was also necessary to accommodate excess factory production. In the usual situation in which a production facility is dedicated to given inventory system, a decrease in demand normally results in over production until the factory production rate can be adjusted. However at CompAir, any excess production is absorbed by original equipment demand and the stock control system only permits delivery to the spares system of outstanding orders a maximum of one month in advance of their current requirement date. In order to maintain a correspondence between the model and the real system, this constraint had to be simulated, but it was necessary to hold the resulting excess factory output in the level OESK (original equipment stock) in order to maintain internal validity.

The whole operation of the interaction of the spares and original equipment stock and the production control systems is very complex and is certainly the least satisfactory section of the model. However, any improvement would have required modelling the original equipment forecasting and production control systems in the same amount of detail as the spares systems, and this was not possible with the available resources.

Seen against its original objective, this model did fulfil the following requirements:-

i. It included the distributor network, which interacted with the inventory control system, and modified its requirements not only to respond to its own "customer demand", but also in response to the service it received, in a manner similar to that believed to apply in the real system.

ii. It included a factory system which responded to the demands placed on it after a period of delay, and this delay varied according to the demand in a manner which emulated the real system.

The model thus included those elements neglected by conventional stock control theory, and was thought to provide a sufficiently realistic environment in which to assess the relative merits of the stock control rules being considered.

11.3. Parameters used in the Industrial Dynamics Section

There are only two new parameters in the industrial dynamics section, plus one, DUF (the "service" delay) which is calculated in a different manner from the original, and is explained in the next section.

The first new parameter is DIC, (Delay in Issuing orders from the Computer), and setting this parameter at one week allowed the majority of orders to be issued by the end of the second week in the month, thus approximating to the situation observed in the factory production control offices.

The other parameter represents the Original Equipment Ideal StocK level (OEISK) and is used to control the rate of input to the inventory control section.

Analysis of the factory parts range, and the relevant production control rules showed a theoretical stock holding of 1.25 weeks. The ratio of spares demand to original equipment demand is approximately 1:7, so that 1.25 weeks of total factory throughput represented 10 weeks of spares demand.

Since the original equipment demand pattern tends to vary in a cyclical fashion and with even greater amplitude than the spares market, this stock holding should increase when activity is high, and decrease when activity is low. In fact, experience indicates that it remains more or less static, and therefore the value of OEISK is calculated on the basis of steady state conditions, and held constant throughout the simulation. As with the development of the original Industrial Dynamics model, the decision to verify this value was held over until model results were available to indicate its importance.

In the original Industrial Dynamics model, the parameters controlling the supply sources had been selected to represent an overall general supply. It was the intention that the composite model should initially represent the CompAir factory, and it was necessary to adjust the parameters to suit. The ones affected were those controlling the lead time, i.e. the manufacturing process time (DPF), the minimum queuing time (DOMF), and the variable queuing time. Of these, the manufacturing process time was left at four weeks, as this was within 20% of the measured value (see 6.4.3.3.) and not thought to be a critical difference. However, the total lead time for the factory was longer than the average for the spares division suppliers as a whole, and this was attributed to the additional queuing delay, some of which was imposed by the production control system.

14.8 weeks

This allows an inter-operational delay of three days per operation on average, so that even under low throughput conditions, the system carries a significant level of work-in-progress, and this was thought to raise the minimum possible queuing delay (DIMF) to some two weeks. With a mean lead time of 20 weeks, this made the variable queuing delay (DOIF) 14 weeks.

11.4. The Inventory Model Section

Although the inventory control section of the model was closely based on the model described in Chapter 10, it differed in two important respects, which necessitated extensive modification. However, the operating principles remained the same.

The first difference concerned the time scale. Whereas the original inventory model had operated on a one month time increment, in order to integrate with the Industrial Dynamics sections, it was necessary to operate on the same time interval, which was usually 0.2 weeks. However, certain routines were still performed on a monthly basis, in order to retain a close resemblence to the real system.

The other difference concerned the inputs and outputs. The original model dealt with abstract but real variables, such as numbers of components and

and their value, and had generated a demand constrained only by the demand pattern of the constituent components. On the other hand, the Industrial Dynamics operated at an even higher level of abstraction, operating on such variables as "gross demand" or "gross output" without specifying in what dimensions these variables should be measured.

In combining the two models, it was necessary to be more specific. For the purposes of this experiment, it was decided that all such measures should refer to value (at constant prices, and with no mark-ups, discounts, etc.).

Wherever the inventory model interfaced with the Industrial Dynamics model, it was necessary to translate the incoming variable (a rate) to cash terms, and then to actual parts.

The first stage was performed by calculating the average steady state throughput value of the inventory section from the input parameters of the parts range (i.e. the average demand per month and the unit value). If the Industrial Dynamics variable is also expressed in terms of its percentage of steady state value, all that remains is to correct for the time scale, so that, using a time increment of 0.2 weeks, the value of orders received in that time increment is:-

Actual demand value = 1/20 x steady state demand value x RRF/RRI (where RRI is the steady state Industrial Dynamics input)

A similar formula is applied to translate the goods received (DTS) into value, and the converse to translate the inventory model outputs into Industrial Dynamics terms.

In generating the outputs (the factory orders and the shipments to distributors) it is merely a question of aggregating the value of the contribution each item in the parts range makes to that output. For example, as the stock is reviewed each time increment, the stock balances are adjusted, and the total value of the despatches is calculated. This is then translated into Industrial Dynamics terms and released as SIW (Shipments Issued from Warehouse). For factory orders, as and when an order is raised, so its value is added to the level OPC (Orders pending Processing by Computer) which is released once per month.

The third output required, DUF (Delay due to Unfilled orders at the Factory warehouse) is calculated from the value of the total backorders, expressed in terms of the order receipt rate. The resulting delay (in weeks) can then be used in calculating LAR (the distributor's outstanding orders).

In the case of the inputs, even after translation, the problem arises of distributing the total values among the various inventory items.

For the orders received, a random demand for each item could be generated which would conform to the known characteristics, as in the original inventory model, and the total value of this demand could be calculated from the unit costs. It would then be possible to adjust each individual demand to ensure that the total demand value agreed with the incoming order value. However, this adjustment would have the effect of distorting the demand characteristics of the individual components, which would no longer be representative of the CompAir parts range. This problem was overcome by making a slight modification to the artificial parts range which was described in Chapter 10. The number of different coefficients of lead time variation was reduced from three to two, giving a parts range of 60 items, which was then duplicated, so that the total range consisted of two sub-ranges, each member of which had a "matched pair". It was then possible to ensure that while any given component demand varied about the mean in the required manner, there was always a corresponding component of the same unit cost varying in a complementary manner, so that under steady state conditions, the sum of their demands was constant from one month to the next. (The random demand factors, being based on monthly statistics, were recalculated monthly and held constant throughout the month). The only constraint remaining was to ensure that the demand of those components with a high coefficient of demand variation did not generate an excessive level of "customer returns". This was achieved by limiting the maximum value of any demand factor to a value of 2.1 times the mean. Since the sum of the demands of any given part and its "antithetic partner" would always equal twice the mean demand of each, this constraint limited the "negative demand" (i.e. stock return or rejection) to 10% of the mean for any given component - a situation which would arise in the real system. The apportionment of the factory output as items received is dependant upon the operation of the inventory section "production control system". As explained in the preceding chapter, when the stock on hand of any item falls below the calculated re-order level, an order is raised.(Following the argument put forward in Chapter 9.2., the size of the order quantity was always calculated on the basis of the CompAir system "value categories", for all the stock control rules tested). When the order is raised, it is allocated a nominal due date, calculated from the relevant lead time parameters and the randomising mechanism as before. On completion of a batch of deliveries, the list of outstanding orders is surveyed, and all those orders with the earliest due date were aggregated to form the next batch for delivery. The total value of this batch is calculated, and the optimum delivery rate is determined such that these orders would be satisfied in four weeks. This optimum rate (SDF, Shipping rate Desired from Factory) is then modified according to ratio of the ideal original equipment stock level to the actual. Thus, if demand from the inventory control section consistently exceeds the factory supply (as in periods of rising demand), then the ratio of actual to ideal original equipment stock is less than one (OESK/OEISK 1) and the outstanding batch of orders takes longer than the one month to be delivered. A gradual and increasing extension of lead times then occurs, emulating the real system.

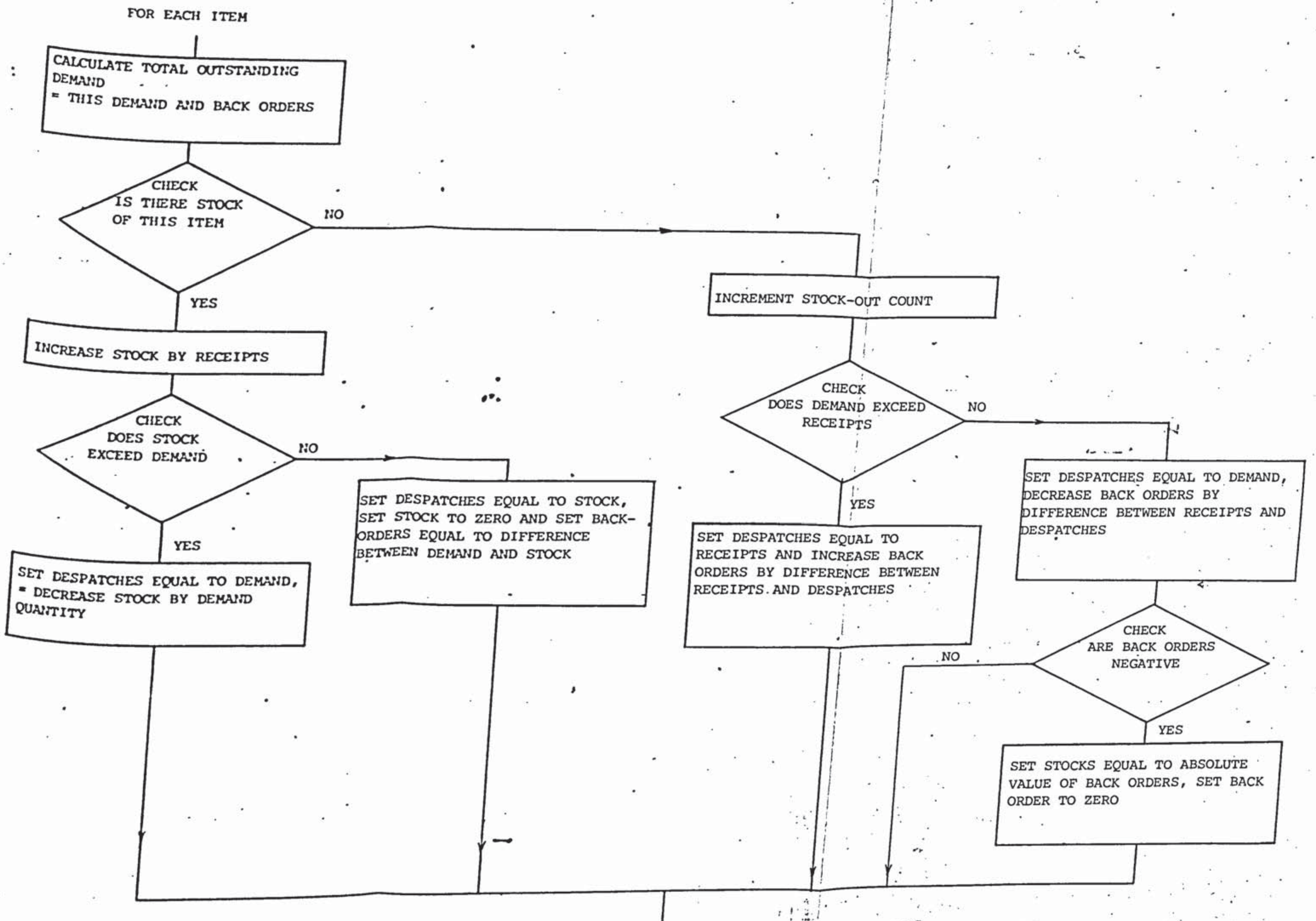
The actual apportionment of the incoming goods (DTS, Deliveries to Stores) is performed each time increment, with each item being credited with a stock receipt in proportion to that item's share of the total batch outstanding. The amount of this batch outstanding is decreased by the relevant amount until the final increment, when there may be a mismatch between the total balance outstanding and the quantity the factory is able to supply. Under these circumstances, only the amount outstanding is used, the balance being returned to the factory stock.

It was explained in Chapter 2 how the CompAir inventory control system interacts with the production control system, so that outstanding orders are rescheduled where necessary to anticipate and prevent possible shortages. This is an essential feature of the CompAir system, and one of the objectives of the model was to test the relative effectiveness of the existing system, so inclusion of this feature in the model was imperative. It was achieved in the following manner. When performing the stock review routine each time increment, the stock level was checked against a "minimum stock" level, set according to the CompAir rules (Chapter 2, 6). If the stock was below this level, then at the next stock delivery review (i.e. on completion of the existing batch of deliveries), the outstanding order for that item with the earliest due date was identified. Provided the adjustment did not exceed half the average lead time (this representing the approximate maximum practical improvement), this due date was amended to allow the order to be delivered in the following period.

In Chapter 6.4.2.3. it was pointed out that the CompAir system allows delivery a maximum of one month in advance of requirements. This refers to the practice of raising the transfer documents one month in advance, in order to allow time for the physical transaction to take place. In fact, the factory production controllers naturally release as many of the items as soon as possible. Consequently, if the factory supply is meeting demand, deliveries can occur up to one month early, but no sooner. This constraint was simulated in the model by checking the due date of the current batch of deliveries against the actual date and suspending deliveries if they became too advanced.

Another major feature distinguishing the inventory section of the composite model from the original detailed inventory control model was the stock accounting routine. The dynamic interactions between the inventory system and the distributor and factory sections concerning such variables as the backorder level and the warehouse supply rate meant that the stock accounting had to be more detailed than in the original model. The logic of the routine is shown diagramatically in Fig.51.

It can be seen that the total composite model embodies the essential features of the system under study. In spite of the reservations expressed in 11.2. it was believed that the model as constructed would provide a sufficiently realistic environment to



STOCK ACCOUNTING ROUTINE

FIG. 51

enable valid judgements to be made on the relative merits of different control rules operating under cyclical conditions. A copy of the source code used for simulating the existing system, is given at Appendix 11.

11.5. Model Output

In constructing the model, the question arose concerning the most suitable data to be output, and in what form. In addition to monitoring the commercial aspects of the stock control rules it was also necessary to examine their effectiveness in damping down the cyclical variations in the system. Consequently, it was decided to retain the outputs which had been found appropriate to each of the different types of model when they had been operating separately. Thus, for the Industrial Dynamics sections, the facility of tabulating the value of each of the variables at selected intervals was included in the model, together with the option of being able to plot selected variables on a time base. It was anticipated that this would be helpful in examining the counter-cyclical or damping effect of any proposals.

The Industrial Dynamics section of themselves could not provide an overall picture of the operation, as several key variables such as IAF, RSF, etc. had been supplanted by the detailed inventory section.

In order to complete the output tables, and in order to utilise the plotting facility, these variables were translated from the detailed inventory section equivalents. Thus, IAF (Inventory Actual at Factory warehouse) was calculated by expressing the total stock value in terms of the steady state weekly average demand, and RSF was translated from the total value of the smoothed demand rate.

To assist in a general appraisal of the results of a particular run, the facility to calculate the mean and standard deviation of the key system variables was retained, and these data were tabulated at the end of each model run, irrespective of which (if either) of the other outputs had been selected.

With the warehouse section of the model emulating the real system more closely than either the original models, it was possible to monitor its operation more closely. Since the operating data from the real system was all based on monthly intervals, (usually derived from month end figures) corresponding data, referring to every important aspect of the section's operation, were available for output. A full list is given in Fig.52 together with the symbols used in the program. As with the Industrial Dynamics output data, the model run concluded by calculating the means and standard deviations of these figures. In this case, however, the analysis ignored the early figures, to allow the transient effects of the start-up to diminish. A copy of the output from one run is given at Appendix 12.

Variable	Symbol
Total Month-End Back Order Value	BKV
Number of Stock-outs in month	NSO
Number of Factory Orders Raised in month	NWORD
Value of Orders Received in month	DMV
Value of Goods Received in month	GIV
Value of Goods Despatched in month	MSV
Value of Stock at month-end	SKV
Value of Factory Orders Outstanding at month-end	(WV
Stock-holding (in months)	STKHLD
Month Number	MONTH
Due Date of Current Delivery Batches	EDD

Fig.52. Table of Warehouse Section Outputs Data

11.6. Validation

The original validation exercise on the Industrial Dynamics model indicated that the general structure of that model provided a reasonable approximiation to the real system.

Since the general information loops and networks in the composite model were closely based on the original Industrial Dynamics model, it was not thought necessary to repeat the exercise. However, with the relatively small number of equations which formerly represented the warehouse activities now being supplanted by a highly complex inventory control model, the question of validating this area was crucial. At a first level of abstraction, this inventory model was designed to have overall transfer functions essentially similar to the relevant groups of Industrial Dynamics equations, the only differences arising from more detailed consideration of individual item demand characteristics. Since the inventory model was largely deterministic, the problem resolved to one of verification, of ensuring that the model equations agreed with the design concept.

Only the demand and lead time generators included random elements, and the lack of bias in these aspects of the model can be seen in Fig.53, which shows the output from the pseudo-random number generator operating with three different seeds.

Random Number	<0.01	0.01 to 0.10	0.1 to 0.2	0.2 to 0.3	0.3 to 0.4	0.4 to 0.5	0.5 to 0.6	0.6 to 0.7	0.7 to 0.8	0.8 to 0.9	0.90 to 0.99	> 0.99
Fre-quency Seed .0	9	100	100	87	102	94	107	111	99	96	84	11
Fre-quency Seed .2	5	88	103	109	74	88	96	112	116	113	86	10
Fre-quency Seed .5	11	78	97	87	111	109	111	102	86	113	83	12

Fig. 53

Random Number Generator (1000 Trials)

At a gross level, the functioning of the model could be monitored running under steady state conditions. The effects of the random aspects of the detailed inventory section was to introduce "noise" into the system at two points, the issue of factory orders, and the supply of parts at the warehouse, so that precise correspondence between the composite model and theoretical figures could not be achieved in the short term. However, the long term average values for the Industrial Dynamics variables could be obtained by referring to results obtained from the original model, while the theoretical operating levels of some of the inventory section variables could be calculated from the input parameters. For example, considering the unit cost, the mean demand

and mean lead time of each item,it was possible to predict what the average monthly demand, goods received, goods despatched and work-in-progress figures should be. By also considering the stock control rules, the steady state mean stock level could also be predicted, and compared with the model results.

The operation of the inventory section was checked for consistency at a gross level by ensuring that the total stock levels in successive months agreed with the stock receipts and despatches for the relevant months. Similarly, the change in back order level from one month to the next should represent the difference between the demand value and the despatches.

Assurances that the inventory model was operating correctly at a detailed level could only be obtained by monitoring the behaviour of specific items. With a parts range of 120^{00} items, it was impractical to check that each equation or conditional test was being applied correctly to every component. However, some confidence that this was the case could be gained by duplicated or circular calculation of certain totals. For example, it has been explained how the incoming goods were allocated to each item in the range. By totalling these incremental additions throughout the delivery period, and then calculating the grand total for the range, the figure arrived at should be identical to the original amount to be allocated. In a similar manner, having calculated the individual item demand for each time increment from the random factors and the total demand value, it was possible at the end of the month to check that the sum of the item demands was the same as the sum of the total demand in each time increment. A further check on the correct operation of the logic was possible by monitoring the status of each item, and signalling a probable error if certain key variables deviated too far from expected values. For example, if the internally calculated average demand or lead time deviated by more than a factor of two from the input value of that parameter average, the program printed a statement showing the stock level, the average demand and average lead time, and the level of backorders and work-in-progress for the item in question.

The two last mentioned approaches required additional output statements, which were removed from the program on completion of the validation exercise in order to improve the efficiency. The effective operation of the rescheduling ability was tested by constructing models with and without this facility, and comparing the results.

A series of trials had also shown that wide variations in the value of OESK had no significant effect on the overall gross behaviour of the model,as measured by the means and standard deviations of the key variables. The effects of this variation at a detailed level were not explored.

In the course of its development, the model eventually satisfied all the necessary conditions, establishing a high level of confidence that it provided a sufficiently realistic simulation of the CompAir spares system to provide useful results. Nevertheless, in spite of the increased level of detail at the inventory stage, the model was totally unsuitable for use as a predictive tool. In the first place, all the reservations mentioned in Chapter 6 concerning the Industrial Dynamics section still applied, and secondly, the inventory model represented a highly idealised situation in which every rule was applied and obeyed with total discipline.

11.7. Initial Conditions

For the inventory section the initial conditions were established in a similar manner to those of the detailed inventory model, as described in Chapter 10.5. In this instance, it was necessary to ensure that the average lead times generated by this section agreed with the total average manufacturing delay of the Industrial Dynamics model of the factory. This was achieved by totalling the delays which make up the manufacturing delay, (i.e. DIC, DCF, DOMF, DOIF and DPF, See Fig.50) and setting the inventory section lead time averages to 70%, 100% and 130% of this value. These figures were subsequently used to generate random lead times in the course of the model run.

Having established the inventory system's initial status, the Industrial Dynamics sections were initialised as before, deriving the value of each level from the relevant delay and the nominal steady state throughput. Initialising the inventory system first enabled the correct delay figures to be used where relevant - such as DUF. The only exception to this procedure was the calculation of OIC (Orders to be Issued from Computer). Although the delay which is applied here (DIC) is one week, the incoming orders are accumulated for the month before issuing. In this case the model was presumed to begin operation at the beginning of the month, so that the delay used to calculate the initial conditions only was four weeks.

11.8. Experimental Design

In Chapter 6.7.2. (i) it was suggested that a more effective stock control system would not only enable the company to achieve a higher level of service from a given stock investment, but would also reduce the system "gain factor", that is, it would tend to stabilise the system and reduce the fluctuations in load which the suppliers experience, thus enabling them to maintain a higher level of service to the warehouse. It was further suggested that by monitoring directly the level of real demand in the field, the warehouse control system could anticipate changes in the level of distributor demand, thus enabling a more consistent level of service to be provided under cyclical (or trend) demand conditions.

The composite model provided a framework for testing these propositions, and would enable a comparison to be made not only between the stock/service balance achieved by each of the sets of stock control rules, but also between their effects on the total system behaviour. Minor changes to the model structure would enable the effect of feeding forward true customer demand information from the distributor directly to the warehouse to be simulated. Examination of the resulting output would indicate whether such timely and uncorrupted information would be of any benefit.

The stock control rules to be compared were those of the existing system, and that set of rules which performed best in the tests described in the previous chapter, i.e. "option 1". It has been mentioned how the existing rules depend upon the rescheduling ability of the production control system to absorb the demand fluctuations for individual piece parts. Since this feature is part of the total production control system, it would be retained even if the spares warehouse stock re-ordering and forecasting rules were changed. Consequently, two models were constructed, with identical Industrial Dynamics representations of the distributors and the factory, and both with the rescheduling facility, but with different warehouse stock control rules.

Before performing any comparison experiments, it was necessary to ensure that the random elements in the models did not introduce any bias. Three potential sources were identified:-

i. The random warehouse stock levels of the individual piece parts at start up.

ii. The lead time generator.

iii. The demand generator.

It was a requirement to ensure that in any comparison, the two models started from identical conditions, but it was still possible that these conditions might favour one of the sets of rules. Similarly, although the demands generated would be absolutely identical, month for month and piece part for piece part, it was still possible that these figures could create a set of circumstances which would bias the results. The problem is greater with the lead time generator, as, although the same random number generator and seed would be used, it would be impossible to ensure equality, since the different rules would generate orders for different parts at different times.

It was thus necessary to establish how sensitive the variables were to these three sources of noise, and to establish what run length was necessary to reduce any bias to an acceptable level.

The total experiment could thus be considered in three parts:-

i. To establish the sensitivity of the model to random factors, and to establish the minimum run time necessary for a given level of confidence in the results. This experiment would also provide the first comparison between the two different sets of rules operating in a total system environment albeit under steady state (and therefore artificial) conditions.

ii. To compare the performance of the two different stock control rules, and their effects on the system as a whole, when the system is subject to a 4¼ year (220 week) cyclical demand pattern.

iii. Having selected the more suitable stock control system, to establish whether any improvements in performance or total system behaviour could be effected by providing up to date information on market conditions to the warehouse.

11.9. Random Factor Sensitivity Tests

The experiment was performed initially using the model with the proposed new stock control rules. The model was run with four different sets of random number generator seed, and a constant level of demand at the distributors. The mean values and standard deviations of the variables were recorded after five different lengths of run. The results for some of the key variables are shown in Fig. 54.

The most striking feature is the unrealistically high level of performance that the simulation achieves showing a mean level of unfilled orders of some two weeks for a stock level of approximately nine weeks. This reflects the perfect functioning of the factory rescheduling system, and the total and perfect discipline with which the rules are applied. It also emphasises the unsuitability of the model in its present form for use as a predictive, as opposed to comparative, tool.

Since the experiment was concerned with the intrinsic

Run Length	Seed Set	UOF		IAF		AMWP		IAR		UOR		SSR	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
336 weeks	a	208.1	12.8	892.8	182.6	99.1	19.6	1599.8	9.4	60.0	0.3	100.0	0.1
	b	206.9	9.4	906.4	178.8	99.3	20.5	1600.0	6.8	60.0	0.3	100.0	0.1
	c	212.5	16.9	855.5	206.2	99.3	19.8	1600.0	12.7	60.0	0.5	100.0	0.1
	d	212.3	15.8	839.6	196.6	98.3	19.4	1599.7	8.9	60.0	0.3	100.0	0.1
Mean		209.95	13.725	873.58	191.05	99.0	19.83	1599.88	9.45	60.0	0.35	100.0	0.1
95% Conf Lim		±4.570	±5.352	±49.71	±20.16	±0.76	±0.76	± 0.24	±3.89	±0	±0.16	±0	±0
536 weeks	a	205.4	10.8	932.4	164.8	99.2	18.2	1599.9	7.6	60.0	0.3	100.0	0.1
	b	206.0	8.5	945.6	159.6	98.8	20.6	1599.9	6.2	60.0	0.2	100.0	0.1
	c	210.1	17.5	944.5	227.9	99.5	20.1	1599.9	12.7	60.0	0.5	100.0	0.1
	d	211.5	15.7	843.1	166.7	99.5	19.6	1599.9	9.9	60.0	0.4	100.0	0.1
Mean		208.25	13.13	916.4	179.75	99.5	19.63	1599.9	9.10	60.0	0.35	100.0	0.1
95% Conf Lim		± 4.79	±6.66	±78.33	±51.29	±0.39	±1.65	± 0	±4.52	± 0	±0.21	± 0	± 0
786 weeks	a	211.6	20.0	916.7	153.7	99.3	18.1	1599.7	12.3	60.0	0.5	100.0	0.1
	b	209.4	15.4	911.4	151.4	99.2	19.4	1599.9	10.7	60.0	0.4	100.0	0.1
	c	214.0	22.4	924.1	214.8	99.2	19.5	1599.5	14.9	60.0	0.6	100.0	0.2
	d	213.4	17.4	893.0	173.1	99.0	19.1	1599.9	11.9	60.0	0.4	100.0	0.1
Mean		212.10	18.8	911.3	173.25	99.18	19.03	1599.75	12.45	60.0	0.48	100.0	0.13
95% Conf Lim		± 3.29	±4.85	±21.11	±46.71	±0.2	±1.02	± 0.30	±2.81	± 0	±0.15	± 0	±.08
1036 weeks	a	211.3	18.6	919.2	143.9	99.8	17.9	1599.8	11.7	60.0	0.4	100.0	0.1
	b	210.8	17.3	888.7	143.4	99.6	19.0	1599.9	12.0	60.0	0.4	100.0	0.1
	c	217.2	26.8	894.9	197.5	99.8	19.2	1599.8	16.9	60.0	0.6	100.0	0.2
	d	213.8	17.3	865.4	165.0	99.0	18.6	1599.9	11.8	60.0	0.4	100.0	0.1
Mean		213.28	20.0	892.05	162.45	99.78	18.68	1599.85	13.10	60.0	0.45	100.0	0.13
95% Conf Lim		± 4.66	±7.28	±35.18	±40.48	±0.2	±0.91	± 0.09	±4.04	± 0	±0.16	± 0	±.08
1236 weeks	a	211.2	18.1	921.5	139.0	99.6	17.8	1599.9	11.7	60.0	0.4	100.0	0.1
	b	210.9	18.8	895.7	136.8	99.8	18.6	1599.9	13.4	60.0	0.5	100.0	0.1
	c	215.4	25.3	927.2	199.1	99.6	19.3	1599.8	15.9	60.0	0.6	100.0	0.2
	d	212.6	16.5	906.8	180.6	99.7	18.8	1599.8	11.1	60.0	0.4	100.0	0.1
Mean		212.3	19.68	912.8	166.88	99.68	18.63	1599.85	13.03	60.0	0.48	100.0	0.13
95% Conf Lim		± 3.27	±6.16	±22.71	±49.23	±0.15	±0.99	± 0.09	±3.42	± 0	±0.15	± 0	±.08

Fig. 54

Demonstrating the effect of starting conditions, seeds and run length on warehouse variables merits of the two systems, on the assumption that the proposed alternative would not be subject to any greater degree of maladministration than the existing system, then this artifically high performance does not invalidate any conclusions about the relative merits of the two schemes. Estimating the scale of any predicted difference in actual application is much more difficult.

Concerning the effect of the starting conditions, it can be seen that the mean levels of the five selected variables reach a close degree of agreement relatively quickly. In fact, the 95% confidence limits for the warehouse stock level (IAF) are ± 4½% after the shortest run (336 weeks). The standard deviations of these variables however, which are a measure of the dynamic behaviour of the system, show a much greater degree of divergence, and the spread of values is still high for the warehouse stock and unfilled order levels even after runs of 1,236 weeks (nearly 25 years). However, both of these variables are influenced almost directly by the random demands and the random lead times.

To assess the effect of the starting conditions, a better indicator is provided by the factory order rate (MWF or AMWF), one of the Industrial Dynamics variables most directly affected by the warehouse activity. From Fig.54 it can be seen that the 95% confidence limit for the mean value decreases with increasing run length, but that this rate of decrease diminishes at higher run lengths. The confidence limits of the mean value of the standard deviations of the factory order rate shows no such trend, but seems to reach a stable value at about 786 weeks, the point at which the rate of decrease in scatter of the mean values begins to fall off. Referring to the other variables shown, the means of the standard deviations generally show a closer degree of agreement for run lengths of over 786 weeks than below. These considerations indicated that a run length of approximately 17 years and above (say 900 weeks) would be more than sufficient to ensure that the initial conditions did not influence the results, and that the various random number generators had produced a sufficiently large "population" to be free of bias. Nevertheless, to obtain some indication of the remaining variability, it was decided that each comparison experiment should be performed twice, using a second set of seeds to initialise the random number generators for the second run.

These results and conclusions had been based on the model of the proposed system, and it was necessary to confirm them for the existing system. The two longest runs were repeated using the model of the existing system, with the results shown in Fig. 55, which indicate that there is little purpose in extending the run length already decided upon.

A detailed comparison between the results obtained from the two different sets of control rules shows that the level of stock necessary to maintain a similar level of unfilled warehouse orders (UOF) is significantly higher for the existing rules than for the proposed alternatives. It should also be noted that the different operating principles of the rules is reflected in the results. The existing rules, which attempt to maintain a specific stock to turnover ratio for each piece part, show a much more stable level of stock, the mean standard deviation being only half the value of that obtained with the proposed rules. The consequences of this are reflected in the resulting factory order rate, which tends to be more stable for the existing rules. The final point to note is that these differences in performance do not have any significant effect on the distibutors service (SSR).

11.10. Comparative Performance Under Cyclic Conditions

To compare the performance of the two models, the approach used for the basic inventory control model described in Chapter 10.7. was adapted. As before, a series of runs were made in which the warehouse

Run Length	Seed Set	UOF		IAF		MWF		IAR		UOR		SSR	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1036 weeks	a	212.9	17.9	1013.1	80.4	99.5	15.4	1599.8	11.4	60.0	0.4	100.0	0.1
	b	212.8	17.3	1004.5	80.5	99.4	13.8	1599.9	10.3	60.0	0.4	100.0	0.1
	c	219.3	25.0	986.0	86.5	99.4	15.4	1599.8	12.3	60.0	0.5	100.0	0.1
	d	219.2	29.0	976.0	81.7	99.4	14.8	1599.8	15.9	60.0	0.6	100.0	0.1
Mean 95% Conf Lim		216.05	22.3	994.88	82.28	99.03	14.85	1599.83	12.48	60.0	0.48	100.0	0.1
		± 5.88	±9.03	±26.88	±4.58	±0.08	±1.20	± 0.08	±3.86	± 0	±0.15	± 0	±0
1236 weeks	a	211.9	17.3	1015.2	76.1	99.5	15.3	1599.9	11.1	60.0	0.4	100.0	0.1
	b	214.5	18.6	998.3	78.0	99.5	13.6	1599.9	11.7	60.0	0.4	100.0	0.1
	c	218.3	24.5	982.8	81.4	99.5	15.0	1599.8	12.6	60.0	0.5	100.0	0.1
	d	219	27.7	974.9	77.8	99.5	14.9	1599.8	15.3	60.0	0.6	100.0	0.1
Mean 95% Conf Lim		215.93	22.03	992.80	78.33	99.5	14.70	1599.85	12.18	60.0	0.48	100.0	0.1
		± 5.30	±7.82	±28.35	±3.53	±0	±1.20	± 0.09	±3.72	±0	±0.15	± 0	±0

Fig. 55

Effect of seeds and starting conditions on the model with the existing stock control rules.

stock objective was set at a different level for each run, and from the results a characteristic curve of stock against service plotted. In this case, the enhanced output, with greater detail about the warehouse, enabled the service to be measured in terms comparable with those used within the real system, i.e. shortages, in terms of value and in terms of demand value. However, it was also necessary to assess the effects of the two warehouse stock control systems on the total system, and various measures were possible. One of these, the stability of the factory order rate, has already been mentioned, but equally valid measures could be the stability of the:-

level of work-in-progress
warehouse stock level
shortage level
supply lead time
supply rate to the distributors
demand rate from the distributors

The last mentioned is particularly important, as it reflects the degree of re-generation, or positive feed back which exists in the system. It is impossible to identify any one of the listed variables as being of greater or lesser relevance than any other, so that to provide a general picture of the system behaviour, plots were made of the following figures:-

i. Shortages, measured by the average back-order value divided by the average monthly demand value ($\overline{BKV}/\overline{DMV}$)

ii. Supply lead time variability, measured by the standard deviation of the lead time (σ_L).

iii. Work-in-Progress Variability, measured by the standard deviation of the total orders outstanding on the suppliers (σ_{WV}).

iv. Variability of the Warehouse Output rate, measured by the standard deviation of the warehouse monthly despatch rate (σ_{MSV}).

v. Stock Variability, measured by the co-efficient of variation of the warehouse stock value ($\sigma SKV/\overline{SKV}$).

vi. Demand Variability, measured by the coefficient of variation of the monthly warehouse demand value ($\sigma DMV/\overline{DMV}$).

vii. Variation in Factory Order Generation Rate, measured by the standard deviation in AMWF.

For the experiment, the run length was set at 936 weeks, and a demand rate of 100%, with a superimposed sine wave of ± 10% amplitude and a period of 220 weeks, was applied to the distributors, after an initial period of 96 weeks, to allow the transient effects of the starting conditions to diminish. Monitoring of the warehouse variables did not begin for a further 100 weeks, to allow time for the effects of the cyclic changes to work their way through the system. With the composite model, there was no need to superimpose noise on this input signal, as this was introduced by the warehouse section of the model, which was the first point at which it had any significance.

11.11. Results from the Standard Model

The results of the four runs (two with each model) are shown in Fig. 56, but a clearer picture can be obtained by studying the various plots of these data (Figs. 57 to 63).

11.11.1. Shortages against Stock Holding (Fig. 57)

As with the steady state case, the service is again unrealistically high. Nevertheless, the curve shows that even with rescheduling of outstanding orders, the existing rules cannot provide as high a level of service for a given level of stock as the proposed rules. Note the close agreement obtained from the two different sets of seeds.

11.11.2. Lead Time Stability (Fig. 58)

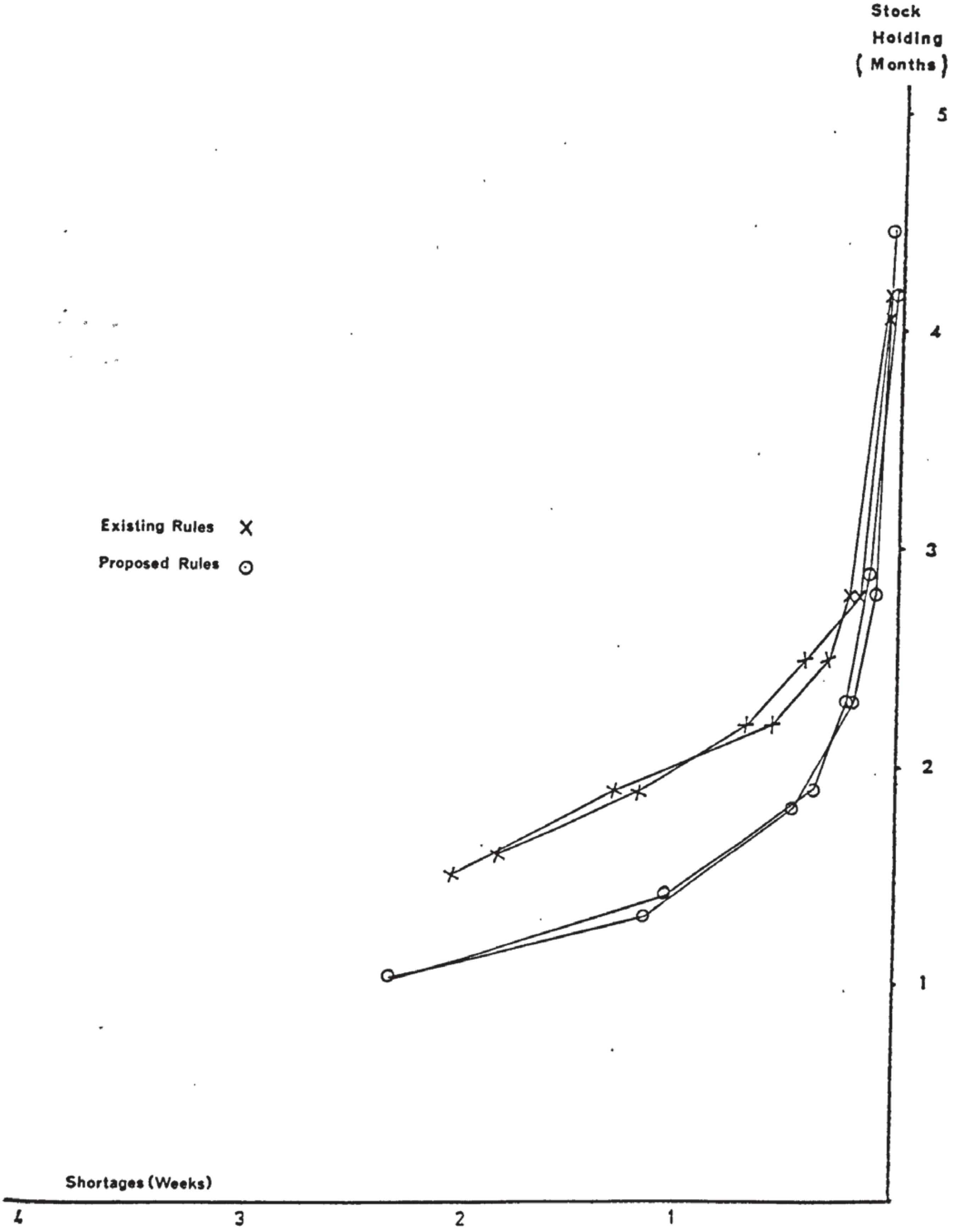
The lead time variability has been plotted against the stock holding, as this is the most direct reflection of the safety stock factor, the variable which is being manipulated. It shows, contrary to expectations (from considera-

	STKHLD (Months)	1.0	1.4	1.9	2.3	2.9	4.5
PROPOSED SYSTEM SEED SET 1	BKV/$\overline{DMV}$	.579	.260	.092	.055	.033	.005
	σL	2.8	2.5	2.1	1.9	2.1	2.3
	σWV	6379	5114	3409	2917	4762	6104
	σMSV	742	661	573	453	432	362
	σAMWF	26.6	25.5	23	20.8	21.9	22.2
	σSKV/$\overline{SKV}$	.335	.251	.180	.175	.219	.149
	σDMV/$\overline{DMV}$	.104	.094	.079	.069	.067	.061
PROPOSED SYSTEM SEED SET 2	STKHLD (Months)	1.0	1.3	1.8	2.3	2.8	4.3
	BKV/$\overline{DMV}$	.586	.288	.116	.051	.025	.006
	σL	2.8	2.4	2.1	2.0	2.0	2.2
	σWV	7021	4875	3568	3269	4240	5744
	σMSV	738	701	555	445	422	368
	σAMWF	28.0	23.9	22.7	22.5	22.5	21.5
	σSKV/$\overline{SKV}$	.329	.226	.182	.177	.200	.150
	σDMV/$\overline{DMV}$	.121	.092	.077	.069	.065	.061
EXISTING SYSTEM SEED SET 1	STKHLD (Months)	1.6	1.9	2.2	2.5	2.8	4.2
	BKV/$\overline{DMV}$	.460	.300	.176	.109	.042	.010
	σL	2.9	2.7	2.5	2.5	2.5	2.6
	σWV	7812	7186	6352	5851	5096	6474
	σMSV	635	562	525	492	418	376
	σAMWF	25.2	23.3	22.8	22.6	21.8	22.8
	σSKV/$\overline{SKV}$	.264	.211	.171	.134	.093	.085
	σDMV/$\overline{DMV}$	.110	.091	.082	.076	.066	.061
EXISTING SYSTEM SEED SET 2	STKHLD (Months)	1.5	1.9	2.2	2.5	2.8	4.1
	BKV/$\overline{DMV}$	.511	.262	.144	.082	.055	.0122
	σL	2.9	2.7	2.5	2.5	2.6	2.7
	σWV	8174	7164	6335	5885	5626	6555
	σMSV	638	606	573	475	458	378
	σAMWF	25.3	23.3	21.7	21.2	22.6	22.5
	σSKV/$\overline{SKV}$	.271	.225	.180	.147	.113	.095
	σDMV/$\overline{DMV}$	.113	.092	.079	.074	.072	.062

For key to abbreviations see Fig. 52.

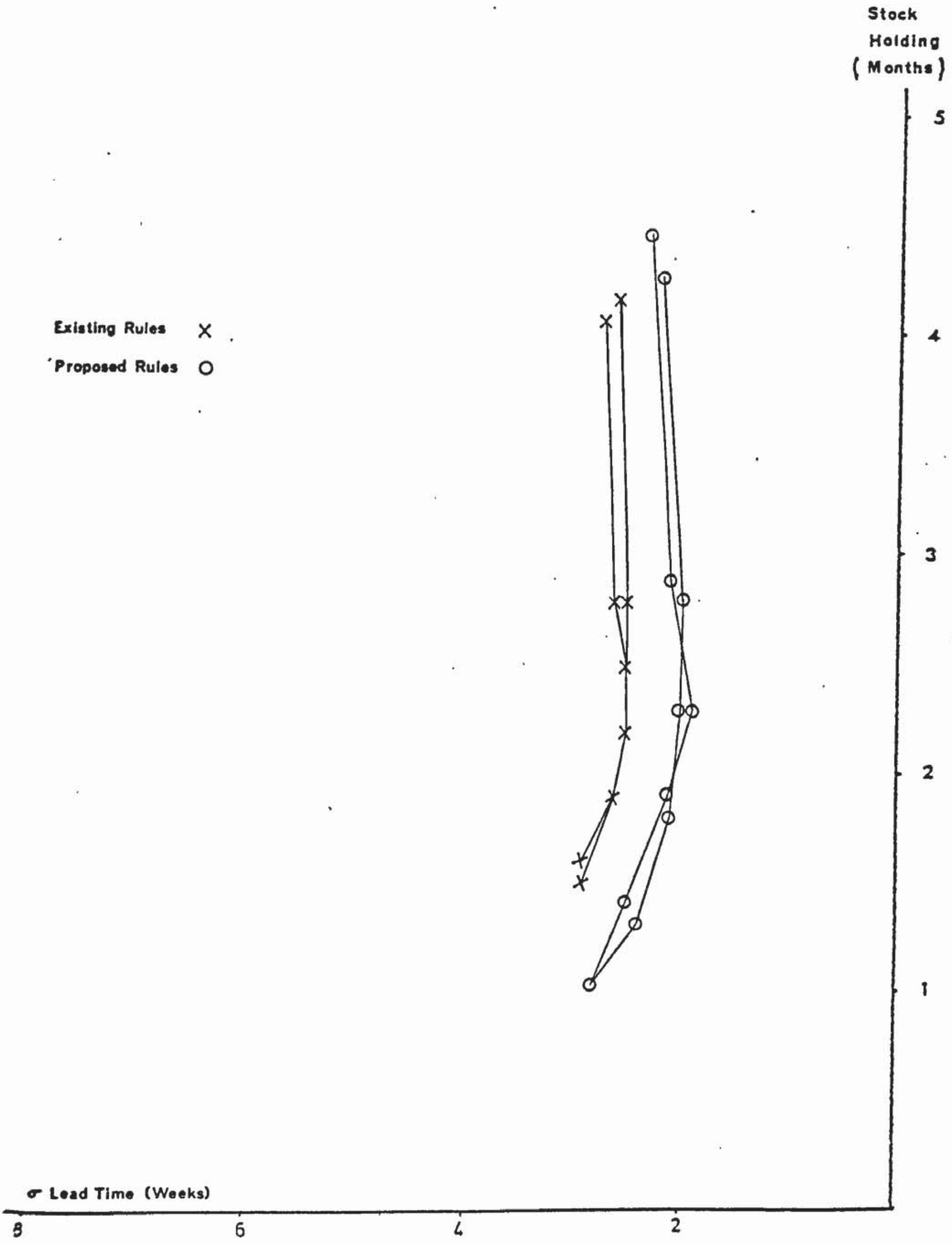
Fig. 56

Results of the Comparison Tests with the Standard Models



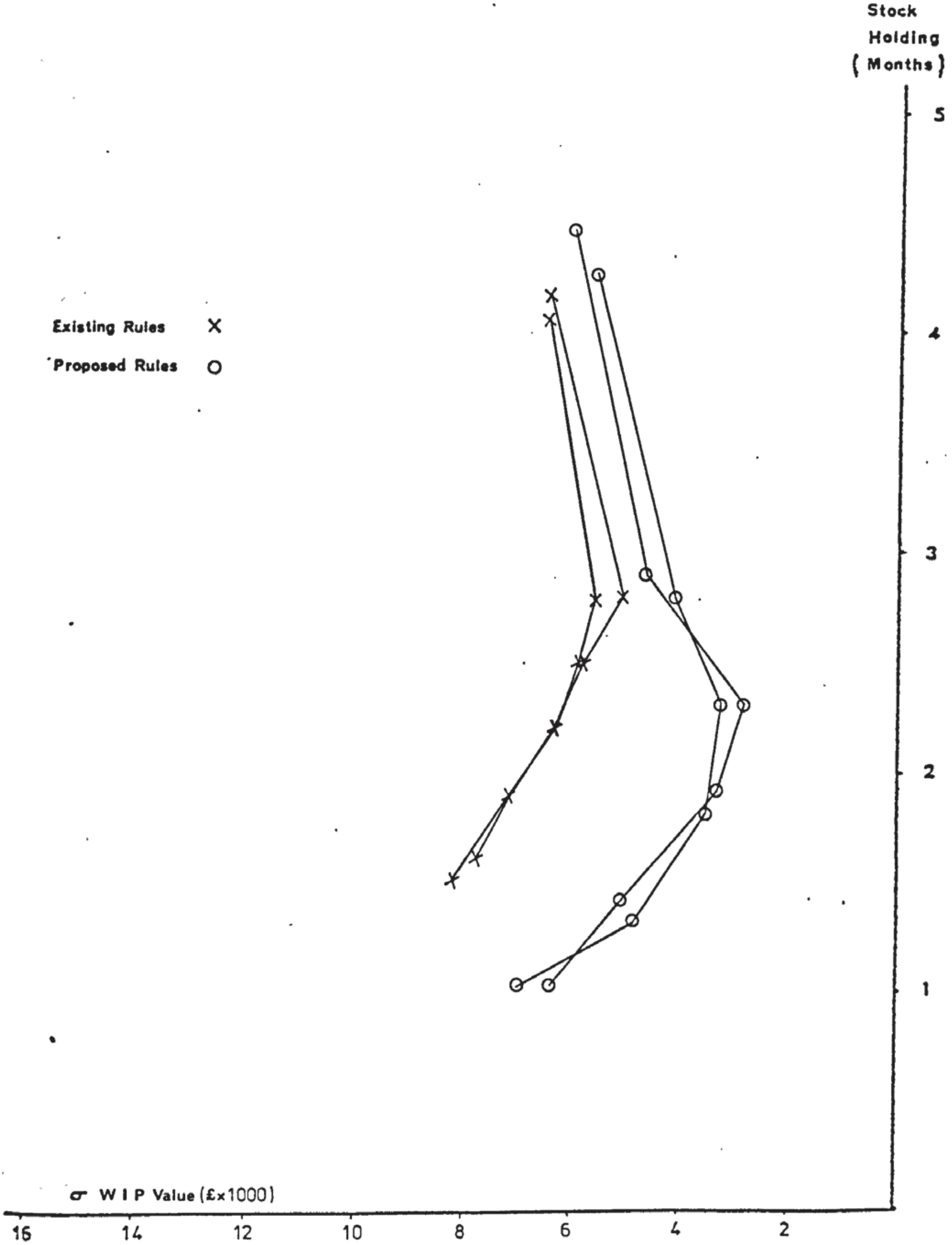
PERFORMANCE OF THE COMPOSITE MODEL (STANDARD VERSION)— MEAN SHORTAGE LEVEL

Fig. 57



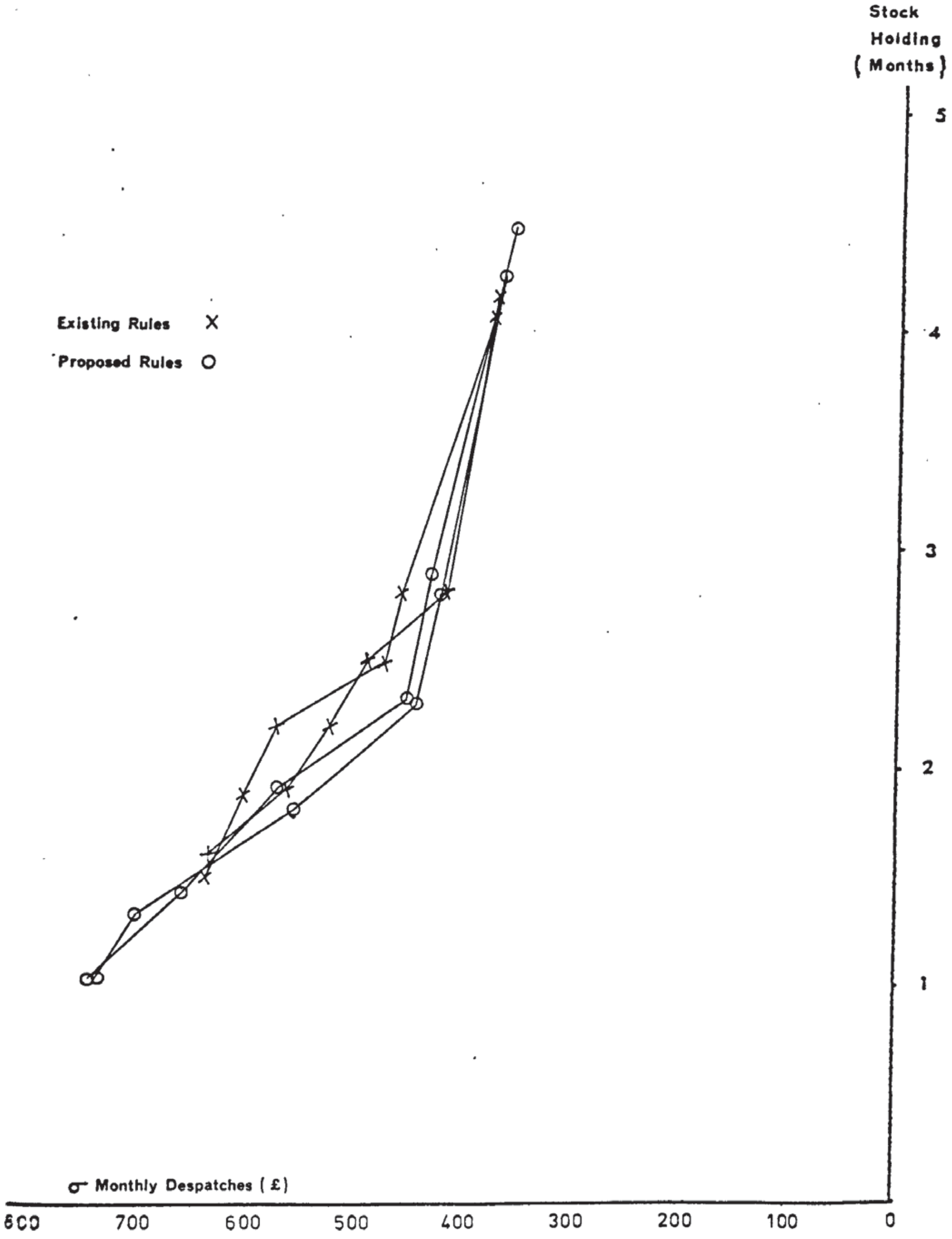
PERFORMANCE OF THE COMPOSITE MODEL (STANDARD VERSION) —LEAD TIME STABILITY

Fig. 58



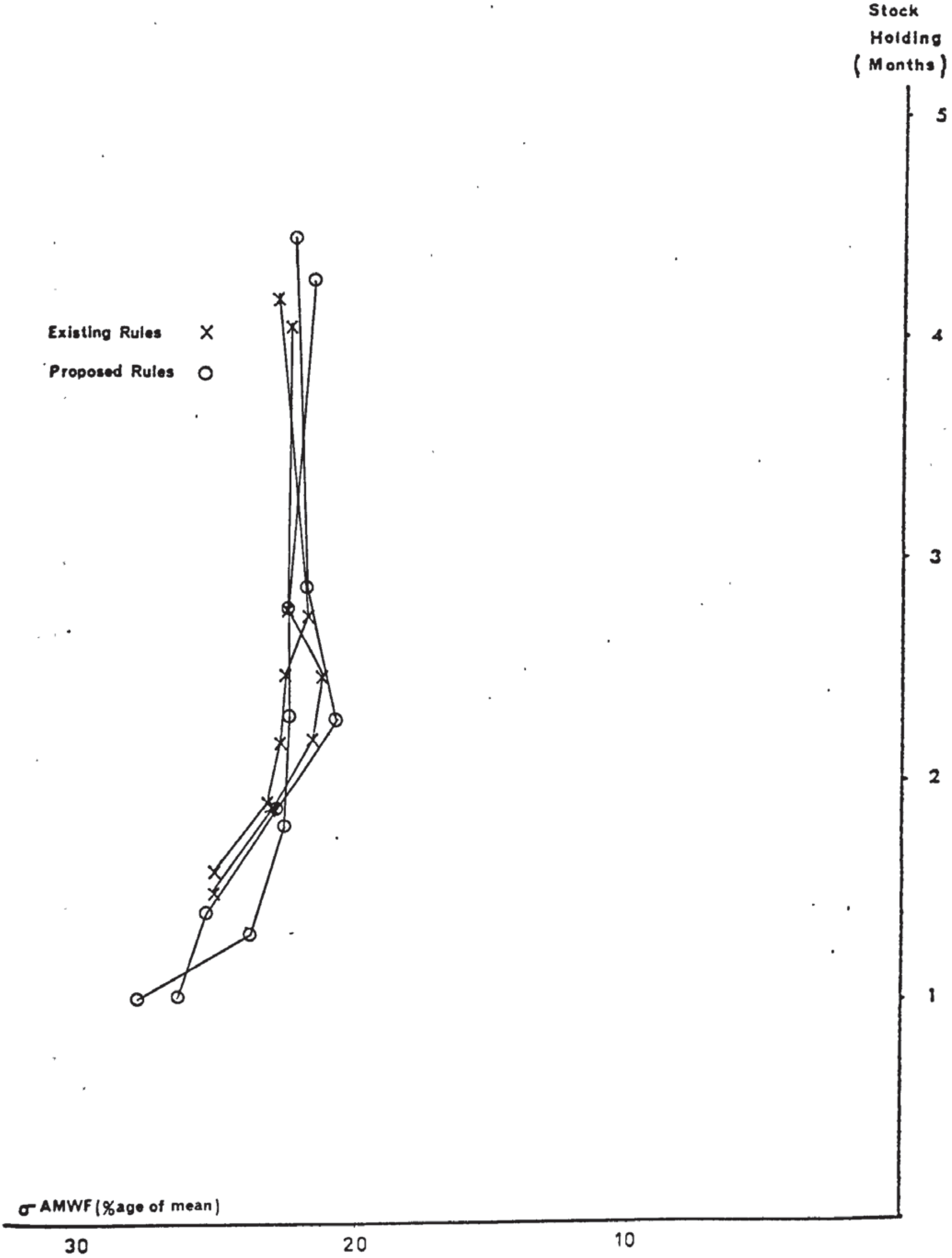
PERFORMANCE OF THE COMPOSITE MODEL (STANDARD VERSION) – W.I.P. VALUE STABILITY

Fig. 59



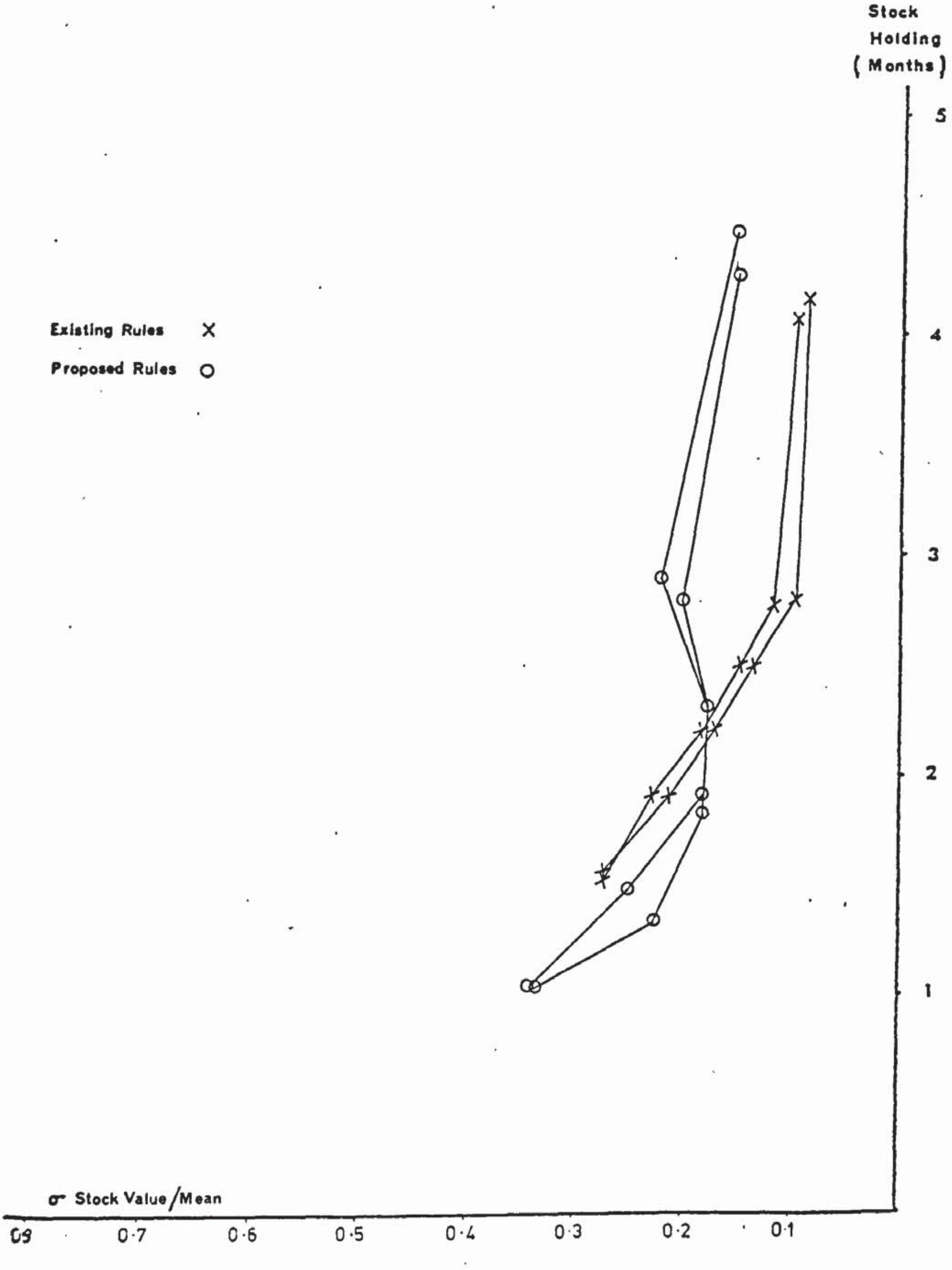
PERFORMANCE OF THE COMPOSITE MODEL (STANDARD VERSION) — STABILITY OF MONTHLY DESPATCH VALUE (EX WAREHOUSE)

Fig. 60



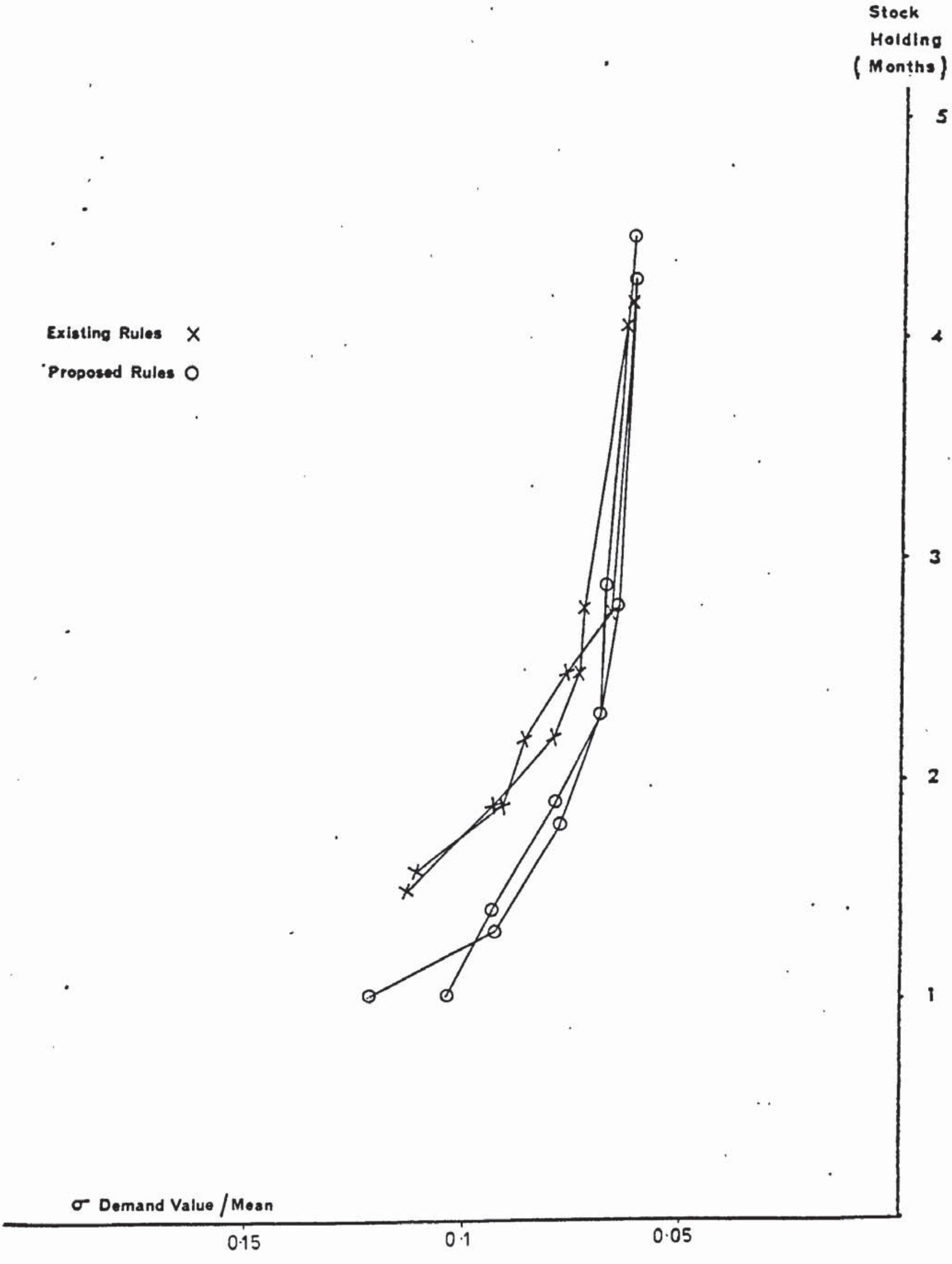
PERFORMANCE OF THE COMPOSITE MODEL (STANDARD VERSION) — STABILITY OF FACTORY ORDER GENERATION RATE

Fig. 61



PERFORMANCE OF THE COMPOSITE MODEL (STANDARD VERSION)—STOCK STABILITY

Fig. 62



PERFORMANCE OF THE COMPOSITE MODEL (STANDARD VERSION) — DEMAND STABILITY

Fig. 63

tion of the effects of the factory order rate in the initial experiment), that the lead time varies less with the proposed rules than with the existing. Also of interest is the suggestion that a minimum may exist.

11.11.3. Stability of Factory Work-in-Progress (Fig. 59)
This curve is again plotted against the stockholding, for the reason given above. It confirms the existence of a point for which the work-in-progress variability (and hence the lead time variability) is a minimum. It is interesting to note that the difference between the two systems is more marked at the lower stock levels, and that the minimum is more emphatic with the proposed rules. Once again the existing rules are inferior.

11.11.4. Variability of Warehouse Monthly Output (Fig. 60)
These curves are much less conclusive than the preceding ones, and there appears to be little to choose between the two systems in this respect.

11.11.5. Variability of the Factory Order Rate (Fig. 61)
The small advantage that the existing system offers in this respect under steady state conditions does not appear to be sustained under

cyclical demands. There is no advantage with either system.

11.11.6. Stock Stability (Fig. 62)

From its operating principals, the existing system would be expected to maintain more stable stocks. However, at lower stock levels, this advantage disappears, possibly as a result of the distributors response to the poor service.

11.11.7. Demand Stability (Fig. 63)

This graph confirms the original hypothesis that the improved stock control system not only offers a better service to the distributors, but also stablises the demand at the warehouse.

11.12. The Exaggerated Lead Time Response Model

One of the problems throughout the project was the lack of firm information on the response of the factory to the changing workload. Although attempts were made to derive reasonable estimates of the relevant parameters from analysis of the real system, these estimates were inevitably open to doubt. In Chapter 3.2.2. it was deduced that the gross average lead time for the production system varied from approximately 28 weeks, in quiet periods, to 37 weeks in times of high activity. If these figures are represenative of the majority of cases, say 95%, then this range represents four standard deviations, i.e. the standard deviation of the actual gross lead time variation is some two weeks.

Although this figure agrees with the results from the model of the existing system running under standard control parameters, the foregoing hardly represents a validation of the parameters. In any case, it is certain that the factory lead time response varies from component to component.

It was thus necessary to confirm that the results obtained from the previous experiment were valid for at least one different level of factory lead time response.

A factory system which showed even larger variations in lead time would provide a more severe test on the stock and production control systems, and this condition was simulated by adjusting two sets of parameters in the Industrial Dynamics section of the model representing the factory. The first change was to slow down the rate at which the factory capacity adjusted to the changing demand pattern (by increasing DIMF). In a cyclical demand pattern, this would have the effect of increasing the discrepancy between the required and actual capacity, creating a greater excess of capacity when demand was falling and a more acute shortage when demand was rising. By increasing the variation in queue length, this would increase the lead time fluctuations.

The second adjustment concerned the queuing delays themselves. In Chapter 6.4.3.1. it was explained that total manufacturing queuing time was aggregated in the model into two components, representing the minimum queue and the variable queue, the latter varying with the outstanding work load. For the composite model, these parameters were set at two weeks and 14 weeks respectively. The equations for the total queuing delay determine that the larger the variable delay factor, the greater the variation will be. In order to obtain a greater variation in lead time, it was thus necessary to increase the variable delay parameter (DOIF) while reducing the minimum delay factor (DOMF) to maintain the same mean queue length. For the purposes of this experiment, this minimum delay was reduced to the minimum the model would allow, i.e. the time increment, and the variable factor was increased to 15.8 weeks.

The resulting models were not meant to represent any real or potential factory structure, but merely to demonstrate that the differences in performance observed in the previous section held true under more testing conditions, and to note whether such conditions increased or decreased these differences.

To obtain the results, the procedure described previously was repeated exactly, except that results were not obtained for the highest stock safety factor.

11.13. Results from the Exaggerated Lead Time Response Model

The results shown in Fig. 64 and Fig. 56 correspond with each other as do the associated graphs. It is thus possible to compare the results with the previous set, as well as the results from the two different control systems.

11.13.1. Shortages (Fig. 65)

While maintaining their relative positions, the performance of the control rules is slightly worse when the lead time is subject to greater fluctuation. This effect is much more marked at low stock levels.

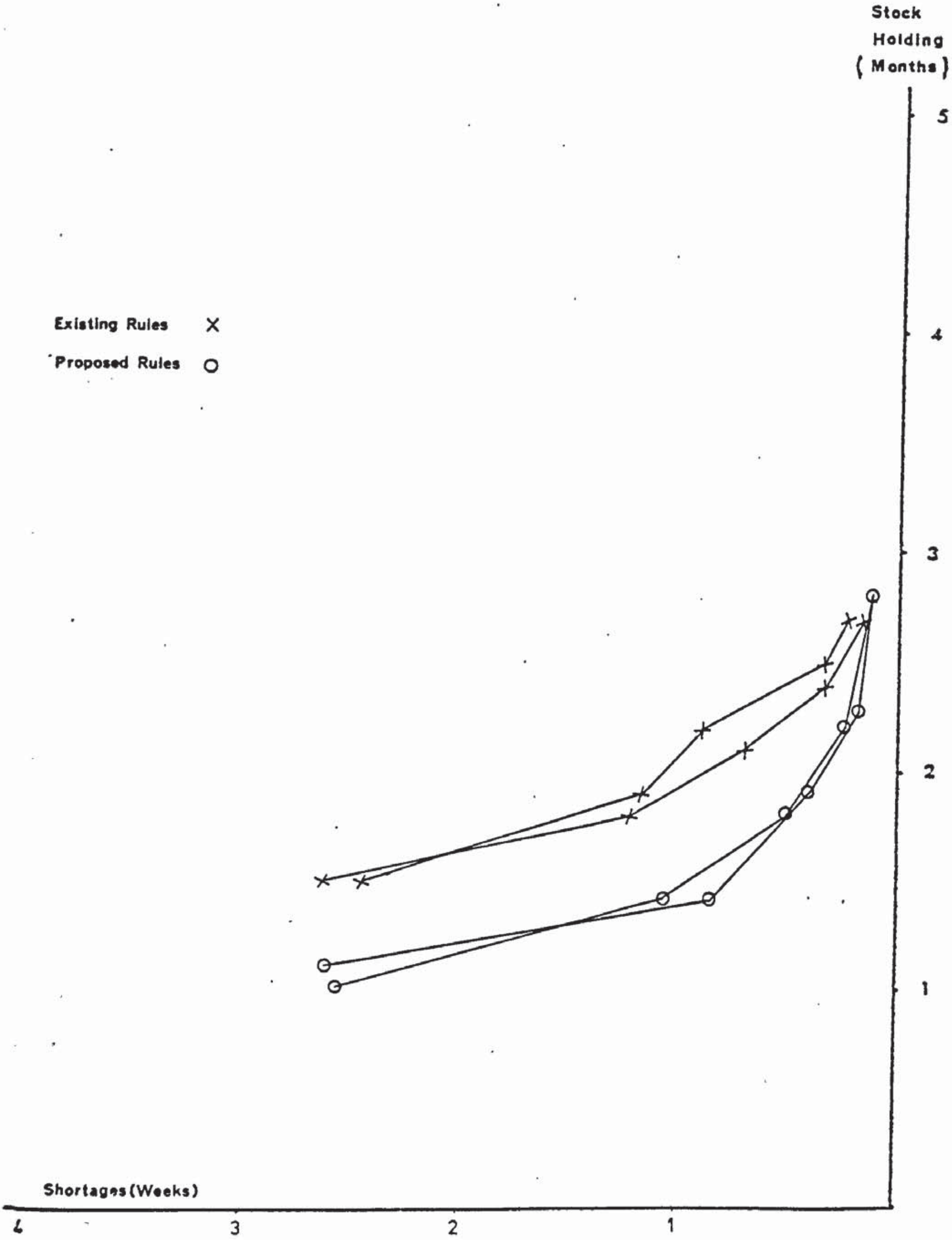
11.13.2. Lead Time Variation (Fig. 66)

Since the models were deliberately adjusted to give a more fluctuating lead time, comparison of the absolute performance with the standard model is pointless. However, it is significant that the increased fluctuation in lead time has a much more severe effect on the existing system

PROPOSED SYSTEM SEED SET 1	STKHLD (Months)	1.1	1.4	1.9	2.3	2.8
	BKV/$\overline{DMV}$	.656	.210	.097	.046	.029
	σL	5.4	3.9	3.4	2.9	3.0
	σWV	7753	4269	2990	2249	3436
	σMSV	779	556	518	458	439
	σAMWF	30.7	23.6	23.2	21.3	21.9
	σSKV/$\overline{SKV}$	.360	.231	.158	.198	.199
	σDMV/$\overline{DMV}$	.156	.093	.081	.070	.067
PROPOSED SYSTEM SEED SET 2	STKHLD (Months)	1.0	1.4	1.8	2.2	2.8
	BKV/$\overline{DMV}$	.644	.267	.124	.059	.032
	σL	5.3	3.9	3.4	3.0	2.9
	σWV	7367	4191	3045	1948	2871
	σMSV	753	686	539	490	426
	σAMWF	28.6	24.0	23.8	21.4	21.1
	σSKV/$\overline{SKV}$	.365	.230	.177	.187	.193
	σDMV/$\overline{DMV}$	.142	.100	.085	.073	.067
EXISTING SYSTEM SEED SET 1	STKHLD (Months)	1.5	1.9	2.2	2.5	2.7
	BKV/$\overline{DMV}$	.611	.294	.221	.082	.056
	σL	6.3	5.1	4.8	4.4	4.4
	σWV	10047	7814	7093	5814	5327
	σMSV	623	544	521	453	424
	σAMWF	29.1	24.8	23.3	22.1	22.4
	σSKV/$\overline{SKV}$	.277	.203	.151	.103	.052
	σDMV/$\overline{DMV}$	.145	.106	.097	.078	.072
EXISTING SYSTEM SEED SET 2	STKHLD (Months)	1.5	1.8	2.1	2.4	2.7
	BKV/$\overline{DMV}$	.655	.300	.173	.081	.038
	σL	6.3	5.1	4.7	4.4	4.5
	σWV	10276	7865	6729	6036	5368
	σMSV	653	633	535	476	410
	σAMWF	28.8	24.4	22.9	22.3	22.4
	σSKV/$\overline{SKV}$	.307	.225	.164	.117	.069
	σDMV/$\overline{DMV}$	.145	.110	.092	.077	.068

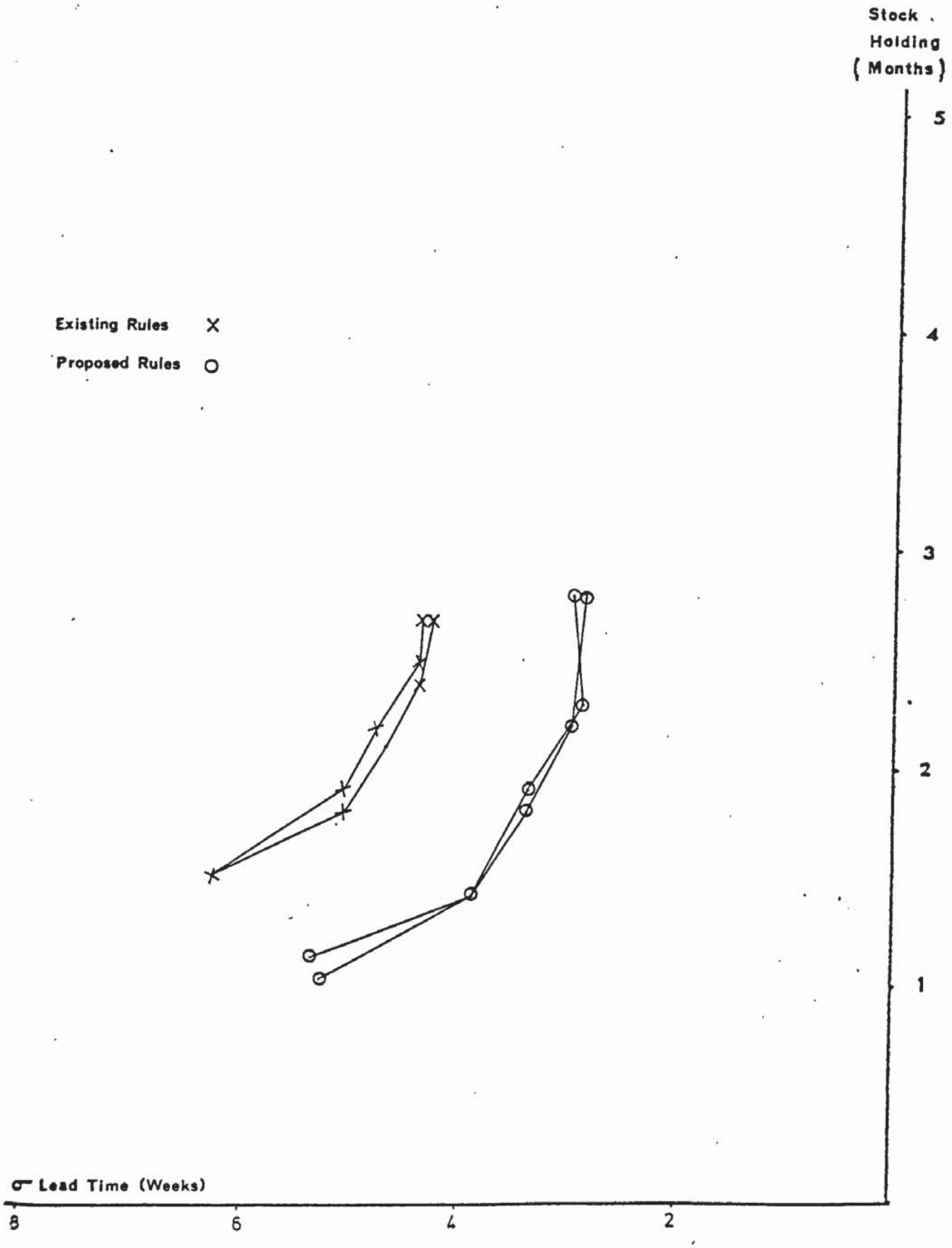
Fig. 64

Results of tests with exagerated lead time response.



PERFORMANCE OF THE COMPOSITE MODEL WITH EXAGERATED LEAD TIME RESPONSE – MEAN SHORTAGE LEVEL

Fig. 65



PERFORMANCE OF THE COMPOSITE MODEL WITH EXAGERATED LEAD TIME RESPONSE — LEAD TIME STABILITY

Fig. 66

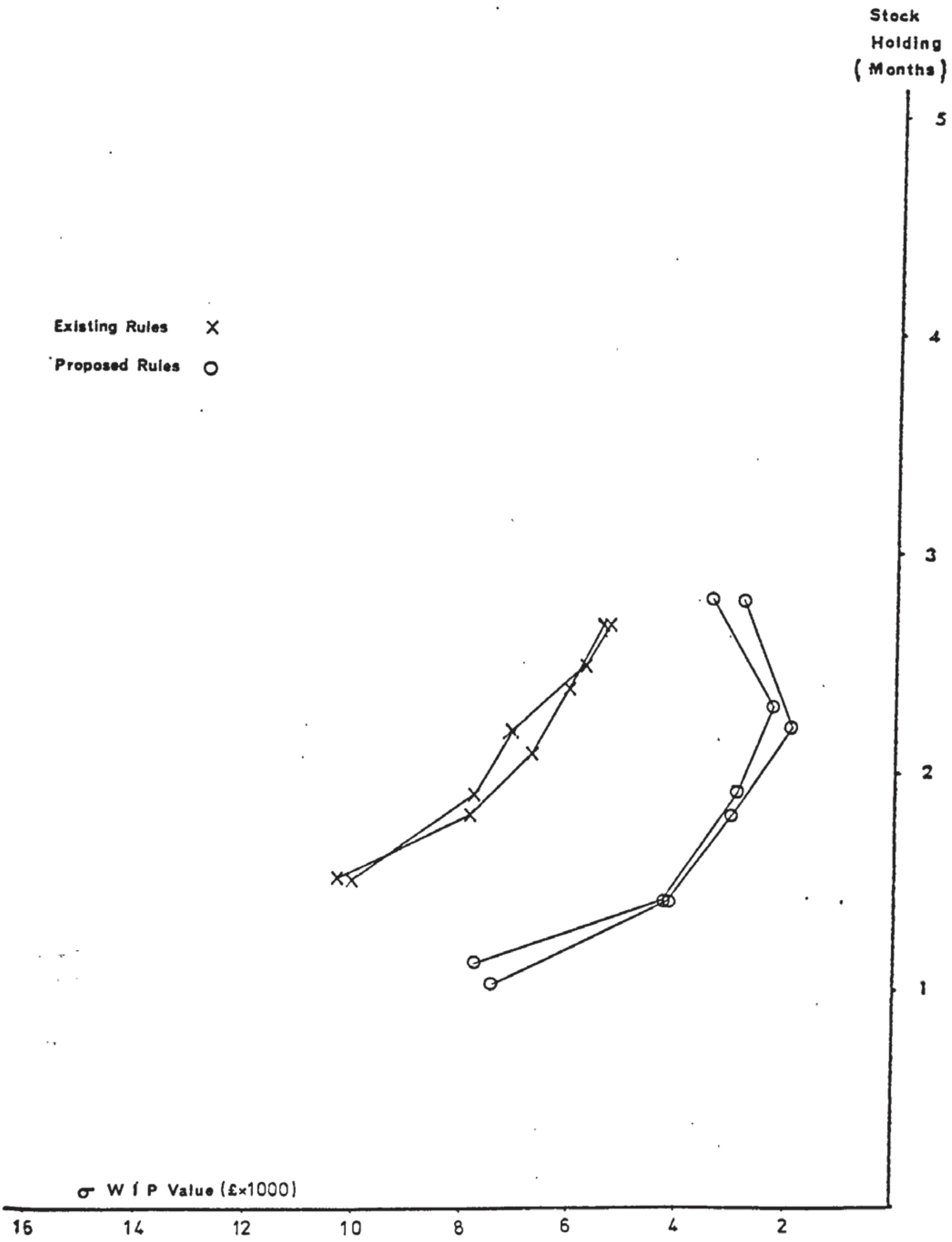
than on the proposed. The sharp deterioration at low stock levels is again most marked.

11.13.3. Work-in-Progress Variation (Fig. 67)

These curves again show an increased margin between the existing and proposed systems compared with their performance with the standard models. Like the previous curves from this experiment, they also show a more rapid falling off in performance with lower stocks. However, it is interesting to note that the point of minimum variation for the proposed system occurs at the same stock level as previously, suggesting that this minimum is not dependent upon the supply system characteristics. The other feature worthy of note is that this minimum is slightly lower than the value obtained from the standard model. Unfortunately, the model was not tested over a sufficiently wide range to confirm the existence of a minimum value of variation for the existing control system.

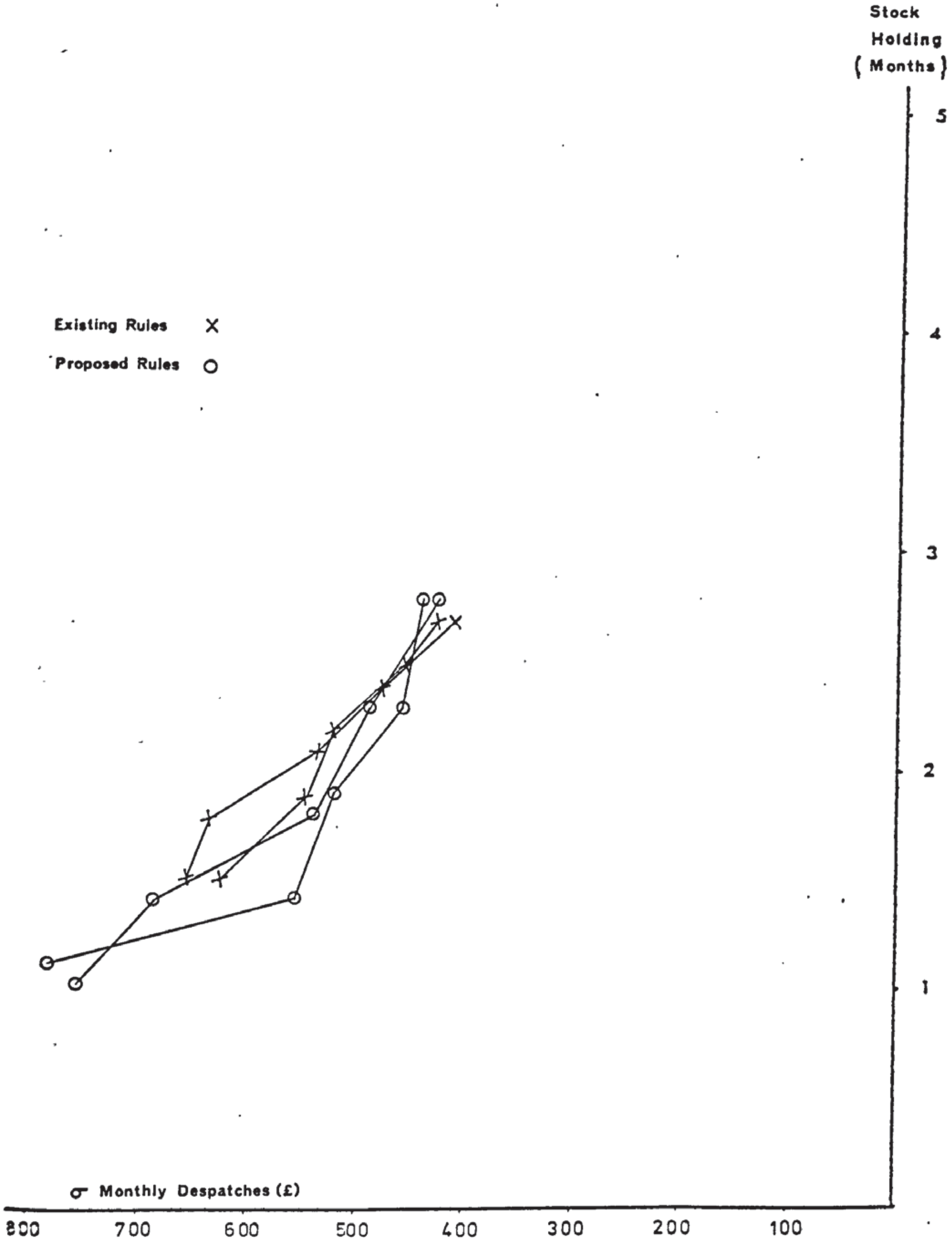
11.13.4. Warehouse Output Stability (Fig. 68)

As with the standard models the difference in performance between the two control systems is too small to be significant, although the proposed system does appear to be slightly superior. The tendency for the performance to



PERFORMANCE OF THE COMPOSITE MODEL WITH EXAGERATED LEAD TIME RESPONSE – W.I.P. VALUE STABILITY

Fig. 67



PERFORMANCE OF THE COMPOSITE MODEL WITH EXAGERATED LEAD TIME RESPONSE – STABILITY OF MONTHLY DESPATCH VALUE (EX WAREHOUSE)

Fig. 68

deteriorate more rapidly with lower stocks than with the standard supply system can again be observed.

11.13.5. Factory Order Generation Rate (Fig. 69)

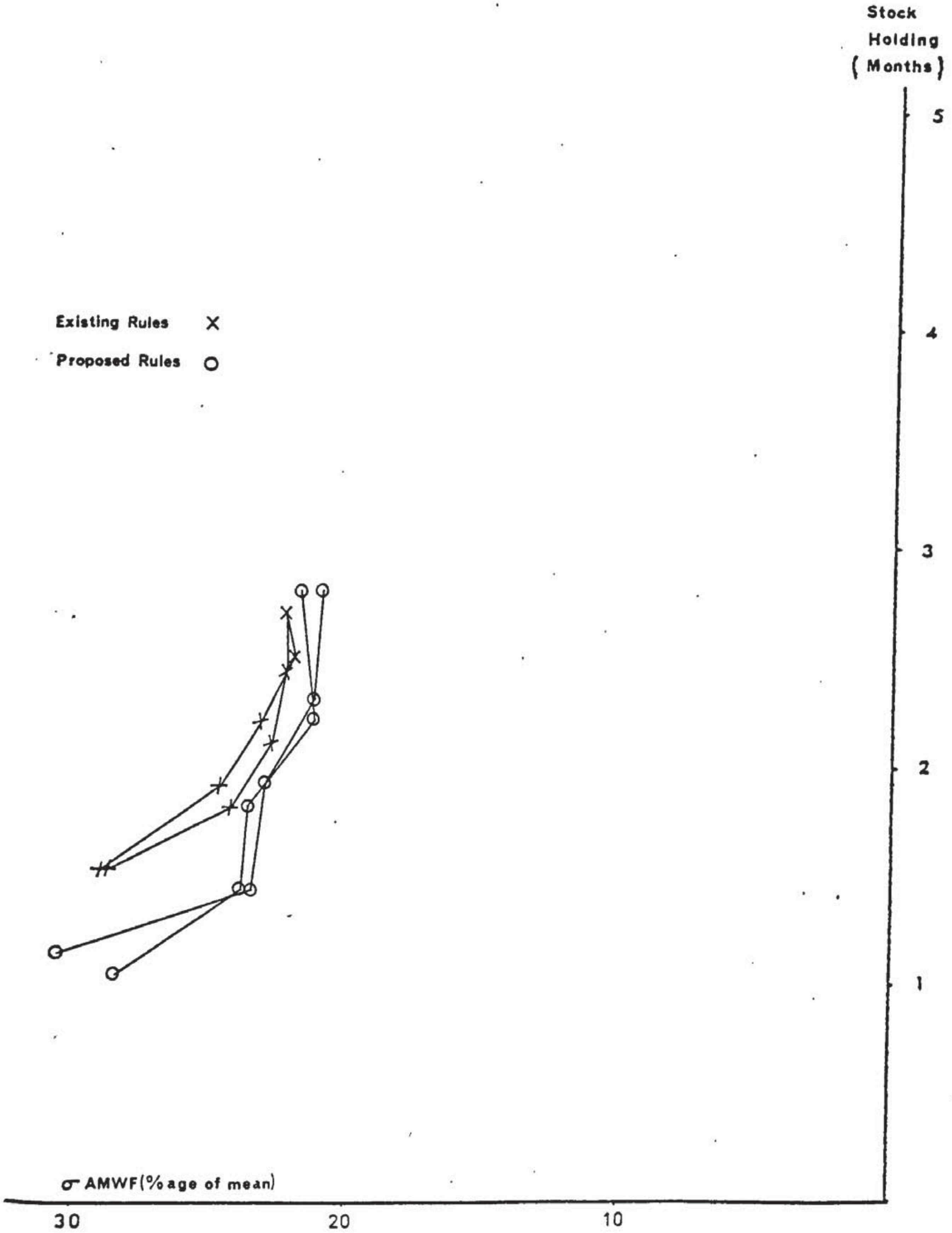
Unlike the results from the standard models, this graph indicates that the proposed system does offer some advantage in maintaining a stable rate of generating factory orders. It is again interesting to note the suggestion of a minimum, which occurs at different stock levels for the two systems.

11.13.6. Stock Stability (Fig. 70)

The pattern is similar here to that observed with the standard models, with the proposed system only performing better at the lower stock levels. In fact, comparison with Fig. 62 shows that the curves for the proposed system are very similar but a marked change in the curve for the existing system has accentuated the difference between the two systems.

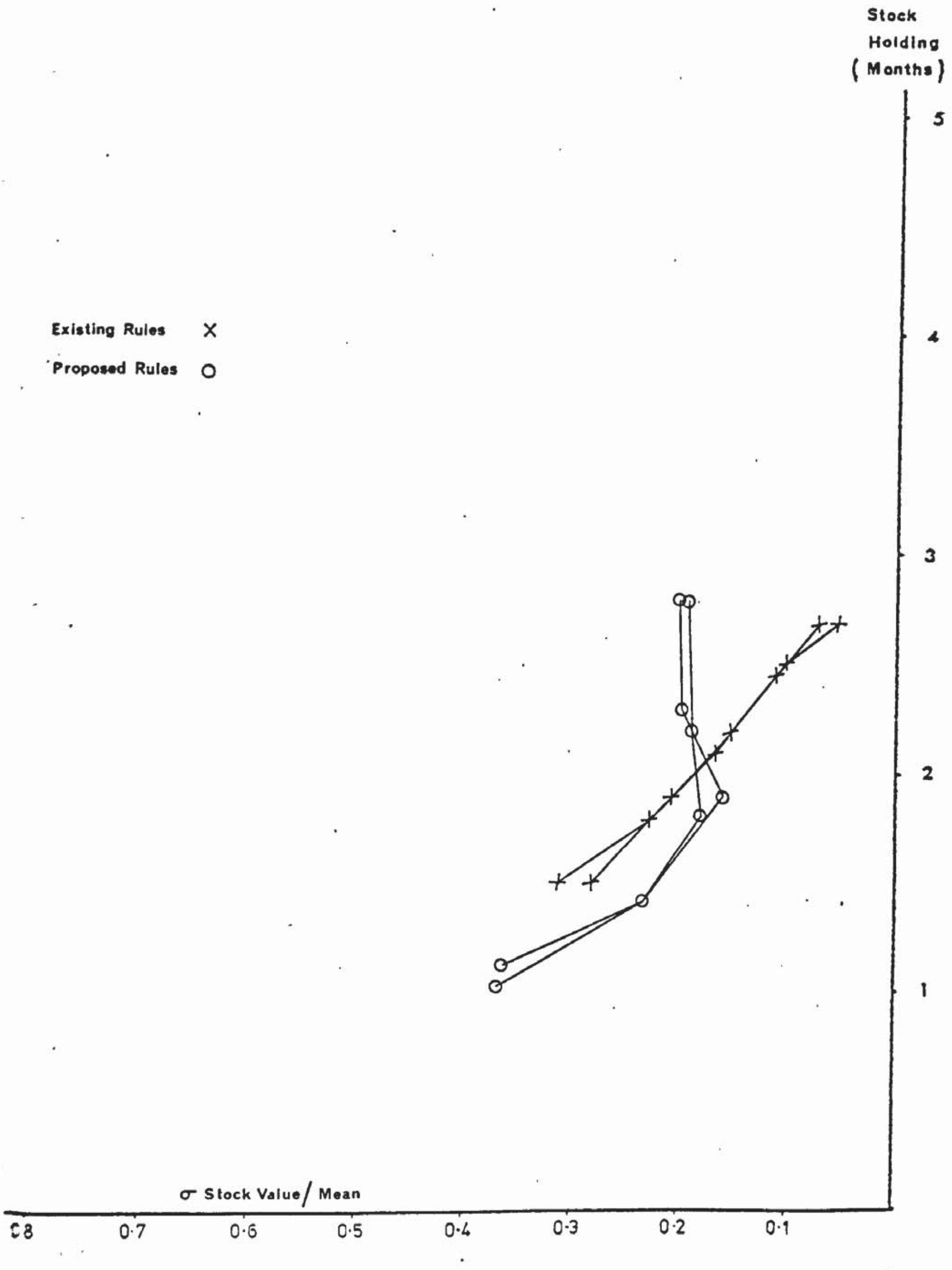
11.13.7. Demand Stability (Fig. 71)

This graph confirms the pattern observed in all the other results, i.e. that the wider fluctuations in lead time tend to increase the difference in performance between the two systems,



PERFORMANCE OF THE COMPOSITE MODEL WITH EXAGERATED LEAD TIME RESPONSE – STABILITY OF FACTORY ORDER GENERATION RATE

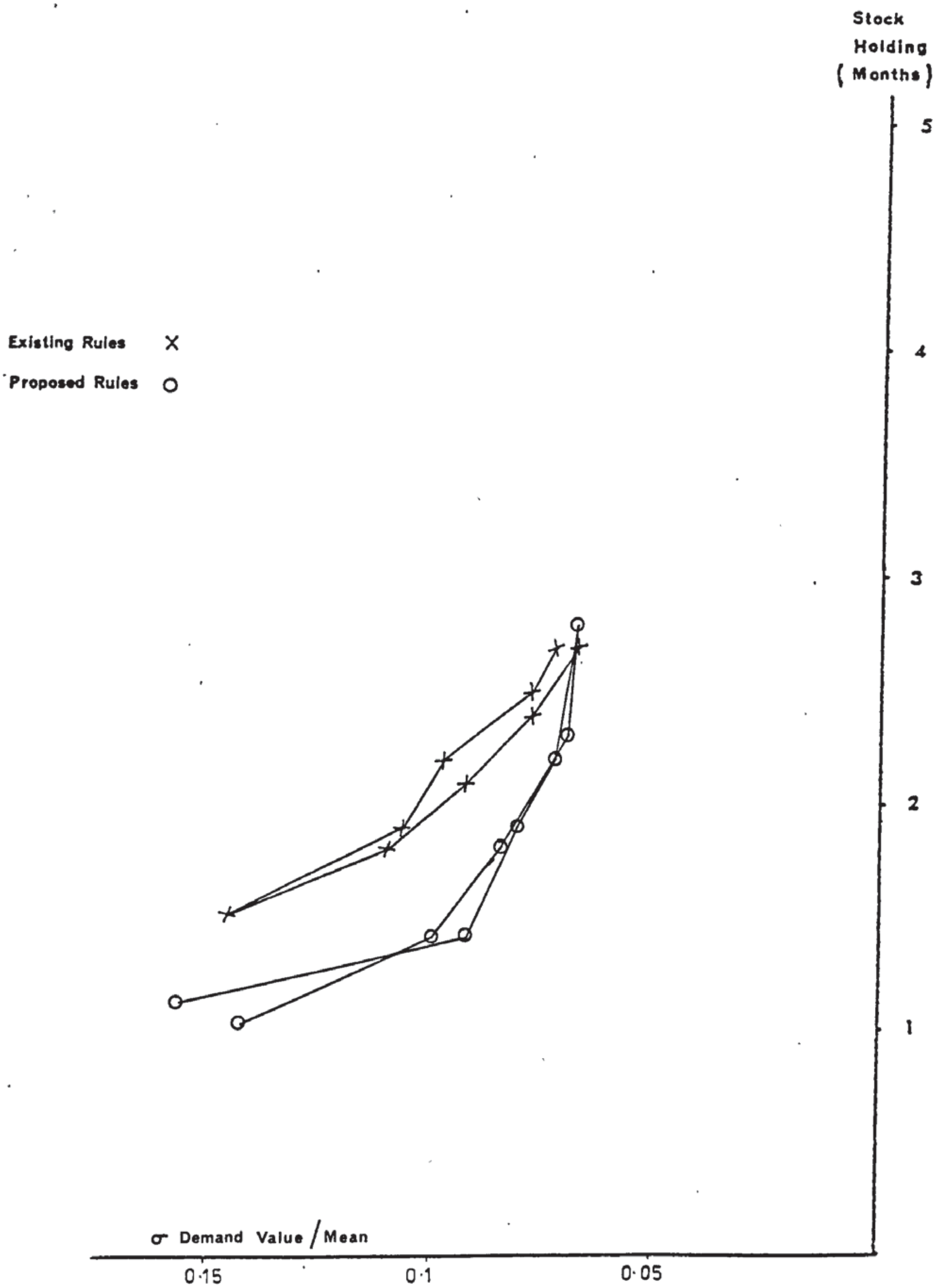
Fig. 69



PERFORMANCE OF THE COMPOSITE MODEL WITH EXAGERATED LEAD TIME RESPONSE–

STOCK STABILITY

Fig. 70



PERFORMANCE OF THE COMPOSITE MODEL WITH EXAGERATED LEAD TIME RESPONSE – DEMAND STABILITY

Fig. 71

especially when the stock safety factor is set relatively low.

11.14. The Feed Forward Loop

The final experiment in the series sought to determine whether there was likely to be any real benefit in feeding forward to the warehouse uncorrupted information on the level of distributors sales.

Fig. 50 illustrates the information links believed to exist in the spares system, and it can be seen that the only information link from the distributors to the warehouse is the one representing the ordering system. Obviously other links, temporary and permanent, exist but such links are likely to be highly informal and intermittent, and the information carried unreliable. It can further be seen that this one formal link is subject to delay, and its prime purpose is to convey information on the distributors perceived requirements, which includes true demand as only one factor, and then only after much processing, such as smoothing. In the real system, this information can also be highly subjective, and a great deal of "noise" is added by the inconsistent application of the decision rules operating at the distributors.

It was surmised that if the demand information available to the distributor were also available to the central warehouse, it would be possible to obtain more accurate and earlier knowledge of the true market conditions, thus removing one of the amplification stages in the system, and also possibly enabling the warehouse to anticipate future changes in trend.

Feeding this information forward from the distributor to the warehouse could not be simulated at a piece part level, but the link could easily be established to deal with gross demand information. Before making the necessary alterations to the model, it was necessary to decide precisely what information was to be fed forward, and also how it was to be used at the warehouse. Concerning the former question, it was considered that in reality the variability of demand at the distributors would be such that a degree of smoothing would be essential. The distributor section already includes such a process, in which the mean age of the information is five weeks, so that this smoothed demand was the information selected. Although the smoothing introduced a delay in response, the link would still bypass the delays and corruption associated with the normal information path, and a degree of delay was thought desirable to reduce any hypersensitivity. The question of how to use the information can again be resolved to one of balancing sensitivity and responsiveness against stability. The obvious course would be to use the information directly to affect the warehouse replenishment decision.

e.g. $MMWF = RSR/RSF \times MWF$

where MWF is the normal desired manufacturing rate.
MMWF is the modified desired manufacturing rate.
RSF is the smoothed demand at the warehouse.
RSR is the smoothed demand fed forward from distributors.

This adjustment was thought to be too coarse, and was likely to lead to instability. However, if the same factor (RSF/RSR) were to be used to modify the re-order level of all the individual piece parts, then the effect would be more subtle and less likely to promote a "nervous" factory response.

The model was modified in this manner, and a diagram is shown in Fig. 72.

Since the earlier experiments had already shown the existing system to be inferior in most important respects to the proposed system, it was decided that any further experiment with the model of the existing system would be pointless, and that the only comparison required at this stage was between the proposed system performance with and without the feed forward loop.

The experimental procedure used previously was followed, using only the feed forward model. However, to facilitate comparison, the graphs are shown alongside the graphs already obtained for the proposed system.

11.15. Results Obtained from the Model with the Feed Forward Link

Fig. 73 gives a tabulation of the selected results, presented in an identical manner to those from previous experiments. The following graphs (Figs. 74 to 80) are in the same sequence as used before, together with the corresponding curves for the proposed system without the feed-forward loop, as shown in Figs. 57 to 63.

11.15.1. Shortages (Fig. 74)

This curve demonstrates that the feed-forward link not only causes the shortages commensurate with any given stock level to increase, but that the performance in this respect is less consistent and more susceptible to variation from random influences.

SCHEMATIC DIAGRAM of the COMPOSITE MODEL with FEED FORWARD

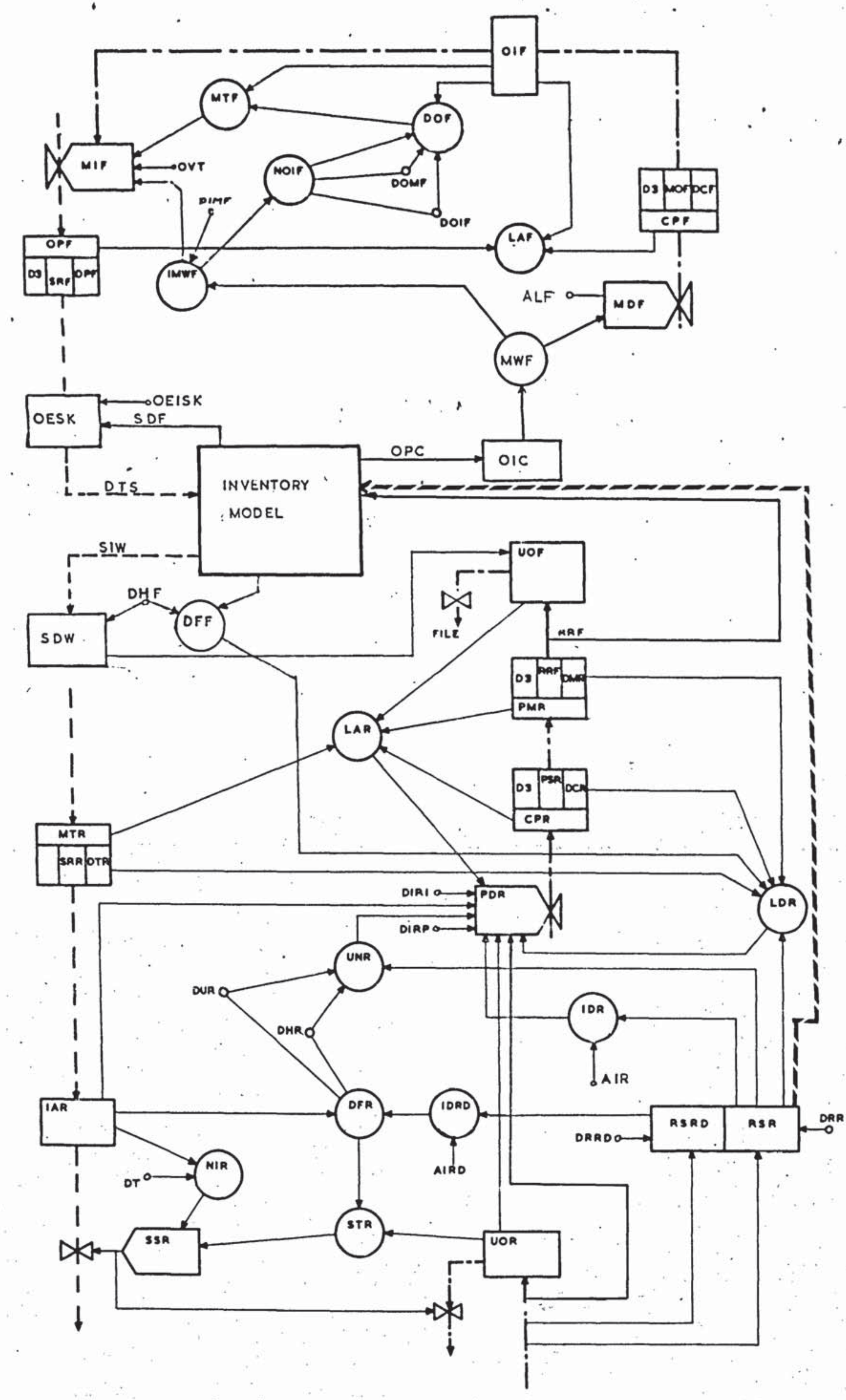
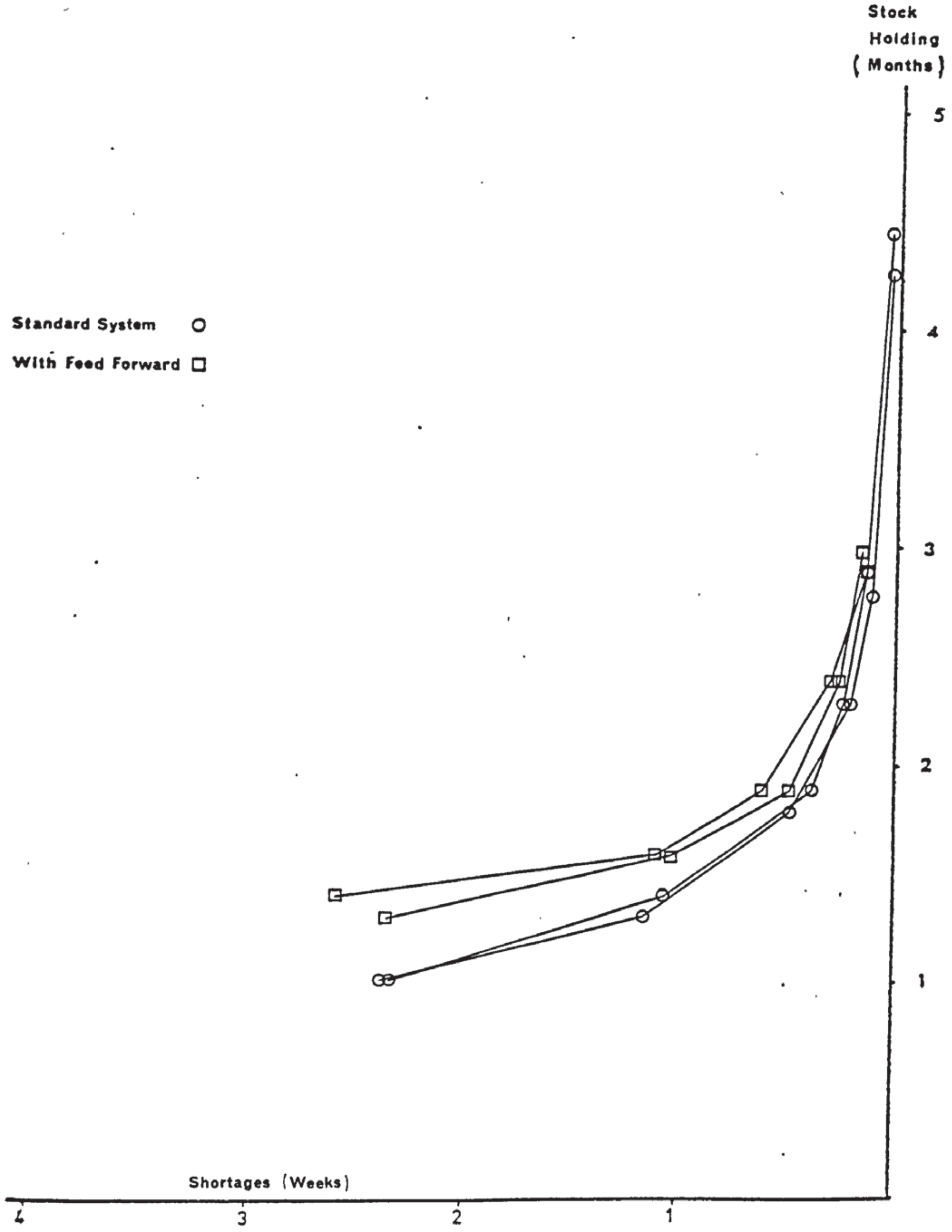


FIGURE 72

	STKHLD (Months)	1.3	1.6	1.9	2.4	3.0
Feed Forward System Seed Set 1	BKV/$\overline{DMV}$	0.58	.256	.121	.06	.039
	σL	3.3	2.6	2.3	2.2	2.5
	σWV	7422	4769	3366	4526	6457
	σMSV	758	622	519	503	429
	σAMWF	33.6	30.1	26.0	25.1	26.3
	σSKV/$\overline{SKV}$	.487	.308	.230	0.28	.310
	σDMV/$\overline{DMV}$	.140	.101	.078	.073	.068
Feed Forward System Seed Set 2	STKHLD (Months)	1.4	1.6	1.9	2.4	2.9
	BKV/$\overline{DMV}$	.642	.277	.147	.069	.031
	σL	3.5	2.7	2.3	2.2	2.4
	σWV	8629	5195	3649	4690	5783
	σMSV	746	650	541	516	412
	σAMWF	36.6	33.0	27	26.7	26.4
	σSKV/$\overline{SKV}$	.519	.337	.244	.284	.298
	σDMV/$\overline{DMV}$	.164	.106	.085	.075	.067

Fig. 73

Tabulated Results Obtained from the Model with the Feed Forward Loop



PERFORMANCE OF THE COMPOSITE MODEL WITH & WITHOUT THE FEED FORWARD LOOP – MEAN SHORTAGE LEVEL

Fig. 74

11.15.2. Lead Time Variability (Fig. 75)

It can be seen that even at best, the lead time varies more with the feed forward loop than without. The minimum in variability which was first suggested by the standard model is much more clearly defined with the feed forward loop.

11.15.3. Work-in-Progress Stability (Fig. 76)

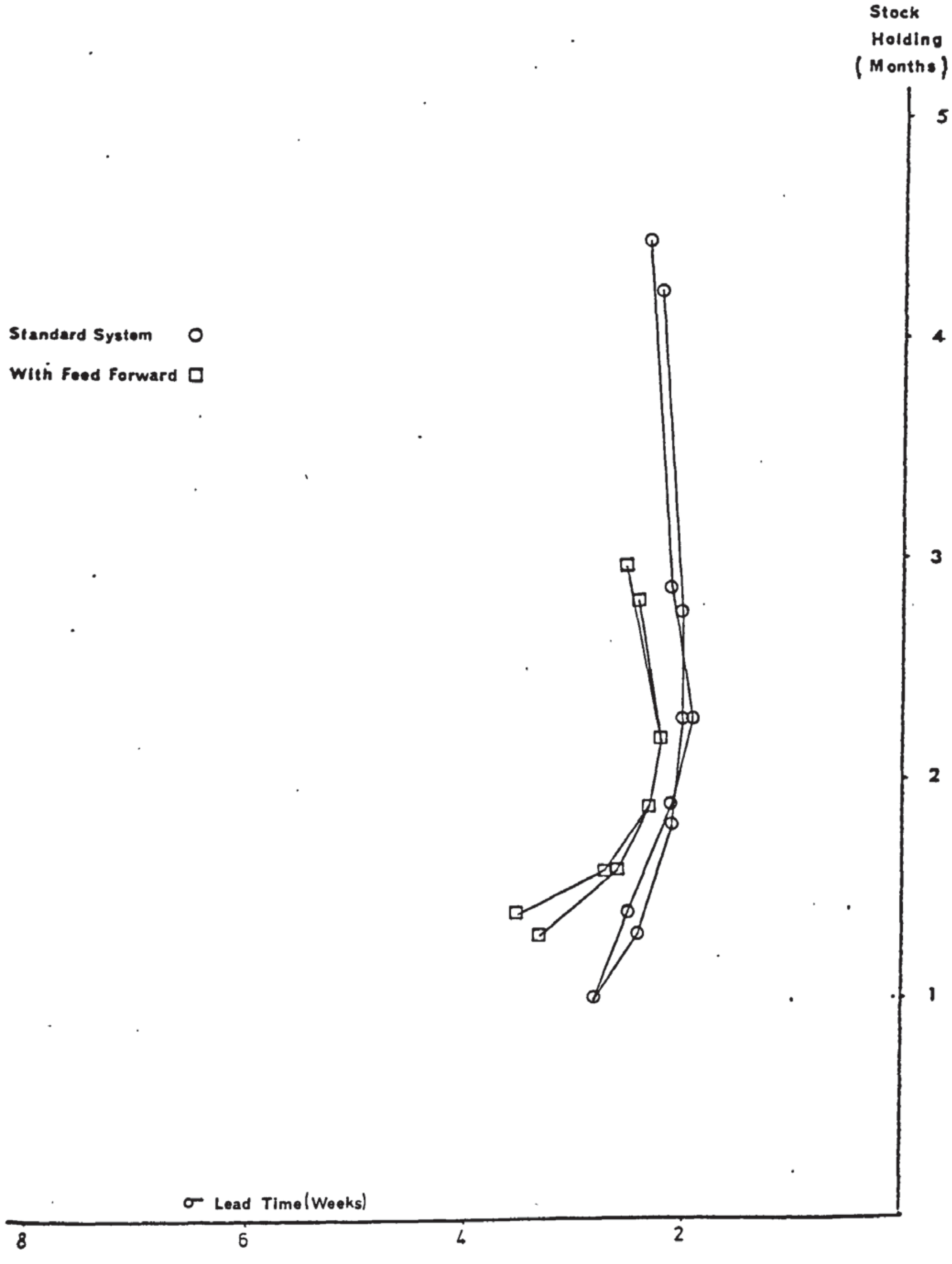
The minimum which had been observed previously also occurred with this version of the model, and at this point, the curves for the two versions are coincident. However, the performance of the feed forward model deteriorates more rapidly either side of this point.

11.15.4. Stability of the Monthly Despatch Value (Fig. 77)

This graph repeats the pattern observed in the previous experiments, in which the monthly despatch value variability decreases approximately linearly as the mean stockholding increases, and this relationship seems to hold for all versions of the model.

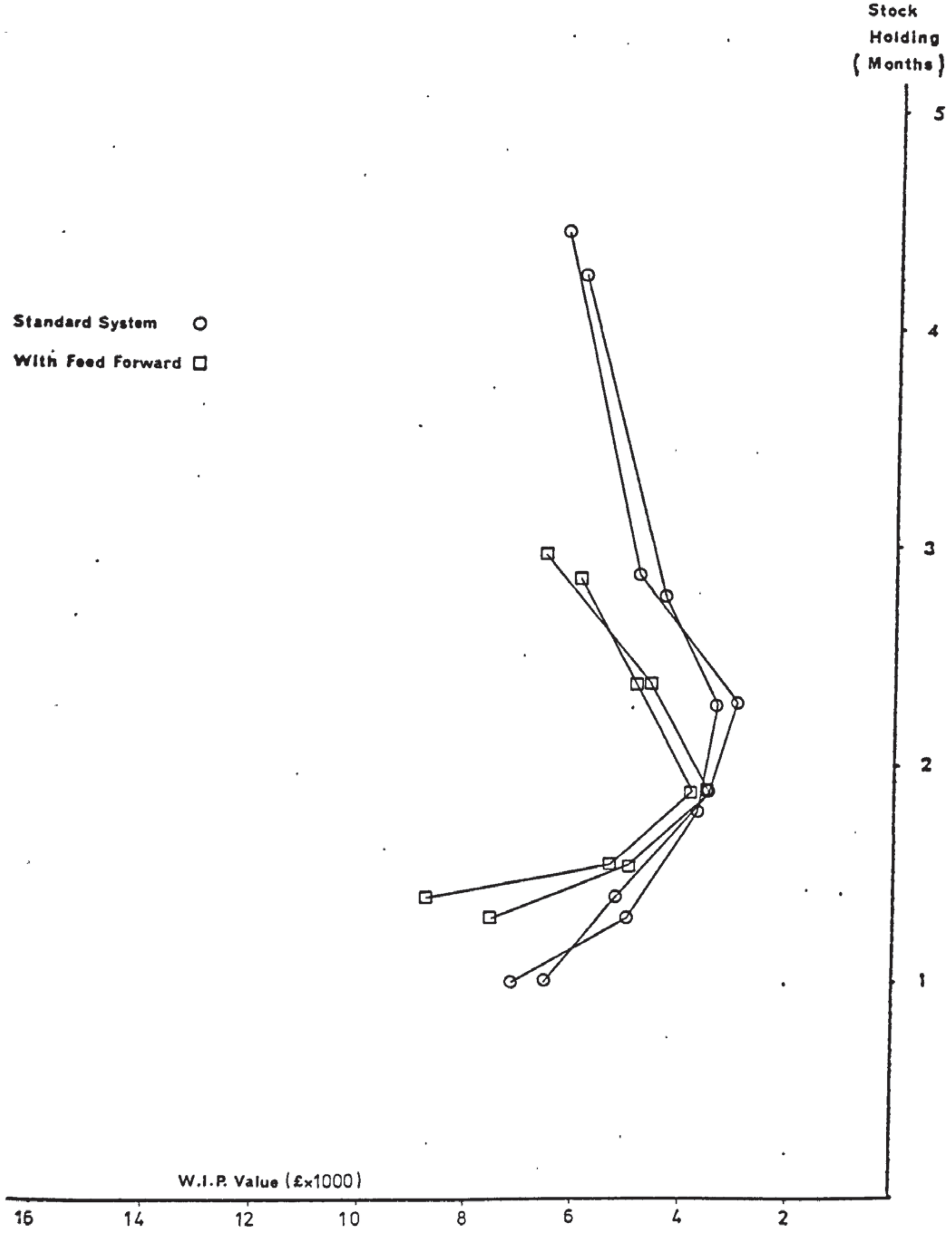
11.15.5. Stability of the Monthly Factory Order Value (Fig. 78)

The feed forward link has a marked adverse effect on this variable, which is more pronounced at



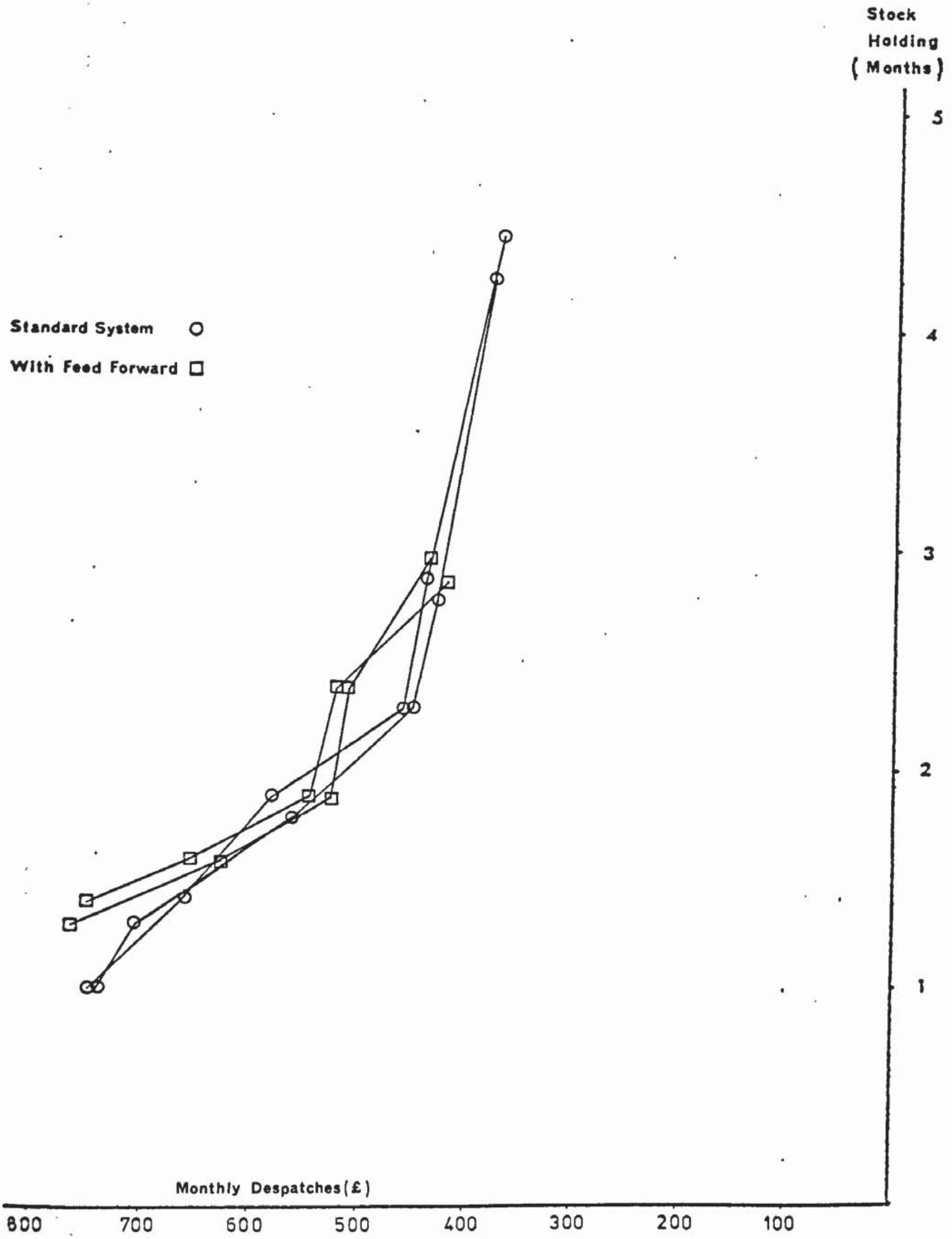
PERFORMANCE OF THE COMPOSITE MODEL WITH & WITHOUT THE FEED FORWARD LOOP – LEAD TIME STABILITY

Fig. 75



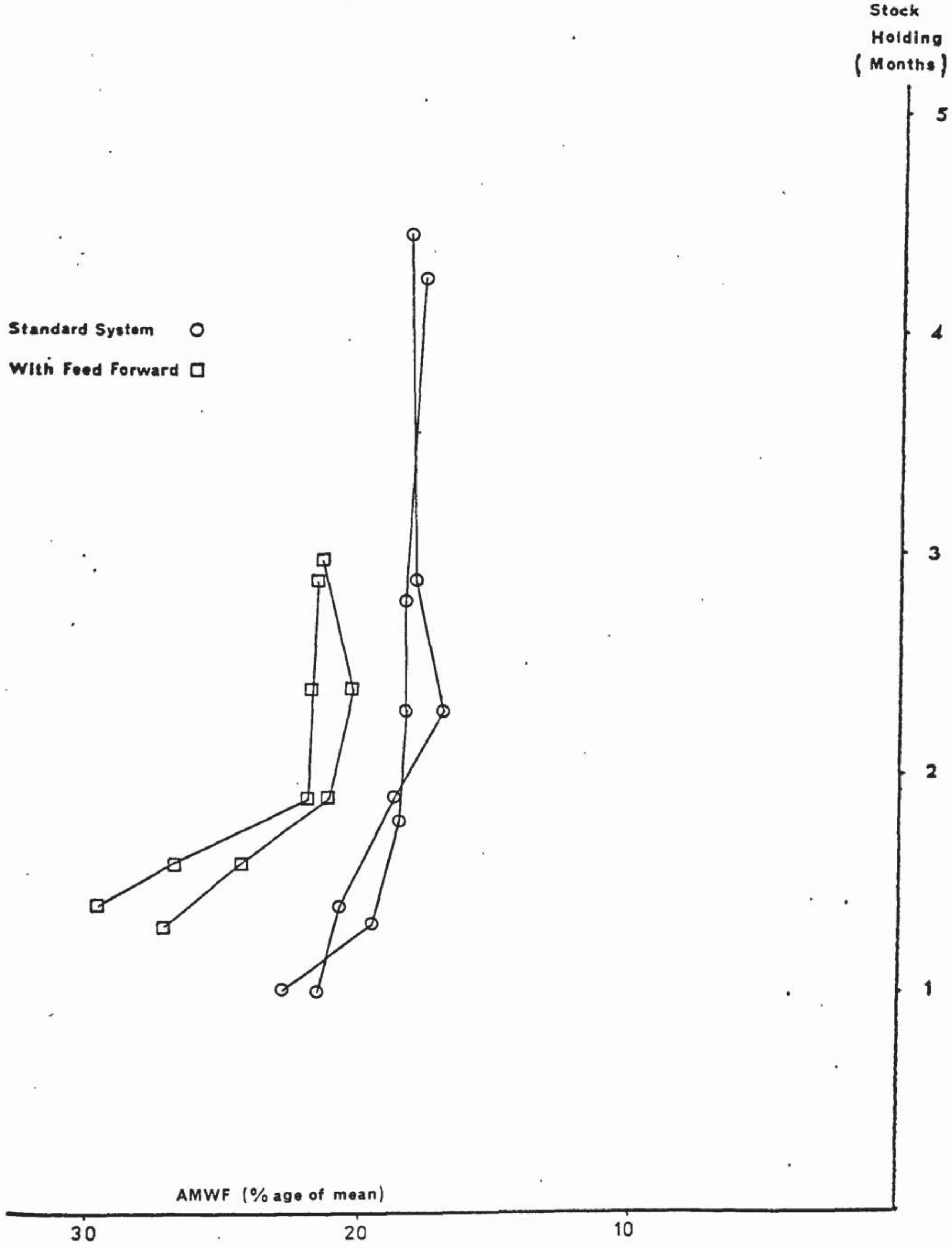
PERFORMANCE OF THE COMPOSITE MODEL WITH & WITHOUT THE FEED FORWARD LOOP —
W.I.P. VALUE STABILITY

Fig. 76



PERFORMANCE OF THE COMPOSITE MODEL WITH & WITHOUT THE FEED FORWARD LOOP— STABILITY OF MONTHLY DESPATCH VALUE (EX WAREHOUSE)

Fig. 77



PERFORMANCE OF THE COMPOSITE MODEL WITH & WITHOUT THE FEED FORWARD LOOP—
STABILITY OF FACTORY ORDER GENERATION RATE

Fig. 78

lower stock levels. It would seem that the induction of a "nervous" response has not been avoided.

11.15.6. Stock Stability (Fig. 79)

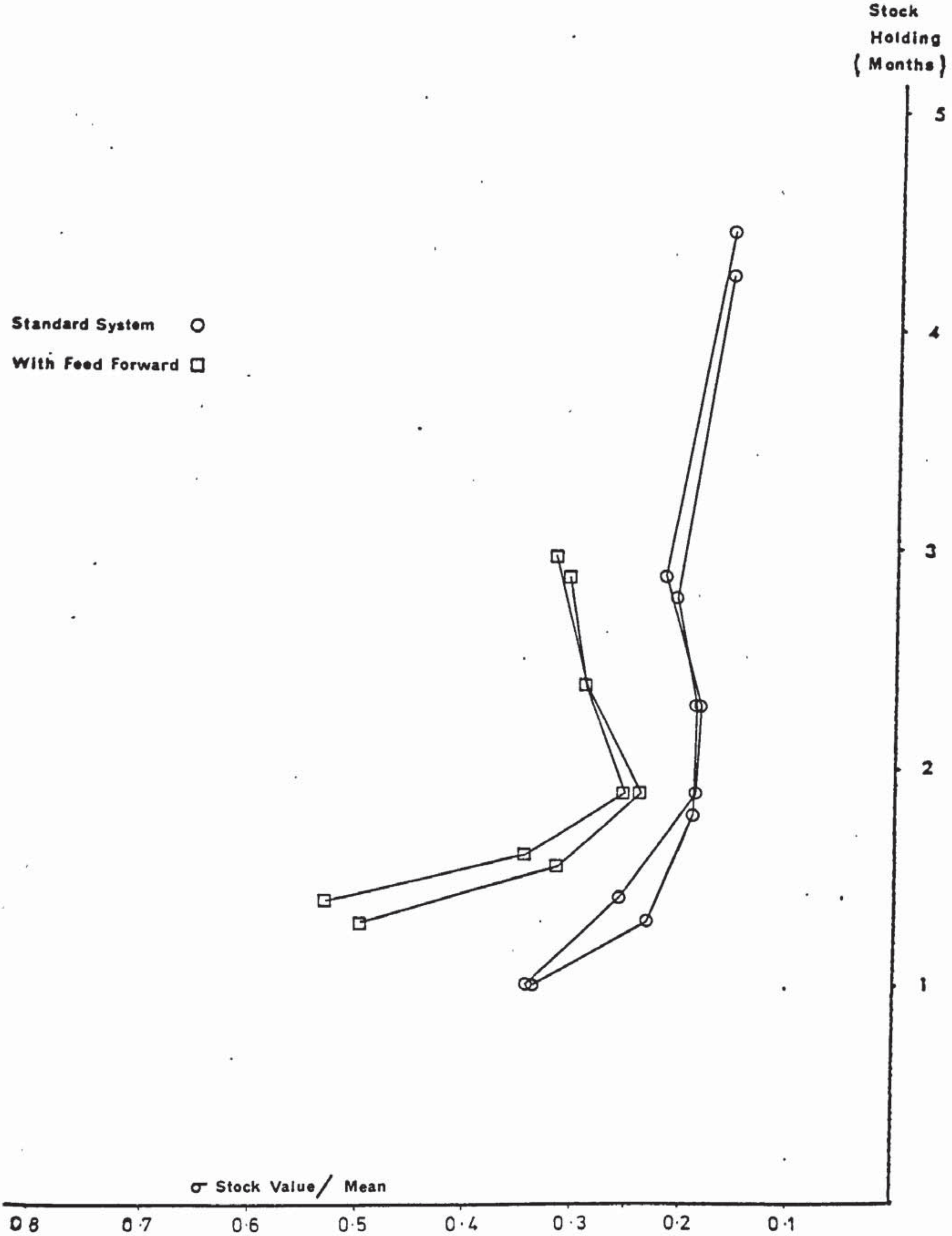
Again the feed forward loop has accentuated the minimum, which was also observed in the other experiments with the proposed system. However, with the feed forward loop the minimum occurs at a lower stock level than with the standard version, but at approximately the same stock level as with the exaggerated lead time response version.

11.15.7. Demand Stability (Fig. 80)

As with the shortages, the deterioration caused by the feed forward loop is greater at the lower levels of stock, but is still significant even at the normal operating levels.

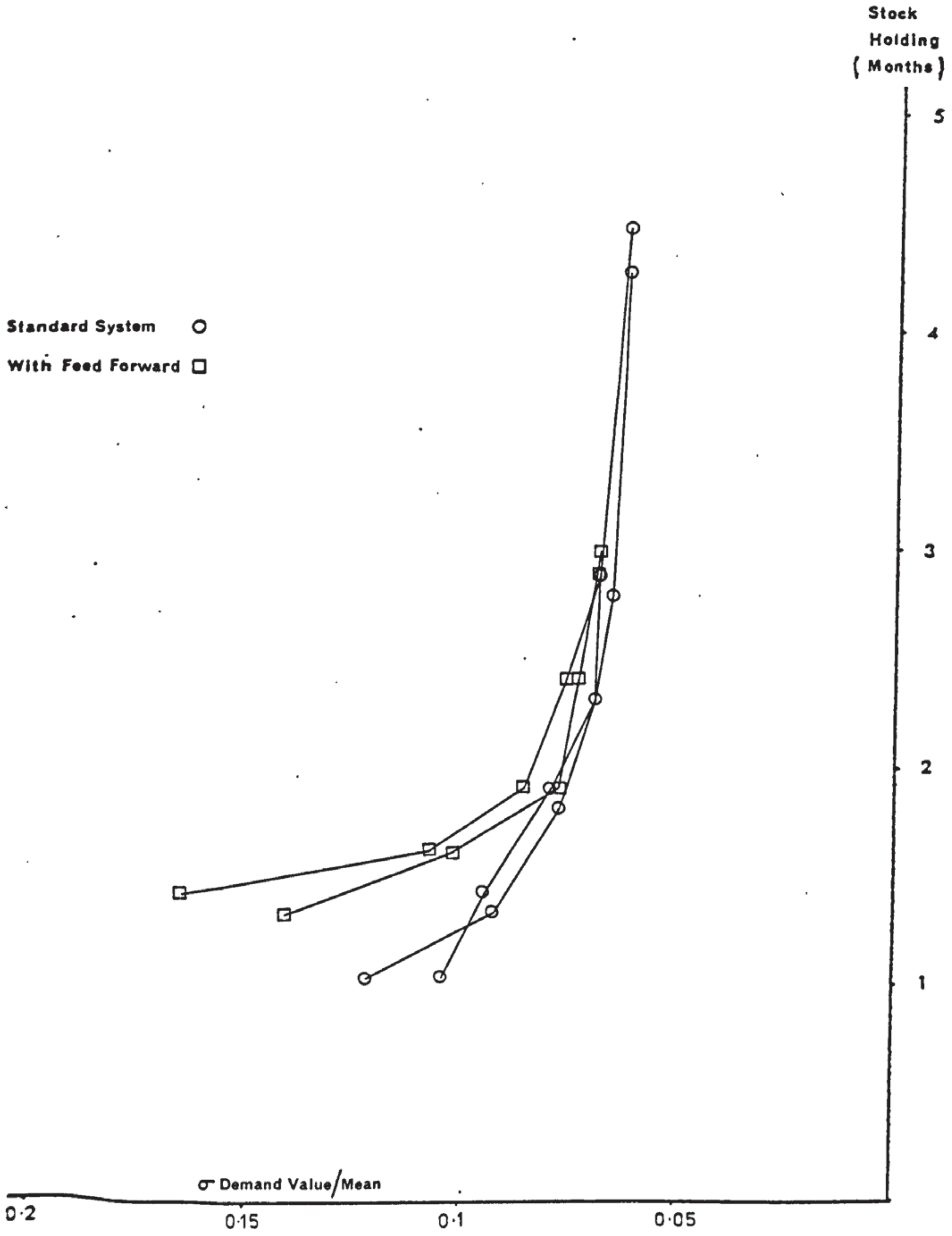
11.16. Discussion of Results

The interpretation of the results is complicated by the unrealistically high levels of performance that the models predicted for the stock levels achieved. Reasons for the stock holding being lower than those achieved in practice have already been discussed (Chapter 6.4.2.3.) but the low level of shortages at these stock levels is attributable to the simulation



PERFORMANCE OF THE COMPOSITE MODEL WITH & WITHOUT THE FEED FORWARD LOOP – STOCK STABILITY

Fig. 79



PERFORMANCE OF THE COMPOSITE MODEL WITH & WITHOUT THE FEED FORWARD LOOP
DEMAND STABILITY

Fig. 80

of the production system and the scheduling rules. In particular, the latter are applied with perfect discipline in the model, which is far from true in the real world. Another factor is the attenuated parts range, with its limited range of demand and supply characteristics.

All of these deficiencies could have been rectified so that the model gave a more realistic output, but this would have required much more investigation of the actual operating and supply conditions in the factory as well as a more complex and expensive model. In addition, the problems of validation would have been far more complicated and in view of the susceptibility of specific output values to vary with different random factors, there would still have been unacceptably high risks in using the results for any other than comparative purposes.

One of the prime purposes in constructing the model was to determine whether the production rescheduling system employed by CompAir could fully compensate for the apparent deficiencies of their stock control system in allowing for demand variability, and if so, whether the parameters could be adjusted to give a more economical level of stock. The first experiment demonstrated that the alternative stock control rules not only reduced the stock holding necessary for a given shortage level quite considerably, but that in general the flow of work through the system was more stable.

The second experiment indicated that these advantages increased as the lead time/load response of the supply factories became more sensitive, suggesting that the inability to achieve stable lead times can be offset by selection of suitable stock holding rules and that such rules need not require a prohibitive investment in inventory.

Reference has already been made to the difficulty of estimating the significance of this predicted advantage in the real system, but Fig. 57 shows that, for a given level of stock, the proposed rules operate with a shortage level of approximately one-third of that for the existing rules. Assuming that the proposed rules would, if introduced, be subject to a similar degree of maladministration, there is no reason to suppose that this relationship would not hold in practice, i.e. that the current four year mean shortage level would be reduced from 2.8 weeks to one week. Equally important, the results suggest that this level of performance would be maintained much more consistently than hitherto. Of secondary importance would be the more stable workloads passed on by the spares system to the supply departments.

The results show that although the standard deviation of the factory order generation rate is higher for the proposed rules, other, more stable indicators of load such as work-in-progress and lead time, are less variable. This suggests that the factory order generation fluctuations are of a low amplitude high frequency nature, which are no real problem to accommodate.

One of the most encouraging results was the demonstration that the standard deviation of gross demand at the warehouse would be greatly reduced by adoption of the proposed rules, thus achieving one of the prime objectives of the whole exercise which was to damp down the effects of the trade cycle (see Fig. 63). This is important not only in terms of the service offered to the distributors, but the more stable stock holding (Fig. 62) implies that the storage facilities can be more effectively utilised, with less spare capacity required for peak loads.

Although the monthly despatch value seems to vary equally for a given stock level, which ever rules are used, the ability of the proposed rules to offer a specified level of service at a lower level of stock implies that here also economies can be made with the physical facilities required.

The final experiment, with the feed forward loop proved most disappointing, as the establishment of such a loop appeared positively detrimental in every respect. It may be that the fault lay with the way the information was applied, and that using the knowledge to adjust factory capacity, for example, would be more beneficial. This area requires further investigation as it still seems a reasonable proposition that reliable, up-to-date information on market conditions would be useful in warehouse control.

As far as the computer is concerned, adoption of the proposed rules can be achieved with only minor adjustments to the existing suite of programs. The question of monitoring lead time performance and updating the lead time data may be more complex, as this is currently performed manually. As a consequence, this task is not generally performed as frequently or at the detailed level that the variability of lead times would indicate is necessary. In the model, the lead time was updated in two stages, firstly upon the calculation of the due date (analagous to the "quoted delivery" from a supplier) and secondly on its lateness (or earliness) against the original "promise". Ideally, this situation should be duplicated in practice, as the system receives earlier notification of extending (or contracting) lead times as a consequence.

It is difficult to compare the actual processing times required for the two sets of calculations, but from the simulation experiments, the proposed rules are marginally faster. In terms of the other aspect of computer efficiency, the quantity of data to be transcribed and carried over from one run to. the next will be less, since the proposed rules carry over only the demand average, instead of twelve months data. However,this advantage is partially offset by the need to carry other vital data across on demand variability.

The implementation of the proposed rules will pose particular problems, as in achieving a correct stock balance, they will attempt to increase the stock of items which are understocked (which can be achieved quickly), whereas the reduction of excess stock could take longer. Thus the introduction will need careful management if a sudden but transient increase in stocks is to be avoided. In view of the general benefit to be obtained, this should represent no deterrent to their adoption.

CHAPTER 12

CONCLUSIONS AND RECOMMENDATIONS

12.1. Conclusions

i. Of all the influences which affect the CompAir spares operation, historically one of the most important has been the so-called "trade cycle". The data show that the three-month average gross demand for spare parts varies by up to 15% either side of the long term mean, and that this variation has a cyclical characteristic with a period of approximately 4¼ years. This cyclical demand pattern coincides with the pattern observed in the demand for original equipment, and also correlates closely with the Department of Industry "Index of Business Activity".

ii. There is a strong connection between the level of spares demand and its trend, and the performance of the spares system. An increase in demand has previously been accompanied by a decrease in stock holding, an increase in shortages, and a decrease in the service offered to the CompAir spares distributors, while the converse is also true.

iii. There is evidence that the effects of the trade cycle become progressively more marked as the variation in demand feeds through the system, being less significant at the distributors, and more marked at the suppliers.

iv. Experiments with the Industrial Dynamics model of the spares system indicated that the behaviour observed in the real system was entirely consistent with the structure postulated in the model, and that the parameters were also of the right order of magnitude.

v. These experiments further suggested that while marginal improvements in system behaviour could result from reducing the delay in order turnround and clerical processing and similar operations, the most significant benefits were likely to result from attention to:-

   (a) The response of the various supply systems.
   (b) The characteristics of the warehouse stock control rules.
   (c) The characteristics of the distributors stock control rules.
   (d) The relationship between the above.

vi. The demand characteristics of the CompAir spare parts range form a typical pareto curve, in which 10% of the total range generates 90% of the turnover. Analysis of individual piece part demand over a seven year period showed that for classes of components within a given range of mean demands, there was a relationship between the mean demand of the class and the mean coefficient of variation.

vii. In spite of the above relationship, within each of the classes, the range of coefficients of variation for each piece part was extremely wide.

viii. It follows from vi. and vii. that the existing stock control rules, based as they are on setting stock objectives according to the monthly usage value of each piece part, do not balance the total stock according to the requirements of the demand pattern.

ix. Although the Industrial Dynamics technique provides a useful tool for analysing the gross behaviour of existing systems, it cannot be used to compare the effect of different demand patterns (especially with respect to variability) and different stock control rules, since it operates at a gross level, in which individual piece part characteristics are lost.

x. The composite model developed by the author overcomes the above problem by operating at a semi detailed level only in those areas relevant to the case being studied. Although slightly more expensive in programming and execution requirements than a pure Industrial Dynamics model, the technique is considerably more economical than the more detailed simulation techniques which would otherwise be required.

xi. In the case of CompAir, it was demonstrated that the ability to rearrange priorities within a provisioning system does not fully compensate for the inability of the stock control system to respond to the variability of demand at component level. It follows that the introduction of more appropriate stock control rules would bring either an improvement in performance or a reduction in stock, or a combination of the two.

Prediction of what degree of improvement would result is difficult, but the models suggest that for any normal level of stock, the proposed rules for both "made in" and 'bought out" items would halve the"inefficiency factor" of the present system, i.e. if the existing system offers a "First Pick" of 88%, that is a shortfall of 12%, the proposed rules, for the same stock level, should provide 94% - a shortfall of 6%.

xii. The introduction of the recommended stock control rules would have the further effect of reducing the "gain factor" of the system as a whole, thus reducing the effects of the cyclical demand pattern.

xiii. The experiments with the composite model suggest that by careful matching of the characteristics of the supply system and the stock control system, variations in lead time may be reduced to a minimum. Whether such conditions are consistent with meeting specified stock and/or service levels has yet to be established, and requires further investigation.

xiv. Although techniques of demand forecasting based on reliability theory, known population figures, or the correlation of historical production and failure rates have been used with some success in other industries, notably the automotive, the scarcity of relevant data, and the complexity of its analysis, precludes the application of such techniques at CompAir.

xv. The composite model technique offers a unique method of exploring the dynamic effects of stock control and provisioning rules on system behaviour. Although this particular model was specifically constructed for CompAir, the technique is not specialised in its approach, and the model could easily be adapted to simulate any stock control and provisioning system. The value of such a technique lies in the comparative economy with which such systems may be investigated, as each run of the model over a simulated 20 year period required only 22K of store in an ICL 1906S computer, and took only five minutes of actual processing time.

12.2. Recommendations to the Company

In the course of the project, a number of points have arisen relating to the organisation structure and other aspects incidental to the work described in the proceding chapters. These points are discussed in the two reports prepared by Mr. D. Love and the author (Refs. 73 and 74). The recommendations put forward here relate solely to the control aspects of the spares division and follow logically from the experimental results and conclusions.

i. That the alternative rules for controlling the stock of both "made in" and "bought out" spares components should be implemented as soon as possible. As described, the rules perform a number of distinct operations:-

Demand forecasting
Lead time forecasting
Demand variability forecasting
Re-order level calculation

Re-order quantity calculation.

The effort involved in implementing all of these is likely to be insignificant, with the exception of the lead time forecasting. The existing system updates the lead time data on bought out items as nominally three months intervals, and then not at the detailed level that accurate control requires. The data for made in items is not updated at all, on the premise that the rescheduling routine makes such information superfluous. In the model, the data for each piece part was updated in two stages for each separate order. Firstly, the lead time was updated with the new lead time calculated when the order was first raised (representing either the suppliers "promise date" or the factory production control systems" calculated lead time) and secondly the information was corrected for the lateness (or earliness) of the order when it eventually arrived. It is recommended that a similar system should be implemented in practice. However, in view of the scale of the work necessary, there is no reason why the other aspects of the alternative rules should not be introduced in advance, as they will generate considerable benefit on their own.

ii. Prior to making the program alterations necessary to change the control rules, a programme of educating all the spares' personnel involved with the control of stock should be undertaken. If they have an appreciation of the basic stock control principles being exploited, and can accept the benefits to be gained, much will have been done to ensure a smooth transition from the existing system.

iii. The present system of transferring stock from the factory to the spares warehouse should be reviewed, with the objective of giving the spares division more effective control on the timing and nature of such transfers. The practice of raising I.S. (Issue to Spares) notes one month early, frequently means that items which are not in short supply are credited into stock one month early, i.e. the spares division is carrying excess stock.

iv. A line by line analysis of the existing stock holding should be carried out to identify the reason for the discrepancy between the theoretical and actual stock holding. It is assumed that this discrepancy will remain at its present size under the alternative rules, but it is possible that the better balanced stock will reduce it, by allowing management greater time to investigate exceptions, and by removing many of the contingencies which create the crisis situations which generate excess stock.

v. Although the experiments were conducted with the rules operating fully automatically, there will always be occasions when manual intervention is necessary, e.g. in the case of new items with no demand history, or the case of non current items being withdrawn from production, or any other instances where the management has specific information which could affect demand. Control of such items can remain at office supervision level. However, the rules can also be easily manipulated to affect the system as a whole, either to reflect changes in policy, or possibly as a means of adjusting the response of the system to changing demand or supply conditions. In both cases, a deeper understanding of the system and the control rules is required than merely an appreciation. It is recommended that the spares stock controller and the spares manager should have the opportunity of understanding and manipulating the model, to gain some "experience" of how to exert control under the new rules.

CHAPTER 13

FURTHER WORK

It is commonly accepted that the provision of a good after-sales service is essential to support a flourishing market for original equipment, as well as usually being a profitable exercise in its own right.

However, although a relationship between the quality of the spares service and the future original equipment market is supposed to exist, the nature of this relationship, particularly in an industrial environment, has never been investigated.

It seems reasonable to suppose that as the level of service deteriorates, so would the number of repeat orders from existing customers, after some delay which would depend on many factors. This is the very type of problem which Forrester and his colleagues claim is amenable to analysis using the Industrial Dynamics technique, but whatever technique is used, any results obtained from an investigation would be profoundly significant in formulating marketing strategies, both for spare parts and original equipment.

The remaining questions raised by this project tend to fall into two categories:- those relating to specific aspects of predicting demand for spare parts at CompAir, and those of a more general nature concerning the interaction between demand patterns and supply system characteristics, and the interface at the warehouse, the stock control system.

Dealing with the former category first, the problem arises that having accepted that the demand is unpredictable, an assessment must be made of how unpredictable. A very superficial study of the historical demand of some dozen components suggested that the variability of demand for a given part was independent of the trade cycle (See Chapter 8). In order not to overstate any potential benefits of the alternative rules, this slim evidence was ignored in the simulation experiments, and the standard deviation of the generated demands was also allowed to vary with the mean, but in view of the importance of this feature, a more detailed study should be made. Such a study should also seek to find whether the variability of demand of a given component is dependent upon any other features, such as type of component, price, duty, etc. This information would be invaluable in setting realistic stock-holding parameters for new components which have no previous demand history.

At the other end of the product life cycle, the proposed rules should provide a greater insurance against excess stock, since they react more sensitively to changing demand trends. However, the rules only react to the trend as it occurs, and cannot anticipate the decline in demand of an obsolescent component. Attempts to investigate the product life cycle patterns of various types of component were thwarted by the lack of sufficient data, particularly demand data. This suggests that the historical demand data should be retained (in sufficiently compact form) for longer periods than the seven to eight years which is current practice, but it would be some years before the benefits could be assessed. An alternative approach would be to investigate the life cycle patterns in similar industries, drawing parallels where possible.

The demand for a spare part obviously depends upon a population of machines using that part, and the prediction of future demands for spares would be facilitated if estimates could be made on probable future populations. This requires knowledge not only of historical supply data for the machines, which is easily obtained, but also information on the life distribution of the various models. Such information would also be valuable to the marketing department.

The final aspect of the demand problem concerns the failure rates of individual piece parts in terms of elapsed time. Limited information is available about the design life of certain key components or assemblies, but this is invariably expressed in terms of running hours, and there is insufficient data on the general operating conditions to enable this data to be translated to elapsed time.

From the Company point of view, the overriding consideration must be whether the cost of such information would be justified by its value, and this in turn depends on answering the first question, and establishing the overall significance of the spares market.

The second class of questions, concerning the interaction of demand and supply patterns at the spares warehouse, all arose from the work with the composite model of the system, and clearly there is a need to investigate the reasons for the discrepancy between the predicted performance and that actually achieved by the system. Possible causes of this discrepancy have already been mentioned, but since the model was not intended originally to be more than a means of comparing the operating characteristics of various stock control rules, and since the results obtained have been sufficient for the original objective, these speculations have never been tested. However, the ability to use the model as a predictive tool would certainly enhance its value.

Having answered the question as to which set of rules perform better under a given set of conditions, the results raise still further questions of interest concerning the CompAir system. For example, the existence of a minimum in the variability of lead times is a feature which warrants further exploration, to establish on what parameters this minimum depends, and how sensitive it is to variations in their values. In a system containing so many parameters, it would be impractical to establish an optimum combination, but certainly the more significant should be investigated, such as the demand smoothing coefficient and the coefficient used to calculate the mean absolute deviation.

So far, the results obtained from the model have only been expressed in general parametric form, as time did not permit a detailed analysis of the time series of individual variables, but a closer study of the graphical output which the model can provide could well prove fruitful.

Although the potential of the existing model is far from exhausted, it must be conceded that in its present form it suffers from several limitations. The most severe of these is the way it combines the spares requirements and original equipment requirements when loading the manufacturing facility, and the way these requirements are subsequently segregated. At CompAir, the interactions of these two seperate requirements is particularly complex, and difficult to simulate in a "single stream" model. A more realistic result could probably be obtained by applying the composite technique to the "multi source" Industrial Dynamics model developed by Mr. D. Love (ref. 72), and taking full cognisance of the interaction between the value category parameters of the spares system and those used in the factory. The "multi-source" model consists of three separate supply systems, and two independent demand generators. The supply systems represent the bought out suppliers, the factory, and sub-contractors, while the two demand streams represent the original equipment and spares markets respectively. Although much more investigation is required to set the parameters at their correct values, and to establish a reasonable "dummy parts range" for the original equipment market, the basic structure is believed to be correct, and the resulting model would be of immense value in assessing the impact of the spares requirements on the performance of the original equipment supply departments. Such a model would obviously be more expensive of computer time and storage capacity than the existing one, but would reflect the unusual complexity of the situation at CompAir.

A much more common situation is where the warehouse and manufacturing facility are mutually dedicated. Here the problem is frequently met by optimising on production schedules and stock levels in order to meet certain operating criteria. A model of the type developed by the author would handle such a problem most economically, and could also provide information on the effects of such policies at distribution outlets. If this problem should prove to be as widespread as the author believes, then it would be sensible to consider writing a program which would construct the program automatically, using an interactive question and answer technique to define the type of structure, the size and type of the various delays, the number of hierarchies, and at what points the model structure should change from Industrial Dynamics to the detailed type. A major step in making the model easier to construct would be achieved by writing a program to construct the dummy parts range from certain input information. It may well prove impossible to make this aspect fully automatic, as the final range depends on a compromise between accuracy and economy of "components" but there is no doubt that the manual iterative method used in this project could be improved upon.

With the rapid advances being made in computer technology, there is no doubt that simulation will be used to an increasing degree to solve industrial problems. The author believes that the modelling technique which has been explained in this project will have a contribution to make, particularly since it can be easily understood by the non-academic practitioners operating in the field.

APPENDIX 1

OTHER SPARES OPERATIONS

In the course of the project, short visits were made by various members of the project team to the following establishments:-

Ford Parts Centre, Daventry
Leyland Cars Parts Division, Cowley
J.C.B. Service, Uttoxeter
Aveling Barford Parts Department, Grantham
CompAir C & M

The findings from these visits were summarised in a series of tables, which are reproduced here from an earlier report to the company (ref 73).

Since the visits were brief, the examination was both general and superficial, and it was impossible to pursue the question of stock control and provisioning to any depth. However, some significant points emerged.

1. The emphasis was generally on providing a fast turnround for customers' orders, especially emergency orders. This latter is important as none of the companies had any influence on their distributors' stock policy at the time, so that emergency orders were frequent. To achieve the fast turnround, much

attention was paid to mechanical handling and fast data processing. For instance, Aveling Barford can produce order picking documents within five minutes of receiving an order.

ii. None of the companies appeared to devote the same resources or attention to maintaining economical and effective stock levels, or to monitoring and forecasting requirements. From the brief descriptions given, the control policies appeared to be extremely simple.

iii. All of the companies sourced their made-in components from the original equipment factories. In cases of conflicting priorities, two companies (Ford and J.C.B.) allocate top priority to emergency spares orders.

iv. All of the companies maintained an autonomous spares purchasing staff to concentrate on provisioning and expediting bought-out components.

v. Attitudes varied with respect to non-current spares. The range of cover given also varied (see Table B). Fords tended to favour the manufacture of an "all time requirement" before withdrawing a machine, but this policy was actively avoided by Leyland.

Comment

The emphasis in achieving a fast turnround seemed to be disproportionate compared with the effort spent in ensuring that components were available ex-stock.

All the companies commented on the poor stock control of their distributors, but none of them had investigated the full effects of this on their own operation or attempted to do anything about it*. The literature has mentioned two companies which have taken this approach, Mercedes Benz and Vauxhall (71 & 2) It has not been possible to investigate the Vauxhall system, but when Mercedes Benz was visted, their scheme had been abandoned during a recent reorganisation.

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* The table suggests that spares management advice is available. Unfortunately, this is usually restricted to advice on stocks of new parts and does not extend to inventory management.

TABLE A - GENERAL

		BROOMWADE	C & M	FORD	LEYLAND	J.C.B.	AVELING BARFORD
TURNOVER (net)	£M	4.96	5.4	100	70	7.3	6.0
NUMBER 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		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

(y) Allocated from Provisioning and Publications

TABLE B - NATURE OF BUSINESS

	BROOMWADE	C & M	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	20-35
NUMBER 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	C & M	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 (%)						
Priority	90/80 (1)	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.

TABLE D - WAREHOUSE

	BROOMWADE	C & M	FORD	LEYLAND	J.C.B.	AVELING BARFORD
AREA sq.ft. x 1000	20	30	1600	820	80	100
HOW DIVIDED	BY PRODUCT	BY PRODUCT NUMERICALLY	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 MOVABLE BINS	FIXED BINS	SUPERMARKET TYPE AREA	SUPERMARKET TYPE ARE	FIXED BINS
PART PLACING	(FORK LIFT (TRUCK AND (MANUAL	(FORK LIFT (TRUCK OR (ORDER	PALLET PLACERS	HIGH LIFT PALLET PLACERS	HIGH LIFT PALLET PLACERS	(CRANE, FORK (LIFT AND (MANUAL
PART PICKING		(PICKER	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 HOP 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

TABLE E - INFORMATION AND ASSISTANCE TO DISTRIBUTORS

	BROOMWADE		FORD	LEYLAND	J.C.B.	AVELING BARFORD
PUBLICATIONS						
PROCEDURE 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
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

ANALYSIS OF DISTRIBUTORS' SPARES TURNOVER

The following pages show the data available and the method of processing in order to compare the total spares demand at High Wycombe with the demand for spares in the field.

Pages 248 - 251 show the following for the four distributors concerned:-

Column 1	Date
Column 2	The revenue generated in that month by CompAir spares. For distributors A and B this is indexed (Jan 1973 = 100)
Column 3	Three month average of Column 2.
Column 4	The correction factor, to remove the effect of price rises.
Column 5	The revenue generated in the month by CompAir spares, corrected to January 1973 prices.
Columns 6 & 7	Three and Six month averages of Column 5.

In arriving at a total (page 252), it was necessary to arrive at the correct weighting for each distributor.

This was easy where actual cash figures were available, but for distributors A & B another method was required. Figures were available for the value of orders each distributor placed with CompAir each financial year. The weighting was apportioned to each distributor so that the weighted indexed figures for the financial year 1974/75 when totalled were in the same proportion as their orders on CompAir, for the same period.

To ease computation, the figures for distributors C & D were added and indexed before applying the same technique.

The layout of Page 252

Columns 2 to 4	gives the 3 month average of the weighted corrected turnover indices for distributors A, B and C & D respectively.
Columns 6 and 7	give the six and twelve month averages.
Columns 8 and 9	give the percentage of the mean of columns 5 and 4 respectively.

Page number 253 shows the following figures for the U.K. spares invoicing for CompAir:-

Column 1	Date
Column 2	Actual Invoicing
Column 3	Three month average of invoicing

Column 4	Correction factor for price increases
Column 5	Corrected actual invoicing
Columns 6 to 8	Three, six and twelve months average corrected invoicing
Columns 9 and 10	Percentage of mean figures for columns 8 and 7 respectively.

Date	Turnover Index	3 Months Average Turnover	Price Correction Factor	Corrected Turnover	3 Months Average Corrected Turnover	6 Months Average Corrected Turnover
Jan 73	100			100.0		
Feb	100			100.0		
March	104	101.3		104.0	101.3	
April	85	96.3		85.0	96.3	
May	96	95.0		96.0	95.0	
June	104	95.0		104.0	95.0	98.2
July	108	102.7		108.0	102.7	99.5
Aug	75	95.7		75.0	95.7	95.4
Sept	104	96.0		104.0	96.0	95.5
Oct	116	98.3		116.0	98.3	100.5
Nov	89	103.0		89.0	103.0	99.4
Dec	87	97.3		87.0	97.3	96.7
Jan 74	84	86.7	1.09	77.1	84.4	91.4
Feb	83	84.7		76.1	80.1	91.6
March	117	94.7		107.3	86.9	92.1
April	105	101.7		96.3	93.3	88.8
May	111	111.0	1.06	96.1	99.9	90.0
June	141	119.0		122.0	104.8	95.8
July	149	133.7		129.0	115.7	104.5
Aug	97	129.0	1.10	76.3	109.1	104.5
Sept	113	119.7		88.9	98.1	101.4
Oct	160	123.3		125.9	97.0	106.4
Nov	126	133.0		99.1	104.6	106.9
Dec	118	134.7		92.8	106.0	102.1
Jan 75	156	133.3		122.7	104.9	101.0
Feb	126	133.3		99.1	104.9	104.8
March	112	131.3	1.15	76.6	99.5	102.8
April	165	134.3		112.9	96.2	100.6
May	128	135.0		87.6	92.4	98.7
June	166	153.0		113.6	104.7	102.1
July	207	167.0		141.6	114.3	105.3
Aug	114	162.3	1.10	70.9	108.7	100.6
Sept	139	153.3		86.5	99.7	102.2
Oct	228	160.3		141.8	99.7	107.0
Nov	169	178.7		105.1	111.1	109.9
Dec	126	174.3		78.4	108.4	104.1
Jan 76	180	158.3	1.10	101.8	95.1	97.4
Feb	182	162.7		102.9	94.4	102.8
March	204	188.7		115.4	106.7	107.6
April	203	196.3		114.8	111.0	103.1
May	176	194.3		99.5	109.9	102.2
June	191	190.0		108.0	107.4	107.1
July	256	207.7		144.8	117.4	114.2
Aug	187	211.3	1.10	96.1	116.3	113.1
Sept	202	215.0		103.8	114.9	112.2
Oct	210	199.7		107.9	102.6	110.0
Nov	244	218.7		125.4	112.4	114.4
Dec	203	219.0		104.4	112.6	113.8

ANALYSIS OF DISTRIBUTOR 'A' SPARES TURNOVER

Date	Turnover Index	3 Months Average Turnover	Price Correction Factor	Corrected Turnover	3 Months Average Corrected Turnover
Jan 73	100				
Feb	106				
March	83	96.33		83.00	96.33
April	75	88.00		75.00	88.00
May	146	101.33		146.00	101.33
June	93	104.67		93.00	104.67
July	159	132.67		159.00	132.67
Aug	77	109.67		77.00	109.67
Sept	113	116.33		113.00	116.33
Oct	169	119.67		169.00	119.67
Nov	109	130.33		109.00	130.33
Dec	104	127.33		104.00	127.33
Jan 74	159	124.00	1.09	145.87	119.62
Feb	123	128.67		112.84	120.91
March	153	145.00		140.37	133.03
April	124	133.33		113.76	122.32
May	180	152.33	1.06	155.79	136.64
June	221	175.00		191.28	153.61
July	179	193.33		154.92	167.33
Aug	37	145.67	1.10	29.11	125.10
Sept	281	165.67		221.10	135.04
Oct	188	168.67		147.92	132.71
Nov	181	216.67		142.41	170.48
Dec	199	189.33		156.58	148.97
Jan 75	127	169.00		99.93	132.97
Feb	130	152.00		102.29	119.60
March	102	119.67	1.15	69.79	90.67
April	140	124.00		95.79	89.29
May	182	141.33		124.52	96.70
June	174	165.33		119.05	113.12
July	223	193.00		152.57	132.05
Aug	147	181.33	1.10	91.43	121.02
Sept	248	206.00		154.25	132.75
Oct	205	200.00		127.51	124.40
Nov	171	208.00		106.36	129.37
Dec	236	204.00		146.79	126.89
Jan 76	207	204.67	1.10	117.05	123.40
Feb	104	182.33		58.81	107.55
March	236	182.33		133.45	103.10
April	339	226.33		191.69	127.98
May	430	335.00		243.14	189.42
June	356	375.00		201.30	212.04
July	313	366.33		176.98	207.14
Aug	243	304.00	1.10	124.91	167.73
Sept	314	290.00		161.41	154.44
Oct	307	288.00		157.81	148.04
Nov	331	317.33		170.15	163.12
Dec	194	277.33		99.72	142.56

ANALYSIS OF DISTRIBUTOR 'B" SPARES TURNOVER

Date	Turnover £	3 Months Average Turnover	Price Correction Factor	Corrected Turnover	3 Months Average Corrected Turnover
Jan 73	12,259			12,259	
Feb	13,034			13,034	
March	17,738	14,344		17,738	14,344
April	7,675	12,816		7,675	12,816
May	13,249	12,887		13,249	12,887
June	13,772	11,565		13,772	11,565
July	11,801	12,941		11,801	12,941
Aug	12,381	12,651		12,381	12,651
Sept	18,318	14,167		18,318	14,167
Oct	14,436	15,045		14,436	15,045
Nov	13,780	15,511		13,780	15,511
Dec	11,754	13,323		11,754	13,323
Jan 74	5,476	10,337	1.09	5,024	10,186
Feb	6,933	8,054		6,361	7,713
March	29,921	14,110		27,450	12,945
April	10,946	15,933		10,042	14,618
May	18,061	19,643	1.06	15,632	17,708
June	18,628	15,878		16,122	13,932
July	13,158	16,616		11,388	14,381
Aug	16,093	15,960	1.10	12,662	13,391
Sept	22,052	17,101		17,351	13,800
Oct	18,687	18,944		14,703	14,906
Nov	21,633	20,791		17,021	16,358
Dec	14,586	18,302		11,477	14,400
Jan 75	15,466	17,228		12,169	13,556
Feb	19,545	16,532		15,378	13,008
March	16,621	17,211	1.15	11,372	12,973
April	28,051	21,406		19,192	15,314
May	19,180	21,284		13,123	14,562
June	19,578	22,270		13,395	15,237
July	21,359	20,039		14,614	13,710
Aug	20,862	20,600	1.10	12,976	13,662
Sept	27,786	23,336		17,283	14,957
Oct	27,148	25,265		16,886	15,715
Nov	18,906	24,613		11,759	15,309
Dec	19,658	21,904		12,227	13,624
Jan 76	13,884	17,483	1.10	7,851	10,612
Feb	27,922	20,488		15,788	11,955
March	24,643	22,150		13,834	12,524
April	26,795	26,453		15,151	14,958
May	32,662	28,033		18,469	15,851
June	26,306	28.588		14,875	16,165
July	25,445	28,138		14,388	15,910
Aug	23,395	25,049	1.10	12,026	13,763
Sept	32,901	27,247		16,913	14,442
Oct	31,998	29,431		16,448	15,129
Nov	39,635	34,845		20,374	17,912
Dec	14,897	28,843		7,658	14,827

ANALYSIS OF DISTRIBUTOR 'C' SPARES TURNOVER

Date	Turnover £	3 Months Average Turnover	Price Correction Factor	Corrected Turnover	3 Months Average Corrected Turnover
Jan 73	29,232			29,232	
Feb	31,479				
March	34,530	31,747		34,530	31,747
April	28,916	31,642		28,916	31,642
May	40,359	34,602		40,357	34,602
June	31,458	33,578		31,458	33,578
July	41,707	37,841		41,707	37,841
Aug	34,435	35,867		34,435	35,867
Sept	29,260	35,134		29,260	35,134
Oct	39,058	34,251		39,058	34,251
Nov	37,505	35,274		37,505	35,274
Dec	28,261	34,941		28,261	34,941
Jan 74	32,193	32,653	1.09	29,535	31,767
Feb	42,383	34,279		38,883	32,226
March	38,527	37,701		35,346	34,588
April	34,648	38,519		31,787	35,339
May	37,693	36,956	1.06	32,623	33,252
June	35,514	35,952		30,737	31,716
July	54,392	42,533		47,076	36,812
Aug	39,983	43,296	1.10	31,459	36,424
Sept	50,651	48,342		39,853	39,463
Oct	54,943	48,526		43,230	38,181
Nov	46,609	50,734		36,673	39,919
Dec	39,041	46,864		30,718	36,874
Jan 75	49,497	45,049		38,945	35,445
Feb	40,436	42,991		31,816	33,826
March	38,747	42,893	1.15	26,510	32,424
April	57,699	45,627		39,477	32,601
May	44,973	47,140		30,770	32,253
June	42,229	48,300		28,893	33,047
July	64,833	50,678		44,358	34,674
Aug	51,667	52,910	1.10	32,136	35,129
Sept	49,236	55,245		30,624	35,706
Oct	47,402	49,435		29,484	30,748
Nov	42,581	46,406		26,485	28,864
Dec	44,393	44,792		27,612	27,860
Jan 76	48,803	45,259	1.10	27,595	27,231
Feb	45,967	46,388		25,992	27,066
March	50,132	48,301		28,347	27,311
April	52,509	49,536		29,691	28,010
May	52,639	51,760		29,765	29,268
June	55,553	53,567		31,412	30,289
July	64,298	57,497		36,357	32,511
Aug	66,197	62,016	1.10	34,028	33,932
Sept	61,602	64,032		31,666	34,017
Oct	61,780	63,193		31,758	32,484
Nov	59,677	61,020		30,677	31,367
Dec	49,405	56,954		25,396	29,277

ANALYSIS OF DISTRIBUTOR'D'SPARES TURNOVER

4 DISTRIBUTORS TOTAL INDEXED TURNOVER

Date	A 3 Months Average	B 3 Months Average	C & D 3 Months Average	TOTAL 3 Months Average	6 Months Average	12 Months Average	% 12 Months Average	% 6 Months Average
Jan 73								
Feb								
March	83.00	232.69	912.76	1228.45				
April	75.00	221.20	880.42	1176.62				
May	146.00	218.22	940.44	1304.66				
June	93.00	218.22	893.98	1205.20	1217			93.6
July	159.00	235.90	1005.76	1400.66	1288			99.1
Aug	77.00	219.82	960.82	1257.64	1281			98.5
Sept	113.00	220.51	976.35	1309.86	1257			96.7
Oct	169.00	225.80	976.23	1371.03	1386			106.6
Nov	109.00	236.59	1005.79	1351.38	1304			100.3
Dec	104.00	223.50	955.79	1283.29	1296	1256	96.84	99.7
Jan 74	145.87	193.87	830.51	1170.25	1271	1280	98.69	97.7
Feb	112.84	183.99	790.23	1087.06	1219	1250	96.38	93.8
March	140.37	199.61	938.98	1278.96	1281	1269	97.84	98.5
April	113.76	210.18	986.68	1310.62	1240	1313	101.23	95.4
May	155.79	225.34	1005.99	1387.12	1237	1271	98.00	95.1
June	191.28	236.59	901.49	1329.36	1304	1300	100.23	100.3
July	154.92	265.76	1011.20	1431.88	1371	1321	101.85	105.4
Aug	29.11	250.60	984.09	1263.80	1325	1272	98.07	101.9
Sept	221.10	225.34	1052.31	1498.75	1414	1348	103.93	108.7
Oct	147.92	222.81	1048.61	1419.34	1425	1333	102.78	109.6
Nov	142.41	240.20	1111.54	1494.15	1379	1308	100.85	106.1
Dec	156.58	243.48	1012.80	1412.66	1455	1380	106.40	111.9
Jan 75	99.93	240.96	967.93	1308.82	1364	1367	105.40	104.9
Feb	102.29	240.96	925.14	1268.39	1381	1353	104.32	106.2
March	69.79	228.55	896.68	1195.02	1304	1359	104.78	100.3
April	95.79	220.97	946.13	1262.89	1285	1355	104.47	98.5
May	124.52	212.24	924.48	1261.24	1265	1322	101.93	97.3
June	119.05	240.50	953.43	1312.98	1254	1355	104.47	96.4
July	152.57	262.55	955.71	1370.83	1316	1340	103.32	101.2
Aug	91.43	249.68	963.75	1304.86	1283	1332	102.70	98.7
Sept	154.25	229.01	1000.61	1383.87	1348	1326	102.24	103.7
Oct	127.51	229.01	917.29	1273.81	1322	1304	100.54	101.7
Nov	106.36	225.20	872.02	1203.58	1254	1260	97.15	96.4
Dec	146.79	249.00	819.07	1214.86	1299	1277	98.46	99.9
Jan 76	117.05	218.44	747.52	1083.01	1178	1247	96.14	90.6
Feb	58.81	216.84	770.61	1046.26	1125	1204	92.83	86.5
March	133.45	245.09	786.63	1165.17	1190	1269	97.84	91.5
April	191.69	254.97	848.22	1294.70	1189	1256	96.84	91.4
May	243.14	252.44	890.66	1386.24	1216	1235	95.22	93.5
June	201.30	246.70	917.04	1365.04	1265	1282	98.84	97.3
July	176.98	269.67	956.05	1402.70	1348	1263	97.38	103.7
Aug	124.91	267.14	942.05	1334.10	1360	1243	95.84	104.6
Sept	161.41	263.93	957.06	1382.40	1374	1282	98.84	105.7
Oct	157.81	235.67	940.17	1333.65	1368	1279	98.61	105.2
Nov	170.15	258.18	972.66	1400.99	1367	1292	99.61	105.1
Dec	99.72	258.64	870.74	1229.10	1306	1286	99.15	100.4

Indexes refer to Distributor B January 73 = 100.
Distributors weighting in proportion to BroomWade sales to that distributor in 1974-75.

Date	In-voicing	3 Months Average Invoicing	Correction Factor	Corrected Invoicing	3 Months Corrected Invoicing	6 Months Average	12 Months Average	% 12 months	% 6 Months
Jan 73	155,971		1.00	155,971					
Feb	149,604			149,604					
March	128,820	144,798		128,820	144,798				
April	101,761	126,728		101.761	126.728				
May	140,681	123,754		140.681	123,754				
June	150,585	131,009		150,585	131,009	137,904			94.9
July	159,087	150,118		159,087	150,118	138,423			95.3
Aug	161,728	157,133		161,728	157,133	140,444			96.7
Sept	143,936	154,917		143,936	154,917	142,963			98.4
Oct	140,486	148,717		140,486	148,717	149,418			102.8
Nov	98,234	127,552		98,234	127,552	142,343			98.0
Dec	130,275	122,998		130,275	122,998	138,958	138,431	95.37	95.6
Jan 74	150,887	126,465	1.09	138,428	122,312	135,515	136,969	94.36	93.3
Feb	147,917	143,026		135,704	134,802	131,177	135,811	93.56	90.3
March	168,112	155,639		154,231	142,788	132,893	137,928	95.02	91.5
April	126,348	147,459		115,916	135,283	128,798	139,108	95.84	88.6
May	202,215	165,558	1.06	175,017	148,388	141,595	141,969	97.81	97.4
June	179,081	169,215		154,995	148,643	145,716	142,337	98.06	100.3
July	198,391	193,229		171,708	167,240	151,262	143,389	98.78	104.1
Aug	169,538	182,337	1.10	133,396	153,366	150,877	141,027	97.16	103.8
Sept	319,684	229,204		251,534	185,546	167,095	149,994	103.34	115.0
Oct	205,554	231,592		161,734	182,221	174,731	151,765	104.56	120.2
Nov	172,711	232,650		135,892	183,053	168,210	154,903	106.72	115.8
Dec	137,413	171,893		108,119	135,248	160,397	153,057	105.45	110.4
Jan 75	241,928	184,017		190,354	144,788	163,505	157,384	108.43	112.5
Feb	223,040	200,794		175,492	157,988	170,521	160,699	110.71	117.4
March	198,097	221,022	1.15	135,536	167,127	151,188	159,142	109.64	104.0
April	218,788	213,308		149,693	153,574	149,181	161,956	111.58	102.7
May	119,833	178,906		81,989	122,406	140,197	154,204	106.24	96.5
June	220,016	186,212		150,533	127,405	147,266	153,832	105.98	101.3
July	209,287	183,045		143,192	125,238	139,406	151,456	104.34	95.9
Aug	217,035	215,446	1.10	134,994	142,206	132,656	151,589	104.34	91.3
Sept	169,332	198,718		105,634	127,940	127,673	139,431	96.06	87.9
Oct	294,874	227,247		183,409	141,346	133,292	141,237	97.30	91.7
Nov	240,211	234,972		149,409	146,151	144,529	142,363	98.08	99.6
Dec	150,696	228,594		93,732	142,183	135,062	141,164	97.25	92.9
Jan 76	210,052	200,320	1.10	118,773	120,638	130,992	135,199	93.14	90.1
Feb	204,506	188,418		115,637	109,381	127,766	130,211	89.71	87.9
March	319,682	244,747		180,763	138,391	140,287	133,980	92.30	96.6
April	300,766	274,985		170,067	155,489	138,064	135,678	93.47	95.0
May	250,691	290,380		141,752	164,194	136,788	140,659	96.90	94.1
June	254,199	268,552		143,736	151,852	145,122	140,092	96.51	99.9
July	230,928	245,273		130,577	135,689	147,089	139,041	95.79	101.2
Aug	326,659	270,595	1.10	167,917	147,410	155,802	141,784	97.68	107.2
Sept	302,815	286,801		155,660	151,385	151,619	145,953	100.55	104.3
Oct	295,843	308,439		152,076	158,551	148,620	143,342	98.75	102.3
Nov	307,220	301,959		157,924	155,220	151,315	144,052	99.24	104.1
Dec	303,462	302,175		155,992	155,331	153,358	149,240	102.82	105.5
Jan 77	245,683	285,455		126,292	146,736	152,644	149,867	103.25	105.0
Feb	245,007	264,717		125,944	136,076	145,648	150,725	103.84	100.2

COMPAIR TURNOVER FOR SPARE PARTS

APPENDIX 3

THE SPARES SYSTEM STOCK OBJECTIVES

The nominal stock objectives of the spares system can be determined from consideration of the minimum stock and delivery quantity of each of the value categories, and the proportion of the total range which falls into each category. The table overleaf shows such an analysis for each of the three groups of components. The nominal stock holding is calculated on the assumption that across a group of components the mean stock holding will be the average of the minimum and maximum stock.

Thus, the stock holding for sub-assemblies would be £27,696, which, for a monthly turnover of £16,463, gives a holding of 1.68 months. For source 1 parts, the holding should be 2.66 months (£376,365 stock value and £141,401 monthly turnover), while for source 2, it should be 3.48 months (£174,865 stock value and £50,235 monthly turnover).

For the total range, the total stock holding should be 2.78 months, based on a stock value of £578,926, and a monthly turnover of £208,099. These figures are based on CompAir standard costs, and are from a standard computer analysis of the value categories produced in January 1977.

Part Type	Minimum Stock	Float	Delivery Quantity	Nominal Average Stock	Monthly Turnover	Value of Nominal Average Stock
	wks	wks	wks	wks	£	£
Sub Assemblies						
Value Class 1	4	0	4	6	10,460	15,690
Remainder	4	0	8	8	6,003	12,006
Source 1 Parts						
Value Class 1	4	4	4	10	96,520	241,300
" " 2	4	4	6	11	28,297	77,816
" " 3	4	4	8	12	10,761	32,283
" " 4	4	6	8	14	3,989	13,962
" " 5	4	8	24	24	1,834	11,004
Source 2 Parts						
Value Class 1	4	4	8	12	29,516	88,548
" " 2	4	4	12	14	14,038	49,133
" " 3	4	4	24	20	4,720	23,600
" " 4	4	6	32	26	1,403	9,120
" " 5	4	8	40	32	558	4,464
					208,099	578,926

APPENDIX 4

SENSITIVITY TEST RESULTS

The following tables show the results of the sensitivity tests. The tables are arranged as follows:-

Pages 257 - 259 inclusive.	Absolute results of means and standard deviations of the variables listed across the top of the page for a step input of 10% in week 4.
Pages 260 - 262 inclusive.	Relative results, in which the above parameters are compared with their equivalent values obtained from a standard run.
Pages 263 - 265 & 266 - 268	show the same observations for a sinusoidal input.

The columns headed 'IN' and 'VALUE' refer to the parameter being changed for that run, and the value it takes. On the extreme right is shown its standard value. The parameter reference numbers are given below:-

5	AIR	14	DCR	22	ALF
6	AIRD	15	DTR	23	DCF
8	DRR	16	DMR	24	DIMF
9	DRRD	17	DRF	25	DPF
10	DHR	18	AIF	26	DOMF
11	DUR	19	DUF	27	DOIF
12	DIRI	20	DHF		
13	DIRP	21	DIF		

IN		VAL	UOF MN	UOF SD	IAF MN	IAF SD	SRF MN	SRF SD	MWF MN	MWF SD	SSF MN	SSF SD	ABS VALUES
1	37	10.0	570.1	87.8	2026.3	232.5	97.2	15.2	98.4	24.9	99.6	9.3	0.0=STD VAL
2	5	2.0	580.7	98.6	2084.9	208.0	100.1	14.8	99.6	32.7	101.7	13.8	16.0=STD VAL
3	5	8.0	569.3	77.9	2048.0	199.1	98.1	13.8	98.2	21.6	99.9	8.5	16.0=STD VAL
4	5	32.0	576.2	109.9	1982.0	302.8	96.1	18.7	99.6	31.7	98.9	11.5	16.0=STD VAL
5	6	2.0	568.8	89.3	2021.6	230.2	97.0	15.0	98.2	25.6	99.2	9.4	16.0=STD VAL
6	6	8.0	569.4	88.6	2023.7	231.1	97.1	15.1	98.3	25.2	99.3	9.4	16.0=STD VAL
7	6	32.0	571.7	87.3	2031.2	236.2	97.5	15.4	98.7	24.6	99.7	9.4	16.0=STD VAL
8	8	5.0	570.8	86.4	2025.0	229.6	97.4	14.7	98.7	24.5	99.5	9.1	10.0=STD VAL
9	8	20.0	568.5	87.9	2031.7	229.6	97.1	15.5	97.9	24.7	99.3	9.5	10.0=STD VAL
10	8	50.0	566.3	83.4	2047.6	205.7	97.5	14.9	97.1	23.0	99.4	9.2	10.0=STD VAL
11	9	0.1	570.1	87.8	2026.3	232.5	97.2	15.2	98.4	24.9	99.4	9.3	3.3=STD VAL
12	9	1.0	570.1	87.8	2026.3	232.5	97.2	15.2	98.4	24.9	99.4	9.3	3.3=STD VAL
13	9	5.0	570.1	87.8	2026.3	232.5	97.2	15.2	98.4	24.9	99.4	9.3	3.3=STD VAL
14	10	0.1	570.0	87.7	2026.5	232.1	97.3	15.1	98.4	24.8	99.4	9.3	0.0=STD VAL
15	10	0.2	570.0	87.6	2026.7	231.6	97.3	15.1	98.4	24.8	99.4	9.3	0.0=STD VAL
16	10	2.0	569.4	85.4	2030.8	223.2	97.4	14.7	98.3	24.1	99.5	9.1	0.0=STD VAL
17	11	0.1	570.2	88.5	2025.1	234.9	97.2	15.3	98.5	25.1	99.4	9.4	0.6=STD VAL
18	11	0.3	570.2	88.2	2025.6	233.9	97.2	15.2	98.4	25.0	99.4	9.4	0.6=STD VAL
19	11	1.2	569.9	87.1	2027.7	229.7	97.3	15.0	98.4	24.6	99.5	9.3	0.6=STD VAL
20	12	2.0	570.6	84.0	2027.2	223.0	97.5	14.3	98.8	23.6	99.6	8.9	4.0=STD VAL
21	12	8.0	568.4	91.0	2028.6	239.2	96.9	16.3	97.7	25.7	99.2	9.9	4.0=STD VAL
22	13	1.0	565.1	85.7	2050.7	207.9	97.3	15.7	96.5	23.5	99.3	9.6	8.0=STD VAL
23	13	4.0	569.1	89.0	2028.3	234.8	97.1	15.7	98.0	25.1	99.3	9.6	8.0=STD VAL
24	13	16.0	570.5	86.7	2025.8	229.7	97.4	14.8	98.6	24.5	99.5	9.7	8.0=STD VAL
25	14	0.3	570.1	87.1	2026.7	230.7	97.3	15.0	98.5	24.6	99.5	9.3	1.0=STD VAL
26	14	0.5	570.1	87.3	2026.6	231.2	97.3	15.1	98.4	24.7	99.5	9.3	1.0=STD VAL
27	14	2.0	570.1	88.9	2025.7	235.1	97.2	15.4	98.4	25.2	99.4	9.5	1.0=STD VAL
28	15	0.3	569.3	85.9	2030.6	224.3	97.3	14.9	98.2	24.2	99.5	9.2	2.0=STD VAL
29	15	1.0	569.6	86.7	2028.8	228.0	97.3	15.0	98.3	24.5	99.5	9.2	2.0=STD VAL
30	15	4.0	571.1	90.4	2020.9	242.1	97.1	15.5	98.7	25.7	99.4	9.5	2.0=STD VAL
31	16	0.3	570.1	87.5	2026.5	231.8	97.3	15.1	98.4	24.8	99.5	9.3	0.6=STD VAL
32	16	1.2	570.1	88.5	2025.9	234.1	97.2	15.3	98.4	25.0	99.4	9.4	0.6=STD VAL
33	17	6.5	570.4	82.9	2007.4	128.9	97.7	13.9	99.6	24.5	99.5	9.4	24.5=STD VAL
34	17	12.5	570.6	85.6	2012.1	210.7	97.5	14.6	99.2	24.9	99.5	9.3	24.5=STD VAL
35	17	49.0	568.3	87.9	2051.6	237.4	97.4	14.9	97.5	23.3	99.4	9.3	24.5=STD VAL
36	18	2.0	596.5	209.4	240.5	107.7	95.6	12.4	100.7	24.5	99.1	10.1	20.0=STD VAL
37	18	10.0	571.9	106.4	1033.9	175.7	97.9	14.5	98.6	22.5	99.4	9.4	20.0=STD VAL
38	18	40.0	570.9	75.2	3996.8	376.9	96.0	18.9	95.9	30.4	99.5	9.3	20.0=STD VAL
39	19	0.1	298.8	28.2	2042.4	255.7	97.2	15.2	97.2	23.5	99.6	9.3	2.8=STD VAL
40	19	1.4	429.3	57.5	2034.1	244.0	97.2	15.2	97.6	24.2	99.5	9.2	2.8=STD VAL
41	19	5.6	852.3	144.2	2014.1	212.5	97.4	15.1	99.4	26.0	99.4	9.7	2.8=STD VAL
42	20	0.3	311.5	65.4	2031.7	240.2	97.3	15.1	98.3	24.6	99.5	9.3	2.9=STD VAL
43	20	1.5	430.9	75.6	2029.2	236.5	97.3	15.1	98.4	24.7	99.5	9.2	2.9=STD VAL
44	20	6.0	578.1	116.3	2020.1	225.8	97.2	15.2	98.5	25.2	99.4	9.5	2.9=STD VAL
45	21	1.0	570.2	86.9	2023.9	229.8	97.3	15.1	98.5	24.9	99.4	9.3	1.6=STD VAL
46	21	3.2	569.6	90.1	2033.3	238.4	97.2	15.3	98.1	24.7	99.4	9.4	1.6=STD VAL
47	21	12.0	565.4	98.4	2076.4	247.7	97.4	15.0	96.6	22.7	99.4	9.4	1.6=STD VAL
48	22	120.0	570.1	87.8	2026.3	232.5	97.2	15.2	98.4	24.9	99.4	9.3	999.0=STD VAL
49	23	0.5	570.5	87.3	2022.6	233.9	97.2	15.2	98.5	25.0	99.4	9.3	1.0=STD VAL
50	23	2.0	569.1	88.8	2033.5	229.2	97.3	15.0	98.2	24.6	99.4	9.5	1.0=STD VAL
51	23	10.0	563.4	92.6	2075.1	196.5	97.9	13.6	97.3	22.1	99.4	9.3	1.0=STD VAL
52	24	12.0	566.2	63.3	2013.7	145.0	98.7	12.7	99.3	14.1	99.5	9.2	50.0=STD VAL
53	24	25.0	567.3	72.2	2018.1	174.0	98.2	13.8	99.1	17.8	99.5	9.3	50.0=STD VAL
54	24	100.0	573.3	101.1	2024.8	260.9	97.5	15.6	97.4	30.1	99.4	9.4	50.0=STD VAL
55	25	2.0	569.6	85.4	2024.4	218.9	97.4	14.8	98.3	24.1	99.4	9.3	4.0=STD VAL
56	25	8.0	571.1	92.7	2030.3	259.6	97.0	15.9	98.7	26.5	99.4	9.4	4.0=STD VAL
57	25	20.0	573.7	106.5	2045.0	331.0	96.5	17.9	99.9	31.9	99.4	9.4	4.0=STD VAL
58	26	1.3	570.3	80.7	2014.2	223.7	97.6	15.1	99.4	21.7	99.5	9.3	0.2=STD VAL
59	26	5.0	567.7	74.6	2020.5	188.6	98.0	14.2	99.5	18.6	99.5	9.3	0.2=STD VAL
60	26	10.0	566.0	75.2	2029.7	166.5	98.2	13.6	99.4	18.3	99.5	9.3	0.2=STD VAL
61	27	5.5	574.4	79.4	1984.2	232.8	97.5	15.6	103.1	21.5	99.5	9.3	11.1=STD VAL
62	27	22.0	564.6	86.9	2056.0	176.7	98.0	13.5	97.8	24.1	99.5	9.3	11.1=STD VAL
63	27	50.0	563.1	82.5	2055.2	119.7	98.7	12.1	99.0	22.3	99.5	9.3	11.1=STD VAL
64	28	12.0	575.9	78.5	1980.5	259.3	97.5	16.1	100.5	28.0	99.5	9.3	24.0=STD VAL
65	28	48.0	564.2	91.9	2065.9	150.2	98.2	13.0	97.7	20.5	99.4	9.3	24.0=STD VAL
66	28	96.0	564.0	93.5	2067.0	156.6	99.0	11.2	98.3	17.9	99.5	9.3	24.0=STD VAL
67	38	1.0	570.3	88.7	2023.8	224.3	97.3	14.9	98.4	25.0	99.4	9.3	1.2=STD VAL
68	38	1.5	570.1	87.8	2026.3	232.5	97.2	15.2	98.4	24.9	99.4	9.3	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

	IN	VAL	DOF		OPF		RRF		IAR		UOR		
			MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	
1	37	10.0	10.3	4.9	388.9	60.6	99.9	9.5	1604.9	116.9	59.9	5.4	0.0=STD VAL
2	5	2.0	10.8	4.9	400.2	59.4	101.9	14.9	382.5	47.7	258.5	52.3	16.0=STD VAL
3	5	8.0	10.4	4.6	392.2	55.1	100.2	8.5	853.4	65.3	112.8	10.4	16.0=STD VAL
4	5	32.0	10.5	5.5	384.6	74.7	99.7	12.0	3180.1	225.5	30.2	2.6	16.0=STD VAL
5	6	2.0	10.2	4.8	388.0	60.1	99.7	9.8	1554.7	114.9	7.7	0.7	16.0=STD VAL
6	6	8.0	10.2	4.6	388.4	60.3	99.8	9.7	1576.6	115.6	30.5	2.5	16.0=STD VAL
7	6	32.0	10.4	4.9	390.0	61.4	100.2	9.5	1658.5	120.4	116.0	10.2	16.0=STD VAL
8	8	5.0	10.3	4.8	389.6	56.9	100.0	9.3	1602.0	119.3	60.0	4.6	10.0=STD VAL
9	8	20.0	10.3	4.9	388.5	62.0	99.8	9.6	1611.7	106.8	59.8	6.3	10.0=STD VAL
10	8	50.0	10.3	4.8	389.8	59.7	99.7	9.2	1624.6	74.2	59.4	7.9	10.0=STD VAL
11	9	0.1	10.3	4.9	388.9	60.6	99.9	9.5	1604.9	116.7	59.9	5.6	3.3=STD VAL
12	9	1.0	10.3	4.9	388.9	60.6	99.9	9.5	1604.9	116.7	59.9	5.5	2.3=STD VAL
13	9	5.0	10.3	4.9	388.9	60.6	99.9	9.5	1604.9	116.9	59.9	5.3	2.3=STD VAL
14	10	0.1	10.3	4.9	389.0	60.5	99.9	9.5	1604.8	116.3	69.9	6.0	0.0=STD VAL
15	10	0.2	10.3	4.9	389.0	60.4	99.9	9.5	1604.8	116.7	79.9	6.7	0.0=STD VAL
16	10	2.0	10.3	4.8	389.5	59.0	99.9	9.3	1604.4	115.5	260.0	19.0	0.0=STD VAL
17	11	0.1	10.3	4.9	388.8	61.0	99.9	9.6	1605.0	116.1	10.0	0.9	0.6=STD VAL
18	11	0.3	10.3	4.9	388.9	60.9	99.9	9.6	1605.0	117.5	30.0	2.7	0.6=STD VAL
19	11	1.2	10.3	4.8	389.1	60.1	99.9	9.4	1604.6	115.3	119.9	10.6	0.6=STD VAL
20	12	2.0	10.3	4.7	393.1	57.2	100.1	9.1	1603.1	113.6	60.0	4.9	4.0=STD VAL
21	12	8.0	10.3	5.1	387.5	65.0	99.6	10.0	1611.7	116.4	59.8	6.7	4.0=STD VAL
22	13	1.0	10.2	5.0	389.0	62.8	99.5	9.5	1630.6	4.2	59.3	7.6	8.0=STD VAL
23	13	4.0	10.3	5.0	388.3	62.6	99.8	9.7	1608.7	113.7	59.9	6.1	8.0=STD VAL
24	13	16.0	10.3	4.8	389.4	59.2	100.0	9.4	1603.3	117.7	60.0	5.0	8.0=STD VAL
25	14	0.3	10.3	4.8	389.1	60.1	99.9	9.4	1604.7	115.7	59.9	5.7	1.0=STD VAL
26	14	0.5	10.3	4.9	389.1	60.2	99.9	9.5	1604.6	116.0	59.9	5.7	1.0=STD VAL
27	14	2.0	10.3	4.9	388.7	61.4	99.9	9.7	1605.1	116.7	59.9	5.5	1.0=STD VAL
28	15	0.3	10.3	4.6	389.3	59.5	99.9	9.3	1604.3	115.0	59.9	5.2	2.0=STD VAL
29	15	1.0	10.3	4.8	389.2	60.0	99.9	9.4	1604.5	115.8	59.9	5.3	2.0=STD VAL
30	15	4.0	10.3	5.0	388.5	62.0	99.9	9.8	1605.6	119.3	59.4	5.6	2.0=STD VAL
31	16	0.3	10.3	4.9	389.0	60.4	99.9	9.5	1604.6	116.3	59.9	5.[illegible]	.6=STD VAL
32	16	1.2	10.3	4.9	388.8	61.1	99.9	9.6	1605.0	117.9	59.9	5.4	0.6=STD VAL
33	17	6.5	10.4	4.6	390.8	55.8	99.9	9.2	1604.3	117.0	59.4	5.3	24.5=STD VAL
34	17	12.5	10.3	4.8	389.9	55.4	99.9	9.3	1604.7	117.1	59.9	5.[illegible]	24.5=STD VAL
35	17	49.0	10.3	4.6	389.5	59.4	99.8	9.7	1605.4	115.[illegible]	59.4	5.4	24.5=STD VAL
36	18	2.0	10.6	4.1	394.6	49.5	101.3	12.4	1596.2	136.4	60.3	5.6	20.0=STD VAL
37	18	10.0	10.3	4.5	391.5	53.9	100.1	9.9	1607.7	119.7	60.[illegible]	5.4	20.0=STD VAL
38	18	40.0	10.5	5.5	384.1	75.8	99.8	9.3	1605.5	115.[illegible]	59.9	5.4	20.[illegible]=STD VAL
39	19	0.1	10.2	4.9	388.5	60.7	99.6	9.0	1605.9	11[illegible].2	59.9	5.1	2.[illegible]=STD VAL
40	19	1.4	10.2	4.9	388.6	60.7	99.6	9.3	1605.4	113.4	59.9	5.2	[illegible]=STD VAL
41	19	5.6	10.4	4.9	389.8	60.3	100.2	10.1	1604.1	123.4	60.0	5.6	[illegible]=STD VAL
42	20	0.3	10.3	4.9	389.0	60.5	99.9	9.2	1603.7	115.7	60.0	5.1	2.9=STD VAL
43	20	1.5	10.3	4.9	389.0	60.5	99.9	9.3	1604.2	116.3	60.1	5.2	2.9=STD VAL
44	20	6.0	10.3	4.9	388.8	61.0	99.9	10.0	1606.4	118.0	59.9	5.7	2.9=STD VAL
45	21	1.0	10.3	4.9	389.1	60.4	99.9	9.5	1604.9	116.5	59.9	5.4	1.6=STD VAL
46	21	3.2	10.3	4.9	388.7	61.1	99.9	9.6	1604.8	117.0	59.9	5.4	1.6=STD VAL
47	21	12.0	10.2	4.8	389.5	59.6	99.8	9.9	1605.3	114.7	59.9	5.4	1.6=STD VAL
48	22	120.0	10.3	4.9	388.9	60.6	99.9	9.5	1604.9	116.9	59.9	5.4	999.0=STD VAL
49	23	0.5	10.3	4.9	388.9	60.8	99.9	9.5	1604.9	116.9	59.9	5.4	1.0=STD VAL
50	23	2.0	10.2	4.8	389.0	60.1	99.9	9.6	1604.9	116.3	59.9	5.4	1.0=STD VAL
51	23	10.0	10.5	3.7	391.6	54.3	99.7	9.8	1605.7	115.7	59.9	5.4	1.0=STD VAL
52	24	12.0	11.3	0.1	395.0	51.1	99.7	9.3	1606.4	113.2	59.9	5.3	50.0=STD VAL
53	24	25.0	10.8	1.8	392.7	55.1	99.8	9.3	1605.8	114.7	59.9	5.3	50.0=STD VAL
54	24	100.0	11.8	7.2	389.6	62.4	99.8	10.0	1605.2	116.6	59.9	5.4	50.0=STD VAL
55	25	2.0	10.3	4.6	194.7	29.5	99.9	9.5	1605.0	116.3	59.9	5.4	4.0=STD VAL
56	25	8.0	10.3	5.1	776.0	127.4	100.0	9.6	1604.6	117.5	60.0	5.4	4.0=STD VAL
57	25	20.0	10.6	5.6	1926.7	356.9	100.1	9.9	1604.0	118.9	60.0	5.4	4.[illegible]=STD VAL
58	26	1.3	11.6	3.2	390.3	60.3	99.9	9.3	1605.2	116.4	59.9	5.3	0.2=STD VAL
59	26	5.0	15.7	1.7	392.1	56.8	99.8	9.3	1605.7	115.1	59.9	5.3	0.2=STD VAL
60	26	10.0	20.8	1.0	392.8	54.6	99.7	9.3	1605.9	114.8	59.9	5.4	0.2=STD VAL
61	27	5.5	6.2	3.4	390.2	62.4	99.9	9.3	1605.2	115.9	59.9	5.4	11.1=STD VAL
62	27	22.0	21.1	3.8	391.7	54.1	99.8	9.6	1605.7	115.6	59.9	5.4	11.1=STD VAL
63	27	50.0	50.2	0.3	394.8	48.2	99.6	9.6	1606.4	114.3	59.9	5.4	11.1=STD VAL
64	28	12.0	10.7	5.1	390.2	64.7	99.9	9.2	1605.0	116.4	59.9	5.5	24.0=STD VAL
65	28	48.0	10.4	4.3	392.5	52.0	99.7	9.8	1605.9	115.3	59.9	5.4	24.0=STD VAL
66	28	96.0	10.6	3.8	395.7	44.9	99.6	9.9	1606.6	114.2	59.9	5.5	24.0=STD VAL
67	38	1.0	10.5	4.9	389.1	59.4	99.9	9.6	1604.9	116.7	59.9	5.4	1.2=STD VAL
68	38	1.5	10.3	4.9	388.9	60.6	99.9	9.5	1604.9	116.9	59.9	5.4	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

```
     IN   VAL        SSR              RSM              RSRD              RRR              RSF
                  MN     SD        MN     SD        MN     SD        MN     SD        MN     SD
  1 37   10.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        0.0=STD VAL
-------------------------------------------------------------------------------------------------------
  2  5    2.0   101.0   8.4     100.2   6.8     100.0   7.0     100.0   7.1     102.2   8.1       16.0=STD VAL
  3  5    8.0   100.0   7.2     100.2   6.8     100.0   7.0     100.0   7.1     100.4   7.0       16.0=STD VAL
  4  5   32.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.5   9.3       16.0=STD VAL
-------------------------------------------------------------------------------------------------------
  5  6    2.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.7   7.7       16.0=STD VAL
  6  6    8.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.8   7.7       16.0=STD VAL
  7  6   32.0   100.0   7.2     100.2   6.8     100.0   7.0     100.0   7.1     100.2   7.8       16.0=STD VAL
-------------------------------------------------------------------------------------------------------
  8  8    5.0   100.0   7.1     100.1   7.0     100.0   7.0     100.0   7.1     100.0   7.5       10.0=STD VAL
  9  8   20.0   100.0   7.1     100.5   6.2     100.0   7.0     100.0   7.1      99.9   7.8       10.0=STD VAL
 10  8   50.0   100.0   7.1     101.1   4.2     100.0   7.0     100.0   7.1     100.1   7.6       10.0=STD VAL
-------------------------------------------------------------------------------------------------------
 11  9    0.1   100.0   7.1     100.2   6.6     100.0   7.1     100.0   7.1     100.0   7.7        3.3=STD VAL
 12  9    1.0   100.0   7.1     100.2   6.8     100.0   7.1     100.0   7.1     100.0   7.7        3.3=STD VAL
 13  9    5.0   100.0   7.1     100.2   6.3     100.1   7.0     100.0   7.1     100.0   7.7        3.3=STD VAL
-------------------------------------------------------------------------------------------------------
 14 10    0.1   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        0.6=STD VAL
 15 10    0.2   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        0.6=STD VAL
 16 10    2.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.5        0.6=STD VAL
-------------------------------------------------------------------------------------------------------
 17 11    0.1   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        0.6=STD VAL
 18 11    0.3   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        0.6=STD VAL
 19 11    1.2   100.0   7.2     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6        0.6=STD VAL
-------------------------------------------------------------------------------------------------------
 20 12    2.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.1   7.3        4.0=STD VAL
 21 12    8.0   100.0   7.2     100.2   6.8     100.0   7.0     100.0   7.1      99.9   8.2        4.0=STD VAL
-------------------------------------------------------------------------------------------------------
 22 13    1.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.9        8.0=STD VAL
 23 13    4.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   7.9        8.0=STD VAL
 24 13   16.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.5        8.0=STD VAL
-------------------------------------------------------------------------------------------------------
 25 14    0.3   100.0   7.1     100.2   6.5     100.0   7.0     100.0   7.1     100.0   7.6        1.0=STD VAL
 26 14    0.5   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6        1.0=STD VAL
 27 14    2.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.5        1.0=STD VAL
-------------------------------------------------------------------------------------------------------
 28 15    0.3   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6        2.0=STD VAL
 29 15    1.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6        2.0=STD VAL
 30 15    4.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   7.9        2.0=STD VAL
-------------------------------------------------------------------------------------------------------
 31 16    0.3   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        0.6=STD VAL
 32 16    1.2   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.5        0.6=STD VAL
-------------------------------------------------------------------------------------------------------
 33 17    6.5   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.8   9.0       24.5=STD VAL
 34 17   12.5   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.8   7.6       24.5=STD VAL
 35 17   49.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.5   5.2       24.5=STD VAL
-------------------------------------------------------------------------------------------------------
 36 18    2.0   100.0   7.2     100.2   6.8     100.0   7.0     100.0   7.1     100.4   8.4       20.0=STD VAL
 37 18   10.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6       20.0=STD VAL
 38 18   40.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6       20.0=STD VAL
-------------------------------------------------------------------------------------------------------
 39 19    0.1   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.5        2.8=STD VAL
 40 19    1.4   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6        2.8=STD VAL
 41 19    5.6   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   9.0        2.8=STD VAL
-------------------------------------------------------------------------------------------------------
 42 20    0.3   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.4        2.9=STD VAL
 43 20    1.5   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6        2.9=STD VAL
 44 20    6.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   9.0        2.9=STD VAL
-------------------------------------------------------------------------------------------------------
 45 21    1.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        1.6=STD VAL
 46 21    3.2   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        1.6=STD VAL
 47 21   12.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   8.0        1.6=STD VAL
-------------------------------------------------------------------------------------------------------
 48 22  120.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7      999.0=STD VAL
-------------------------------------------------------------------------------------------------------
 49 23    0.5   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        1.0=STD VAL
 50 23    2.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        1.0=STD VAL
 51 23   10.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.8   7.9        1.0=STD VAL
-------------------------------------------------------------------------------------------------------
 52 24   12.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   7.6       50.0=STD VAL
 53 24   25.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   7.6       50.0=STD VAL
 54 24  100.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   8.1       50.0=STD VAL
-------------------------------------------------------------------------------------------------------
 55 25    2.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        4.0=STD VAL
 56 25    8.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        4.0=STD VAL
 57 25   20.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.9        4.0=STD VAL
-------------------------------------------------------------------------------------------------------
 58 26    1.3   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6        0.2=STD VAL
 59 26    5.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   7.6        0.2=STD VAL
 60 26   10.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   7.6        0.2=STD VAL
-------------------------------------------------------------------------------------------------------
 61 27    5.5   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.6       11.1=STD VAL
 62 27   22.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.9   7.3       11.1=STD VAL
 63 27   50.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.8   7.2       11.1=STD VAL
-------------------------------------------------------------------------------------------------------
 64 28   12.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.1   7.5       24.0=STD VAL
 65 28   48.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.8   8.0       24.0=STD VAL
 66 28   96.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1      99.7   8.1       24.0=STD VAL
-------------------------------------------------------------------------------------------------------
 67 38    1.0   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        1.2=STD VAL
 68 38    1.5   100.0   7.1     100.2   6.8     100.0   7.0     100.0   7.1     100.0   7.7        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
```

```
  IN    VAL          UOF             IAF             SRF             RWF             SSF
                   MN     SD       MN     SD       MN     SD       MN     SD       MN     SD
                                                                                              RATIO VALUES
 1 37   10.0      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    1.1      1.0    0.9      1.0    1.0      1.0    1.3      1.0    1.2     16.0=STD VAL
 3  5    8.0      1.0    0.9      1.0    0.9      1.0    0.9      1.0    0.9      1.0    0.9     16.0=STD VAL
 4  5   32.0      1.0    1.3      1.0    1.3      1.0    1.2      1.0    1.3      1.0    1.2     16.0=STD VAL
-------------------------------------------------------------------------------------------------
 5  6    2.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0     16.0=STD VAL
 6  6    8.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0     16.0=STD VAL
 7  6   32.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0     16.0=STD VAL
-------------------------------------------------------------------------------------------------
 8  8    5.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0     10.0=STD VAL
 9  8   20.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0     10.0=STD VAL
10  8   50.0      1.0    0.9      1.0    0.9      1.0    1.0      1.0    0.9      1.0    1.0     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    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      0.0=STD VAL
-------------------------------------------------------------------------------------------------
17 11    0.1      1.0    1.0      1.0    1.0      1.0    1.0      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    1.0      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    1.0      1.0    1.0      1.0    0.9      1.0    1.0      1.0    1.0      4.0=STD VAL
21 12    8.0      1.0    1.0      1.0    1.0      1.0    1.1      1.0    1.0      1.0    1.1      4.0=STD VAL
-------------------------------------------------------------------------------------------------
22 13    1.0      1.0    1.0      1.0    0.9      1.0    1.0      1.0    0.9      1.0    1.0      8.0=STD VAL
23 13    4.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      8.0=STD VAL
24 13   16.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      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    1.0      1.0    1.0      1.0    1.0      1.0=STD VAL
-------------------------------------------------------------------------------------------------
28 15    0.3      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      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    1.0      2.0=STD VAL
30 15    4.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      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    1.0      1.0    1.0      1.0    1.0      0.6=STD VAL
-------------------------------------------------------------------------------------------------
33 17    6.5      1.0    0.9      1.0    0.5      1.0    0.9      1.0    1.0      1.0    1.0     24.5=STD VAL
34 17   12.5      1.0    1.0      1.0    0.9      1.0    1.0      1.0    1.0      1.0    1.0     24.5=STD VAL
35 17   49.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    0.9      1.0    1.0     24.5=STD VAL
-------------------------------------------------------------------------------------------------
36 18    2.0      1.0    2.4      0.1    0.5      1.0    0.6      1.0    1.0      1.0    1.1     20.0=STD VAL
37 18   10.0      1.0    1.2      0.5    [illegible]      1.0    0.9      1.0    0.9      1.0    1.0     20.0=STD VAL
38 18   40.0      1.0    0.9      2.0    1.6      1.0    1.2      1.0    1.2      1.0    1.0     20.0=STD VAL
-------------------------------------------------------------------------------------------------
39 19    0.1      0.5    0.3      1.0    1.1      1.0    1.0      1.0    0.9      1.0    1.0      2.3=STD VAL
40 19    1.4      0.6    0.7      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      2.3=STD VAL
41 19    5.6      1.5    1.6      1.0    0.9      1.0    1.0      1.0    1.0      1.0    1.0      2.3=STD VAL
-------------------------------------------------------------------------------------------------
42 20    0.3      0.5    0.7      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      0.9=STD VAL
43 20    1.5      0.8    0.9      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      0.9=STD VAL
44 20    6.0      1.5    1.3      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      0.9=STD VAL
-------------------------------------------------------------------------------------------------
45 21    1.0      1.0    1.0      1.0    1.0      1.0    1.0      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    1.0      1.0    1.0      1.6=STD VAL
47 21   12.0      1.0    1.1      1.0    1.1      1.0    1.0      1.0    0.9      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    1.0      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    1.1      1.0    0.8      1.0    0.9      1.0    0.9      1.0    1.0      1.0=STD VAL
-------------------------------------------------------------------------------------------------
52 24   12.0      1.0    0.7      1.0    0.6      1.0    0.8      1.0    0.6      1.0    1.0     50.0=STD VAL
53 24   25.0      1.0    0.5      1.0    0.7      1.0    0.9      1.0    0.7      1.0    1.0     50.0=STD VAL
54 24  100.0      1.0    1.2      1.0    1.1      1.0    1.0      1.0    1.2      1.0    1.0     50.0=STD VAL
-------------------------------------------------------------------------------------------------
55 25    2.0      1.0    1.0      1.0    0.9      1.0    1.0      1.0    1.0      1.0    1.0      4.0=STD VAL
56 25    8.0      1.0    1.1      1.0    1.1      1.0    1.0      1.0    1.1      1.0    1.0      4.0=STD VAL
57 25   20.0      1.0    1.2      1.0    1.4      1.0    1.2      1.0    1.3      1.0    1.0      4.0=STD VAL
-------------------------------------------------------------------------------------------------
58 26    1.3      1.0    0.9      1.0    1.0      1.0    1.0      1.0    0.9      1.0    1.0      0.2=STD VAL
59 26    5.0      1.0    0.9      1.0    0.8      1.0    0.9      1.0    0.7      1.0    1.0      0.2=STD VAL
60 26   10.0      1.0    0.9      1.0    0.7      1.0    0.9      1.0    0.7      1.0    1.0      0.2=STD VAL
-------------------------------------------------------------------------------------------------
61 27    5.5      1.0    0.9      1.0    1.0      1.0    1.0      1.0    0.9      1.0    1.0     11.1=STD VAL
62 27   22.0      1.0    1.0      1.0    0.8      1.0    0.9      1.0    1.0      1.0    1.0     11.1=STD VAL
63 27   50.0      1.0    0.9      1.0    0.5      1.0    0.8      1.0    0.9      1.0    1.0     11.1=STD VAL
-------------------------------------------------------------------------------------------------
64 28   12.0      1.0    0.9      1.0    1.1      1.0    1.1      1.0    1.1      1.0    1.0     24.0=STD VAL
65 28   48.0      1.0    1.0      1.0    0.8      1.0    0.9      1.0    0.6      1.0    1.0     24.0=STD VAL
66 28   96.0      1.0    1.1      1.0    0.7      1.0    0.7      1.0    0.7      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
```

```
    IN    VAL        DOF            OPF            RRF            IAR            UOR
                   MN     SD      MN     SD      MN     SD      MN     SD      MN     SD
 1 37    10.0     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    1.0     1.0    1.0     1.0    1.6     0.2    0.4     4.3    9.7       16.0=STD VAL
 3  5     8.0     1.0    0.9     1.0    0.9     1.0    0.9     0.5    0.6     1.9    1.9       16.0=STD VAL
 4  5    32.0     1.0    1.1     1.0    1.2     1.0    1.3     2.0    1.9     0.5    0.5       16.0=STD VAL
----------------------------------------------------------------------------------------
 5  6     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     0.1    0.1       16.0=STD VAL
 6  6     8.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     0.5    0.5       16.0=STD VAL
 7  6    32.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.9    1.9       16.0=STD VAL
----------------------------------------------------------------------------------------
 8  8     5.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9       10.0=STD VAL
 9  8    20.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9     1.0    1.2       10.0=STD VAL
10  8    50.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.6     1.0    1.5       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     1.2    1.1        0.0=STD VAL
15 10     0.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.3    1.2        0.0=STD VAL
16 10     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     4.3    3.5        0.0=STD VAL
----------------------------------------------------------------------------------------
17 11     0.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     0.2    0.2        0.6=STD VAL
18 11     0.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     0.5    0.5        0.6=STD VAL
19 11     1.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     2.0    2.0        0.6=STD VAL
----------------------------------------------------------------------------------------
20 12     2.0     1.0    1.0     1.0    0.9     1.0    1.0     1.0    1.0     1.0    0.9        4.0=STD VAL
21 12     8.0     1.0    1.0     1.0    1.1     1.0    1.1     1.0    1.0     1.0    1.2        4.0=STD VAL
----------------------------------------------------------------------------------------
22 13     1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.7     1.0    1.4        8.0=STD VAL
23 13     4.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1        8.0=STD VAL
24 13    16.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9        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    1.0     1.0    1.0     1.0    1.0        1.0=STD VAL
----------------------------------------------------------------------------------------
28 15     0.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        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    1.0        2.0=STD VAL
30 15     4.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        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    1.0     1.0    1.0     1.0    1.0        0.6=STD VAL
----------------------------------------------------------------------------------------
33 17     6.5     1.0    0.9     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0       24.5=STD VAL
34 17    12.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       24.5=STD VAL
35 17    49.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       24.5=STD VAL
----------------------------------------------------------------------------------------
36 18     2.0     1.0    0.8     1.0    0.7     1.0    1.3     1.0    1.2     1.0    1.0       20.0=STD VAL
37 18    10.0     1.0    0.9     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0       20.0=STD VAL
38 18    40.0     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       20.0=STD VAL
----------------------------------------------------------------------------------------
39 19     0.1     1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9     1.0    0.9        2.6=STD VAL
40 19     1.4     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        2.6=STD VAL
41 19     5.6     1.0    1.0     1.0    1.0     1.0    1.1     1.0    1.1     1.0    1.0        2.6=STD VAL
----------------------------------------------------------------------------------------
42 20     0.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9        2.9=STD VAL
43 20     1.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        2.9=STD VAL
44 20     6.0     1.0    1.0     1.0    1.0     1.0    1.1     1.0    1.0     1.0    1.1        2.9=STD VAL
----------------------------------------------------------------------------------------
45 21     1.0     1.0    1.0     1.0    1.0     1.0    1.0     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    1.0     1.0    1.0        1.6=STD VAL
47 21    12.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     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    1.0     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    0.8     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0        1.0=STD VAL
----------------------------------------------------------------------------------------
52 24    12.0     1.1    0.0     1.0    0.8     1.0    1.0     1.0    1.0     1.0    1.0       50.0=STD VAL
53 24    25.0     1.0    0.4     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0       50.0=STD VAL
54 24   100.0     1.1    1.5     1.0    1.0     1.0    1.1     1.0    1.0     1.0    1.0       50.0=STD VAL
----------------------------------------------------------------------------------------
55 25     2.0     1.0    1.0     0.5    0.5     1.0    1.0     1.0    1.0     1.0    1.0        4.0=STD VAL
56 25     8.0     1.0    1.0     2.0    2.1     1.0    1.0     1.0    1.0     1.0    1.0        4.0=STD VAL
57 25    20.0     1.0    1.1     5.0    5.9     1.0    1.0     1.0    1.0     1.0    1.0        4.0=STD VAL
----------------------------------------------------------------------------------------
58 26     1.3     1.1    0.7     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        0.2=STD VAL
59 26     5.0     1.5    0.3     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0        0.2=STD VAL
60 26    10.0     2.0    0.2     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0        0.2=STD VAL
----------------------------------------------------------------------------------------
61 27     5.5     0.6    0.7     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       11.1=STD VAL
62 27    22.0     2.0    0.6     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0       11.1=STD VAL
63 27    50.0     4.9    0.1     1.0    0.8     1.0    1.0     1.0    1.0     1.0    1.0       11.1=STD VAL
----------------------------------------------------------------------------------------
64 28    12.0     1.0    1.0     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0       24.0=STD VAL
65 28    48.0     1.0    0.9     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0       24.0=STD VAL
66 28    96.0     1.0    0.8     1.0    0.7     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
```

```
     IN     VAL          SSR             RSR             RSRD             RRR             RSF
                       MN     SD       MN     SD       MN     SD       MN     SD       MN     SD
  1 37     10.0        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    1.2      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.1        16.0=STD VAL
  3  5      8.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    0.9        16.0=STD VAL
  4  5     32.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.2        16.0=STD VAL
---------------------------------------------------------------------------------------------------
  5  6      2.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        16.0=STD VAL
  6  6      8.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        16.0=STD VAL
  7  6     32.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        16.0=STD VAL
---------------------------------------------------------------------------------------------------
  8  8      5.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        10.0=STD VAL
  9  8     20.0        1.0    1.0      1.0    0.9      1.0    1.0      1.0    1.0      1.0    1.0        10.0=STD VAL
 10  8     50.0        1.0    1.0      1.0    0.6      1.0    1.0      1.0    1.0      1.0    1.0        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    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         0.0=STD VAL
---------------------------------------------------------------------------------------------------
 17 11      0.1        1.0    1.0      1.0    1.0      1.0    1.0      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    1.0      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    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    0.9         4.0=STD VAL
 21 12      8.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.1         4.0=STD VAL
---------------------------------------------------------------------------------------------------
 22 13      1.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         8.0=STD VAL
 23 13      4.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         8.0=STD VAL
 24 13     16.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         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    1.0      1.0    1.0      1.0    1.0         1.0=STD VAL
---------------------------------------------------------------------------------------------------
 28 15      0.3        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         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    1.0         2.0=STD VAL
 30 15      4.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         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    1.0      1.0    1.0      1.0    1.0         0.6=STD VAL
---------------------------------------------------------------------------------------------------
 33 17      6.5        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.2        24.5=STD VAL
 34 17     12.5        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.1        24.5=STD VAL
 35 17     49.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    0.9        24.5=STD VAL
---------------------------------------------------------------------------------------------------
 36 18      2.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.1        20.0=STD VAL
 37 18     10.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        20.0=STD VAL
 38 18     40.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        20.0=STD VAL
---------------------------------------------------------------------------------------------------
 39 19      0.1        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         2.8=STD VAL
 40 19      1.4        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         2.8=STD VAL
 41 19      5.6        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         2.8=STD VAL
---------------------------------------------------------------------------------------------------
 42 20      0.3        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         2.9=STD VAL
 43 20      1.5        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         2.9=STD VAL
 44 20      6.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         2.9=STD VAL
---------------------------------------------------------------------------------------------------
 45 21      1.0        1.0    1.0      1.0    1.0      1.0    1.0      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    1.0      1.0    1.0         1.6=STD VAL
 47 21     12.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      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       200.0=STD VAL
---------------------------------------------------------------------------------------------------
 49 23      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
 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    1.0      1.0    1.0         1.0=STD VAL
---------------------------------------------------------------------------------------------------
 52 24     12.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        50.0=STD VAL
 53 24     25.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        50.0=STD VAL
 54 24    100.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.1        50.0=STD VAL
---------------------------------------------------------------------------------------------------
 55 25      2.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         4.0=STD VAL
 56 25      8.0        1.0    1.0      1.0    1.0      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    1.0      1.0    1.0      1.0    1.0      1.0    1.0         4.0=STD VAL
---------------------------------------------------------------------------------------------------
 58 26      1.3        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         0.2=STD VAL
 59 26      5.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         0.2=STD VAL
 60 26     10.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0         0.2=STD VAL
---------------------------------------------------------------------------------------------------
 61 27      5.5        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        11.1=STD VAL
 62 27     22.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        11.1=STD VAL
 63 27     50.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        11.1=STD VAL
---------------------------------------------------------------------------------------------------
 64 28     12.0        1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0      1.0    1.0        24.0=STD VAL
 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    1.0      1.0    1.0      1.0    1.0      1.0    1.1        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
```

```
      IN    VAL         UOF               IAF              SRF              MWF              SSF
                    MN       SD       MN       SD      MN       SD      MN       SD      MN       SD
                                                                                                      ABS VALUES
 1 31   10.0     691.5    63.8    1906.7    73.2    113.0     8.3    128.4    24.1    112.6     6.5        0.0=STD VAL
----------------------------------------------------------------------------------------------------
 2  5    2.0     744.2   119.9    1903.4   157.0    120.5     9.4    134.0    56.0    117.5    11.8       16.0=STD VAL
 3  5    8.0     685.9    48.9    1914.2    64.7    112.7     7.1    127.3    18.9    112.2     4.8       16.0=STD VAL
 4  5   32.0     719.4    93.4    1887.5    99.6    115.9    10.6    132.6    36.8    115.0     9.4       16.0=STD VAL
----------------------------------------------------------------------------------------------------
 5  6    2.0     682.7    68.2    1909.4    72.7    111.6     8.4    127.0    25.2    111.6     7.2       16.0=STD VAL
 6  6    8.0     686.4    65.9    1908.3    72.2    112.2     8.3    127.6    24.5    112.0     6.8       16.0=STD VAL
 7  6   32.0     702.0    63.3    1903.6    80.0    114.5     8.3    129.8    25.2    113.6     6.2       16.0=STD VAL
----------------------------------------------------------------------------------------------------
 8  8    5.0     691.5    69.0    1909.5    81.6    113.4     6.1    127.7    28.4    112.5     7.2       10.0=STD VAL
 9  8   20.0     687.1    56.8    1908.4    62.5    112.1     8.0    126.7    18.6    112.2     5.6       10.0=STD VAL
10  8   50.0     674.5    48.6    1917.4    51.5    110.5     7.2    126.9    13.4    111.1     4.8       10.0=STD VAL
----------------------------------------------------------------------------------------------------
11  9    0.1     691.5    63.8    1906.7    73.2    113.0     8.3    128.4    24.1    112.6     6.5        3.3=STD VAL
12  9    1.0     691.5    63.8    1906.7    73.2    113.0     8.3    128.4    24.1    112.6     6.5        3.3=STD VAL
13  9    5.0     691.5    63.8    1906.7    73.2    113.0     8.3    128.4    24.1    112.6     6.5        3.3=STD VAL
----------------------------------------------------------------------------------------------------
14 10    0.1     691.3    63.7    1906.9    73.0    113.0     8.3    128.3    24.0    112.6     6.4        0.0=STD VAL
15 10    0.2     691.1    63.5    1907.0    72.8    112.9     8.3    128.3    23.9    112.5     6.4        0.0=STD VAL
16 10    2.0     687.5    60.5    1909.4    69.6    112.5     8.0    127.7    22.5    112.2     6.1        0.0=STD VAL
----------------------------------------------------------------------------------------------------
17 11    0.1     692.5    64.7    1906.1    74.0    113.1     8.4    128.5    24.4    112.7     6.5        0.6=STD VAL
18 11    0.3     692.1    64.3    1906.3    73.7    113.0     8.3    128.4    24.3    112.6     6.5        0.6=STD VAL
19 11    1.2     690.3    62.8    1907.5    72.1    112.8     8.2    128.2    23.6    112.5     6.4        0.6=STD VAL
----------------------------------------------------------------------------------------------------
20 12    0.5    2740.6  4574.4    2153.8   916.3    182.1   237.5    812.1  4265.5    169.0   335.6        4.0=STD VAL
21 12    2.0     690.8    78.7    1915.8    86.2    113.1     7.7    128.3    37.5    112.6     8.5        4.0=STD VAL
22 12    8.0     687.1    55.8    1907.8    57.2    111.6     8.1    129.3    15.1    112.3     5.4        4.0=STD VAL
----------------------------------------------------------------------------------------------------
23 13    1.0     668.1    46.3    1922.1    45.0    109.5     6.8    126.5    10.1    110.5     4.5        8.0=STD VAL
24 13    4.0     689.0    55.7    1907.3    61.1    112.2     8.1    129.2    17.9    112.5     5.5        8.0=STD VAL
25 13   16.0     690.4    74.4    1909.5    85.9    113.3     8.4    127.2    30.0    112.4     7.7        8.0=STD VAL
----------------------------------------------------------------------------------------------------
26 14    0.3     690.8    60.4    1908.2    71.4    113.0     8.0    128.3    23.1    112.5     6.1        1.0=STD VAL
27 14    0.5     691.0    61.4    1907.8    71.9    113.0     8.1    128.3    23.4    112.6     6.2        1.0=STD VAL
28 14    2.0     692.7    68.4    1904.4    75.4    113.0     8.7    128.5    25.3    112.6     5.9        1.0=STD VAL
----------------------------------------------------------------------------------------------------
29 15    0.3     687.7    58.7    1909.2    67.3    112.5     8.0    128.0    21.4    112.3     5.9        2.0=STD VAL
30 15    1.0     689.2    60.6    1908.2    69.6    112.7     8.1    128.2    22.5    112.4     6.1        2.0=STD VAL
31 15    4.0     696.3    71.4    1903.4  [illegible] 113.6   8.7    128.6    27.5    112.9     7.2        2.0=STD VAL
----------------------------------------------------------------------------------------------------
32 16    0.3     691.2    62.4    1907.4    72.4    113.0     8.2    128.3    23.6    112.6     6.7        0.6=STD VAL
33 16    1.2     692.2    66.7    1905.4    74.6    113.0     8.5    128.4    24.9    112.6     6.7        0.6=STD VAL
----------------------------------------------------------------------------------------------------
34 17    6.5     684.1    88.4    1989.6    60.8    114.2     9.4    125.0    52.1    112.3     8.0       24.5=STD VAL
35 17   12.5     689.9    75.4    1954.6    70.1    114.2     8.9    126.5    37.0    112.5     7.0       24.5=STD VAL
36 17   49.0     688.7    56.8    1862.8    83.4    111.1     7.3    127.1    16.1    112.5     6.3       24.5=STD VAL
----------------------------------------------------------------------------------------------------
37 18    2.0     905.3   219.0     140.4    35.6    114.7    10.5    127.8    36.5    114.6     7.9       20.0=STD VAL
38 18   10.0     725.0    62.3     889.7    70.4    112.2     8.0    126.6    22.1    112.9     6.2       20.0=STD VAL
39 18   40.0     675.3    56.8    3961.2    94.4    115.6     9.8    132.1    31.4    112.5     6.6       20.0=STD VAL
----------------------------------------------------------------------------------------------------
40 19    0.1     339.1    20.5    1860.3    83.9    111.3     7.1    127.3    17.4    112.4     6.6        2.8=STD VAL
41 19    1.4     509.4    39.3    1883.7    79.4    112.1     7.6    128.0    20.5    112.4     6.5        2.8=STD VAL
42 19    5.6    1054.6   116.6    1948.3    60.6    114.5     9.5    129.0    31.2    113.1     6.7        2.8=STD VAL
----------------------------------------------------------------------------------------------------
43 20    0.3     399.8    45.2    1892.5    78.7    112.7     8.1    128.3    22.5    112.5     6.2        2.9=STD VAL
44 20    1.5     534.3    53.7    1899.2    76.5    112.8     8.2    128.3    23.3    112.5     6.3        2.9=STD VAL
45 20    6.0    1040.3    85.7    1922.1    64.6    113.3     8.5    128.5    25.3    112.7     6.5        2.9=STD VAL
----------------------------------------------------------------------------------------------------
46 21    1.0     690.5    63.6    1911.4    72.0    113.1     8.3    128.3    24.6    112.6     6.5        1.6=STD VAL
47 21    3.2     694.0    64.3    1895.4    76.0    112.6     8.3    128.4    22.4    112.6     6.4        1.6=STD VAL
48 21   12.0     702.9    65.4    1855.6    88.0    110.9     7.5    127.2    15.5    112.6     6.3        1.6=STD VAL
----------------------------------------------------------------------------------------------------
49 22  120.0     691.5    63.8    1906.7    73.2    113.0     8.3    128.4    24.1    112.6     6.5      999.0=STD VAL
----------------------------------------------------------------------------------------------------
50 23    0.5     691.1    63.8    1908.6    73.3    113.1     8.3    128.4    24.4    112.6     6.5        1.0=STD VAL
51 23    2.0     692.2    63.8    1903.4    72.9    112.8     8.2    128.2    23.5    112.6     6.4        1.0=STD VAL
52 23   10.0     694.4    63.2    1891.5    70.0    111.9     7.4    126.8    22.6    112.5     6.4        1.0=STD VAL
----------------------------------------------------------------------------------------------------
53 24   12.0     656.8    59.9    2081.6   110.4    116.2    12.4    118.5    22.0    112.3     7.1       50.0=STD VAL
54 24   25.0     671.8    62.9    2004.0    94.0    115.8     9.9    121.7    24.3    112.5     6.8       50.0=STD VAL
55 24  100.0     710.8    66.6    1821.3   106.1    109.0     6.2    136.7    22.2    112.5     6.2       50.0=STD VAL
----------------------------------------------------------------------------------------------------
56 25    2.0     687.7    62.0    1923.3    65.0    113.2     7.8    127.7    22.9    112.5     6.5        4.0=STD VAL
57 25    8.0     699.3    66.6    1874.1    88.3    112.4     9.0    129.8    26.2    112.6     6.3        4.0=STD VAL
58 25   20.0     719.3    71.3    1794.0   127.8    109.5     8.9    134.9    31.2    112.7     6.1        4.0=STD VAL
----------------------------------------------------------------------------------------------------
59 26    1.3     685.3    63.9    1937.3    78.3    114.3     9.0    125.3    25.2    112.6     6.5        0.2=STD VAL
60 26    5.0     677.2    64.1    1978.1    92.5    115.6     9.9    122.6    27.1    112.5     6.7        0.2=STD VAL
61 26   10.0     675.8    63.9    1964.3    91.8    115.5     9.9    122.1    28.7    112.5     6.7        0.2=STD VAL
----------------------------------------------------------------------------------------------------
62 27    5.5     690.3    64.0    1913.1    75.5    113.5     8.6    127.6    22.1    112.6     6.5       11.1=STD VAL
63 27   22.0     689.0    63.3    1917.6    69.7    113.1     8.2    127.9    28.2    112.5     6.5       11.1=STD VAL
64 27   50.0     682.3    62.1    1947.9    64.9    113.6     8.4    125.8    38.0    112.5     6.6       11.1=STD VAL
----------------------------------------------------------------------------------------------------
65 28   12.0     686.7    64.8    1932.0    84.5    114.5     9.5    130.7    28.8    112.6     6.5       24.0=STD VAL
66 28   48.0     694.8    63.3    1889.2    70.4    111.8     7.3    125.4    22.5    112.5     6.4       24.0=STD VAL
67 28   96.0     696.9    63.1    1878.8    71.5    111.0     6.8    123.2    22.2    112.5     6.4       24.0=STD VAL
----------------------------------------------------------------------------------------------------
68 38    1.0     693.1    63.8    1899.1    72.9    112.6     6.0    128.8    23.9    112.6     5.4        1.2=STD VAL
69 38    1.5     691.5    63.8    1906.7    73.2    113.0     8.3    128.4    24.1    112.6     6.5        1.2=STD VAL
----------------------------------------------------------------------------------------------------
70  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
----------------------------------------------------------------------------------------------------
```

	IN	VAL	DOF		OPF		RRF		IAR		UOR		
			MN	SD	MN	SD	MN	SD	MN	SD	MN	SD	
1	31	10.0	15.4	2.3	453.6	32.3	114.0	10.1	1678.3	83.7	68.0	3.8	0.0=STD VAL
2	5	2.0	17.3	2.3	483.6	35.8	118.5	24.7	385.8	84.6	324.5	85.5	16.0=STD VAL
3	5	8.0	15.3	1.9	452.4	27.6	113.6	7.5	883.4	61.8	129.5	8.0	16.0=STD VAL
4	5	32.0	16.1	2.8	465.4	41.2	116.3	15.6	3343.3	144.6	34.2	1.7	16.0=STD VAL
5	6	2.0	15.0	2.4	448.1	33.1	113.2	11.1	1626.9	74.9	8.8	0.5	16.0=STD VAL
6	6	8.0	15.2	2.4	450.4	32.7	113.5	10.5	1649.4	78.1	34.6	2.0	16.0=STD VAL
7	6	32.0	15.8	2.2	459.9	31.9	115.0	10.1	1733.0	97.7	131.8	6.9	16.0=STD VAL
8	8	5.0	15.5	2.2	455.0	31.5	113.9	12.2	1696.1	56.7	67.3	3.6	10.0=STD VAL
9	8	20.0	15.2	2.2	450.1	31.5	114.0	7.7	1650.1	70.7	69.2	3.8	10.0=STD VAL
10	8	50.0	14.7	2.1	443.7	28.4	113.0	5.6	1511.0	45.1	70.8	3.7	10.0=STD VAL
11	9	0.1	15.4	2.3	453.6	32.3	114.0	10.1	1678.7	83.3	68.4	4.1	3.3=STD VAL
12	9	1.0	15.4	2.3	453.6	32.3	114.0	10.1	1678.6	83.4	68.3	4.0	3.3=STD VAL
13	9	5.0	15.4	2.3	453.6	32.3	114.0	10.1	1678.1	83.9	67.9	3.6	3.3=STD VAL
14	10	0.1	15.4	2.3	453.5	32.2	114.0	10.0	1678.6	83.4	79.9	4.7	0.0=STD VAL
15	10	0.2	15.4	2.3	453.4	32.2	114.0	10.0	1678.9	83.1	89.8	4.1	0.0=STD VAL
16	10	2.0	15.3	2.2	451.7	31.2	113.7	9.4	1683.7	78.6	285.3	8.4	0.0=STD VAL
17	11	0.1	15.4	2.3	454.1	32.5	114.1	10.2	1674.6	87.5	11.4	0.7	0.6=STD VAL
18	11	0.3	15.4	2.3	453.9	32.4	114.1	10.2	1676.1	85.9	34.1	1.9	0.6=STD VAL
19	11	1.2	15.4	2.3	453.0	32.0	113.9	9.9	1682.3	79.9	135.6	7.2	0.6=STD VAL
20	12	0.5	46.5	917.7	823.9	1116.1	256.5	1259.2	1643.4	659.3	139.6	222.6	4.0=STD VAL
21	12	2.0	15.4	2.2	454.1	29.9	114.2	17.1	1699.8	60.4	67.2	3.3	4.0=STD VAL
22	12	8.0	15.0	2.3	448.4	32.1	114.3	6.2	1633.7	66.5	69.9	3.9	4.0=STD VAL
23	13	1.0	14.5	2.0	439.7	27.0	112.7	4.3	1584.7	33.1	71.9	3.9	8.0=STD VAL
24	13	4.0	15.2	2.3	450.7	31.7	114.2	7.4	1653.6	72.1	69.0	3.8	8.0=STD VAL
25	13	16.0	15.4	2.3	454.5	32.6	113.7	12.8	1692.3	89.7	67.5	3.3	8.0=STD VAL
26	14	0.3	15.4	2.2	453.6	31.2	114.0	9.6	1681.1	80.3	67.9	3.6	1.0=STD VAL
27	14	0.5	15.4	2.2	453.6	31.5	114.0	9.8	1680.3	81.3	68.0	3.7	1.0=STD VAL
28	14	2.0	15.4	2.4	453.6	33.8	114.0	10.6	1674.2	88.5	68.2	4.[illegible]	1.0=STD VAL
29	15	0.3	15.3	2.2	451.6	31.1	113.8	9.0	1684.4	76.5	67.8	3.4	2.0=STD VAL
30	15	1.0	15.3	2.2	452.4	31.6	113.9	9.4	1681.9	79.4	67.9	3.6	2.0=STD VAL
31	15	4.0	15.5	2.4	456.2	34.1	114.2	11.5	1671.1	92.8	68.4	4.3	2.0=STD VAL
32	16	0.3	15.4	2.3	453.6	31.8	114.0	9.9	1679.5	82.2	68.0	3.7	0.6=STD VAL
33	16	1.2	15.4	2.4	453.6	33.2	114.0	10.4	1675.9	86.6	68.2	4.0	0.6=STD VAL
34	17	6.5	15.6	2.6	457.9	36.8	113.3	12.4	1681.8	94.8	67.9	4.2	24.5=STD VAL
35	17	12.5	15.7	2.4	458.3	34.5	113.5	11.2	1680.2	89.2	68.0	4.0	24.5=STD VAL
36	17	49.0	14.9	2.1	446.2	26.8	114.3	9.3	1677.5	80.3	68.1	3.7	24.5=STD VAL
37	18	2.0	15.8	2.8	460.4	40.9	116.3	21.7	1654.0	112.9	59.2	5.1	20.0=STD VAL
38	18	10.0	15.2	2.2	450.4	31.2	114.5	11.2	1474.6	85.4	68.2	5.9	20.0=STD VAL
39	18	40.0	16.1	2.6	464.2	36.0	113.8	9.6	1560.1	62.9	68.0	3.7	20.0=STD VAL
40	19	0.1	15.0	2.0	447.0	27.7	113.0	7.2	1691.2	72.9	67.5	3.2	2.8=STD VAL
41	19	1.4	15.2	2.1	450.2	29.8	113.5	8.5	1684.9	78.1	67.8	3.5	2.8=STD VAL
42	19	5.6	15.8	2.6	459.8	37.2	114.9	13.5	1664.1	92.9	68.7	4.3	2.8=STD VAL
43	20	0.3	15.3	2.2	452.6	31.5	113.6	9.0	1686.6	78.9	67.7	3.5	2.9=STD VAL
44	20	1.5	15.4	2.3	453.0	31.8	113.8	9.5	1682.8	81.4	67.9	3.6	2.9=STD VAL
45	20	6.0	15.5	2.4	454.8	33.3	114.5	11.2	1657.9	86.6	68.5	4.1	2.9=STD VAL
46	21	1.0	15.4	2.3	454.1	32.2	114.0	10.1	1678.5	83.7	68.0	3.[illegible]	1.6=STD VAL
47	21	3.2	15.3	2.3	452.3	32.3	114.1	10.1	1677.9	83.5	68.1	3.6	1.6=STD VAL
48	21	12.0	14.9	2.1	445.5	29.5	114.4	9.9	1676.2	82.1	68.1	3.8	1.6=STD VAL
49	22	120.0	15.4	2.3	453.6	32.3	114.0	10.1	1678.3	83.7	68.0	3.8	999.0=STD VAL
50	23	0.5	15.5	2.3	454.0	32.5	114.0	10.1	1678.4	83.7	68.0	3.8	1.0=STD VAL
51	23	2.0	15.1	2.3	452.9	31.9	114.0	10.1	1678.2	83.6	68.1	3.8	1.0=STD VAL
52	23	10.0	13.3	2.0	449.3	28.8	114.2	9.9	1677.6	82.9	68.1	3.8	1.0=STD VAL
53	24	12.0	11.2	0.2	465.4	46.9	113.2	9.9	1683.0	85.3	67.9	3.8	50.0=STD VAL
54	24	25.0	12.9	0.9	464.6	36.6	113.4	10.2	1681.5	85.6	67.9	3.9	50.0=STD VAL
55	24	100.0	18.2	4.2	437.5	24.7	114.8	9.8	1674.4	80.6	68.2	3.7	50.0=STD VAL
56	25	2.0	15.3	2.2	226.8	15.3	113.9	10.0	1676.7	83.5	68.0	3.8	4.0=STD VAL
57	25	8.0	15.6	2.4	906.8	70.1	114.2	10.2	1677.3	83.5	68.1	3.8	4.0=STD VAL
58	25	20.0	16.3	2.8	2246.5	188.9	114.9	9.9	1673.4	80.5	68.2	3.8	4.0=STD VAL
59	26	1.3	15.5	1.7	459.0	35.1	113.8	10.2	1679.5	84.6	68.0	3.8	0.2=STD VAL
60	26	5.0	17.7	1.0	464.0	38.3	113.5	10.2	1680.9	85.6	67.9	3.8	0.2=STD VAL
61	26	10.0	22.1	0.6	463.5	38.5	113.5	10.2	1681.1	85.6	67.9	3.8	0.2=STD VAL
62	27	5.5	10.0	2.4	455.6	33.6	113.9	10.1	1678.6	83.9	68.0	3.8	11.1=STD VAL
63	27	22.0	25.2	1.7	454.1	31.9	113.9	10.1	1678.7	83.9	68.0	3.8	11.1=STD VAL
64	27	50.0	49.9	0.4	455.7	32.6	113.8	10.0	1679.7	84.3	68.0	3.8	11.1=STD VAL
65	28	12.0	15.3	2.6	460.0	37.0	113.8	10.2	1679.4	84.8	68.0	3.8	24.0=STD VAL
66	28	48.0	15.0	2.1	448.5	28.6	114.2	9.9	1677.5	82.9	68.1	3.8	24.0=STD VAL
67	28	96.0	14.8	1.9	445.2	26.3	114.3	9.9	1677.0	82.4	68.1	3.8	24.0=STD VAL
68	38	1.0	15.5	2.4	452.0	31.4	114.1	10.0	1672.0	83.4	68.1	3.6	1.2=STD VAL
69	38	1.5	15.4	2.3	453.6	32.3	114.0	10.1	1678.3	83.7	68.0	3.8	1.2=STD VAL
70	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

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     IN    VAL         SSR              RSR              RSRD             RRR              RSF
                     MN      SD       MN      SD       MN      SD       MN      SD       MN      SD
  1 31    10.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          0.0=STD VAL
---------------------------------------------------------------------------------------------------------
  2  5     2.0     113.0    6.8     107.5    3.1     108.7    2.9     109.3    2.6     114.4    6.1         16.0=STD VAL
  3  5     8.0     109.3    3.0     107.5    3.1     108.7    2.9     109.3    2.6     109.4    3.8         16.0=STD VAL
  4  5    32.0     109.2    2.6     107.5    3.1     108.7    2.9     109.3    2.6     111.8    6.5         16.0=STD VAL
---------------------------------------------------------------------------------------------------------
  5  6     2.0     109.3    2.6     107.5    3.1     108.7    2.9     109.3    2.6     108.8    5.2         16.0=STD VAL
  6  6     8.0     109.2    2.6     107.5    3.1     108.7    2.9     109.3    2.6     109.2    5.0         16.0=STD VAL
  7  6    32.0     109.2    2.9     107.5    3.1     108.7    2.9     109.3    2.6     110.7    4.6         16.0=STD VAL
---------------------------------------------------------------------------------------------------------
  8  8     5.0     109.2    2.7     108.4    3.0     108.7    2.9     109.3    2.6     109.8    4.9         10.0=STD VAL
  9  8    20.0     109.2    2.7     106.0    3.0     108.7    2.9     109.3    2.6     109.2    4.7         10.0=STD VAL
 10  8    50.0     109.1    2.7     103.5    2.0     108.7    2.9     109.3    2.6     108.2    4.2         10.0=STD VAL
---------------------------------------------------------------------------------------------------------
 11  9     0.1     109.2    2.9     107.5    3.1     109.3    2.6     109.3    2.6     109.7    4.3          3.3=STD VAL
 12  9     1.0     109.2    2.8     107.5    3.1     109.1    2.7     109.3    2.6     109.7    4.8          3.3=STD VAL
 13  9     5.0     109.2    2.7     107.5    3.1     108.4    3.0     109.3    2.6     109.7    4.8          3.3=STD VAL
---------------------------------------------------------------------------------------------------------
 14 10     0.1     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          0.0=STD VAL
 15 10     0.2     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          0.0=STD VAL
 16 10     2.0     108.8    2.9     107.5    3.1     108.7    2.9     109.3    2.6     109.4    4.6          0.0=STD VAL
---------------------------------------------------------------------------------------------------------
 17 11     0.1     109.3    2.6     107.5    3.1     108.7    2.9     109.3    2.6     109.8    4.9          0.6=STD VAL
 18 11     0.3     109.3    2.6     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.2          0.6=STD VAL
 19 11     1.2     109.1    2.9     107.5    3.1     108.7    2.9     109.3    2.6     109.6    4.3          0.6=STD VAL
---------------------------------------------------------------------------------------------------------
 20 12     0.5     109.8  109.0     107.5    3.1     108.7    2.9     109.3    2.6     177.0  181.3          4.0=STD VAL
 21 12     2.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.9          4.0=STD VAL
 22 12     8.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.1    4.3          4.0=STD VAL
---------------------------------------------------------------------------------------------------------
 23 13     1.0     109.1    2.7     107.5    3.1     108.7    2.9     109.3    2.6     107.6    4.1          8.0=STD VAL
 24 13     4.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.4    4.7          8.0=STD VAL
 25 13    16.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    5.1          8.0=STD VAL
---------------------------------------------------------------------------------------------------------
 26 14     0.3     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.6          1.0=STD VAL
 27 14     0.5     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.7          1.0=STD VAL
 28 14     2.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    5.1          1.0=STD VAL
---------------------------------------------------------------------------------------------------------
 29 15     0.3     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.4    4.6          2.0=STD VAL
 30 15     1.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.5    4.7          2.0=STD VAL
 31 15     4.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     110.1    5.2          2.0=STD VAL
---------------------------------------------------------------------------------------------------------
 32 16     0.3     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.7          0.6=STD VAL
 33 16     1.2     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    5.0          0.6=STD VAL
---------------------------------------------------------------------------------------------------------
 34 17     6.5     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     112.3    9.7         24.5=STD VAL
 35 17    12.5     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     111.8    6.8         24.5=STD VAL
 36 17    49.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     106.5    3.4         24.5=STD VAL
---------------------------------------------------------------------------------------------------------
 37 18     2.0     109.3    2.7     107.5    3.1     108.7    2.9     109.3    2.6     113.8    8.4         20.0=STD VAL
 38 18    10.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     110.3    5.3         20.0=STD VAL
 39 18    40.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.4    4.6         20.0=STD VAL
---------------------------------------------------------------------------------------------------------
 40 19     0.1     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     108.4    3.9          2.8=STD VAL
 41 19     1.4     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.0    4.3          2.8=STD VAL
 42 19     5.6     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     111.1    5.9          2.8=STD VAL
---------------------------------------------------------------------------------------------------------
 43 20     0.3     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.3    4.5          2.9=STD VAL
 44 20     1.5     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.5    4.6          2.9=STD VAL
 45 20     6.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     110.3    5.2          2.9=STD VAL
---------------------------------------------------------------------------------------------------------
 46 21     1.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          1.6=STD VAL
 47 21     3.2     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.8    4.8          1.6=STD VAL
 48 21    12.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.9    4.9          1.6=STD VAL
---------------------------------------------------------------------------------------------------------
 49 22   120.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8        999.0=STD VAL
---------------------------------------------------------------------------------------------------------
 50 23     0.5     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          1.0=STD VAL
 51 23     2.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          1.0=STD VAL
 52 23    10.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.8    4.8          1.0=STD VAL
---------------------------------------------------------------------------------------------------------
 53 24    12.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.0    4.4         50.0=STD VAL
 54 24    25.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.3    4.6         50.0=STD VAL
 55 24   100.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     110.1    5.0         50.0=STD VAL
---------------------------------------------------------------------------------------------------------
 56 25     2.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.6    4.8          4.0=STD VAL
 57 25     8.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.9    4.9          4.0=STD VAL
 58 25    20.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     110.3    5.1          4.0=STD VAL
---------------------------------------------------------------------------------------------------------
 59 26     1.3     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.6    4.8          0.2=STD VAL
 60 26     5.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.4    4.7          0.2=STD VAL
 61 26    10.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.4    4.7          0.2=STD VAL
---------------------------------------------------------------------------------------------------------
 62 27     5.5     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.9         11.1=STD VAL
 63 27    22.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.6    4.8         11.1=STD VAL
 64 27    50.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.5    4.7         11.1=STD VAL
---------------------------------------------------------------------------------------------------------
 65 28    12.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.6    4.8         24.0=STD VAL
 66 28    48.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.8    4.8         24.0=STD VAL
 67 28    96.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.8    4.9         24.0=STD VAL
---------------------------------------------------------------------------------------------------------
 68 38     1.0     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          1.2=STD VAL
 69 38     1.5     109.2    2.7     107.5    3.1     108.7    2.9     109.3    2.6     109.7    4.8          1.2=STD VAL
---------------------------------------------------------------------------------------------------------
 70  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
---------------------------------------------------------------------------------------------------------
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     IN    VAL        UOF            IAF            SRF            MWF            SSF
                   MN     SD      MN     SD      MN     SD      MN     SD      MN     SD    RATIO VALUES
 1 31     10.0    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    1.1    1.9     1.0    2.1     1.1    1.1     1.0    2.3     1.0    1.8      16.0=STD VAL
 3  5      8.0    1.0    0.8     1.0    0.9     1.0    0.9     1.0    0.8     1.0    0.7      16.0=STD VAL
 4  5     32.0    1.0    1.5     1.0    1.4     1.0    1.3     1.0    1.5     1.0    1.4      16.0=STD VAL
--------------------------------------------------------------------------------------------------
 5  6      2.0    1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1      16.0=STD VAL
 6  6      8.0    1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0      16.0=STD VAL
 7  6     32.0    1.0    1.0     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0      16.0=STD VAL
--------------------------------------------------------------------------------------------------
 8  8      5.0    1.0    1.1     1.0    1.1     1.0    1.0     1.0    1.2     1.0    1.1      10.0=STD VAL
 9  8     20.0    1.0    0.9     1.0    0.9     1.0    1.0     1.0    0.8     1.0    0.9      10.0=STD VAL
10  8     50.0    1.0    0.8     1.0    0.7     1.0    0.9     1.0    0.6     1.0    0.7      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    0.9     1.0    0.9       0.0=STD VAL
--------------------------------------------------------------------------------------------------
17 11      0.1    1.0    1.0     1.0    1.0     1.0    1.0     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    1.0     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      0.5    4.0   71.7     1.1   12.5     1.6   28.6     6.3  177.0     1.5   51.6       4.0=STD VAL
21 12      2.0    1.0    1.2     1.0    1.2     1.0    0.9     1.0    1.6     1.0    1.4       4.0=STD VAL
22 12      8.0    1.0    0.9     1.0    0.5     1.0    1.0     1.0    0.6     1.0    [illegible]       4.0=STD VAL
--------------------------------------------------------------------------------------------------
23 13      1.0    1.0    0.7     1.0    0.6     1.0    0.8     1.0    0.4     1.0    0.7       8.0=STD VAL
24 13      4.0    1.0    0.9     1.0    0.6     1.0    1.0     1.0    0.7     1.0    [illegible]       8.0=STD VAL
25 13     16.0    1.0    1.2     1.0    1.2     1.0    1.0     1.0    1.2     1.0    1.2       8.0=STD VAL
--------------------------------------------------------------------------------------------------
26 14      0.3    1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9       1.0=STD VAL
27 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
28 14      2.0    1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1       1.0=STD VAL
--------------------------------------------------------------------------------------------------
29 15      0.3    1.0    0.9     1.0    0.9     1.0    1.0     1.0    0.9     1.0    0.9       2.0=STD VAL
30 15      1.0    1.0    0.9     1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9       2.0=STD VAL
31 15      4.0    1.0    1.1     1.0    1.1     1.0    1.0     1.0    1.1     1.0    1.1       2.0=STD VAL
--------------------------------------------------------------------------------------------------
32 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
33 16      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
--------------------------------------------------------------------------------------------------
34 17      6.5    1.0    1.4     1.0    0.8     1.0    1.1     1.0    2.2     1.0    1.2      24.5=STD VAL
35 17     12.5    1.0    1.2     1.0    1.0     1.0    1.1     1.0    1.5     1.0    1.1      24.5=STD VAL
36 17     49.0    1.0    0.9     1.0    1.1     1.0    0.9     1.0    0.7     1.0    1.0      24.5=STD VAL
--------------------------------------------------------------------------------------------------
37 18      2.0    1.3    3.4     3.1    0.5     1.0    1.3     1.0    1.5     1.0    1.2      20.0=STD VAL
38 18     10.0    1.0    1.5     0.5    1.0     1.0    1.0     1.0    0.9     1.0    1.0      20.0=STD VAL
39 18     40.0    1.0    0.9     2.1    1.3     1.0    1.2     1.0    1.3     1.0    1.0      20.0=STD VAL
--------------------------------------------------------------------------------------------------
40 19      0.1    0.5    0.3     1.0    1.1     1.0    0.9     1.0    0.7     1.0    1.0       2.8=STD VAL
41 19      1.4    0.7    0.6     1.0    1.1     1.0    0.9     1.0    0.9     1.0    1.0       2.8=STD VAL
42 19      5.6    1.5    1.8     1.0    0.8     1.0    1.1     1.0    1.3     1.0    1.0       2.8=STD VAL
--------------------------------------------------------------------------------------------------
43 20      0.3    0.6    0.7     1.0    1.1     1.0    1.0     1.0    0.9     1.0    1.0       2.9=STD VAL
44 20      1.5    0.8    0.8     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       2.9=STD VAL
45 20      6.0    1.5    1.3     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0       2.9=STD VAL
--------------------------------------------------------------------------------------------------
46 21      1.0    1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       1.6=STD VAL
47 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
48 21     12.0    1.0    1.0     1.0    1.2     1.0    0.9     1.0    0.6     1.0    1.0       1.6=STD VAL
--------------------------------------------------------------------------------------------------
49 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
--------------------------------------------------------------------------------------------------
50 23      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
51 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
52 23     10.0    1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9     1.0    1.0       1.0=STD VAL
--------------------------------------------------------------------------------------------------
53 24     12.0    0.9    0.9     1.1    1.5     1.0    1.5     0.9    0.9     1.0    1.1      50.0=STD VAL
54 24     25.0    1.0    1.0     1.1    1.3     1.0    1.2     0.9    1.0     1.0    1.0      50.0=STD VAL
55 24    100.0    1.0    1.0     1.0    1.4     1.0    0.7     1.1    0.9     1.0    1.0      50.0=STD VAL
--------------------------------------------------------------------------------------------------
56 25      2.0    1.0    1.0     1.0    0.9     1.0    0.9     1.0    1.0     1.0    1.0       4.0=STD VAL
57 25      8.0    1.0    1.0     1.0    1.2     1.0    1.1     1.0    1.1     1.0    1.0       4.0=STD VAL
58 25     20.0    1.0    1.1     0.9    1.7     1.0    1.1     1.1    1.3     1.0    0.9       4.0=STD VAL
--------------------------------------------------------------------------------------------------
59 26      1.3    1.0    1.0     1.0    1.1     1.0    1.1     1.0    1.0     1.0    1.0       0.2=STD VAL
60 26      5.0    1.0    1.0     1.0    1.3     1.0    1.2     1.0    1.1     1.0    1.0       0.2=STD VAL
61 26     10.0    1.0    1.0     1.0    1.3     1.0    1.2     1.0    1.2     1.0    1.0       0.2=STD VAL
--------------------------------------------------------------------------------------------------
62 27      5.5    1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9     1.0    1.0      11.1=STD VAL
63 27     22.0    1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.2     1.0    1.0      11.1=STD VAL
64 27     50.0    1.0    1.0     1.0    0.9     1.0    1.0     1.0    1.6     1.0    1.0      11.1=STD VAL
--------------------------------------------------------------------------------------------------
65 28     12.0    1.0    1.0     1.0    1.2     1.0    1.1     1.0    1.2     1.0    1.0      24.0=STD VAL
66 28     48.0    1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9     1.0    1.0      24.0=STD VAL
67 28     96.0    1.0    1.0     1.0    1.0     1.0    0.8     1.0    0.9     1.0    1.0      24.0=STD VAL
--------------------------------------------------------------------------------------------------
68 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
69 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
--------------------------------------------------------------------------------------------------
70  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
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   IN    VAL         DOF            OPF            RRF            IAR            UOR
                  MN     SD      MN     SD      MN     SD      MN     SD      MN     SD
 1 31    10.0     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     1.1    1.0     1.1    1.1     1.0    2.4     0.2    1.0     4.8   22.5    16.0=STD VAL
 3  5     8.0     1.0    0.8     1.0    0.9     1.0    0.7     0.5    0.7     1.9    2.1    16.0=STD VAL
 4  5    32.0     1.0    1.2     1.0    1.3     1.0    1.5     2.0    1.7     0.5    0.4    16.0=STD VAL
----------------------------------------------------------------------------------------
 5  6     2.0     1.0    1.0     1.0    1.0     1.0    1.1     1.0    0.9     0.1    0.1    16.0=STD VAL
 6  6     8.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9     0.5    0.5    16.0=STD VAL
 7  6    32.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.2     1.9    1.8    16.0=STD VAL
----------------------------------------------------------------------------------------
 8  8     5.0     1.0    1.0     1.0    1.0     1.0    1.2     1.0    1.0     1.0    0.9    10.0=STD VAL
 9  8    20.0     1.0    1.0     1.0    1.0     1.0    0.8     1.0    0.8     1.0    1.0    10.0=STD VAL
10  8    50.0     1.0    0.9     1.0    0.9     1.0    0.6     1.0    0.5     1.0    1.0    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    1.1     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    1.1     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    0.9     3.3=STD VAL
----------------------------------------------------------------------------------------
14 10     0.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.2    1.1     0.0=STD VAL
15 10     0.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.3    1.1     0.0=STD VAL
16 10     2.0     1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9     4.2    2.2     0.0=STD VAL
----------------------------------------------------------------------------------------
17 11     0.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     0.2    0.2     0.6=STD VAL
18 11     0.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     0.5    0.5     0.6=STD VAL
19 11     1.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     2.0    1.9     0.6=STD VAL
----------------------------------------------------------------------------------------
20 12     0.5     3.0  399.0     1.8   34.6     2.2  124.7     1.0    7.9     2.1   58.6     4.0=STD VAL
21 12     2.0     1.0    1.0     1.0    0.9     1.0    1.7     1.0    1.0     1.0    0.9     4.0=STD VAL
22 12     8.0     1.0    1.0     1.0    1.0     1.0    0.6     1.0    0.8     1.0    1.0     4.0=STD VAL
----------------------------------------------------------------------------------------
23 13     1.0     0.9    0.9     1.0    0.8     1.0    0.4     0.9    0.4     1.1    1.0     8.0=STD VAL
24 13     4.0     1.0    1.0     1.0    1.0     1.0    0.7     1.0    0.9     1.0    1.0     8.0=STD VAL
25 13    16.0     1.0    1.0     1.0    1.0     1.0    1.3     1.0    1.1     1.0    1.0     8.0=STD VAL
----------------------------------------------------------------------------------------
26 14     0.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9     1.0=STD VAL
27 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
28 14     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1     1.0    1.1     1.0=STD VAL
----------------------------------------------------------------------------------------
29 15     0.3     1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9     1.0    1.9     2.0=STD VAL
30 15     1.0     1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9     1.0    0.9     2.0=STD VAL
31 15     4.0     1.0    1.0     1.0    1.1     1.0    1.1     1.0    1.1     1.0    1.1     2.0=STD VAL
----------------------------------------------------------------------------------------
32 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
33 16     1.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1     0.6=STD VAL
----------------------------------------------------------------------------------------
34 17     6.5     1.0    1.1     1.0    1.1     1.0    1.2     1.0    1.1     1.0    1.1    24.5=STD VAL
35 17    12.5     1.0    1.0     1.0    1.1     1.0    1.1     1.0    1.1     1.0    1.1    24.5=STD VAL
36 17    49.0     1.0    0.9     1.0    0.9     1.0    0.9     1.0    1.0     1.0    1.0    24.5=STD VAL
----------------------------------------------------------------------------------------
37 18     2.0     1.0    1.2     1.0    1.3     1.0    2.1     1.0    1.3     1.0    1.3    20.0=STD VAL
38 18    10.0     1.0    1.0     1.0    1.0     1.0    1.1     1.0    1.0     1.0    1.0    20.0=STD VAL
39 18    40.0     1.0    1.1     1.0    1.2     1.0    1.0     1.0    1.0     1.0    1.0    20.0=STD VAL
----------------------------------------------------------------------------------------
40 19     0.1     1.0    0.9     1.0    0.9     1.0    0.7     1.0    0.9     1.0    0.8     2.8=STD VAL
41 19     1.4     1.0    0.9     1.0    0.9     1.0    0.8     1.0    0.9     1.0    0.9     2.8=STD VAL
42 19     5.6     1.0    1.1     1.0    1.2     1.0    1.3     1.0    1.1     1.0    1.1     2.8=STD VAL
----------------------------------------------------------------------------------------
43 20     0.3     1.0    1.0     1.0    1.0     1.0    0.9     1.0    0.9     1.0    0.9     2.9=STD VAL
44 20     1.5     1.0    1.0     1.0    1.0     1.0    0.9     1.0    1.0     1.0    0.9     2.9=STD VAL
45 20     6.0     1.0    1.0     1.0    1.0     1.0    1.1     1.0    1.0     1.0    1.1     2.9=STD VAL
----------------------------------------------------------------------------------------
46 21     1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.6=STD VAL
47 21     3.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.6=STD VAL
48 21    12.0     1.0    0.9     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0     1.6=STD VAL
----------------------------------------------------------------------------------------
49 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
----------------------------------------------------------------------------------------
50 23     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
51 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
52 23    10.0     0.9    0.9     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0     1.0=STD VAL
----------------------------------------------------------------------------------------
53 24    12.0     0.7    0.1     1.0    1.5     1.0    1.0     1.0    1.0     1.0    1.0    50.0=STD VAL
54 24    25.0     0.8    0.4     1.0    1.2     1.0    1.0     1.0    1.0     1.0    1.0    50.0=STD VAL
55 24   100.0     1.2    1.8     1.0    0.8     1.0    1.0     1.0    1.0     1.0    1.0    50.0=STD VAL
----------------------------------------------------------------------------------------
56 25     2.0     1.0    1.0     0.5    0.5     1.0    1.0     1.0    1.0     1.0    1.0     4.0=STD VAL
57 25     8.0     1.0    1.0     2.0    2.2     1.0    1.0     1.0    1.0     1.0    1.0     4.0=STD VAL
58 25    20.0     1.1    1.2     5.0    5.8     1.0    1.0     1.0    1.0     1.0    1.0     4.0=STD VAL
----------------------------------------------------------------------------------------
59 26     1.3     1.0    0.7     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0     0.2=STD VAL
60 26     5.0     1.1    0.4     1.0    1.2     1.0    1.0     1.0    1.0     1.0    1.0     0.2=STD VAL
61 26    10.0     1.4    0.3     1.0    1.2     1.0    1.0     1.0    1.0     1.0    1.0     0.2=STD VAL
----------------------------------------------------------------------------------------
62 27     5.5     0.6    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0    11.1=STD VAL
63 27    22.0     1.6    0.7     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0    11.1=STD VAL
64 27    50.0     3.2    0.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0    11.1=STD VAL
----------------------------------------------------------------------------------------
65 28    12.0     1.0    1.1     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0    24.0=STD VAL
66 28    48.0     1.0    0.9     1.0    0.9     1.0    1.0     1.0    1.0     1.0    1.0    24.0=STD VAL
67 28    96.0     1.0    0.8     1.0    0.8     1.0    1.0     1.0    1.0     1.0    1.0    24.0=STD VAL
----------------------------------------------------------------------------------------
68 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
69 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
----------------------------------------------------------------------------------------
70  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
----------------------------------------------------------------------------------------
```

```
    IN    VAL         SSR            RSR            RSPD            RRR            RSF
                   MN     SD      MN     SD      MN     SD      MN     SD      MN     SD
 1 31    10.0     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    2.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.3       16.0=STD VAL
 3  5     8.0     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.8       16.0=STD VAL
 4  5    32.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.4       16.0=STD VAL
--------------------------------------------------------------------------------------------------------
 5  6     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1       16.0=STD VAL
 6  6     8.0     1,0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       16.0=STD VAL
 7  6    32.0     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       16.0=STD VAL
--------------------------------------------------------------------------------------------------------
 8  8     5.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       10.0=STD VAL
 9  8    20.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       10.0=STD VAL
10  8    50.0     1.0    1.0     1.0    0.6     1.0    1.0     1.0    1.0     1.0    0.9       10.0=STD VAL
--------------------------------------------------------------------------------------------------------
11  9     0.1     1.0    1.1     1.0    1.0     1.0    0.9     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    0.9     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    1.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        0.0=STD VAL
--------------------------------------------------------------------------------------------------------
17 11     0.1     1.0    1.0     1.0    1.0     1.0    1.0     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    1.0     1.0    1.0     1.0    1.0        0.6=STD VAL
19 11     1.2     1.0    1.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        0.6=STD VAL
--------------------------------------------------------------------------------------------------------
20 12     0.5     1.0   40.4     1.0    1.0     1.0    1.0     1.0    1.0     1.6   37.8        4.0=STD VAL
21 12     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        4.0=STD VAL
22 12     8.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        4.0=STD VAL
--------------------------------------------------------------------------------------------------------
23 13     1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9        8.0=STD VAL
24 13     4.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        8.0=STD VAL
25 13    16.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1        8.0=STD VAL
--------------------------------------------------------------------------------------------------------
26 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
27 14     0.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        1. =STD VAL
28 14     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1        1.0=STD VAL
--------------------------------------------------------------------------------------------------------
29 15     0.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        2.0=STD VAL
30 15     1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        2.0=STD VAL
31 15     4.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1        2.0=STD VAL
--------------------------------------------------------------------------------------------------------
32 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
33 16     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
--------------------------------------------------------------------------------------------------------
34 17     6.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    2.0       24.5=STD VAL
35 17    12.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.4       24.5=STD VAL
36 17    49.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.7       24.5=STD VAL
--------------------------------------------------------------------------------------------------------
37 18     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.5       20.0=STD VAL
38 18    10.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1       20.0=STD VAL
39 18    40.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       20.0=STD VAL
--------------------------------------------------------------------------------------------------------
40 19     0.1     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.6        2.8=STD VAL
41 19     1.4     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9        2.8=STD VAL
42 19     5.6     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.2        2.8=STD VAL
--------------------------------------------------------------------------------------------------------
43 20     0.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9        2.9=STD VAL
44 20     1.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        2.9=STD VAL
45 20     6.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1        2.9=STD VAL
--------------------------------------------------------------------------------------------------------
46 21     1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        1.6=STD VAL
47 21     3.2     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        1.6=STD VAL
48 21    12.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        1.6=STD VAL
--------------------------------------------------------------------------------------------------------
49 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
--------------------------------------------------------------------------------------------------------
50 23     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
51 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
52 23    10.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        1.0=STD VAL
--------------------------------------------------------------------------------------------------------
53 24    12.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    0.9       50.0=STD VAL
54 24    25.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       50.0=STD VAL
55 24   100.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       50.0=STD VAL
--------------------------------------------------------------------------------------------------------
56 25     2.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        4.0=STD VAL
57 25     8.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        4.0=STD VAL
58 25    20.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.1        4.0=STD VAL
--------------------------------------------------------------------------------------------------------
59 26     1.3     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        0.2=STD VAL
60 26     5.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        0.2=STD VAL
61 26    10.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0        0.2=STD VAL
--------------------------------------------------------------------------------------------------------
62 27     5.5     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       11.1=STD VAL
63 27    22.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       11.1=STD VAL
64 27    50.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       11.1=STD VAL
--------------------------------------------------------------------------------------------------------
65 28    12.0     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    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
67 28    96.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0     1.0    1.0       24.0=STD VAL
--------------------------------------------------------------------------------------------------------
68 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
69 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
--------------------------------------------------------------------------------------------------------
70  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
--------------------------------------------------------------------------------------------------------
```

APPENDIX 5

1. The following five tables show how the coefficients of variation of demand are related to the mean demand. These tables are direct copies of the computer print.

   The first row shows the distribution of the sample according to coefficient of variation, the second row according to mean monthly demand, and the third row according to standard deviation of demand. The final row shows the distribution according to length of history.

2. The graphs in Figures 81 - 85 show how the coefficients of variation of demand are dispersed about the class mean.

CLASS NO:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Largest Coefficient of Variation :- 26.15																				
Upper Class Boundaries	.127	.163	.208	.265	.338	.431	.550	.701	.894	1.14	1.46	1.86	2.37	3.02	3.85	4.92	6.27	8.00	10.2	OVER
Distribution	8					1	1	9	76	276	463	547	485	447	290	131	85	76	21	10
Largest Average Demand :- 5.0																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	936	829	757	404																
Largest Standard Deviation of Demand:- 50.75																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	1677	410	772	812	514	222	69	22	2											
Longest History:- 93																				
Upper Class Boundaries	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
Distribution	1615	30	69	62	35	77	98	128	62	137	73	81	67	72	49	1845	0	0	0	0

LAST
PART NUMBER: C20120/31

DEMAND PATTERN ANALYSIS

DISTRIBUTION OF PARAMETERS THROUGH TOTAL RANGE

COMPONENTS WITH AVERAGE SALES BETWEEN 1 AND 5 PER MONTH ONLY

1,574 LINES WITH ZERO SALES
12,321 COMPONENTS INSPECTED

CLASS NO:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Largest Coefficient of Variation:- 9.64																				
Upper Class Boundaries	.127	.163	.208	.265	.338	.431	.550	.701	.894	1.14	1.46	1.86	2.37	3.02	3.85	4.92	6.27	8.00	10.2	OVER
Distribution	1	0	0	0	0	0	10	114	294	363	340	264	168	98	41	28	14	8	2	0
Largest Average Demand :- 24.97																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution				254	557	448	398	88												
Largest Standard Deviation of Demand:-174.73																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	1256		4	119	357	505	478	179	80	19	2	1								
Longest History:- 93																				
Upper Class Boundaries	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
Distribution	1267	4	28	20	7	11	38	38	21	46	18	29	27	51	44	1351				

DEMAND PATTERN ANALYSIS

DISTRIBUTION OF PARAMETERS THROUGH TOTAL RANGE

COMPONENTS WITH AVERAGE SALES BETWEEN 5 AND 25 PER MONTH ONLY

1,255 LINES WITH ZERO SALES
12,385 COMPONENTS INSPECTED

LAST
PART NUMBER: C11360/107

CLASS NO:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Largest Coefficient of Variation :- 6.59																				
Upper Class Boundaries	.127	.163	.208	.265	.338	.431	.550	.701	.894	1.14	1.46	1.86	2.37	3.02	3.85	4.92	6.27	8.00	10.2	OVER
Distribution	1211					9	83	203	206	135	59	45	17	22	5	3	1	1	0	0
Largest Average Demand :- 124.94																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution								228	243	196	122									
Largest Standard Deviation of Demand :- 530.68																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	1211					6	90	229	228	161	48	15	10	1	1					
Longest History :- 93																				
Upper Class Boundaries	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
Distribution	1212		7	14	1	0	10	12	8	7	9	6	11	15	23	665				

DEMAND PATTERN ANALYSIS

DISTRIBUTION OF PARAMETERS THROUGH TOTAL RANGE

COMPONENTS WITH AVERAGE SALES BETWEEN 25 AND 125 PER MONTH ONLY

1,211 LINES WITH ZERO SALES
11,828 COMPONENTS INSPECTED

LAST
PART NUMBER: C11293/2

CLASS NO:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Largest Coefficient of Variation:- 1.84																				
Upper Class Boundaries	.127	.163	.208	.265	.338	.431	.550	.701	.894	1.14	1.46	1.86	2.37	3.02	3.85	4.92	6.27	8.00	10.2	OVER
Distribution					1	14	8	9	8	5	2	4								
Largest Average Demand :- 3920																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution															20	15	11	4	1	
Largest Standard Deviation of Demand:- 3920																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution													7	16	10	8	3	6	1	
Longest History:- 93																				
Upper Class Boundaries	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
Distribution	1449					2		1	6	1					4	37				

LAST

PART NUMBER: C16003/170

DEMAND PATTERN ANALYSIS

DISTRIBUTION OF PARAMETERS THROUGH TOTAL RANGE

COMPONENTS WITH AVERAGE SALES BETWEEN 625 AND 5000 PER MONTH ONLY

1,449 LINES WITH ZERO SALES
13,874 COMPONENTS INSPECTED

CLASS NO:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Largest Coefficient of Variation :- 3.96																				
Upper Class Boundaries	.127	.163	.208	.265	.338	.431	.550	.701	.894	1.14	1.46	1.86	2.37	3.02	3.85	4.92	6.27	8.00	10.2	OVER
Distribution	1247					22	60	71	37	26	19	9	4	3	1	1				
Largest Average Demand :- 621.11																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	1247										17	117	61	48	10					
Largest Standard Deviation of Demand :-1327.02																				
Upper Class Boundaries	1.56	2.43	3.80	5.93	9.24	14.4	22.5	35.1	54.8	85.5	133	208	325	506	790	1232	1923	3000	4681	OVER
Distribution	1247								1	44	65	71	42	21	8		1			
Longest History :- 93																				
Upper Class Boundaries	6	12	18	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
Distribution	1247	1	0	1	1	0	2	9	3	3	0	2	0	1	11	219				

LAST

PART NUMBER: C11359/258

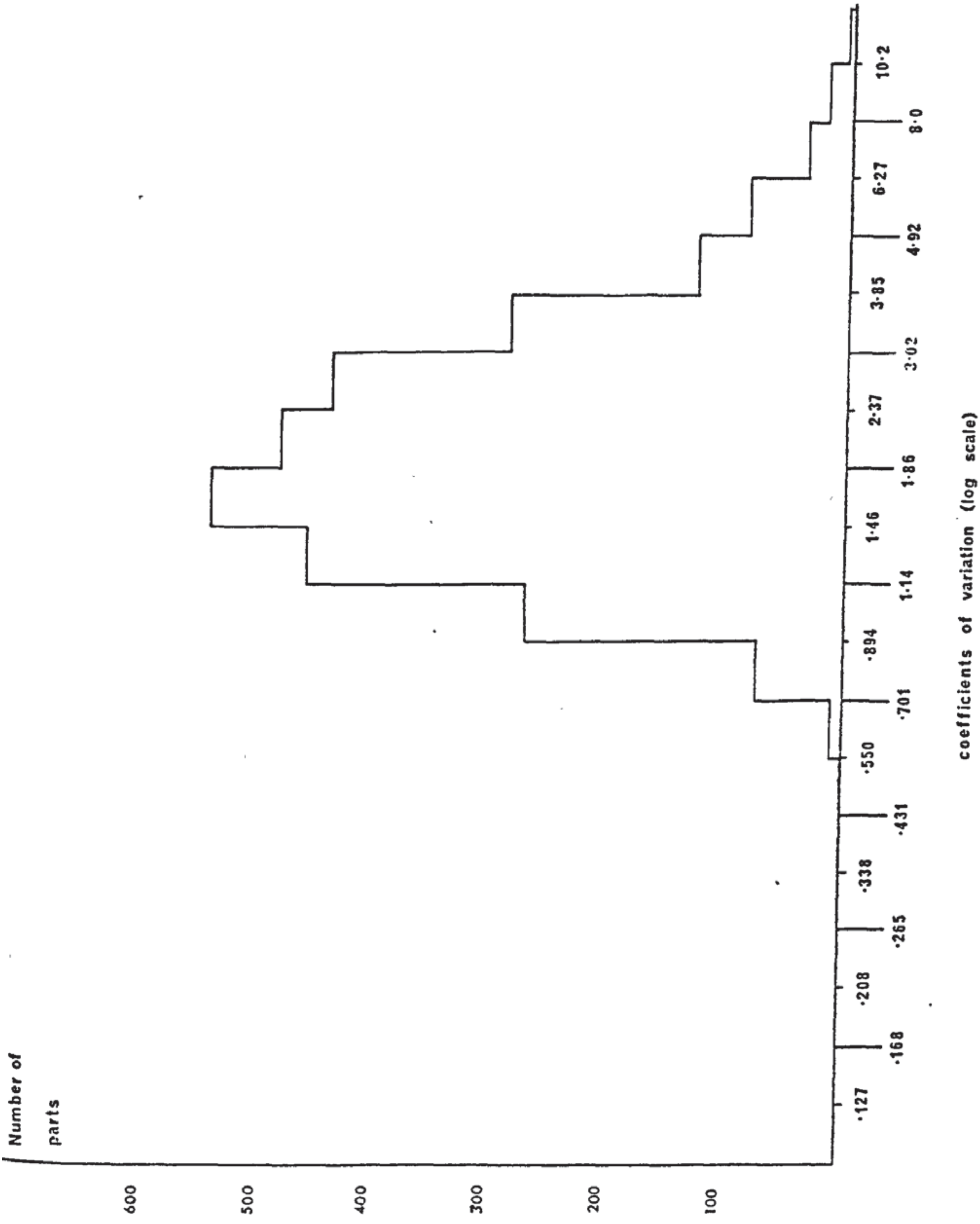
DEMAND PATTERN ANALYSIS

DISTRIBUTION OF PARAMETERS THROUGH TOTAL RANGE

COMPONENTS WITH AVERAGE SALES BETWEEN 125 AND 625 PER MONTH ONLY

1,247	LINES WITH ZERO SALES
12,290	COMPONENTS INSPECTED

APPENDIX 5

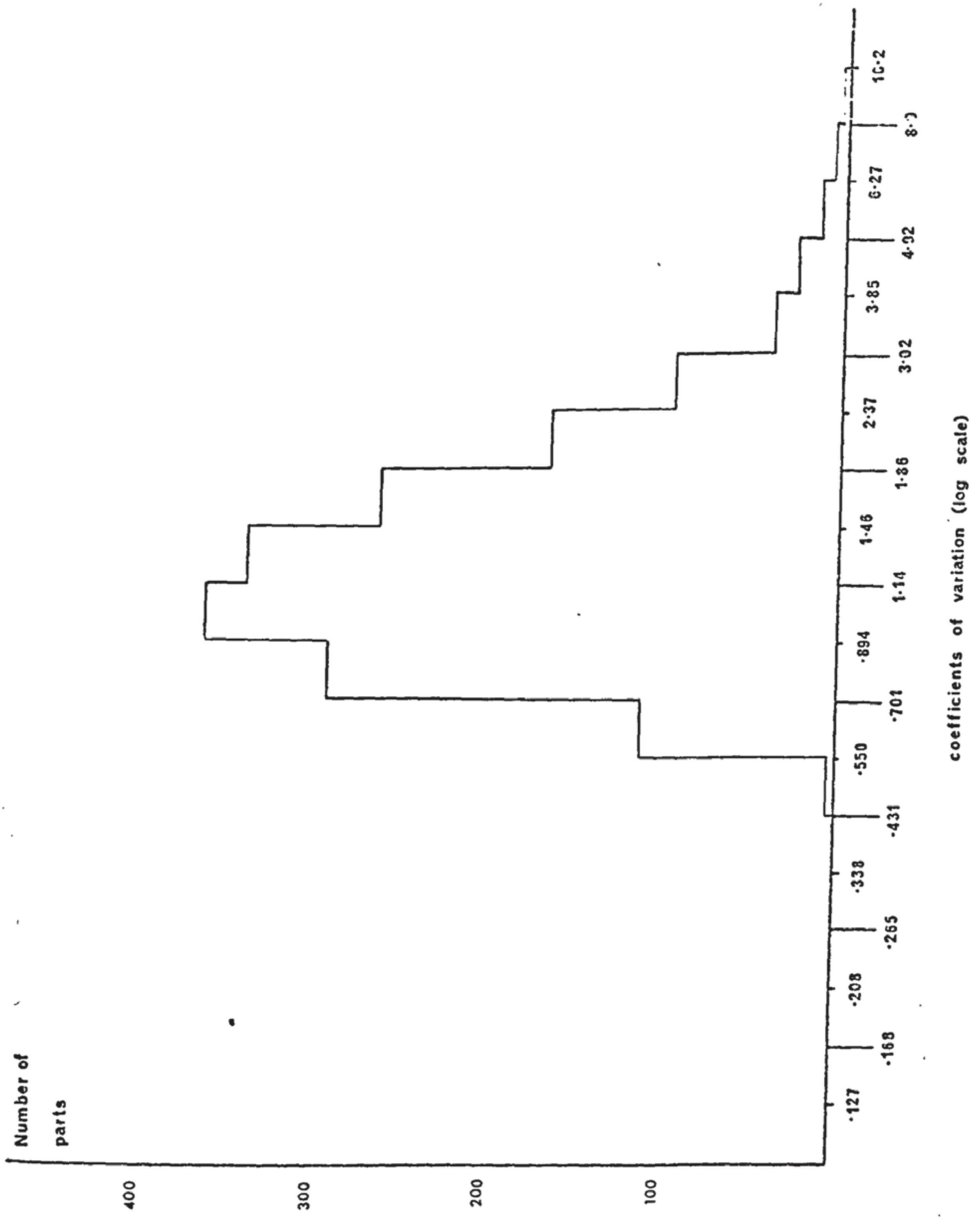


RANGE OF COEFFICIENTS OF VARIATION

(For parts with average monthly demand between 1 and 5)

Fig. 81

APPENDIX 5

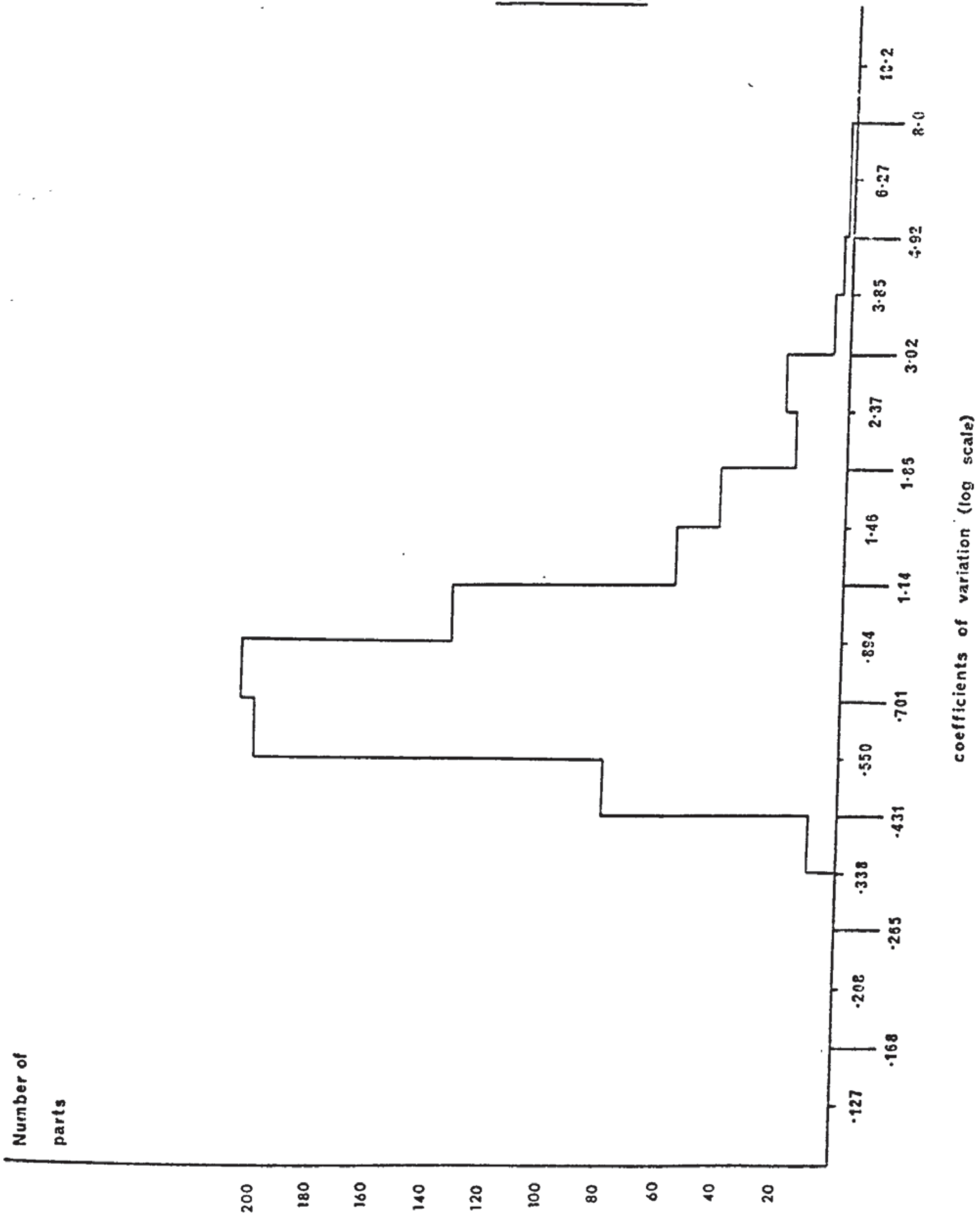


RANGE OF COEFFICIENTS OF VARIATION

(For parts with average monthly demand between 5 and 25)

Fig 82

APPENDIX 5

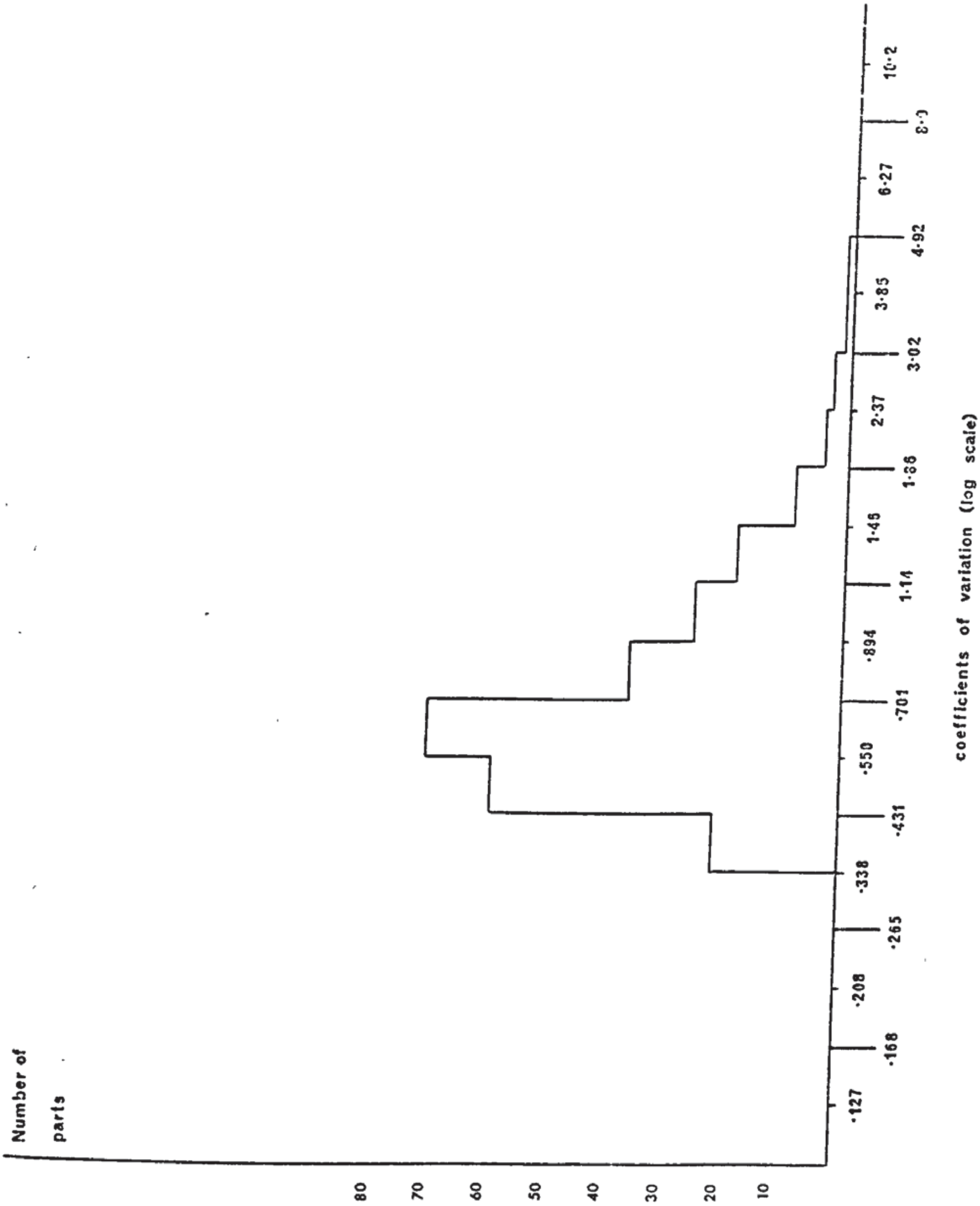


RANGE OF COEFFICIENTS OF VARIATION

(For parts with average monthly demand between 25 and 125)

Fig. 83

APPENDIX 5

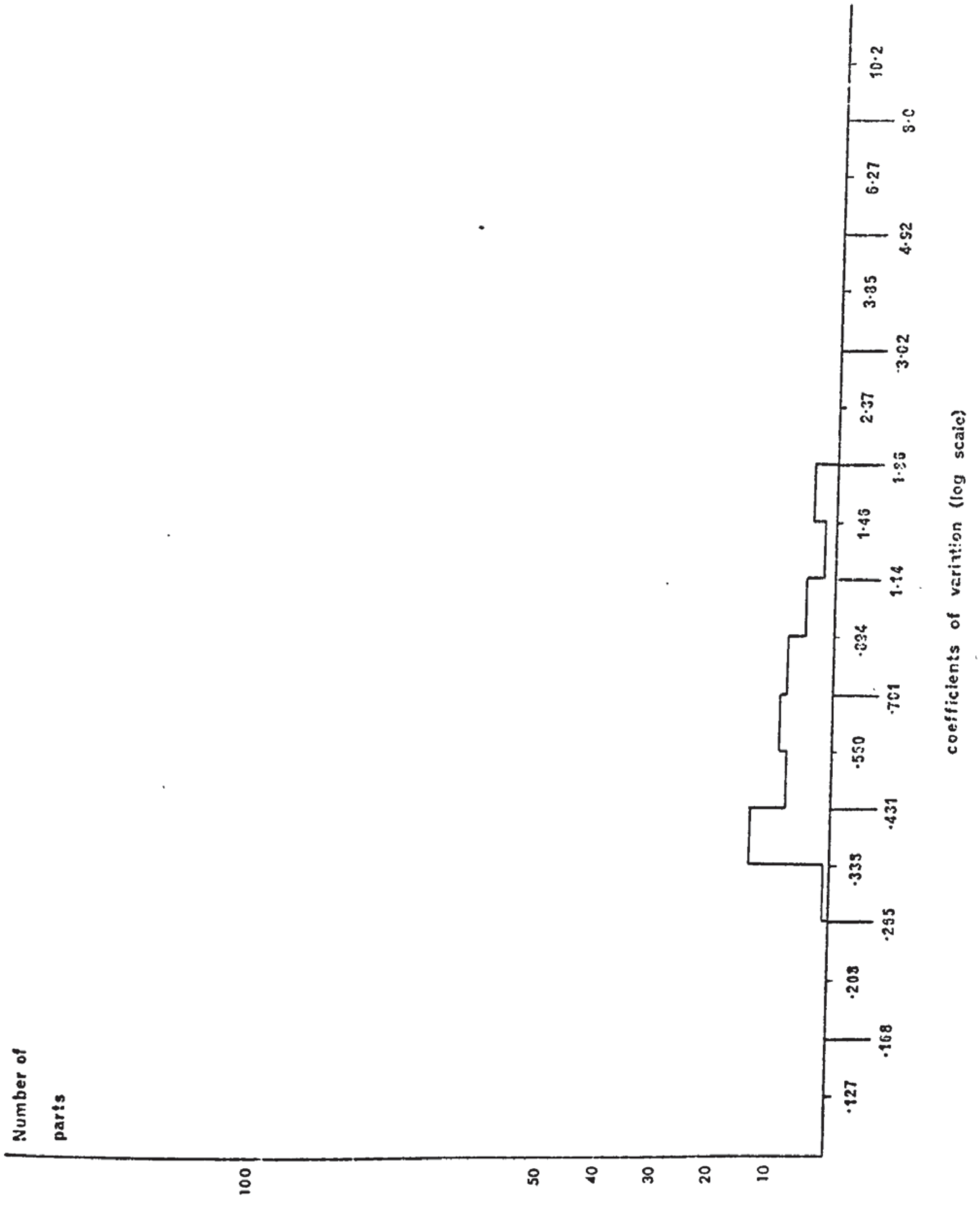


RANGE OF COEFFICIENTS OF VARIATION

(For parts with average monthly demand between 125 and 625)

Fig. 84

APPENDIX 5



RANGE OF COEFFICIENTS OF VARIATION

(For parts with average monthly demand between 625 and 5000)

Fig. 85

APPENDIX 6

The following table shows the mean demand, the standard deviation and the coefficient of variation for the respective years for a small sample of components. Although such a small sample cannot be regarded as evidence, there is little in the pattern of variation of the coefficient of variation to suggest any underlying cycle.

PART NO.		1970	1971	1972	1973	1974	1975
C3472/2	$\bar{D}$	649	496	512	603	660	584
	σD	274.3	245.2	222.5	235.6	234.17	359
	C_v	.42	.49	.44	.39	.35	.61
C10500/26	$\bar{D}$	689.25	683	970	1012	1209	1041
	σD	247.2	302.34	329	203	248	508
	C_v	.36	.44	.34	.20	.20	.49
C10002/16	$\bar{D}$	1081	1595	1776	2106	2172	1597
	σD	332	430	741	.653	707	545
	C_v	.307	.27	.41	.31	.33	.34
CD651/28	$\bar{D}$	314	308	350	445	550	428
	σD	77	77	132	120	131	180
	C_v	.24	.25	.38	.27	.238	.42
CB211/40E	$\bar{D}$	2603.8	2818	3178	4042	3738	2823
	σD	557.6	1249	1202	1217	1392	759
	C_v	.21	.44	.38	.30	.37	.27
C11158/266	$\bar{D}$	649	809	681	799	933	683
	σD	288	294	391	244	389	484
	C_v	.44	.36	.57	.31	.42	.71
C10737/5	$\bar{D}$	811	974	1063	1174	1326	1024
	σD	170	457	332	318	427	592
	C_v	.21	.47	.31	.27	.32	.58
C11304/159	$\bar{D}$	378	270	225	280	540	441
	σD	311	152.17	85	120	364	168
	C_v	.82	.56	.38	.43	.67	.38
CB1587/120	$\bar{D}$	1182	1256	1152	1219	1161	996
	σD	341.8	388	356	333	344	386
	C_v	.29	.31	.31	.27	.30	.39
CB1587/24	$\bar{D}$	1153	849	933	1051	860	781
	σD	750	353	312	398	440	448
	C_v	.65	.42	.33	.38	.51	.57

November, 1978

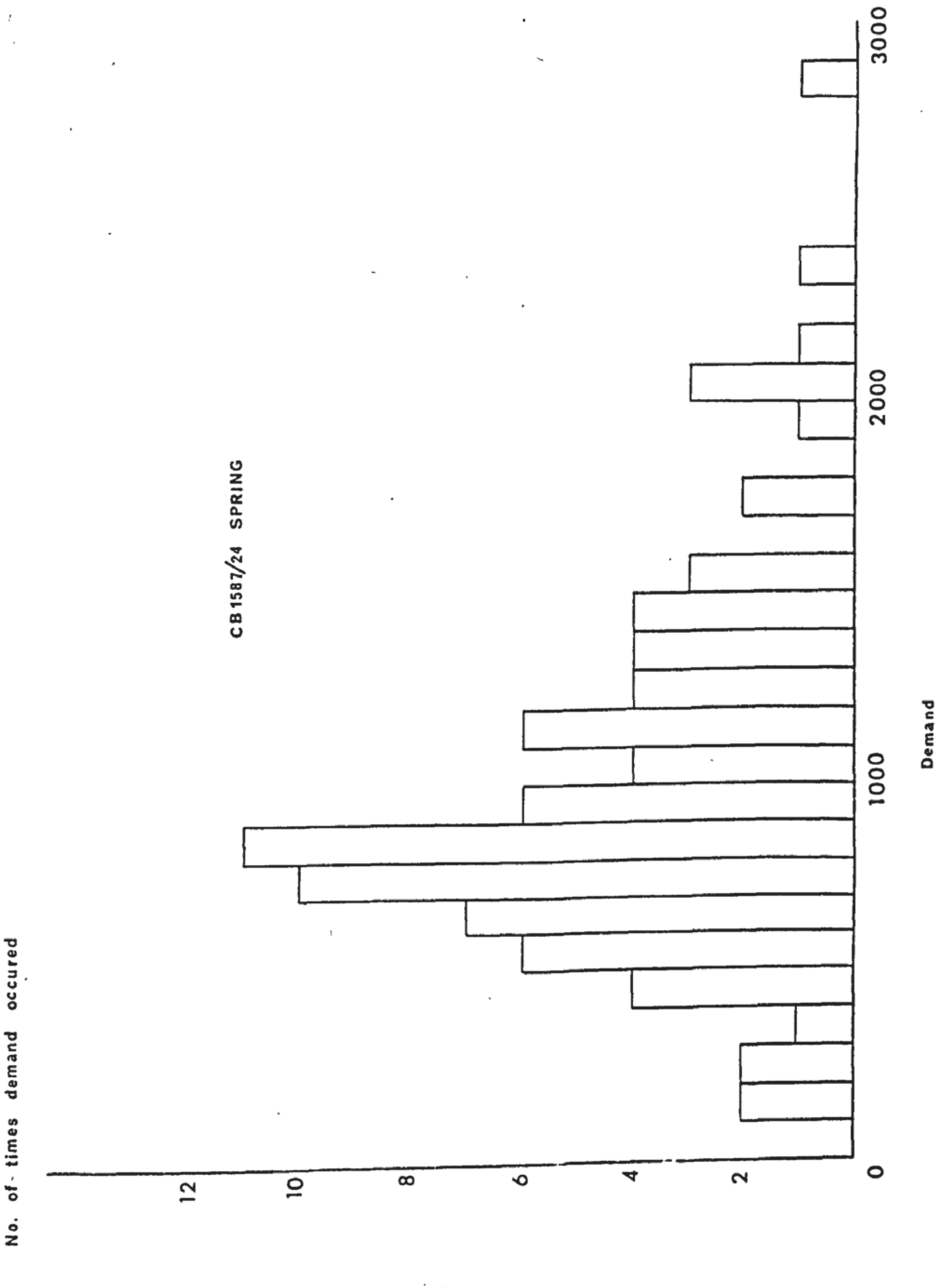
Table of Mean Demand & Coefficient of Variation

Fig. 86

APPENDIX 7

DEMAND PATTERNS

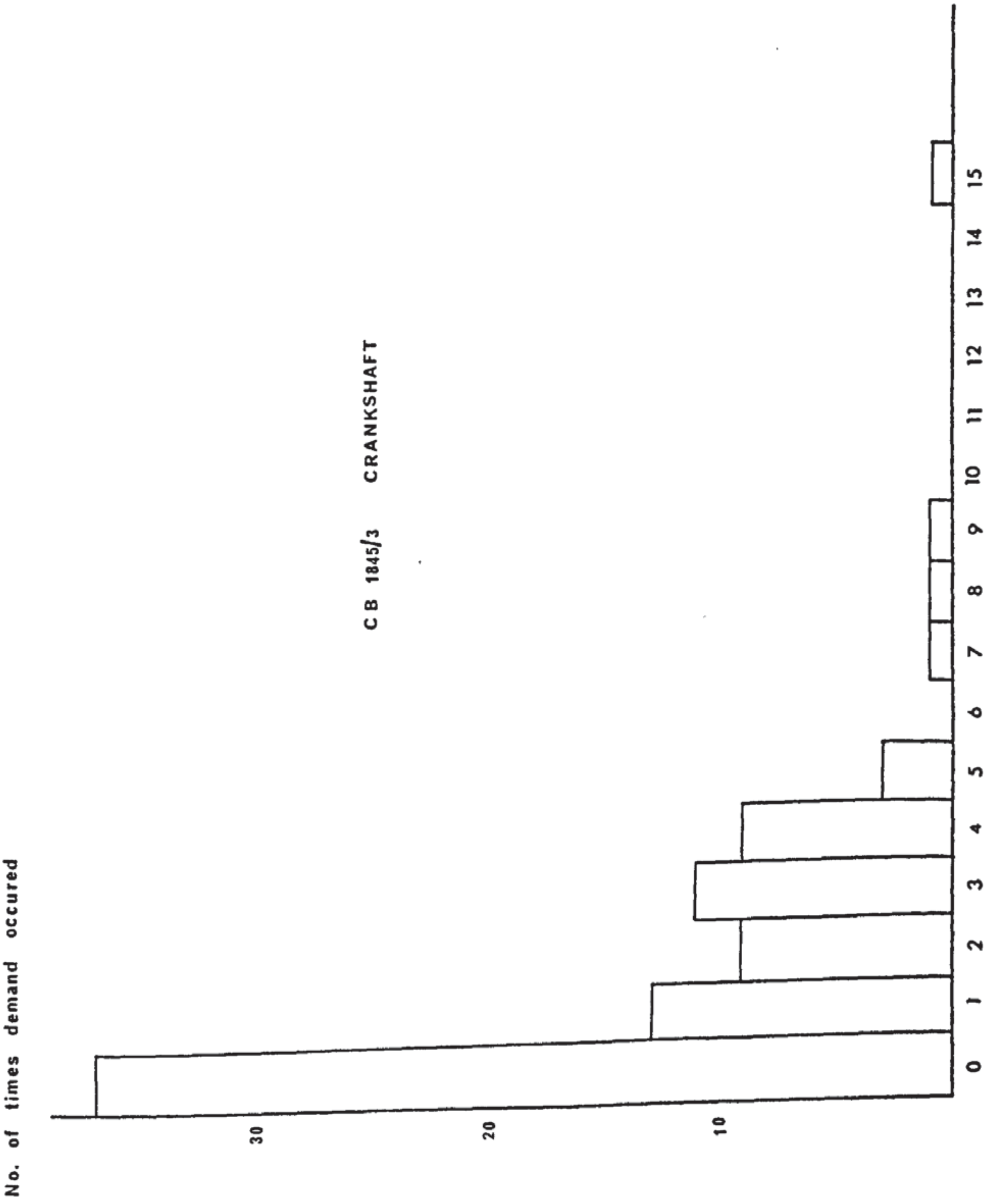
The following curves show typical examples of the demand patterns found in the CompAir spare parts range. Page 277 shows a calculation for the goodness of fit for the demand of one part number - CB1845/3.



DEMAND PATTERN

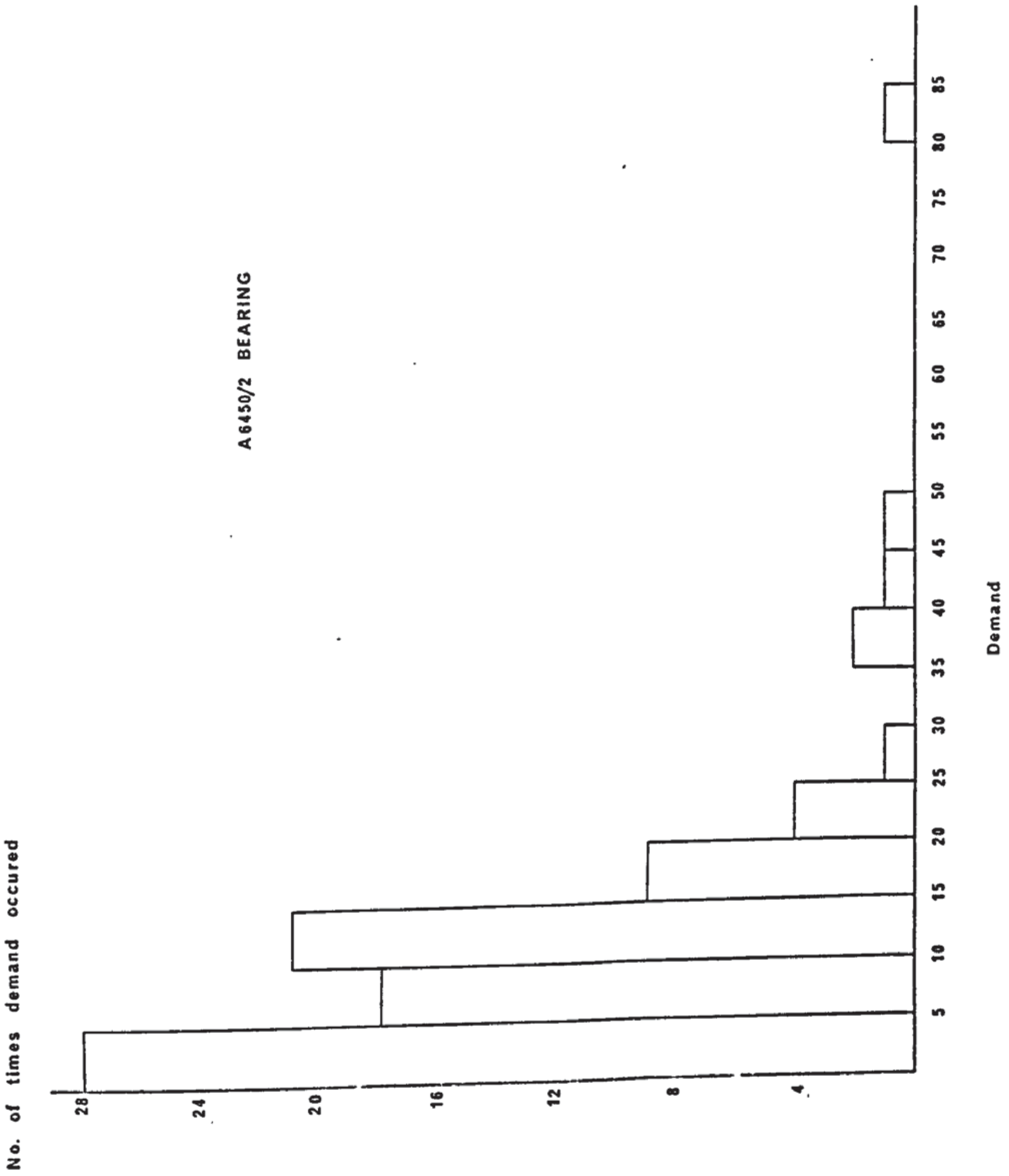
CB 1587/24

Fig. 87



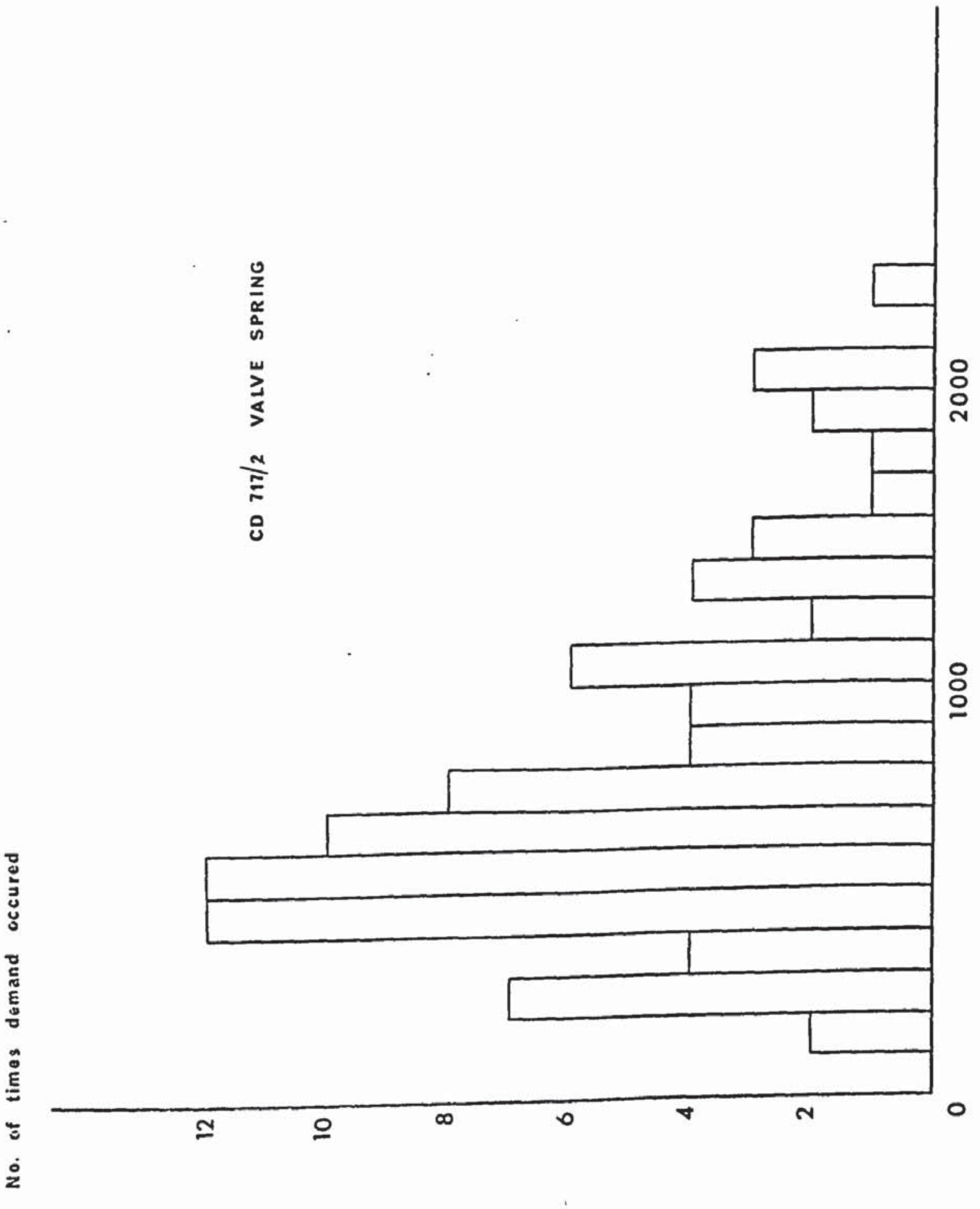
DEMAND PATTERN
CB 1845/3

Fig. 88



DEMAND PATTERN
A 6420/2

Fig. 89



DEMAND PATTERN

CD 717/2

Fig. 90

GOODNESS OF FIT TESTS

PART NUMBER CB1845/3.

			NEGATIVE EXPONENTIAL				NORMAL DISTRIBUTION			
Demand Items/Month	Actual Frequency	Actual Cumulative Frequency	Expected Frequency	Expected Cumulative Frequency	(Actual - Expected) Cumulative Frequency	2	Expected Frequency	Cumulative Frequency	(Actual-Expected) Cumulative Frequency	2
0	37	37	36.8	36.8	0.2	0.001	32.116	32.116	4.884	0.744
1	13	50	21.05	57.85	7.85	3.079	13.8	45.92	4.08	0.047
2	9	59	12.05	69.90	10.90	0.772	13.35	59.27	0.27	1.417
3	11	70	6.89	76.79	6.79	2.45	10.93	70.2	0.2	0
4	9	79	3.94	80.73	1.73	0.53	7.62	77.82	1.18	0.25
5	3	82	2.25	82.98	0.98		4.49	82.31	0.31	0.17
6	0	82	1.29	84.27	2.27		2.29	84.60	2.6	
7	1	83	0.74	85.01	2.01		0.92	85.52	2.52	
8	1	84	0.43	85.44	1.44		0.34	85.86	1.86	
9	1	85	0.24	85.68	0.68		0.11	85.97	0.97	
10	0	85	0.14	85.82			0.02	85.99	0.99	
11	0	85	0.07	85.89						
12	0	85	0.05	85.94						
13	0	85	0.03	85.97						
14	0	85								
15	1	86								
Actual Mean = 1.7907 Standard Deviation = 2.45005			$\sum \chi^2 = 6$				$\sum \chi^2 = 2.63$			

Therefore, if all expected sub zero demands of the normal distribution are included with the zero demands, this distribution provides a better fit to the actual pattern observed, using both the Kalmagorov-Smirnoff and the chi-squared test.

APPENDIX 8

PARAMETERS OF THE DUMMY PARTS RANGE

The dummy parts range was constructed as an array or matrix with four dimensions, viz :-

Mean lead time	3
Coefficient of variation of lead time	3
Mean demand	3
Unit cost	4

In the original basic model version, there were three values of lead time, three values of lead time coefficient of variation, three values of mean demand and four values of unit cost.

The lead time values were set at three, five and seven months, with coefficients of variation of 0.1, 0.15 and 0.4, these values being typical of those found in practice.

Since the cost and demand profile depended upon the values selected for mean demand and unit cost, a great deal of care was necessary to ensure that these values combined in the required manner. Their combination is best represented in the form of a matrix of their monthly usage values.

	Unit Cost			
Mean Demand	£0.05	£0.20	£0.80	£2.00
1.0	0.05	0.20	0.80	2.00
150.0	7.50	30.00	120.00	300.00
50.0	2.50	10.00	40.00	100.00

As it stands, this range of values does not adequately represent the CompAir range since it places an excessive proportion of the range (by value and by volume) in value category 2 (£35-£150). However, by eliminating the £40 and £100 combinations, the analysis by volume and by value becomes that shown in Fig.41.

The total monthly usage value of the ten eligible parts in this table is 473.05, and in the total dummy range, there are nine such sets of parts (three different lead times and three different lead time coefficients of variation), giving a range of 90 parts with a monthly usage value of £4,257.45. The mean demand of Value Category 1 in this distribution is 150 units per month, corresponding with the figure of 140 found in practice.

For the composite model, the main difference occurred in the lead time coefficient of variation. The number of values was reduced to two, and duplicated, so that in effect, there were two ranges of sixty parts, of identical form, but whose demand varied antithetically, so that the total monthly usage value was a constant under steady state conditions. The only other difference with the composite model was the derivation of the lead time values, which were calculated from the sum of the relevant mean delays in the Industrial Dynamics section representing the supply sources, giving values of 3.8, 5.5 and 7.2 months.

APPENDIX 9

The following six pages show the source code for the detailed inventory control model of the existing system. It is written in ICL extended Fortran and occupied less than 12K words of store. This figure is heavily dependent upon the size of the dummy parts range.

```
#LISTING OF :EPS8055.DM2B(58/)  PRODUCED ON 13SEP78 AT 14.52.54
#OUTPUT BY LISTFILE IN ':EPS8055.MOPDM2B' ON  3NOV78 AT 15.46.11
DOCUMENT     DM2B
      SUBROUTINE CLASSIFY(VC1,VC2,VC3,VC4,VCAT,NV,J,OR,SM,AVDEM)
      DIMENSION NV(J)
      IF(VCAT.LE.VC1)GOTO 210
      NV(1)=NV(1)+1
      OR=2.0
      SM=2.0*AVDEM
      GOTO 299
  210 IF(VCAT.LE.VC2)GOTO 220
      NV(2)=NV(2)+1
      OR=3.0
      SM=AVDEM*2.0
      GOTO 299
  220 IF(VCAT.LE.VC3)GOTO 230
      NV(3)=NV(3)+1
      OR=6.0
      SM=AVDEM*2.0
      GOTO 299
  230 IF(VCAT.LE.VC4)GOTO 240
      NV(4)=NV(4)+1
      OR=8.0
      SM=AVDEM*2.5
      GOTO 299
  240 OR=10.0
      NV(5)=NV(5)+1
      SM=AVDEM*3.0
  299 RETURN
      END


      SUBROUTINE DEM(REQ,IT,DUR,IST,HTT,RE)
      IF(IT.GT.IST)REQ=REQ+HTT*(SIN(FLOAT(IT-IST)*6.28319/DUR))*REQ
      RE=REQ
      RETURN
      END


      SUBROUTINE RAND(AV,SDV,VAL,PROB)
      PROB=((PROB+3.1416)**5)
      PROB=PROB-IFIX(PROB)
      IP=IFIX(PROB*10.0)
      IF(IP.EQ.0)VAL=-1.6449
      IF(IP.EQ.1)VAL=-1.0364
      IF(IP.EQ.2)VAL=-0.6745
      IF(IP.EQ.3)VAL=-0.3853
      IF(IP.EQ.4)VAL=-0.1257
      IF(IP.EQ.5)VAL=0.1257
      IF(IP.EQ.6)VAL=0.3853
      IF(IP.EQ.7)VAL=0.6745
      IF(IP.EQ.8)VAL=1.0364
      IF(IP.EQ.9)VAL=1.6449
      VAL=VAL*SDV+1.0
      VAL=VAL*AV
      IF(VAL.LT.0.0)VAL=0.0
      RETURN
      END
```

```
      SUBROUTINE POISSON(AV,VAL,PROB)
      PROB=((PROB+3.1416)**5)
      PROB=PROB-IFIX(PROB)
  510 DIV=0.0
      VAL=0.0
      SUM=0.0
      POIS=1.0
      Z=EXP(-AV)
  530 SUM=SUM+POIS
      VAL=SUM*Z
      IF(VAL.GT.PROB)GOTO 540
      DIV=DIV+1.0
      POIS=POIS*AV/DIV
      GOTO 530
  540 VAL=DIV
      RETURN
      END
```

```
      MASTER DM2M
      INTEGER TIM,DD(90,15),ST,ANDEM
      REAL LEAD, LD(90),LA(3),LDAV(90)
      DIMENSION DA(3),SD(3),SL(3),DE(90),DEAV(90),DESD(90),PRD(90),P
     &RL(90),TSO(90),UC(4),SK(90),OU(90,15),NVC(5),WIP(90)
     &,WIPV(90),MONDEM(90,12),SKV(90),VRD(3),PARAM(15)
      EQUIVALENCE (WIP,WIPV),(SK,SKV)
     &,(PARAM(1),SAF),(PARAM(2),A),(PARAM(3),B),(PARAM(4),C)
     &,(PARAM(5),D),(PARAM(6),E),(PARAM(7),F),(PARAM(8),G)
     &,(PARAM(9),VC1),(PARAM(10),VC2),(PARAM(11),VC3),(PARAM(12),VC4)
     &,(PARAM(13),PRDO),(PARAM(14),PRLO),(PARAM(15),XO)

      READ DATA AVELEAD,AVE DEMAND,SD LEAD,SD DEMAND,UNIT COSTS
      READ(1,310)(LA(K),K=1,3)
      READ(1,310)(DA(K),K=1,3)
      READ(1,310)(SL(K),K=1,3)
      READ(1,310)(SD(K),K=1,3)
      READ(1,320)(UC(K),K=1,4)
      READ(1,330)PER,ST,HT
      READ(1,340)SAF,A,B,C,D,E,F,G,H
      READ(1,345)LENGTH
      READ(1,346)VC1,VC2,VC3,VC4
      READ(1,347)IW
      READ(1,310)PRDO,PRLO,X
      WRITE(2,9000)
      WRITE(2,300)
      WRITE(2,301)(LA(K),K=1,3)
      WRITE(2,302)(DA(K),K=1,3)
      WRITE(2,303)(SL(K),K=1,3)
      WRITE(2,305)(UC(K),K=1,4)
    3 READ(5,440,END=1,ERR=1)NPARAM,PARAMV
      IF(NPARAM.LT.0)GOTO 2000
      IF(NPARAM.GT.20)GOTO 1
      PARAM(NPARAM)=PARAMV
      IF(NPARAM.EQ.1)D=SAF
      GOTO 3
    1 WRITE(2,306)PER,ST,HT
      WRITE(2,307)A,B,C,D,E,F,G,H
```

```
      WRITE(2,308)LENGTH
      WRITE(2,309)VC1,VC2,VC3,VC4

      HTL=HT*3.0
      TIM=0
C SET INITIAL CONDITIONS
      LNQ=0
      PRD(1)=PRD0
      PRL(1)=PRL0
      CUMDEM=0.0
      TOTDEM=0.0
      DO 110 NN=2,90
CDEMAND PROBABILITY FACTORS
C LEAD PROB FACTORS
      PRD(NN)=(PRD(NN-1)+3.1416)**5
      PRL(NN)=(PRL(NN-1)+3.1416)**5
      PRD(NN)=PRD(NN)-IFIX(PRD(NN))
  110 PRL(NN)=PRL(NN)-IFIX(PRL(NN))
      DO 121 KAT=1,5
  121 NVC(KAT)=0
      WV=0.0
      SLV=0.0
      NN=0
      DEV=0.0
      DO 130 L=1,4
CUNIT COST(L)
CSD DEMAND(M)
      DO 130 N=1,3
C AVE DEMAND(N)
      VRD(N)=2.47/(DA(N)**(0.197))
      DO 130 K=1,3
C AVE LEAD(K)
      DO 130 J=1,3
C SD LEAD(J)
      IF(N.GE.3.AND.L.GE.3)GOTO 130
      NN=NN+1
      DEAV(NN)=DA(N)
      LDAV(NN)=LA(K)
      DO 122 MON=1,12
  122 MONDEM(NN,MON)=NINT(DA(N))
      TSO(NN)=0.0
      VCAT=DA(N)*UC(L)
      CALL CLASSIFY(VC1,VC2,VC3,VC4,VCAT,NVC,5,QR,SM,DEAV(NN))
      X=((X+3.1416)**5)
      X=X-IFIX(X)
      NQ=NINT(LA(K)/QR+(1-X))
      IF(NQ.GT.LNQ)LNQ=NQ
      DO 123 I=1,15
      QU(NN,I)=0.0
  123 DD(NN,I)=-1
      SK(NN)=SM+X*QR*DA(N)
      DD(NN,1)=IFIX(X*QR)
      QU(NN,1)=QR*DEAV(NN)
      IF(DD(NN,1).GT.0)GOTO 124
      SK(NN)=SK(NN)+QU(NN,1)
      QU(NN,1)=0.0
  124 WIP(NN)=QU(NN,1)
      IF(NQ.LT.2)GOTO 126
      DO 125 I=2,NQ
      DD(NN,I)=DD(NN,1)+IFIX((I-1)*(QR))
      QU(NN,I)=QR*DA(N)
  125 WIP(NN)=WIP(NN)+QU(NN,I)
  126 SLV=SLV+SK(NN)*UC(L)
```

```
      DEV=DEV+VCAT
      WV=WV+WIP(NN)*UC(L)
  130 CONTINUE
      SSLV=0.0
      SWV=0.0
      SDEV=0.0
      NSSO=0
      TSLV=0.0
      TWV=0.0
      TDEV=0.0
      NTSO=0
      SKTN=SLV/DEV
      WRITE(2,360)
      WRITE(2,361)
      WRITE(2,365)SLV,WV,TIM,(NVC(JA),JA=1,5)
      TSH=0.0
      KNT=LNG
      DO 1000 TIM=1,LENGTH
      DO 135 KAT=1,5
  135 NVC(KAT)=0
      WV=0.0
      SLV=0.0
      DEV=0.0
      NSO=0
      NV=0
      I=0
      KNT=KNT+1
      IF(KNT.EQ.16)KNT=1
      DO 10 L=1,4
      DO 10 N=1,3
      DO 10 K=1,3
      DO 10 J=1,3
      IF(N.GE.3.AND.L.GE.3)GOTO 10
      I=I+1
      IF(DA(N).GT.5.0)GOTO 7
      CALL POISSON(DA(N),DE(I),PRD(I))
      GOTO 8

    7 CALL RAND(DA(N),VRD(N),DE(I),PRD(I))
    8 IF(TIM.GE.ST)CALL DEM(DE(I),TIM,PER,ST,HT,DE(I))
      ANDEM=0
      DO 15 MON=1,11
      MONDEM(I,13-MON)=MONDEM(I,12-MON)
   15 ANDEM=ANDEM+MONDEM(I,13-MON)
      MONDEM(I,1)=NINT(DE(I))
      ANDEM=ANDEM+MONDEM(I,1)
      DEAV(I)=FLOAT(ANDEM)/12.0
      SK(I)=SK(I)-DE(I)
      VCAT=DEAV(I)*UC(L)
      CALL CLASSIFY(VC1,VC2,VC3,VC4,VCAT,NVC,5,QA,SM,DEAV(I))
      IF(FLOAT(TIM)/6.0-IFIX(FLOAT(TIM)/6.0).NE.0.0)GOTO 40
      QR=G*QA
      IF(QR.LT.1.0)QR=1.0
      LD(I)=LDAV(I)
   40 ROL=LD(I)*DEAV(I)+D*SM-WIP(I)
      IF(SK(I).GT.ROL)GOTO 20
      QU(I,KNT)=QU(I,KNT)+QR*DEAV(I)
      WIP(I)=WIP(I)+DEAV(I)*QR
      IF(DD(I,KNT).LT.LENGTH)GOTO 19
      CALL RAND(LA(K),SL(J),LEAD,PRL(I))
      IF(TIM.GE.ST)CALL DEM(LEAD,TIM,PER,ST,HTL,LEAD)
      IF(LEAD.LT.1.0)LEAD=1.0
      DD(I,KNT)=TIM+IFIX(LEAD)
```

```
      LDAV(I)=LDAV(I)-C*(LDAV(I)-LEAD)
   19 GOTO 40
   20 CONTINUE
      DO 30 LI=1,15
      IF(DD(I,LI).GT.TIM)GOTO 30
      DD(I,LI)=500
      SK(I)=SK(I)+OU(I,LI)
      WIP(I)=WIP(I)-OU(I,LI)
      OU(I,LI)=0.0
   30 CONTINUE
      IF(SK(I).LE.0.0)NSO=NSO+1
      IF(SK(I).GT.0.0)SLV=SLV+SK(I)*UC(L)
      DEV=DEV+DE(I)*UC(L)
      IF(SK(I).LT.0.0)TSO(I)=TSO(I)-SK(I)
      WV=WV+WIP(I)*UC(L)
      IF(TIM.LE.50)GOTO 10
      TOTDEM=TOTDEM+DE(I)
      TSH=TSH+TSO(I)
   10 CONTINUE
      SKTN=SLV/DEV
      IF(IW.LE.0)GOTO 80
      WRITE(2,350)NSO,DEV,SLV,WV,SKTN,TIM,(NVC(LI),LI=1,5)
   80 CONTINUE
      IF(TIM.LE.50)GOTO 1000
      SSLV=SSLV+SLV*SLV
      SWV=SWV+WV*WV
      SDEV=SDEV+DEV*DEV
      NSSO=NSSO+NSO*NSO

      TSLV=TSLV+SLV
      TDEV=TDEV+DEV
      TWV=TWV+WV
      NTSO=NTSO+NSO
      CUMDEM=CUMDEM+TOTDEM
 1000 CONTINUE
      MONSTAB=LENGTH-50
      SLV=TSLV/MONSTAB
      WV=TWV/MONSTAB
      ANSO=FLOAT(NTSO)/FLOAT(MONSTAB)
      DEV=TDEV/MONSTAB
      SKTN=SLV/DEV
      WRITE(2,357)MONSTAB
      WRITE(2,356)ANSO,DEV,SLV,WV,SKTN

      ANSO=SQRT(ABS(FLOAT(NSSO)/FLOAT(MONSTAB)-ANSO**2))
      DEV=SQRT(ABS(SDEV/MONSTAB-DEV*DEV))
      SLV=SQRT(ABS(SSLV/MONSTAB-SLV*SLV))
      WV=SQRT(ABS(SWV/MONSTAB-WV*WV))
      WRITE(2,356)ANSO,DEV,SLV,WV,SKTN
      WRITE(2,370)TSH
      SERV2=100.0*(1.0-(TSH/CUMDEM))
      WRITE(2,375)SERV2
   90 CONTINUE
   99 WRITE(2,9000)
      GOTO 3
 2000 STOP
  300 FORMAT(12X,'INPUT PARAMETERS',//)
  301 FORMAT(' LEAD TIME AVERAGES',3(2X,F6.1),/)
  302 FORMAT(' DEMAND AVERAGES    ',3(2X,F7.2),/)
  303 FORMAT(' LEAD TM VARN RATIO',3(2X,F6.2),/)
  304 FORMAT(' DEMAND VARN RATIO ',3(2X,F6.2),/)
  305 FORMAT(' UNIT COSTS',4(2X,F6.2),//)
```

```
 306 FORMAT(' CYCLIC PARAMETERS-PERIOD=',F5.1,'  START=',I2,
    &'  HEIGHT=',F4.1)
 307 FORMAT(' SMOOTHING PARAMETERS:-',' DEM',F4.2,' ADAPT',F4.2,
    &'  LEAD',F4.2,3('  N.A',F3.1),'  QR',F4.2,', N.A',F3.1,/)
 308 FORMAT(' RUN LENGTH',I4,'MONTHS',/)
 309 FORMAT(' VALUE CATEGORIES LIMITS',4(2X,F4.0))
 310 FORMAT(3F0.0)
 320 FORMAT(4F0.0)
 330 FORMAT(F0.0,I0,F0.0)
 340 FORMAT(9F0.0)
 345 FORMAT(I0)
 346 FORMAT(4(F0.0))
 347 FORMAT(I0)
 350 FORMAT(6X,I3,10X,F8.1,6X,F9.1,T47,F10.1,T62,F5.1,2X,I3,
    &5(2X,I3))
 356 FORMAT(6X,F5.2,8X,F8.1,6X,F9.1,T47,F10.1,T62,F5.1,//)
 357 FORMAT('   AVERAGE & STD DEVN VALUES OVER LAST',I4,'  PERIODS'
 360 FORMAT('  NO OF STOCK',T18,'VAL OF MONTHS',T36,'MONTH-END',T51
    &'WIP',T60,'STOCK',T69,'MONTH  VC1  VC2  VC3  VC4  VC5 ')
 361 FORMAT('   -OUTS',T18,'   SALES',T36,'STOCK-VAL',T51,'VAL',T59
    &'HELD(AV)',T72,'NO',//)
 365 FORMAT(33X,F9.1,4X,F10.1,10X,I3,6X,5(2X,I3))
 370 FORMAT(' TOTAL MONTHS/ITEMS WITH ZERO STOCK:',F8.0,//)
 375 FORMAT(' ',/,'  SERVICE(2)=',F8.4)
 380 FORMAT('  TABLE OF INDIVIDUAL  RECORDS ',//)
 390 FORMAT(31X,3(7X,'AVE LEAD=',F6.2,8X))
 400 FORMAT(31X,9('SDL=',F3.2,3X),//)
 410 FORMAT('  UNIT COST=',F6.2,4X,'STCK VAL',T30,9(2X,F6.0,2X))
 420 FORMAT(' V/R DEMAND=',F6.2,4X,'WIP VAL',T30,9(2X,F6.0,2X))
 430 FORMAT(' AVE DEMAND=',F6.1,4X,'STCK OUT',T30,9(2X,F6.0,2X),//)
 440 FORMAT(I0,F0.0)
9000 FORMAT('0',10X,30('-'),'DET INV MODEL2,(B&W B.0),DIP.09.08.78.'
     END
     FINISH
```

APPENDIX 10

TABULATION OF RESULTS OBTAINED FROM THE BASIC STOCK CONTROL MODEL

Figure 91	Results obtained under steady stage input, i.e. stationary mean demand and lead times.
Figure 92	Results obtained under cyclically varying input.

In both tables "service 1" refers to the service calculated solely on the basis of the number of stock-outs each month, whereas "service 2" takes into account the duration of the stock out.

BASIC INVENTORY CONTROL MODEL RESULTS - STEADY CONDITIONS

CONTROL RULES							.
Existing Rules	Average stock holding	2.2	2.9	3.4	4.9	6.0	6.9
	Average demand value	4683	4683	4683	4683	4683	4683
	Average no. stock-outs	8.94	5.09	3.26	0.73	0.28	0.11
	Service Level 1	90.07	94.34	96.38	99.19	99.69	99.88
	Service Level 2	87.75	93.26	95.78	98.86	99.56	99.89
	Std Dev'n Stock Value	3232	3752	4178	4726	4966	5314
	Stock Stability	0.69	0.801	0.892	1.009	1.060	1.135
Option 1	Average stock holding	2.3	2.7	3.0	4.0	4.7	5.3
	Average demand value	4683	4683	4683	4683	4683	4683
	Average no. stock-outs	3.9	2.72	1.94	0.7	0.35	0.2
	Service Level 1	95.67	97.00	97.84	99.22	99.61	99.78
	Service Level 2	91.86	94.52	96.05	98.62	99.36	99.76
	Std Dev'n Stock Value	2300	2425	2501	2753	2887	3006
	Stock Stability	0.491	0.518	0.534	0.588	0.616	0.642
Option 2	Average stock holding	2.3	2.8	3.2	3.5	4.3	5.2
	Average demand value	4683	4683	4683	4683	4683	4683
	Average no. stock-outs	3.74	2.46	1.70	1.23	0.53	0.26
	Service Level 1	95.84	97.27	98.11	98.63	99.40	99.71
	Service Level 2	91.93	95.03	96.64	97.74	99.07	99.66
	Std Dev'n Stock Value	2365	2572	2765	2851	2999	3235
	Stock Stability	0.505	0.549	0.59	0.609	0.640	0.691
Option 3	Average stock holding	2.4	2.9	3.7	4.5	5.3	5.9
	Average demand value	4683	4683	4683	4683	4683	4683
	Average no. stock-outs	2.96	1.75	0.73	0.21	0.1	0.03
	Service Level 1	96.71	98.06	99.19	99.77	99.89	99.97
	Service Level 2	94.56	96.81	98.64	99.63	99.87	99.96
	Std Dev'n Stock Value	2586	2778	2835	2939	3122	3258
	Stock Stability	0.552	0.593	0.605	0.628	0.667	0.696

Fig. 91

BASIC INVENTORY CONTROL MODEL RESULTS - CYCLICAL CONDITIONS

CONTROL RULES							
Existing Rules	Average stock holding	2.3	2.9	3.4	4.0	5.0	6.1
	Average demand value	4656					
	Average no. stock-outs	9.85	6.21	4.28	2.83	1.27	0.65
	Service Level 1	89.05	93.1	95.24	96.86	98.59	99.28
	Service Level 2	84.28	90.56	94.19	96.24	98.62	99.25
	Std Dev'n Stock Value	3987	4392	4916	5310	5721	6126
	Stock Stability	0.856	0.943	1.056	1.140	1.229	1.316
Option 1	Average stock holding	2.4	2.7	3.4	4.1	4.8	5.4
	Average demand value	4656					
	Average no. stock-outs	4.48	3.37	1.87	1.09	0.61	0.38
	Service Level 1	95.02	96.26	97.92	98.79	99.32	99.58
	Service Level 2	89.40	92.35	96.29	97.63	98.98	99.38
	Std Dev'n Stock Value	3050	3425	3502	3983	4093	4435
	Stock Stability	0.655	0.736	0.752	0.855	0.879	0.952
Option 2	Average stock holding	2.4	2.8	3.6	4.5	5.3	5.9
	Average demand value	4656	4656	4656	4656	4656	4656
	Average no. stock-outs	4.37	3.04	1.61	0.75	0.42	0.16
	Service Level 1	95.14	96.26	98.21	99.17	99.53	99.82
	Service Level 2	89.56	93.24	96.86	98.46	99.30	99.79
	Std Dev'n Stock Value	3179	3521	3893	4196	4475	4769
	Stock Stability	0.683	0.756	0.836	0.901	0.961	1.024
Option 3	Average stock holding	2.4	2.8	3.6	4.4	5.3	5.9
	Average demand value	4656					
	Average no. stock-outs	4.06	2.6	1.26	0.62	0.24	0.14
	Service Level 1	95.49	97.11	98.6	99.31	99.73	99.84
	Service Level 2	91.82	94.86	97.84	99.05	99.30	99.80
	Std Dev'n Stock Value	3493	3739	3992	4357	4698	4964
	Stock Stability	0.750	0.803	0.857	0.936	1.009	1.066

Fig. 92

APPENDIX 11

The following pages show the source code of the composite model of the proposed system, also written in ICL extended Fortran. This programme occupied approximately 24K words of store in its binary form.

```
#####    #####   #####   #####        EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
#   #    #   #   #       #            EEEE                            EEEEEEEEEEEE
#   #    #   #   #       #            EEEE                            EEEEEEEEEEEE
#####    #   #   #####   #####        EEEE          MOP               EEEEEEEEEEEE
#   #    #   #       #       #        EEEE                            EEEEEEEEEEEE
#   #    #   #       #       #        EEEE                            EEEEEEEEEEEE
#####    #####   #####   #####        EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE

#LISTING OF :EPS8055.MH2PR(49/) PRODUCED ON 22NOV78 AT 17.06.17

#G8.62T AT ASTON    IN ':EPS8055.MOP1' ON 10JAN79 AT 18.01.19 USING  U14

DOCUMENT    MH2PR

      LIST(LP)
      PROGRAM (FXXX)
      INPUT  1= CR0
      INPUT  3= TR0
      INPUT  5= CR1
      INPUT  7= TR1
      OUTPUT 2= LP0
      OUTPUT 6= LP1
      OUTPUT 8= TP1
      CREATE 4= ED1
      OUTPUT 9= LP2
      COMPRESS INTEGER AND LOGICAL
      EXTENDED DATA
      TRACE 0
      END


      SUBROUTINE MP(VAR,S,SS)
      S=S+VAR
      SS=SS+(VAR*VAR)
      RETURN
      END


      SUBROUTINE RANDOM(RAND)
      RAND=(RAND+3.141592664)**5
      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 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


      SUBROUTINE CLASSIFY(VC1,VC2,VC3,VC4,VCAT,NV,J,OR,SM,AVDEM)
      DIMENSION NV(J)
      IF(VCAT.LE.VC1)GOTO 210
      NV(1)=NV(1)+1
      OR=1.0
      SM=2.0*AVDEM
      GOTO 299
  210 IF(VCAT.LE.VC2)GOTO 220
      NV(2)=NV(2)+1
      OR=1.5
      SM=AVDEM*2.0
      GOTO 299
  220 IF(VCAT.LE.VC3)GOTO 230
      NV(3)=NV(3)+1
      OR=2.0
      SM=AVDEM*2.0
      GOTO 299
  230 IF(VCAT.LE.VC4)GOTO 240
      NV(4)=NV(4)+1
      OR=2.0
      SM=AVDEM*2.5
      GOTO 299
  240 OR=6.0
      NV(5)=NV(5)+1
      SM=AVDEM*3.0
  299 RETURN
      END


      SUBROUTINE PRNG(AV,SDV,VAL,PROB)
      PROB=((PROB+3.1416)**5)
      PROB=PROB-IFIX(PROB)
      IF(PROB.GT.0.01.OR.PROB.LT.0.99)GOTO 4001
      IF(PROB.LT.0.01)VAL=2.0
      IF(PROB.GT.0.99)VAL=-2.6
      GOTO 4002
 4001 CONTINUE
      IP=IFIX(PROB*10.0)
      IF(IP.EQ.0)VAL=-1.6449
      IF(IP.EQ.1)VAL=-1.0364
      IF(IP.EQ.2)VAL=-0.6745
      IF(IP.EQ.3)VAL=-0.3853
      IF(IP.EQ.4)VAL=-0.1257
      IF(IP.EQ.5)VAL=0.1257
      IF(IP.EQ.6)VAL=0.3853
      IF(IP.EQ.7)VAL=0.6745
      IF(IP.EQ.8)VAL=1.0364
      IF(IP.EQ.9)VAL=1.6449
 4002 CONTINUE
      VAL=VAL*SDV+1.0
      VAL=VAL*AV
      IF(VAL.LT.0.0)VAL=0.0
      RETURN
      END
```

```
      SUBROUTINE POISSON(AV,VAL,PROB)
      PROB=((PROB+3.1416)**5)
      PROB=PROB-IFIX(PROB)
  510 DIV=0.0
      VAL=0.0
      SUM=0.0
      POIS=1.0
      Z=EXP(-AV)
  530 SUM=SUM+POIS
      VAL=SUM*Z
      IF(VAL.GT.PROB)GOTO 540
      DIV=DIV+1.0
      POIS=POIS*AV/DIV
      GOTO 530
  540 VAL=DIV
      RETURN
      END




      MASTER HYBRID
      INTEGER TIN,T(15),DD(120,16),ST,AMDEM,W,EDD,ORDNUM(120)
      REAL MWF,LDF,LAF,MDF,IMWF,MOF,LDR,LAR,MTR,IAF,NIF,IDF,IAR,MSV
     &,IDR,IDRD,NIR,M1,M2,NIRK(50),LINE(100),MIF,NOIF,MTF,IDFD,
     &LEAD,INIT(50),LEFD,LA(3),LDAV(120),NORDMV,NORDLV
      DIMENSION AB(60),P(60),DEMAD(120),THISMONDEM(120),STKMIN(120),
     &DA(3),VRD(3),VRL(4),DE(120),DEAV(120),DESD(120),PRD(120),
     &PRL(120),U(120),DF(120),UC(4),SK(120),QU(120,16),NVC(5),WIP(120),
     &DEMFCR(120),DELFCR(120),RECPT(120),BKORD(120),ROL(120)
     &,SVSUM(10),SVSQ(10)



      EQUIVALENCE(AB(1),UUF),(AB(2),IAF),(AB(3),SRF),(AB(4),AMWF),
     &(AB(5),SSF).(AB(6),DOF),(AB(7),OPF),(AB(8),RRF),(AB(9),RSF),
     &(AB(10),CPF),(AB(11),OIC),(AB(12),MIF),(AB(13),OTF),(AB(14),SIW),
     &(AB(15),LDF),(AB(16),LAF),(AB(17),OPC),(AB(18),DFF),(AB(19),SDW),
     &(AB(20),IMWF),(AB(21),MOF),(AB(22),MDF),(AB(23),DSF),(AB(24),OESK)
     &,(AB(25),DTS),(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(34),MTR)
     &,(AB(35),RRR),(AB(36),NIR),(AB(37),IDR),(AB(38),IDRD),
     &(AB(39),RRRC),(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)
     &,(AB(50),BKV),(AB(51),ANSO),(AB(52),ANWT),(AB(53),DMV),
     &(AB(54),SKV),(AB(55),GIV),(AB(56),MSV),(AB(57),WV),(AB(58),STKHLD)

      DIMENSION IP(12),NOP(12),V(50),SYM(12),
     &AMEAN(18),SD(18),PERC(50),AVERAGE(12),STDEVN(12)


      DATA V(1)/'   UOF'/,V(2)/'   IAF'/,V(3)/'   SRF'/,V(4)/'  AMWF'/,
     &V(5)/'   SSF'/,V(6)/'   DUF'/,V(7)/'   OPF'/,V(8)/'   RRF'/,
     &V(9)/'   RSF'/,V(10)/'   CPF'/,V(11)/'   OIC'/,V(12)/'   MIF'/,
     &V(13)/'   OTF'/,V(14)/'   SIW'/,V(15)/'   LDF'/,V(16)/'   LAF'/,
     &V(17)/'   OPC'/,V(18)/'   DFF'/,V(19)/'   SDW'/,V(20)/'  IMWF'/,
     &V(21)/'   MOF'/,V(22)/'   MDF'/,V(23)/'   DSF'/,V(24)/'  OESK'/,
     &V(25)/'   DTS'/,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'/
     &,T(1)/1/,T(2)/2/,T(3)/3/,T(4)/4/,T(5)/5/,T(6)/6/,T(7)/26/,T(8)/8/,
     &T(9)/27/,T(10)/28/,T(11)/29/,T(12)/30/,T(13)/31/,T(14)/35/,
     &T(15)/9/
     &,INFIN/99999/


C    READ DETAILED MODEL DATA


      READ(7,1310)(LA(K),K=1,3)
      READ(7,1310)(DA(K),K=1,3)
      READ(7,1320)(VPL(K),K=1,4)
      READ(7,1310)(VRD(K),K=1,3)
      READ(7,1320)(UC(K),K=1,4)
      READ(7,1330)RUBBISH,JUNK,GARBAGE
      READ(7,1340)SAF,(P(K),K=41,44),DIC
      READ(7,1900)LENGTH
      READ(7,1320)VC1,VC2,VC3,VC4
      READ(7,1900)W
      READ(7,1320)(P(K),K=45,48)


C READ FORRESTER INITIAL DATA

      READ(1,107)(P(I),I=1,38)
      WRITE(9,9000)
      WRITE(6,431)(P(I),I=1,48)
      FAIF=P(18)


      READ(1,400)DOT,STAR,A,B,C,D,E,F,G,H,R,S,X,Z,BLANK
      P(49)=0.0
C INPUT GRAPH DATA


      READ(5,410)MAX
      IF(MAX.EQ.0)GOTO 407
      DO 405 K=1,MAX
  405 READ(5,415)NOP(K)
  407 SYM(1)=A
      SYM(2)=B
      SYM(3)=C
      SYM(4)=D
      SYM(5)=E
      SYM(6)=F
      SYM(7)=G
      SYM(8)=H
      SYM(9)=R
      SYM(10)=S
      SYM(11)=X
      SYM(12)=Z
C READ IN CHANGE DATA
   81 READ(3,302)IN,VAL
      WRITE(6,432)IN,VAL
      IF(IN.EQ.60)GOTO 83
      IF(IN.EQ.50)GOTO 82
      IF(IN.EQ.40)W=-W
      P(IN)=VAL
      GOTO 81
   82 CONTINUE
      DO 84 K=1,MAX
      AVERAGE(K)=0.0
```

```
      STDEVN(K)=0.0
   96 CONTINUE
      RRI=P(1)
      DT=P(2)
      DI=P(3)
      RI=P(4)
      AIR=P(5)
      AIRD=P(6)
      RRCD=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)
      DIC=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)
      ALFA=P(41)
      BETA=P(42)
      GAMA=P(43)
      DELTA=P(44)
      PRD(1)=P(45)
      PRL(1)=P(46)
      XD=P(47)
      DOESK=P(48)
      SAF=AIF/FAIF


      LA(2)=(DIC+DCF+DOMF+DOIF+DPF+2.0)/4.0
      LA(1)=0.7*LA(2)
      LA(3)=1.3*LA(2)


      WRITE(3,9000)
      WRITE(2,9000)
      WRITE(3,1300)
      WRITE(2,1300)
      WRITE(3,1301)(LA(K),K=1,3)
      WRITE(2,1301)(LA(K),K=1,3)
      WRITE(3,1302)(DA(K),K=1,3)
      WRITE(2,1302)(DA(K),K=1,3)
      WRITE(3,1303)(VRL(K),K=1,4)
      WRITE(2,1303)(VRL(K),K=1,3)
```

```
      WRITE(8,1304)(VRD(K),K=1,3)
      WRITE(2,1304)(VRD(K),K=1,3)
      WRITE(8,1305)(UC(K),K=1,4)
      WRITE(2,1305)(UC(K),K=1,4)
      WRITE(8,1307)ALFA,BETA,GAMA,DELTA
      WRITE(2,1307)ALFA,BETA,GAMA,DELTA
      WRITE(8,1308)SAF,DIC
      WRITE(2,1308)SAF,DIC
      WRITE(2,715)RRI,DT,DI,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,DPRD,DHR,DUR,DIRI,DIRP,DCR,DTR,DMR
      WRITE(2,740)
      WRITE(2,750)DIC,DOESK,DUF,DHF,DIF,ALF,DCF,DIMF,DPF,DOMF,DOIF,DSPF
      WRITE(8,715)RRI,DT,DI,RI
      WRITE(8,760)
      WRITE(8,770)DEV,STPT,STPH,RMPST,RMPFT,RMPH,SNEST,PER,SNEH
      WRITE(8,720)
      WRITE(8,730)AIR,AIRD,RRCO,DRR,DPRD,DHR,DUR,DIRI,DIRP,DCR,DTR,DMR
      WRITE(8,740)
      WRITE(8,750)DIC,DOESK,DUF,DHF,DIF,ALF,DCF,DIMF,DPF,DOMF,DOIF,DSPF

C   SET INITIAL CONDITIONS
      ISTAB=IFIX(PI/4.0)-LENGTH
      LNQ=0
      DO 1110 NN=2,120
C DEMAND PROBABILITY FACTORS
      PRD(NN)=(PRD(NN-1)+3.1416)**7
      PRL(NN)=(PRL(NN-1)+3.1416)**7
      PRD(NN)=PRD(NN)-IFIX(PRD(NN))
      PRL(NN)=PRL(NN)-IFIX(PRL(NN))
 1110 CONTINUE
      NN=0
      DO 1121 KAT=1,5
 1121 NVC(KAT)=0
      NSO=0
      BKV=0.0
      WV=0.0
      SKV=0.0
      MSV=0.0
      DMV2=0.0
      NORDMV=0.0
      DO 1130 L=1,4
C UNIT COST(L)
C SD DEMAND(M)
      DO 1130 N=1,3
C   AVE DEMAND(N)
      VRD(N)=2.47/(DA(N)**0.197)
      DO 1130 K=1,3
C   AVE LEAD(K)
      DO 1130 J=1,4
C   SD LEAD(J)
      IF(N*L.GE.9)GOTO 1130
      NN=NN+1
      DEAV(NN)=DA(N)
      THISMUNDEM(NN)=DEAV(NN)

      DEMAD(NN)=VRD(N)/1.25*DEAV(NN)
      LDAV(NN)=LA(K)
      VCAT=DA(N)*UC(L)
      NORDMV=NORDMV+VCAT
      CALL CLASSIFY(VC1,VC2,VC3,VC4,VCAT,NVC,5,Q(NN),SM,DEAV(NN))
      XO=((XO+3.1416)**5)
      XO=XO-IFIX(XO)
      NQ=IFIX(LA(K)/Q(NN))-1
```

```
      ORDNUM(NN)=NQ
      IF(NQ.GT.LNQ)LNQ=NQ
      DO 1123 I=1,16
      QU(NN,I)=0.0
 1123 DD(NN,I)=INFIN
      DD(NN,1)=NINT(XO*Q(NN))
      INITDD=DD(NN,1)
      QU(NN,1)=Q(NN)*DEAV(NN)
      SK(NN)=SN*(XO*QU(NN,1))
      IF(DD(NN,1).GT.0)GOTO 1124
      SK(NN)=SK(NN)-QU(NN,1)
      QU(NN,1)=0.0
      DD(NN,1)=INFIN
 1124 WIP(NN)=QU(NN,1)
      IF(NQ.LT.2)GOTO 1126
      DO 1125 I=2,NQ
      DD(NN,I)=INITDD-IFIX((I-1)*Q(NN))
      QU(NN,I)=Q(NN)*DA(N)
 1125 WIP(NN)=WIP(NN)+QU(NN,I)
 1126 CONTINUE
      SKV=SKV+SK(NN)*UC(L)
      BKORD(NN)=0.0
      WV=WV+WIP(NN)*UC(L)
 1130 CONTINUE
      EDD=0
      MONTH=0
      WEEK=4.0
      MINMINDD=0
      DELDUV=0.0
      DMV=NORDMV
      SDU=RRI*DHF
      DTS=0.0
      OEISK=DUESK*RRI
      OESK=OEISK
      SDF=RRI
      OIC=0.0
      NORDLV=NORDMV
      IAF=4.0*SKV/NORDMV*RRI
      FCORDV=NORDMV
      I=0
      DO 1150 L=1,4
      DO 1150 N=1,3
      DO 1150 K=1,3
      DO 1150 J=1,4
      IF(N.GE.3.AND.L.GE.3)GOTO 1150
      I=I+1
      DEMFCR(I)=DA(N)/DMV
 1150 CONTINUE
      DO 1160 ISV=1,9
      SVSUM(ISV)=0.0
 1160 SVSQ(ISV)=0.0
      WRITE(3,1300)
      WRITE(3,1301)
      TSH=0.0

      NWORD=0
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)=0.0
      RRR=RRI
      RSR=RRR
      RSRD=RRR
```

```
      RRF=RRR
      CPR=RRR*DCR
      PMR=RRR*DMR
      MTR=RRR*DTR
      PDR=RRR
      SSF=RRR
      IAR=RSR*AIR
      RSF=RRF
      RSFD=RRF
      CPF=RRF*DCF
      OPF=RRF*DPF
      IMWF=RRF
      MWF=RRR
      AMWF=RRR
      DUF=0.0
      PSR=PDR
      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=DUMF+DOTF
      DSF=DUF
      OIF=RRF*DUF
C INITIAL AUX EQUNS
      NIR=IAR/DT
      IDR=RSR*AIR
      IDRD=AIRD*RSRD
      RRRC=RRR*RRCO
      LAR=CPR+PMR+UOF+MTR
      UNR=RSR*(DHR+DUR)
      CALL AVG(DT,DSF,DOF,DSPF)
      LDF=RSF*(DCF+DPF+DSF)
      LAF=CPF+OPF+OIF
      DFR=DHR+DUR+(IDRD/IAR)
      DFF=DHF+DUF
      STR=UOR/DFR
      LDR=RSR*(DCR+DMR+DFF+DTR)
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)

      CALL AVG(DT,IMWF,MWF,DIMF)
      NOIF=(DUIF+DOMF)*IMWF
      DOF=DUMF+(OIF/NOIF)*DUIF
      MTF=OIF/DUF
      LEAD=DCF+DPF+DOF
        OVL=OVT*IMWF
      IF(MTF.LE.OVL)GOTO 16
```

```
      MIF=OVL
      GOTO 17
   16 MIF=NTF
   17 MDF=MIF
   13 IF(NIR.GE.STR)GOTO 14
      SSR=NIR
       GOTO 15
   14 SSR=STR
   15 PDR=RERC*((IDR-IAR)-(UDR-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)
      MI=NINT(OI/DT)
      OI=DT*FLOAT(MI)
      NI=NINT(RI/OI)
      RI=OI*FLOAT(NI)



C INPUT GENERATOR
      ISPT=NINT(STPT/DT)
      IRPST=NINT(RMPST/DT)
      IRPFT=NINT(RMPFT/DT)
      ISNST=NINT(SNEST/DT)
      IPER=NINT(PER/DT)
      PROB=0.5
C START OF MAIN CALCULATIONS
      LP=1
      TIM=1
      DO 21 IL=1,NI
      DO 20 JL=1,MI
C NOISE GENERATOR
      IF(DEV.EQ.0.0)GOTO 29
      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
   29 CONTINUE
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-RHD)*(RRI+STP+PHP+SNE)
      PRR=RII
C     START OF LEVEL CALCS
      CALL LEVEL(DT,UOR,RRR,SSR)
      CALL LEVEL(DT,IAR,SRR,SSR)
      CALL AVG(DT,RSR,PRR,DRR)
      CALL AVG(DT,RSRD,RRR,DRRD)
      CALL LEVEL(DT,CPR,PDR,PSR)
      CALL LEVEL(DT,PHR,PSR,RRF)
      CALL LEVEL(DT,MTR,SSF,SRR)
      CALL LEVEL(DT,UOF,RRF,SSF)
      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+PHR+UOF+MTR
      UNR=RSR*(DHR+DUR)
      CALL AVG(DT,DSF,DOF,DSPF)
      LDF=RSF*(DCF+DPF+DSF)
      LAF=CPF+OPF+OIF
      DFR=DHR+DUR+(IDRD/IAR)
      STR=UOR/DFR
C     START  OF  RATE  EQUATION  CALC.
      CALL DELAY3(R1,R2,PSR,RRF,DT,DHR)
      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)

      OESK=OESK+DT*(SRF-DTS)
      DTS=OESK/OEISK*SDF

      DTSMAX=OESK/DT
      IF(DTSMAX.LT.DTS)DTS=DTSMAX
      ACTDLV=DT*DTS/RRI*NORDLV/4.0
      ACTDMV=DT*RRF/RRI*NORDMV/4.0


      WEEK=WEEK+DT
      IF(WEEK.LT.3.99)GOTO 1010
      WEEK=0.0
         OPC=4.0*FCORDV/NORDMV*RRI
         AMMF=OPC/4.0
         FCORDV=0.0
         OIC=OIC+OPC
         AVDMV=0.0
         DO 2015 NNC=1,5
 2015    NVC(NNC)=0
         I=0
         DO 2010 M=1,4
         DO 2010 N=1,3
         DO 2010 K=1,3
         DO 2010 J=1,4
         IF(N*L.GE.9)GOTO 2010
         I=I+1
         DEMAD(I)=DEMAD(I)+BETA*(ABS(THISMONDEM(I)-DEAV(I))-DEMAD(I))
         DEAV(I)=DEAV(I)+ALFA*(THISMONDEM(I)-DEAV(I))
         THISMONDEM(I)=0.0
         VCAT=DEAV(I)+UC(L)
```

```
          CALL CLASSIFY(VC1,VC2,VC3,VC4,VCAT,NVC,5,Q(I),SM,DEAV(I))
             ROL(I)=LDAV(I)*(DEAV(I)+SAF*(1.25*DEMAD(I)/SQRT(LDAV(I))))
          Q(I)=DELTA*Q(I)
          STKMIN(I)=2.5*DEMAD(I)
          AVDMV=AVDMV+VCAT
 2010     CONTINUE
          STKHLD=SKV/DMV
          RSF=AVDMV/NORDMV*RRI
         IF(I.LT.0)GOTO 2222
          WRITE(6,1350)BKV,NSO,NWORD,DMV,SKV,GIV,MSV,WV,STKHLD,MONTH,EDD,
     &    (NVC(JA),JA=1,5)
 2222 CONTINUE
      IF(MONTH.LT.LENGTH)GOTO 2009
      ANWT=FLOAT(NWORD)
      ANSO=FLOAT(NSO)
      DO 2006 ISV=1,9
 2006 CALL OP(AB(29+ISV),SVSUM(ISV),SVSQ(ISV))
 2009 CONTINUE
      IF(SKV.LT.0.1)GOTO 22
      NWORD=0
          MSV=0.0
          MONTH=MONTH+1
      WV=0.0
          GIV=0.0
          DMV=0.0
          WEEK=0.0
C OBTAIN RANDOM FACTORS
      I=0
      DO 2011 L=1,4
      DO 2011 N=1,3
      DO 2011 K=1,3
      DO 2011 J=2,4,2
      IF(N*L.GE.9)GOTO 2011
      I=I+2
          IF(DA(N).GT.5.0)GOTO 2002
          CALL POISSON(DA(N),DF(I),PRD(I))
          GOTO 2004
 2002     CALL PRNG(DA(N),VRD(N),DF(I),PRD(I))
 2004 CONTINUE
          IF(DF(I)/DA(N).GT.2.1)DF(I)=2.1*DA(N)
          DF(I-1)=2.0*DA(N)-DF(I)
 2011 CONTINUE
          I=0
          DO 2020 L=1,4
          DO 2020 N=1,3
          DO 2020 K=1,3
          DO 2020 J=1,4
          IF(N*L.GE.9)GOTO 2020
          I=I+1
C RE-ORDER ROUTINE
          STKOH=SK(I)+UIP(I)-BKORD(I)
          IF(ROL(I).LT.STKOH)GOTO 2006
          ORDNUM(I)=ORDNUM(I)+1
          IF(ORDNUM(I).GT.16)ORDNUM(I)=1
          KNT=ORDNUM(I)
          CALL PRNG(LA(K),VRL(J),LEED,PRL(I))
          OD(I,KNT)=MONTH+IFIX(LEED)
          LDAV(I)=LDAV(I)+GAMA*(LEED-LDAV(I))
          NWORD=NWORD+1
          QU(I,KNT)=DEAV(I)*Q(I)*(IFIX((ROL(I)-STKOH)/(Q(I)*DEAV(I)))+1)
          UIP(I)=UIP(I)+QU(I,KNT)
          ECORDV=ECORDV+QU(I,KNT)*UC(L)
 2006 WV=WV+UIP(I)*UC(L)
          DEMFCP(I)=DF(I)/NORDMV
 2020     CONTINUE
 1010 DMV=DMV+ACTDMV
```

```
      OIC=OIC-DT*MWF
      MWF=OIC/DIC
C DELIVERY TO WAREHOUSE ROUTINE
              IF(DELDUV.GT.0.0)GOTO 1020
              IF(EDD.LT.MONTH-1)EDD=EDD+1
              I=0
              DO 3010 L=1,4
              DO 3010 N=1,3
              DO 3010 K=1,3
              DO 3010 J=1,4
              IF(N*1.GE.9)GOTO 3010
               I=I+1
C       RESCHEDULING ROUTINE
                 MINSUF=1
                 DO 3003 LI=2,16
                 IF(DD(I,LI).LT.DD(I,MINSUF))MINSUF=LI
 3003            CONTINUE
                 MINDD=DD(I,MINSUF)
                 IF(MINDD.LT.MINMINDD)MINMINDD=MINDD
                 IF(SK(I).GT.STKMIN(I))GOTO 3004
                 IF(MINDD-IFIX(LA(K)/2.0).GT.MONTH)GOTO 3004
              DD(I,MINSUF)=EDD
              LDAV(I)=LDAV(I)-GAMA*FLOAT(MINDD-EDD)
 3004         CONTINUE
              DO 3005 LI=1,16
              IF(DD(I,LI).NE.EDD)GOTO 3005
              DELDUV=DELDUV+QU(I,LI)*UC(L)
 3005         CONTINUE
 3010       CONTINUE
              SDF=DELDUV/NORDUV*RRI
       IF(DELDUV.EQ.0.0)GOTO 3030
              I=0
              DO 3020 L=1,4
              DO 3020 N=1,3
              DO 3020 K=1,3
              DO 3020 J=1,4
              IF(N*1.GE.9)GOTO 3020
              I=I+1
              DELFCR(I)=0.0
              DO 3015 LI=1,16
              IF(DD(I,LI).NE.EDD)GOTO 3015
              DELFCR(I)=QU(I,LI)/DELDUV+DELFCR(I)
              IF(EDD.LT.MONTH)LDAV(I)=LDAV(I)+GAMA*FLOAT(MONTH-EDD)
              QU(I,LI)=0.0
              DD(I,LI)=INFIN
 3015         CONTINUE
              IF(EDD.LT.MINMINDD)EDD=MINMINDD
 3020         CONTINUE
              GOTO 1020

 3030         ACTDLV=0.0
              DTS=0.0

 1020   CONTINUE
      IF(DELDUV.GE.ACTDLV)GOTO 1025
       DTS=DTS*DELDUV/ACTDLV
      ACTDLV=DELDUV
 1025 CONTINUE
      SUPLYV=0.0
      BKV=0.0
      SKV=0.0
      NSU=0
      I=0
      DO 1030 L=1,4
      DO 1030 N=1,3
      DO 1030 K=1,3
```

```
      DO 1030 J=1,4
      IF(N*L.GE.9)GOTO 1030
      I=I+1
      DE(I)=DEMFCR(I)*ACTDMV
      THISMONDEM(I)=THISMONDEM(I)+DE(I)
      RECPT(I)=DELFCK(I)*ACTDLV
      DEMAND=DE(I)+BKORD(I)
      BKORD(I)=0.0
      WIP(I)=WIP(I)-RECPT(I)
      IF(SK(I).GT.0.0)GOTO 1040
      NSO=NSO+1
      IF(DEMAND.LT.RECPT(I))GOTO 1050
      SUPLYV=SUPLYV+RECPT(I)*UC(L)
      BKORD(I)=DEMAND-RECPT(I)
      GOTO 1080
 1050 SUPLYV=SUPLYV+DEMAND*UC(L)
      SK(I)=RECPT(I)-DEMAND
      GOTO 1080
 1040 SK(I)=SK(I)+RECPT(I)
      IF(SK(I).GE.DEMAND)GOTO 1070
      SUPLYV=SUPLYV+SK(I)*UC(L)
      BKORD(I)=DEMAND-SK(I)
      SK(I)=0.0
      GOTO 1030
 1070 SK(I)=SK(I)-DEMAND
      SUPLYV=SUPLYV+DEMAND*UC(L)
 1080 SKV=SKV+SK(I)*UC(L)
      BKV=BKV+BKORD(I)*UC(L)
 1030 CONTINUE
      DELDUV=DELDMV-ACTDLV
      GIV=GIV+ACTDLV
      MSV=MSV+SUPLYV
      SIW=SUPLYV/NORDMV*4.0*RRI/DT
      IAF=4.0*SKV/NORDMV*RRI
      SDW=SDW+DT*(SIW-SSF)
      DUF=BKV*DT/ACTDMV
      DFF=DHF+DUF
      SSF=SDW/DHF



         LDR=RSR*(DCR+DHR+DFF+DTR)
      CALL AVG(DT,IMWF,MWF,DIMF)
      NOIF=(DOIF+DOMF)*IMWF
      DOF=DOMF+(OIF/NOIF)*DOIF
      MTF=OIF/DOF
      LEAD=DCF+DPF+DOF
        OVL=OVT*IMWF
       IF(MTF.LE.OVL)GOTO 46
       MIF=OVL
      GOTO 47
   46 MIF=MTF
   47 MOF=MWF
   43 IF(NIR.GE.STR)GOTO 44
       SSR=NIR
      GOTO 45
   44 SSR=STR
   45 PDR=RRRC+((IDR-IAR)+(UOR-UNR))/DIFI+(LDR-LAR)/DIOP
      IF(PDR.LT.0.0)PDR=0.0
      KB=1
      DO 205 K=1,15
      KA=T(KB)
      CALL DP(AB(KA),AMEAN(K),SD(K))
       KB=KB+1
  205 CONTINUE
      DO 206 K=1,MAX
```

```
 200 CALL DP(AB(NOP(K)),AVERAGE(K),STDEYN(K))
     NUM=NUM+1
     TIM=TIM+1
  20 CONTINUE
     LP=LP+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
  22 REWIND4
     WRITE(8,1400)ISTAB
     DO 1500 ISV=1,9
1500 AB(49+ISV)=SVSUM(ISV)/ISTAB
     NWORD=NINT(ANWT)
     NSO=NINT(ANSO)
     WRITE(8,1350)BKV,NSO,NWORD,DMV,SKV,GIV,MSV,WV,STKHLD
     WRITE(8,1410)
     DO 1510 ISV=1,9
1510 AB(49+ISV)=SQRT(SVSQ(ISV)/ISTAB-(AB(49+ISV))**2)
     NWORD=NINT(ANWT)
     NSO=NINT(ANSO)
     WRITE(8,1350)BKV,NSO,NWORD,DMV,SKV,GIV,MSV,WV,STKHLD
     DO 1520 ISV=1,9
1520 AB(ISV+49)=0.0
1000 WRITE(8,9000)
     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 390
     WRITE(2,800)(V(K),K=1,13)
     DO 90 L=1,NI+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(2,800)(V(K),K=14,26)
     DO 91 L=1,NI+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)(V(K),K=27,37)
     DO 92 L=1,NI+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)(V(K),K=38,47)
      DO 93 L=1,NI+1
      READ(4)
      READ(4)
      READ(4)
      READ(4)(AB(K),K=38,48)
      LI=L-1
   93 WRITE(2,800)(AB(I),I=38,47),LI
      REWIND4
  690 CONTINUE
C  PICK UP WHICH OUTPUTS ARE REQUIRED
      WRITE(2,505)
      WRITE(2,900)
      IF(MAX.EQ.0)GOTO 280
      DO 600 M=1,MAX
      AVERAGE(M)=AVERAGE(M)/FLOAT(NUM)
      STDEVN(M)=(STDEVN(M)/FLOAT(NUM)-AVERAGE(M)**2)
      IF(STDEVN(M).LT.0.0)STDEVN(M)=0.0
      STDEVN(M)=SQRT(STDEVN(M))
  600 WRITE(2,510)V(NOP(M)),SYM(M),AVERAGE(M),STDEVN(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,MAX
   95 INIT(NOP(K))=AVERAGE(K)
      REWIND4
C START PLOTTING LOOP
      DO 240 L=1,NI+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,MAX
      PERC(NOP(K))=ABS(AB(NOP(K))/INIT(NOP(K)))*100.0
      IF(PERC(NOP(K)).GT.200.0)PERC(NOP(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))=SYM(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 01
   33 CONTINUE
      STOP
```

```
 397 FORMAT(F0.0)
 400 FORMAT(15A1)
 410 FORMAT(I0)
 415 FORMAT(I0)
 420 FORMAT(1X,'                 UOF      IAF      SRF     AMWF      SSF     DOF     LEAD
   1     RRF      IAR     UOR      SSR      RSR    RSRD      RRR      RSF  ')
 430 FORMAT(1X,'  MEAN  ',15(F6.1,1X))
 435 FORMAT(10(2X,F6.1),/,T1,5(2X,F6.1))
 440 FORMAT(1X,'    SD  ',15(F6.1,1X))
 451 FORMAT(1X,45(F6.1))
 452 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,'WITH MEAN',F8.2,'& SD',F8.2)
 710 FORMAT('1',20X,'DATA',///)
 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       DIPI       DIRP        DCR         DTP        DMR')
 730 FORMAT(1X,11(2X,F6.1,2X),2X,F6.1,//)
 740 FORMAT(1X,'   DIC          DUESK      DJF          DHF          DIF              AL
    &F          DCF        DIHF       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),//)
 800 FORMAT('1',13(1X,A7,1X))
 802 FORMAT(I2,F0.0)
 810 FORMAT(1X,13(1X,F7.1,1X),I3)
 830 FORMAT(1X,13(1X,F7.1,1X),I3)
 850 FORMAT('1',11(1X,A7,1X))
 860 FORMAT(1X,11(1X,F7.1,1X),6X,I3)
 870 FORMAT('1',10(1X,A7,1X))
 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,/)
1300 FORMAT(12X,'INPUT PARAMETERS',///)
1301 FORMAT(' LEAD TIME AVERAGES',3(2X,F6.1),/)
1302 FORMAT(' DEMAND AVERAGES    ',3(2X,F7.2),/)
1303 FORMAT(' LEAD TM VARN RATIO',4(2X,F6.2),/)
1304 FORMAT(' DEMAND VARN RATIO ',3(2X,F6.2),/)
1305 FORMAT(' UNIT COSTS',4(2X,F6.2),//)
1307 FORMAT(' SMOOTHING PARAMETERS=',4(3X,F5.2),/)
1308 FORMAT(' SAFETY STOCK FACTOR:',F4.1,'COMPUTER ORDER'
1   &' ISSUE DELAY:',F4.1)
1309 FORMAT(' VALUE CATEGORIES LIMITS',4(2X,F4.0))
1310 FORMAT(3F0.0)
1320 FORMAT(4F0.0)
1330 FORMAT(F0.0,I0,F0.0)
1340 FORMAT(6F0.0)
1350 FORMAT(1X,F8.1,2(1X,I3),2(1X,F8.1),2(1X,F7.1),1X,F8.1,1X,F4.1,
    &2(1X,I3),4X,5(1X,I3))
1360 FORMAT(' BACK ORD STK NEW  MONTHS  MNTH-END  MNTHS   MNTHS  ',
    &'MNTH-END STCK MON EDU    VC1 VC2 VC3 VC4 VC5')
1361 FORMAT(' VALUE    OUT ORDS DEM VAL STCK VAL G/I VAL DESP VAL ',
    &'WIP VAL  MID  TH',/,1X,110('='),/)
1365 FORMAT(46X,F10.1,3X,F10.1,10X,I3)
```

```
 7500 FORMAT('0        MEAN VALUES OVER LAST',I4,' MONTHS',/)
 7510 FORMAT('   STANDARD DEVIATIONS FOR SAME PERIOD',/)
 7099 FORMAT(F6.0,I3,F6.2)
 7900 FORMAT(I3)
 9000 FORMAT(32('*'),'HYBRID MODEL2/16,(DM1R,RSCHD),DIP.20.11.78.',/,
     *1X,'1 MONTH EARLY DELY PERMITTED,RESCHD ON ≥.5 MAN.',/,
     *1X,'MODIFIED STKMIN & LEADTIME MONITORING EXTENDED PRNG-2.6 SD',/)
      END
      FINISH
****

+EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
+EEEEEEE                                EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
+EEEEEEE        NUMBER OF PAGES   17    EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
+EEEEEEE                                EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
+EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
```

APPENDIX 12

COMPOSITE MODEL OUTPUT

The illustration shows the output from the inventory or warehouse section of the composite model. In this instance the facility to output monthly values of the variables has not been utilised, but the means and standard deviations of these variables are shown.

Fig. 93

Example of Output from Warehouse Section of the Composite Model

```
1 MONTH EARLY DELY PERMITTED

          INPUT PARAMETERS


LEAD TIME AVERAGES     4.2     6.0     7.8

DEMAND AVERAGES        1.00   150.00    50.00

LEAD TM VARN RATIO    0.10    0.20    0.10    0.20

DEMAND VARN RATIO     2.47    0.92    1.14

UNIT COSTS    0.05    0.20    0.80    2.00


SMOOTHING PARAMETERS=    0.20    0.05    0.20    1.00

SAFETY STOCK FACTOR; 1.0COMPUTER ORDER' ISSUE DELAY; 1.0
  INPUT LEVEL= 100.0    CALCULATION INTERVAL=0.20    OUTPUT INTERVAL=  4.0    RUN LENGTH= 900.0


NOISE STD DEV;STEP START;STEP  HT ;RAMP START ;RAMP STOP ;RAMP  HT  ;SINE START;  PERIOD  ; AMPLITUDE;
    0.00        0.00        0.00         0.00        0.00        0.00      +1201.00     +208.00       10.00


   AIR      AIRD      RRCO       DRR      DRRD        DHR      DUR     DIRI      DIRP      DCR      DTR      DMR
    16.0     16.0       1.0      10.0       3.3      0.0      0.6       4.0       8.0       1.0       2.0       0.6

   DIC      DOESK      DUF      DHF      DIF      ALF      DCF      DIMF      DPF      DOMF      DOIF      DSPF
     1.0     10.0       2.8       2.0      2.1    999.0      1.0      50.0       4.0       2.0      14.0      24.0

BACK ORD STK NEW  MONTHS  MNTH-END  MNTHS   MNTHS  MNTH-END STCK MON EDD    VC1 VC2 VC3 VC4 VC5
VALUE    OUT ORDS DEM VAL STCK VAL G/I VAL DESP VAL WIP VAL  HLD  TH
=================================================================================================

0      MEAN VALUES OVER LAST 201 MONTHS

   190.0   2  38   5676.6  13958.4  5674.6  5075.3  37235.9  2.5
  STANDARD DEVIATIONS FOR SAME PERIOD

   386.5   1   4     99.5    670.0   611.4   216.2   1128.7  0.1
00000000000000000000000000000000000HYBRID MODEL1/17,(B&W M/I,RSCHD),DIP.19.10.78.
 1 MONTH EARLY DELY PERMITTED
```

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