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To Nims

The University of Aston in Birmingham

DESIGN OF A STOCK CONTROL METHODOLOGY FOR USE WITHIN AN OIL BLENDING COMPANY

by

Paul Cane

A Thesis submitted for the Degree of Doctor of Philosophy, 1982

This research was carried out with the support of Edgar Vaughan & Co. Limited under the overall control of the Interdisciplinary Higher Degrees Scheme of the University of Aston in Birmingham.

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SUMMARY

The thesis deals with the background, development and description of a mathematical stock control methodology for use within an oil and chemical blending company, where demand and replenishment lead-times are generally non-stationary.

The stock control model proper relies on, as input, adaptive forecasts of demand determined for an economical forecast/replenishment period precalculated on an individual stock-item basis. The control procedure is principally that of the continuous review, reorder level type, where the reorder level and reorder quantity 'float', that is, each changes in accordance with changes in demand.

Two versions of the Methodology are presented; a cost minimisation version and a service level version.

Realising the importance of demand forecasts, four recognised variations of the Trigg and Leach adaptive forecasting routine are examined. A fifth variation, developed, is proposed as part of the stock control methodology.

The results of testing the cost minimisation version of the Methodology with historical data, by means of a computerised simulation, are presented together with a description of the simulation used. The performance of the Methodology is in addition compared favourably to a rule-of-thumb approach considered by the Company as an interim solution for reducing stock levels.

The contribution of the work to the field of scientific stock control is felt to be significant for the following reasons:-

(1) The Methodology is designed specifically for use with non-stationary demand and for this reason alone appears to be unique.

(2) The Methodology is unique in its approach and the cost-minimisation version is shown to work successfully with the demand data presented.

(3) The Methodology and the thesis as a whole fill an important gap between complex mathematical stock control theory and practical application.

A brief description of a computerised order processing/stock monitoring system, designed and implemented as a pre-requisite for the Methodology's practical operation, is presented as an appendix.

Key Words: Inventory Control, Non-Stationary Demand, Adaptive Forecasting, Simulation

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List of Nomenclature

(Presented in Approximate Order of Appearance Within the Thesis)

ERP = Economical Replenishment Period.

P_E = Length of ERP.

F_D = Forecast of demand calculated to occur over ERP.

σ_D = Standard Deviation relating to the Normal Probability distribution of demand forecasting-errors.

K_D = Standard Normal Deviate relating to the Normal Probability distribution of demand forecasting-errors.

$K_D\sigma_D$ = Demand safety stock.

α_D = Probability of stockout during ERP due to excessive demand, i.e. the probability of actual demand during ERP being greater than $F_D + K_D\sigma_D$.

β_D = $(1 - \alpha_D)$ and describes the probability of actual demand being less than or equal to $F_D + K_D\sigma_D$.

Q^* = ERP Requirement Quantity and is equal to $F_D + K_D\sigma_D +$ lead-time safety stock.

ROQ = Actual Reorder Quantity.

ROL = Reorder Level; i.e. that quantity which the stock level must fall to or below before stock replenishment action is taken.

P = Current forecast-period and is equal to the calculated ERP.

P-1 = Forecast-period immediately prior to period P.

P-2 = Forecast-period immediately prior to period P-1.

F_P = Demand forecast for period P.

D_P = Actual demand in period P.

α = Smoothing Constant used in calculating forecasts of demand.

MAD = Mean Absolute Deviation.

e_P = Demand forecasting-error for period P.

$|e_P|$ = Absolute value of forecasting-error for period P.

$\bar{e}_P$ = Smoothed Mean Error of demand forecasts calculated for period P.

M_P = Value of Mean Absolute Deviation of demand forecasting-errors calculated for period P.

δ = Smoothing Constant used in calculating $\bar{e}_P$ and M_P .

T_P = Trigg's Tracking Signal for period P.

$|T_{P-1}|$ = Absolute value of the Tracking Signal for period P-1.

α_P = Value of α for period P.

α_1 = Fixed value of α used in the tracking routine ('first forecasting routine') of forecasting models 3,4 and 5.

α_{2P} = Variable value of α used in the actual forecasting routine ('second forecasting routine') of forecasting models 3,4 and 5, calculated for period P.

L = Statistical Confidence Limit used in testing absolute value of Tracking Signal for statistical significance.

N = Number of forecast periods.

σ_e^2 = Variance of forecasting-errors.

σ_e = Standard Deviation of forecasting-errors.

AC_e = Autocorrelation Coefficient of forecasting-errors.

PA_{P-1} = Actual length of period P-1.

DA_{P-1} = Actual demand occurring in period P-1, where P-1 is in this case considered as being of length PA_{P-1} .

$\overline{DR}_{P-1}$ = Actual average demand rate for period P-1, where P-1 is in this case considered as being of length PA_{P-1} .

EBQ = Economic Batch Quantity.

A_D = Forecasted annual demand.

C_R = Total ancillary cost actually incurred, independently of replenishment quantity, as a result of generating a stock replenishment order.

q^* = EBQ assuming demand is constant.

H_C = Holding cost/unit of storage/year.

R = Average Stock Holding Ratio.

$\bar{Q}^*$ = Average ERP Requirement Quantity.

N_R = Number of stock replenishments per year.

N_R^* = Economical number of stock replenishments per year.

$E(HC_D)$ = Expected holding cost associated with carrying demand safety stock.

D' = Current average demand-rate.

$E(K)$ = Partial Expectation for a (0,1) Normal distribution.

$E(K_D)$ = Partial Expectation relating to (0,1) Normal distribution of demand forecasting-errors.

D'' = Average excess demand-rate.

$E(SC_D)$ = Expected stockout cost associated with carrying demand safety stock.

C_H = Holding cost/unit of storage/unit time

C_{SO} = Stockout cost associated with the loss of sale of one unit of storage.

$E(TC_D)$ = Expected total cost associated with carrying demand safety stock.

$E(TC_D)^*$ = Minimum expected total cost associated with carrying demand safety stock.

F_{LT} = Forecast of stock replenishment lead-time.

K_{LT} = Standard Normal Deviate relating to the Normal Probability distribution of lead-time forecasting-errors.

σ_{LT} = Standard Deviation relating to the Normal Probability distribution of lead-time forecasting-errors.

$K_{LT}\sigma_{LT}$ = Lead-time safety stock.

α_{LT} = Probability of stockout due to excessive stock replenishment lead-time; i.e. the probability of actual stock replenishment lead-time being greater than $F_{LT} + K_{LT}\sigma_{LT}$.

$E(HC_{LT})$ = Expected holding cost associated with carrying lead-time safety stock.

$E(SC_{LT})$ = Expected stockout cost associated with carrying lead-time safety stock.

$E(K_{LT})$ = Partial Expectation relating to (0,1) Normal distribution of lead-time forecasting-errors.

$E(TC_{LT})$ = Expected total cost associated with carrying lead-time safety stock.

$E(TC_{LT})^*$ = Minimum expected total cost associated with carrying lead-time safety stock.

SL = Current Free Stock Level.

B = Current backorders.

U = Anticipated usage (demand) during stock replenishment lead-time.

Glossary of Terms

(Listed in Order of Reference)

Transhipment	The transfer of goods from one vehicle to another for final distribution to customers.
Simple Blends	Finished products whose manufacture requires only a few raw materials (e.g. two or three), no application of heat and one to three hours for completion.
Ordinary Blends	Finished products whose manufacture requires the application of heat, generally three to five hours for completion and usually involves more raw materials than for Simple Blends.
Complex Blends	These differ from Ordinary Blends only in that manufacture involves a chemical reaction between the raw materials and, as a result, require carefully controlled conditions, in particular the control of temperature. Such products are thus normally manufactured in a reactor.
Spirit Blends	These are finished products with a low 'flash point' (i.e. they can ignite at temperatures less than 120°F/49°C) and include, for example, white spirit and Kerosene. Such products require special equipment for manufacture as well as a controlled work area environment. The quantities manufactured of these products are generally smaller than those for the three groups previously referred to.
Annual Usage Value (of a stock-item)	Forecasted annual demand for stock-item multiplied by the stock-item's prime cost (i.e. production labour cost, raw material cost and manufacture cost).

Stockout	A stock situation where the customer requirement (demand) exceeds the quantity of free stock held.
Overshoot	Where applicable,overshoot describes the extent to which the free stock level is taken below the reorder level as a result of a demand transaction that triggers replenishment.
Backorder	A customer's order for which there is no stock available immediately but which will be <u>retained</u> within the system until sufficient stock is provided.
Stock depletion	This refers to a system whereby customers are provided with a suitable quantity of stock, at their own premises, for which they donot initially pay but are instead charged as the stock is used.
Real-time	The term real-time describes the technique of updating computer files with transaction data immediately (or, in practice, as soon as possible) the event to which it relates occurs. Hence, a real-time computer system is communications orientated and provides for random enquiries from remote locations with instantaneous responses. Such a system may thus be considered at all times as being 'live' and always available for use.

Chapter 1

Introduction

1 Introduction

1.1 Edgar Vaughan & Co. Limited

The company was originally founded by Thomas Edgar Vaughan in 1889 and initially manufactured paints and general engineering supplies. However, the gradual increase in the usage of oil products within the industry played an increasing part in Vaughan's product range, culminating in the management of an official agency operation for E. F. Houghton & Co. of Philadelphia, U.S.A., in 1912. The association with Houghton strengthened until, eventually, the U.K. manufacture of Houghton products was taken over completely by Edgar Vaughan & Co. Limited, including their Trafford Park works, in exchange for 50% of Vaughan's equity. This immediately made Edgar Vaughan part of an international association of companies, with all the attendant commercial and technical resources.

From sales of approximately £½ million in 1950, the company developed to one having sales of around £9 million in 1977/78 and employing 350 people. During this time the product line changed considerably, from virtually 100% mineral oil, to its present mix of over 800 synthetic, chemical and oil-based products. These are categorised within the company as follows:

(1) Metal Forming
(2) Metal Cutting
(3) Hydraulic Fluids and Lubricants
(4) Paper Processing Chemicals
(5) Metal Treatment

Edgar Vaughan & Co. Ltd. (henceforth referred to as 'Edgar Vaughan' or 'the company') consequently regard themselves as 'oil specialists', although it must be stressed that on no occasion do they refine oil. The manufacturing process is, instead, one that basically involves mixing together various raw materials* in a large metal vat, the required agitation being supplied by either a paddle, a revolving screw or air. Certain products frequently require, in addition, the application of heat and this is normally supplied by heat-exchanger pipes located in the base of the mixer. However, where temperature control is vital, manufacture is achieved by using a reactor.

Raw materials and finished products are stored primarily in 45 gallon barrels and in bulk storage tanks, depending upon the size and nature of demand. Smaller packages/containers of certain finished products are also stored.

Fundamentally, the company's prime sales-market comprises the requirement for specialised oil products of the type listed earlier. This is, though, supplemented by sales of more simpler products, where the order quantities involved are too small to be handled profitably by larger companies such as Shell, Esso, Texaco, etc.

The basic operational structure of the business at the start of the project was as shown in Table 1.1 and Figure 1.1.

For details of the company's basic operations-control structure see Appendix A.

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* Refined oils in their basic state

Location	Nature of Site	Facilities
Birmingham (city centre)	Headquarters	Location of Directors and majority of administrative staff; £150,000 research and development laboratories completed January 1978; ICL System Ten computer installed 1973, comprising facilities for handling sales data, associated works order documentation, account ledgers and wages.
Burntwood (Staffordshire)	Manufacture and Distribution	Established 1960, responsible for manufacturing high volume non-complex blends (see Table 1.3 for manufacturing and bulk storage facility details). Facilities also included warehouse for barrels and packages and a transport fleet of 17 vehicles.
Trafford Park Industrial Estate (Manchester)	Manufacture and Distribution	Factory operated under Edgar Vaughan's name since 1930s; manufacture primarily concerned with complex blends (see Table 1.3 for manufacturing and bulk storage facility details). Facilities also included warehouse and a transport fleet of 7 vehicles.
Paisley (Scotland)	Distribution [A very small % of manufacture carried out.]	Storage facilities plus a few very small mixers.
High Wycombe (Buckinghamshire)	Distribution	Storage facilities only.

Table 1.1 Organisation Structure of Edgar Vaughan on Commencement of Project in October 1978.

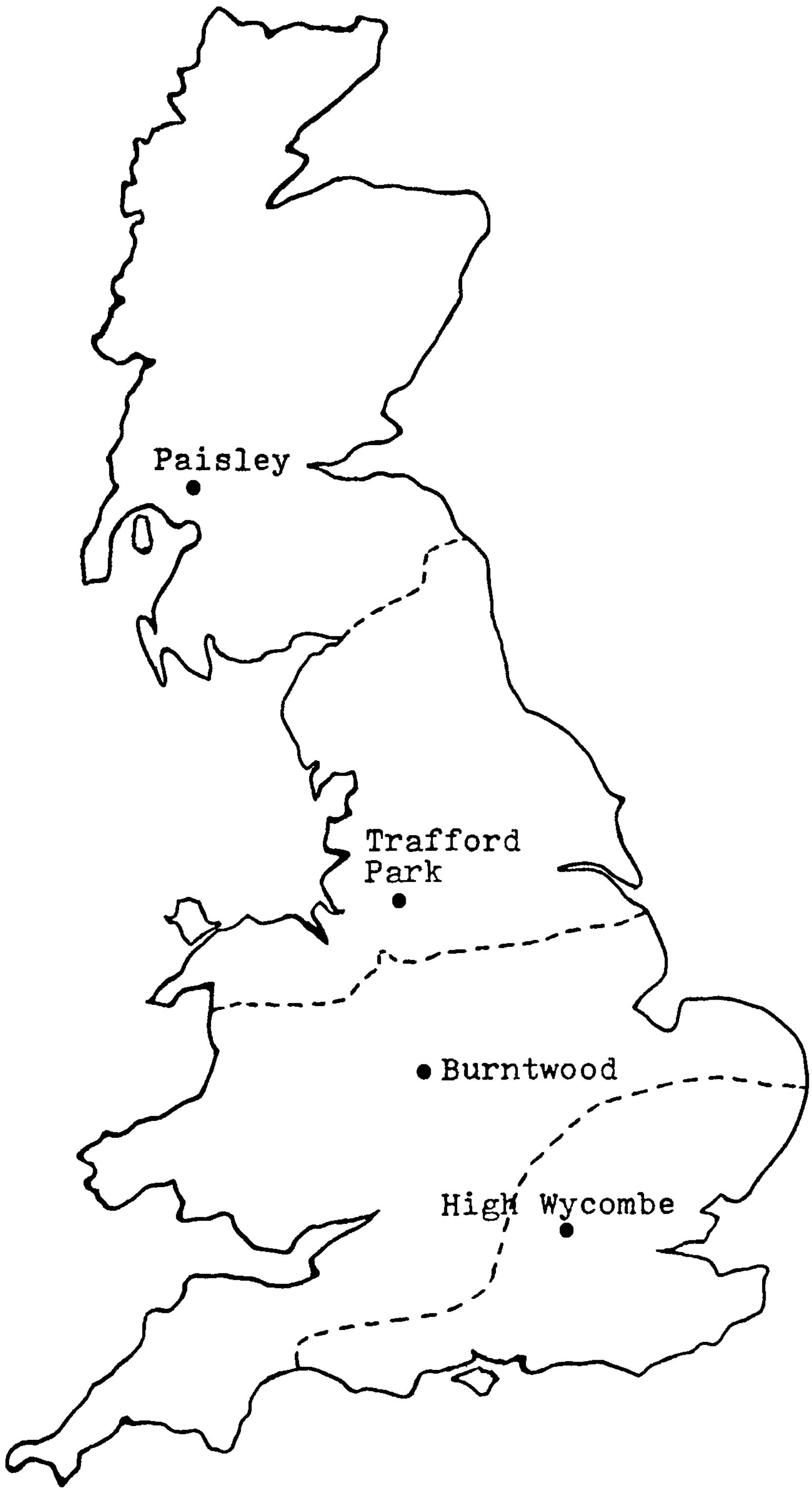

Fig. 1.1 Map Showing Edgar Vaughan's Manufacturing and Distribution Sites and the Areas Covered by Each Within the U.K. upon Commencement of the Project in October 1978.

1.2 Original Problem Statement

As the principal means of successfully competing in a market environment where the majority of their rivals are, in every respect, far larger than themselves, Edgar Vaughan continually do their utmost to meet customer requirements as quickly as possible.

Upon commencement of the project, the supply service given to their customers by Edgar Vaughan was, by consensus of the directors, felt to be a satisfactory one. However, it was feared by the company that a substantial increase in workload, based on anticipated growth in sales over the following years (see Table 1.2), would have a detrimental effect on the effficiency of the service offered.

The project's terms of reference, therefore, required the development of a financially efficient solution for maintaining, if not improving, Edgar Vaughan's overall supply service to customers, despite any upward trend in finished product sales.

1.3 Problem Investigation

To begin with, the company's proposed solution was to improve both control of its finished stocks and the method of production scheduling. However, rather than assume this solution as being appropriate/the best, it was decided initially to analyse the existing system by which customers' orders were dealt with. (Note: as a result of this analysis production scheduling was not pursued and is not, therefore, discussed in the thesis).

	1977/78 (Actual)	1981/82 [Four Year Forecast]
Sales (weight)	24,000 tonnes	33,000 tonnes
Sales (value)	£8.25 million	£19.5 million
Gross Contribution	£2.55 million	£6.24 million
Profit before Tax	£0.74 million	£1.95 million
Capital Employed	£2.55 million	£4.50 million
<u>Ratios</u>:		
Gross Contribution to Sales	31.0%	32.0%
Profit to Sales	9.0%	10.0%
Sales to Capital Employed	3.2	4.3
Profit to Capital Employed	29.0%	43.0%

<u>Table 1.2</u> Edgar Vaughan's Forecasted Growth to 1981/1982, Made Towards the End of 1978.

As a starting point, and so as first to gain a 'feel' for the type of business operated by Edgar Vaughan, general familiarisation with the company took place covering each of the following areas:

- Product range
- Manufacturing techniques
- Operational structure
- Management organisation structure
- Company history
- Recent development
- Plans for the next 5 years

The actual supply service received by customers was also examined. This was accomplished by randomly choosing 100 completed orders for 1977/78 and plotting the associated data as shown in Figure 1.2. Unfortunately, it was not possible to obtain values of actual lead-time requested by the relevant customers. Nevertheless, on the basis that it was reported that most customers were agreeable to a delivery lead-time of less than two weeks, the results were considered to show the directors' original appraisal of the total supply service to be reasonably accurate.

Upon completion of the above, the system analysis proper was commenced by examining the sales procedures carried out at the company's headquarters in Birmingham. This was later supplemented by extended visits to both the main manufacturing and distribution sites, located at Burntwood and Trafford Park. During such visits, manufacturing and auxiliary facilities were examined and the procedures for the processing of orders established. Stock control procedures at both sites were also analysed.

Actual Lead-Time (A.L.T.) (including w/ends)	% of Orders with A.L.T. Shown	Cumulative % of Orders with A.L.T. > that Shown
1	zero	100
2	7	93
3	6	87
4	10	77
5	8	69
6	10	59
7	4	55
8	4	51
9	4	47
10	8	39
11	3	36
12	2	34
13	5	29
14	5	24
15	2	22
16	4	18
17	1	17
18	zero	17
19	1	16
20	1	15
21	2	13
22	1	12
23	zero	12
24	zero	12
25	2	10
26	zero	10
27	zero	10
> 28	10	zero

Table 1.3 Details of Order Sample Used in Determining Supply Service to Customers for 1977/78

[Note: The number of orders chosen (i.e. 100) represents approximately a 5% sample of the total number of orders in the system for any one month during 1978]

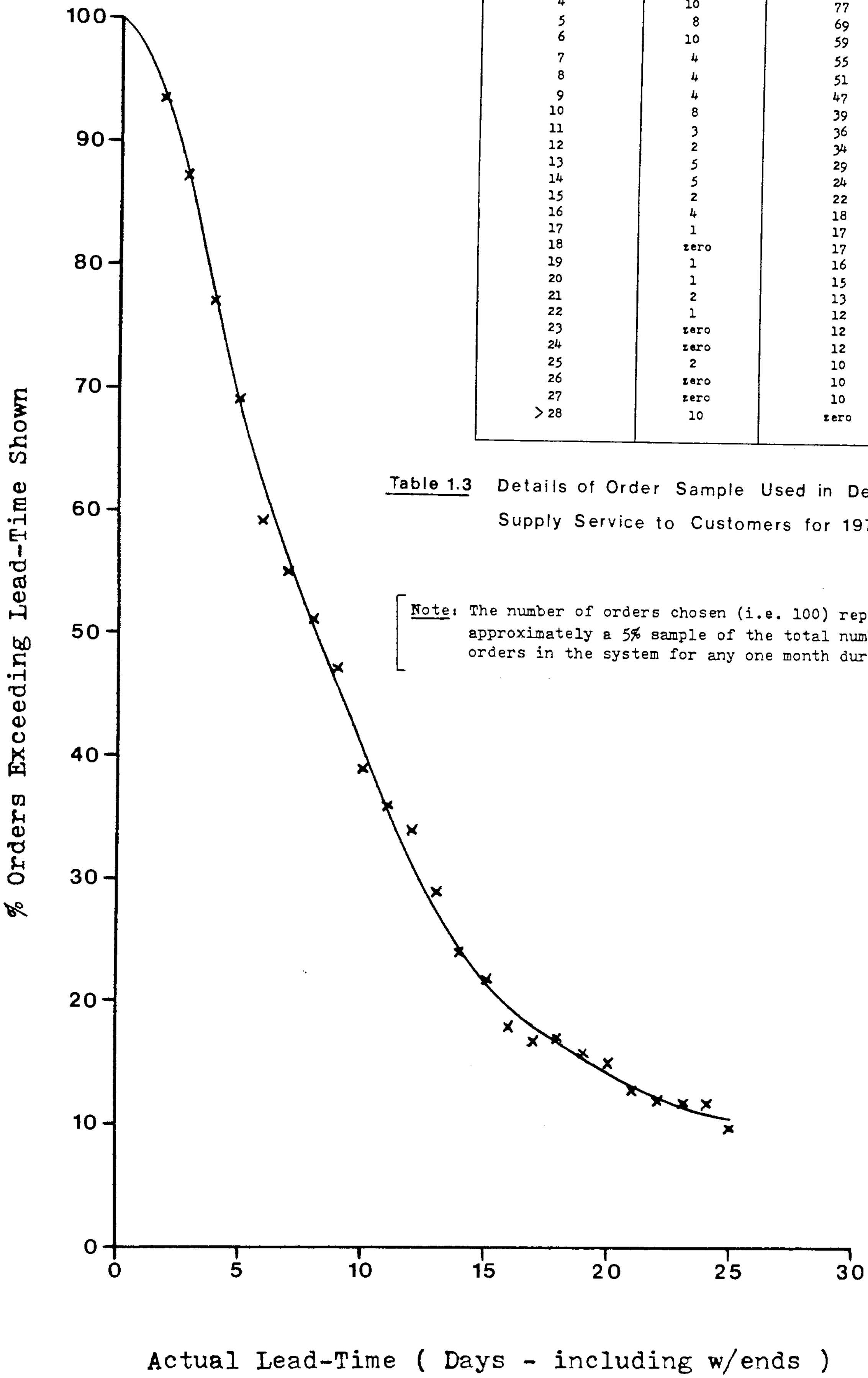

Fig.1.2. Graph Showing Supply Service to Customers for 1977/78

In view of the distance of the two manufacturing sites from the company's headquarters, two detailed system write-ups were produced as a more convenient source of reference (see Appendices N and P). Copies of the write-ups were, however, first given to both Works Managers and to certain other members of staff for validation.

1.4 Overall Method of Solution

In an attempt to obtain the best solution, all methods of potentially maintaining/improving the supply service to customers were listed as shown below and the suitability of each objectively assessed:

(1) Speed up production process, e.g. increase mixer-motor speeds; increase number of bulk raw material delivery pumps; increase filling speeds by improving filtration methods or by employing more fillers, etc.; improve material-handling; etc.

(2) Increase capacity.

(3) Provide better method of scheduling orders.

(4) Improve order-processing procedures.

(5) Provide better method of stock control.

(6) Provide better day-to-day distribution procedures.

(7) Increase size of tanker fleet (carry out analysis of present tanker movements and loads).

(8) Revise factory layout.

(9) Increase warehouse capacity (Edgar Vaughan was to be ultimately advised on this matter by PW International).

(10) Adopt completely different manufacturing method (this was being examined by the company itself at the time).

(11) Completely change distribution set-up (this was being examined by PW International at the time).

(12) Implement a combination of the above recommendations.

Although each method offered potential for handling a larger work-load, investigation at works level showed the basic systems operated at the two plants to be markedly inefficient. The main criticism was that owing to there being very little control of finished stocks, customers' orders were dealt with largely on a 'make-to-order' basis. This had the effect of:

(1) Placing a heavy work-load at times on the manufacturing equipment available;

(2) frequent revision of production schedules;

(3) poor utilisation of manufacturing capacity (analysis showed utilisation per mixer to be less than 60% for approximately 50% of the orders dealt with).

Other criticisms were:

- Insufficient information at the production scheduling stage regarding raw material availability.

  [The above resulted in the need to revise the production schedule and order raw material several days after receipt of the customer's order.]

- Insufficient control of raw material stock.

- Inefficient order-processing procedures.

- Lack of concise performance/management information required for effective overall control.

- Different documentation/procedures used at the two manufacturing sites.

The sales procedures at the company's headquarters were, in the main, computerised and appeared quite efficient.

In view of the findings of the system investigation, the improvements put forward to Edgar Vaughan as being the most needed for future operation were:

i) Provide a better method of stock control at the Trafford Park and Burntwood sites for both finished products and raw materials.

ii) Improve and standardise order-processing procedures at each of the aforementioned sites.

Further it was felt that the new systems associated with (i) and (ii) must be designed for operation on a computer. The reasons offered as justification were as follows:

(A) So as to divorce the direct and disruptive effect of customer demand from production scheduling and manufacture, with the aim of making both easier and more efficient, the company should operate an 'off-the-shelf' service for nearly all items of stock. To obtain such a supply service would require precise control of stocks on an individual stock-item basis. It was argued that this could only be achieved realistically, in dealing with over 1,400 stock-items (raw materials and finished products), by using a computer-operated scientific stock control model incorporating a demand forecasting routine.

(B) For the stock control model described under (A) to work efficiently in practice, it was further argued that it must be an integral part of a computerised order-processing/stock monitoring* system.

(C) Bearing in mind the size of Edgar Vaughan's rivals; the company's plans for growth; and the trend of moving towards real-time computer systems in industry as a whole; it was considered that the majority of the procedures associated with handling a customer's order would ultimately have to be computerised for the company to remain competitive.

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* [The difference between the role played by the scientific stock control model and that of the stock monitoring aspect of the order-processing system is made clear in Appendix B.]

Both recommendations were accepted by the company and, in principle, by the academic supervisors. Nevertheless, it was stressed by the latter that although recommendation (ii) was of importance to Edgar Vaughan and a vital prerequisite to the actual implementation of the stock control model, the design of an order-processing/stock monitoring system would be unlikely to provide the basis for original research work.

In contrast, however, the practical requirement for a scientific stock control model was regarded as offering adequate scope for making a "... useful and original contribution to knowledge"*.

The initial assessments of each recommendation's research potential were in practice proved correct. The thesis is, therefore, fundamentally given over to the Scientific Stock Control Methodology developed, as it is this on which all original research work of significance was completed.

Description of the order-processing/stock monitoring system, designed prior to commencing work on the stock control methodology, is confined to Appendix B.

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* [Extract from the University's ' Regulations and Procedures for Higher Degrees by Research '.]

1.5 Change in Company Structure and the Effect on the Project

A little over a year after the commencement of the project (December 1979), Edgar Vaughan purchased an additional manufacturing site (referred to as the 'Barton site') from Gulf Petroleum Limited. This was located approximately half a mile from the Trafford Park Industrial Estate, Manchester, and was considerably larger and different in appearance to the two existing manufacturing sites. The difference was particularly noticeable in the size of some of the blending equipment and bulk storage tanks available, when compared with those used previously by Edgar Vaughan (see Table 1.3).

The purchase was made largely as a result of the findings of the consultancy firm Planned Warehousing International (more popularly referred to as PW International). This company had been employed earlier by Edgar Vaughan to examine their distribution network, with the prime aim of determining whether it should remain 'decentralised', or be changed to a 'centralised' arrangement.

Following the use of their own computer simulation package, to test both approaches with data relating to Edgar Vaughan, PW International concluded that centralised distribution appeared the most cost-effective.

Further operational changes, influenced by the results of the simulation tests, are listed on page 18:

Company Site	Manufacturing Capacity Qty.		Manufacturing Capacity	Bulk-Storage Capacity Qty.		Bulk-Storage Capacity
Trafford Park (1978)	1	x	12 tonnes	3*	x	54 tonnes
	5	x	10 "	5	x	36 "
	4	x	6 "	4*	x	27 "
	1	x	5 "	1	x	18 "
	1	x	3.5 "	4*	x	14 "
	1	x	3 "			
	4	x	2 "			
	1	x	1.5 "			
	1	x	1 "			
	5 various < 1 t'ne					
Total:	≏ 103 tonnes			108.5 tonnes		
Burntwood (1978)	1	x	10 tonnes	1	x	400 tonnes
	3	x	7 "	3	x	48 "
	2	x	4.5 "	1	x	32 "
	2	x	2 "	1	x	28 "
	1	x	1 "	6	x	20 "
				10	x	16 "
				2	x	14 "
				1	x	10 "
				4	x	6 "
Total:	45 tonnes			946 tonnes		
Barton [At Time of Purchase]	1	x	275 tonnes	1	x	4500 tonnes
	6	x	30 "	2	x	2500 "
	10	x	10 "	10	x	1000 "
	12	x	5 "	2	x	660 "
				6	x	550 "
				2	x	500 "
				1	x	375 "
				1	x	350 "
				8	x	275 "
				9	x	50 "
				1	x	36 "
				10	x	26 "
				4	x	20 "
				20	x	18 "
Total:	615 tonnes			29,231+ tonnes		

+ [Note: Approximately 12,500 tonnes, at the time of writing, was rented out to other major oil producers.]

* Compartments of one bulk storage tank.

Table 1.4 Comparison of Manufacturing and Storage Capacities of Edgar Vaughan's Manufacturing Sites.

(1) All blending previously carried out at the Burntwood site was transferred to the Barton location by June 1980, along with most of the blending equipment.

(2) The Burntwood site was retained and serves principally as a distribution/trans-shipment* point for deliveries to the south.

(3) Manufacture of certain products originally made at the Trafford Park site was also transferred to the Barton location. The Trafford Park site, however, remains primarily responsible for the manufacture of complex blends*.

(4) High Wycombe site sold; Paisley site sold at the end of 1981.

(5) Distribution to northern customers is now dealt with by the Barton site in conjunction with contract distributors.

Fortunately, the changes in the business structure had little effect on the basic design concept of the order-processing/stock monitoring system, the work on which was completed just prior to the Barton site being purchased. However, it was clearly necessary that the exact details of the original design would have to be modified, particularly as it was requested by the company that the entire new system be installed at the Barton site. Although this required more thought to be applied to new daily methods of operation, it did allow better opportunities to improve

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* see Glossary of Terms

order-processing procedures as there were no 'current practices' to be changed. A revised system design was completed without too much difficulty, following the return from five months sabbatical leave taken whilst the company established precisely its new overall operational strategy.

Chapter 2

Scientific Stock Control

2 Scientific Stock Control

2.1 Introduction

The phrase 'Scientific Stock Control' describes a subject area concerned with the efficient control of inventory, ultimately within a business or organisation, through the development and use of mathematical formulae commonly referred to as 'Scientific Stock Control Models'. The principal objective of such 'models', as with any stock control methodology, is that of determining how much stock should be held of a particular item and when replenishment should occur. More specific objectives relate to system-operating cost or service performance to customers. Stock control models attempt to achieve their objectives by first providing a logical-mathematical representation of the inventory problem under consideration. In this way controlling parameters may subsequently be calculated.

The need for a scientific approach to the task of controlling inventories is covered by many text-books (refs. 1, 2 and 3) but can be partially appreciated by examining Figure 2.1. This shows that the inventory problem is very complex and embraces many business aspects. Certainly in the case of Edgar Vaughan, it was clear that all aspects shown in Figure 2.1 would require consideration and that selection of a scientific stock control model for the company would be crucial.

For the purpose of providing a background to the scientific stock control methodology developed for Edgar Vaughan, prior mathematical approaches to inventory control are discussed in relationship to the company in the following sub-sections.

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Fig. 2.1 The Inventory Problem (Reproduced from Ref. 4)

2.2 Basic Stock Control Policies

There are five general stock control policies that may be operated almost independently of the type of analytical technique used in setting control values:

1. The Reorder Level Policy

This policy is one in which a fixed replenishment order is placed when the quantity of 'free*' stock held, plus any free stock quantity on order, falls to or below a predesignated level of stock referred to as the 'reorder level'. In this policy, therefore, the quantity of free stock held must be reviewed following every demand transaction.

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* [Stock available for allocation to customers' orders, having taken into account any 'backorders' (see Glossary of Terms for definition of backorder).]

The most basic application of the reorder level policy is the 'two-bin' system. This consists of the physical division of stock into two convenient amounts and may involve two containers or separation of one storage unit into two compartments. The system is then worked by usage being restricted to the one bin/container/compartment and when empty a replenishment order is placed. The remaining stock is used to satisfy demand during the replenishment lead-time.

The two-bin system is simple and can thus be operated easily. Further, it lends itself to situations where continual precise monitoring of stock quantities would be difficult/time consuming. The system is, consequently, ideal for physically small items, such as: nuts, bolts, washers, etc.

2. The Reorder Level Policy with Periodic Peviews

As already stated, the reorder level policy generally requires that stock quantities be reviewed after every demand transaction. However, this is not always possible, particularly when running a manual system for a wide range of stock-items, some of which are held in different locations. Under such circumstances, a reorder level policy with periodic reviews may be more suitable.

The manner of operation is that the review of stocks occurs only when a fixed period of time has elapsed. At this point, should the existing free stock quantity, plus any free stock quantity on order, be found to be equal to or less than the stated reorder level, a replenishment order for a fixed quantity is generated.

3. The Reorder Cycle Policy

This too is a policy in which stock quantities are reviewed periodically. However, it differs from the previous policy described in that there is no reorder level and the size of replenishment orders may vary. What happens instead is that a replenishment order is raised at every review, that is equal in size to the difference in the free stock quantity remaining (plus, once more, any free stock on order) and that of some fixed precalculated quantity 'S' (i.e. a maximum stock level figure).

4. The s, S, Policy

This is almost identical to policy No. 3, the one difference being that when stock is reviewed periodically a replenishment order is raised only if the remaining free stock quantity, plus any free stock on order, is found to be equal to or less than a fixed reorder level 's'. The quantity ordered, under such circumstances, is then calculated as described for policy No. 3.

Note:

When applying periodic review policies 2, 3 and 4 in practice, it is suggested that a worthwhile modification is to also examine stock levels following unusually large demand transactions. In doing this, greater safeguard is made against running out of stock as a result of such isolated peaks in demand.

5. The Combined Reorder Level and Reorder Cycle Policy

Although both the reorder level policy with periodic reviews and the 's,S' policy are variants of the two basic policies (i.e. the reorder level policy and the reorder cycle policy), Lewis (p9, Ref 1) suggests that there is a fifth general control policy that combines the first two. This is a policy whereby stock replenishments are governed by both a fixed review period and a fixed reorder level. Consequently, a replenishment order may be generated either when stock is reviewed on a periodic basis, the quantity ordered being calculated as described for policies 3 and 4, or it may be triggered by the reorder level between stock reviews. In the latter instance the replenishment order should, logically, be fixed but Lewis states that this varies in the same manner as do replenishments that are placed at each periodic review.

It is considered that the above policy would be of little practical value in most cases, unless dealing with extremely important stocks, or stocks that may deteriorate; examples being drugs and blood held in a Blood Bank. The reason is that because the policy employs, in part, a reorder level, the implication is that stock quantities must be examined following each demand transaction. Consequently, assuming the reorder level is fundamentally correct, the additional use of periodic reviews would, for most applications, be superfluous.

In the case of Edgar Vaughan, because demand is often random (see Appendix C), it was felt that stocks must be examined immediately quantities altered as a result of a demand transaction. Further, so that sufficient stock remained to cover replenishment lead-time, it was also decided that the timing of replenishment orders would be best controlled by a precalculated reorder level. For these reasons, the reorder level policy (policy 1) was chosen, in principle, as the basic approach to controlling stocks within the company.

Review policies 2, 3 and 4 were considered to offer inadequate control in dealing with the type of demand experienced by Edgar Vaughan.

Finally, for the type of stocks in question, the periodic review feature of policy 5 was felt to be an unnecessary supplement to the basic policy agreed upon.

2.3 Analytical Approaches to Stock Control

2.3.1 Deterministic Stock Control Models

In a deterministic model, it is assumed that the values of all parameters of the inventory system are known at every point in time. For example, there is no uncertainty about demand in any week or the lead-time necessary to replenish stock. One has perfect knowledge of their values. In addition, it is often assumed that the values do not change from period to period; i.e. demand occurs at a constant rate over time; the replenishment quantity is the same every time it is called upon and the lead-time is constant.

The most fundamental of the deterministic models is the Economic Order/Batch Quantity Formula, frequently referred to as the 'EOQ' or 'EBQ Formula' (Ref Appendix D). The earliest derivation of this formula, as well as being the first recognised reference to the use of mathematics in the field of stock control, was by Ford Harris of the Westinghouse

Corporation in 1915 (Ref 5). At that time, however, the formula was referred to as the 'Simple Lot Size Formula'. This same formula was developed, apparently independently, by many individuals after that date and is sometimes known as the 'Wilson Formula', since it was also derived by R. H. Wilson in 1929 (Ref 6). Unfortunately, the model has several weaknesses, as many of the assumptions made in the development of the model rarely exist in practice. As a result, criticism of this model is extensive (e.g. Refs 7, 8 and 9).

Nevertheless, because the development of the EBQ Formula is the simplest to understand and is basic in its approach, it is the one most commonly used in providing an initial insight as to how the problem of stock control can be dealt with through the use of mathematical modelling. For the same reason, and despite the model's weaknesses, it is the formula most used by the relatively few computer packages/practical applications of scientific stock control; respective examples being Hoskyns' 'Inventory Control' package and the computerised spares provisioning system within Lucas Aerospace Limited, Birmingham.

In an effort to refine the model's representation of the real world, extensions of the EBQ formula have been developed that cater for quantity price-discounts (price-breaks), lost sales, etc. (Ref 2). All models, however, continue to make the basic assumptions that demand-rate and stock replenishment lead-times are known and are, in most cases, constant.

Owing to the above assumptions being invalid in the case of Edgar Vaughan (see Chapter 3), all deterministic models were considered unsuitable for use by the company.

2.3.2 Stochastic Stock Control Models

It was not until after World War II, when management science and operational research emerged, that detailed attention was focused on the stochastic nature of inventory problems. As a result, several stochastic/probabilistic stock control models exist today which, by their very nature, recognise that demand and lead-times are unlikely to remain constant in the real operating environment.

Nearly all models of the above type rely on the assumption of steady-state demand, that can be described in total by a recognised frequency distribution such as Poisson, Normal, Log-Normal, etc. The assumption is also extended sometimes to replenishment lead-time.

The significance of the assumptions described is that, because variability in demand and lead-time can be mathematically represented, values of both parameters no longer have to be considered constant. Such an assumption is quite acceptable when considering, for example, most consumer goods. The reason is that demand is made up of a <u>very large number</u> of <u>similar</u> individual demands, the effect of which is one of stabilising the shape of the total demand frequency distribution in relation to time. Thus, it permissible to regard it as being stationary.

However, although stock control models of the above type more closely approach realism, the assumption that values of demand and lead-time respectively form standard stationary distributions is not always true. Certainly when dealing with finished products such as those sold by Edgar Vaughan and, in turn, their raw materials, demand is unlikely to be as stable. This is because demand is made up from few customers,whose needs may vary substantially along with their ordering pattern. Subsequent analysis, discussed in Chapter 3, showed this in fact to be the case and that demand patterns were not only random but at times also displayed trends. For this reason, it was decided that stock control models based on assumptions of stationarity in demand could not be used in controlling stocks belonging to Edgar Vaughan.

Not all stochastic stock control models, though, rely upon the assumption of steady state demand and lead-time. There are a few that make use of the operational research technique called 'dynamic programming'. Briefly, this is a multi-stage analytical technique that, by means of an iterative process, considers the cumulative effect of each possible decision that might be taken at each stage of the problem (Ref 10).

Unfortunately, the methodology would be intractable if applied to most real stock control problems, particularly those involving a wide range of stock-items, as in the case of Edgar Vaughan. As a consequence, the stock control models employing this approach are designed for simple stock control problems and are themselves often mathematically complex (Ref 11 and 12). The use of dynamic programming was thus disregarded as a possible solution to the company's stock control problem.

2.3.3 Materials Requirements Planning

Materials Requirements Planning, more commonly referred to as 'MRP', is not in the strict sense a scientific stock control methodology as it does not involve analysis, hypothesis nor the formulation of mathematical models as a means of solving the general inventory problem. It is, nevertheless, included in this Chapter since it is now a well recognised method of controlling stocks within certain types of business/organisation and, by its systemised approach, may be considered as being somewhat scientific. This appears to be a commonly accepted view, as the subject of MRP is frequently included in both operations management text-books and research papers reviewing the literature on scientific stock control (Ref 13, 14,15 and 16).

The ultimate objective of MRP is the efficient control of both stocks and production scheduling and involves establishing precise total stock requirements over a period usually no smaller than six to twelve months. In order to obtain the precision mentioned, at all levels of stock, (i.e. finished product, assemblies and raw materials) MRP relies upon the vital prerequisite of knowing in advance how much will be required of the final product and when. Given this 'Master Production Schedule', the technique involves working backwards through the relationships between raw materials, components and various levels of assemblies to produce accurate discrete stock requirements.

As implied, practical application of MRP requires prior knowledge of demand, that needs to be described in both terms of quantity and timing. Moreover, for MRP to be successful, such knowledge has to be extremely accurate. The reason is that in cases of stock-item dependency, often certain components/raw materials are common to more than one product/ assembly/sub-assembly. Any errors, therefore, in the demand values used for parent stock-items may accumulate when calculating discrete component/raw material stock requirements. Use of this technique is thus restricted to those types of business/organisation where demand is either stated in advance by the customer (e.g. the car industry, the aircraft industry, etc.), or the market demand can be predicted/forecast with a great deal of accuracy (e.g. colour televisions, electric mowers, alcoholic beverages, etc.).

In view of the nature of their business and the diversification of products sold, Edgar Vaughan does not fall into either of the above categories and, as a result, MRP was regarded as an unsuitable means of solution.

2.3.4 Coverage Analysis

Coverage Analysis (Ref 1) is designed for use in a multi-product system, the objective of the technique being to reduce stock investment capital whilst ensuring that the overall number of stock replenishments remain unchanged. It differs from most scientific stock control models in that it does not readily provide continuous control of stocks. Instead, it is best suited for 'once only' application.

As part of the technique's approach, the number of replenishments per year for a stock-item is made proportional to the square root of the item's annual usage value*, subject to certain constraints. In spite of the fact that the exact methodology would require a more extensive explanation, practical application is simple, regardless of the computer-facilities available. Further, several applications of Coverage Analysis have shown up to 30% reductions in invested capital and very few recorded with less than a 20% reduction.

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* see Glossary of Terms

Although the evidence quoted shows Coverage Analysis to be successful in achieving its objective , the technique is one that requires cautious use. For example, following application each stock-item has a fixed replenishment order quantity; this is considered acceptable only in cases where demand is constant or forms a stationary frequency distribution. In addition, the technique relies heavily upon the total number of replenishments placed per year being 'appropriate' to begin with. Such an assumption was felt to be dubious for most practical applications.

Finally, the most serious criticism of Coverage Analysis is that it does not at any time give regard to the service offered to customers. As stated in Chapter 1, maintaining a good supply service to customers is a vital factor of Edgar Vaughan's success in the oil/chemical product market and must be retained in any new system. For this reason and those criticisms made earlier, the application of Coverage Analysis was not pursued.

2.3.5 ABC Analysis

The originator of this popular analytical technique was the 19th century philosopher Vilfredo Pareto and it is for this reason that it is also referred to as Pareto Analysis. Pareto developed the technique following his observation that the majority of the nation's wealth was owned by a minority of its people. Originally confined to economics, it was only many years later that it was discovered that the same type of relationship is often true of stocked-items; i.e. a small percentage of items can represent the majority of a company's sales turnover. Where this is the case, the entire 'percentage of annual sales turnover' to 'percentage of total stock' relationship would, if plotted, approximate to the graph in Figure 2.2. The technique when applied to stock-items thus requires each item's contribution to turnover to be calculated. Upon completion, stock-items are listed in descending order of contribution and then categorised into three groups labelled A, B and C, in the manner shown in Figure 2.2. However, the values that decide the category boundaries do not have to be the same as those illustrated and can be

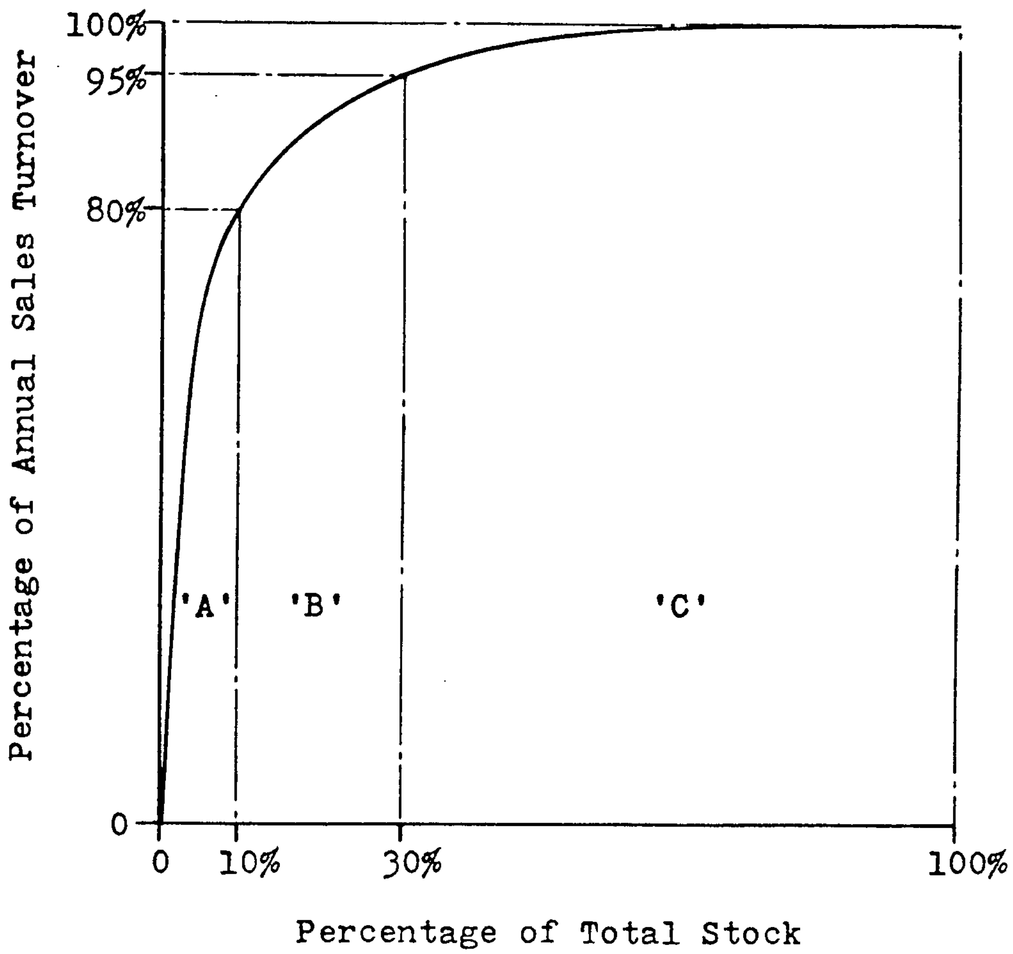

Fig. 2.2 The Pareto Curve

Having established which items belong in each category, the technique then proposes three levels of control:

Category 'A' Stock-items - These are high sales value items that require tightest possible control regarding accuracy of records (or data files), costs, and forecasts of demand and replenishment lead-time.

Category 'B' Stock-items - These are medium sales value items for which less rigid control may be exercised.

Category 'C' Stock-items - These are low sales value items for which simple control methods are acceptable.

Classification of stock in this way can be extremely useful where a company's stock range is large, a manual system is operated and resources would be stretched to exercise rigid control on all stock-items.

Where there is a computerised system it is as easy to control all stock-items in a rigid manner as it is to restrict such control to high or high and medium sales value items. Consequently, the commercial availability of micro and minicomputers, at a reasonable cost level, has caused the usefulness of ABC Analysis of stocks to diminish. However, it is still worth applying the technique where identical stocks are held at different locations and, as a result of a capital expenditure constraint, computer facilities are restricted to one location.

Since none of the above circumstances existed within Edgar Vaughan, ABC Analysis was regarded as not being useful for the company's stock control problem.

2.4 Literature Review

2.4.1 Introduction

The amount of research and literature relating to scientific stock control is enormous. A review by Lamkin (Ref 17) showed that between 1954 and 1965 alone, approximately 400 research papers were produced. Discussion of all individual papers available would thus constitute a mammoth task and would, for that matter, serve little purpose in the case of this thesis (see sub-sections 2.3, 2.4.2 and 3.1). Such research is, therefore, examined under the headings shown below, concentration being given to research of either general interest, or specific interest regarding the stock control problem as it existed within Edgar Vaughan:

2.4.2 Pure Analytical Literature

2.4.3 Practical Applications

2.4.4 Surveys of Literature

2.4.2 Pure Analytical Literature

The phrase 'pure analytical' refers, in this instance, to research literature that does not include the testing of hypotheses/the stock control models developed, either by practical application or by simulation.

The majority of the literature falls into the above category and includes both papers on stock control models and ones that confine themselves to specific aspects of scientific stock control; e.g. variable lead-time (Ref 18, 19 and 20); calculation of safety stocks (Ref 21 and 22); definition of customer service levels (Ref 23 and 24); and so on.

With specific regard to papers concerned with the control of liquid stocks, such as in the case of Edgar Vaughan, only one was found (Ref 25). However, the methodology described does not concern itself with stock control in the more recognised sense; i.e. the determination of on-going replenishment control parameters. Instead, the authors restrict analysis to a two-product, three-storage tank problem, with the objective of obtaining a general solution for scheduling shared storage. The problem is made easier by assuming demand and production rates to be constant and known, and that of the three storage tanks available, two are permanently allocated to the two products in question. The third tank represents the shared storage referred to. Analysis is made throughout the paper by primarily representing various aspects of the problem in a geometric manner as shown in Figure 2.3. The variables used are defined as follows:

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Fig. 2.3 Graphical Representation for Sheduled Sharing of Storage (Reproduced from Ref. 25).

As a basic explanation of Figure 2.3, the demand/replenishment pattern for product i is presented in a 'conventional' manner, constructed from the base line i. S_i represents the tank permanently assigned to product i, and S_s is available for use on a scheduled sharing basis. Therefore, the maximum inventory storage available to product i is $S_i + S_s$ and is measured upwards from the base line i. The demand/replenishment pattern for product j is inverted and constructed from the base line j. S_j represents the tank permanently assigned to this product and again S_s is available for use on a scheduled sharing basis. Therefore, the maximum inventory storage available to product j is $S_j + S_s$ and is measured downwards from the base line j.

The authors make the point that geometrical representation of the problem, in the way shown in Figure 2.3, permits greater visibility in analysing the interactions of the demand/replenishment patterns of the two products. The geometric presentation is, however, augmented by an algebraic analysis.

In general, the subsequent models and formulae developed were considered unduly complex, in view of the simplicity of the problem examined. As a result, it was felt that for a more realistic problem the methodology would be intractable. Consequently, the approach was not considered for use within Edgar Vaughan.

As for other research papers that concern themselves with the development of stock control models, these always contain assumptions regarding demand and replenishment lead-times. The most common assumptions are that demand and lead-time may be considered stationary and that the former may be described by a known frequency distribution

(Ref 26, 27, 28 and 29). In support of this approach, there are papers that solely examine the suitability of certain frequency distributions (Ref 30, 31, 32 and 33).

As stated earlier in this thesis, the assumption of stationary demand is quite acceptable for certain types of business/organisation. The assumption is, for example, true for popular consumer goods. However, it must be recognised that demand cannot always be considered stationary. Rarely do the research authors qualify their assumption by stating this fact, nor do they state the type of business/organisation for which such an assumption might be valid. Certainly in the case of Edgar Vaughan the assumption is not permissible (see sub-section 2.3.2) and, for this reason, nearly all previous recorded research was of little use in structuring a workable stock control model. Further, published research examined showed no example of a scientific stock control model that could be used in instances where demand could neither be assumed constant nor stationary.

On the basis of the above findings, it was decided that the model/methodology formulated for use by Edgar Vaughan must also be directed towards filling the gap in the research, left by other researchers/practitioners.

2.4.3 Practical Applications

As indicated in the previous sub-section, the number of research papers that discuss practical application are few. Those models/methodologies considered worthy of discussion number only four and although developed originally for different businesses to that of Edgar

Vaughan are, nonetheless, interesting if only for their practical adaptation. Each is described and commented upon in this sub-section, in reverse order of merit. Thus, that paper felt to be the most interesting is dealt with last.

The first of the four papers is by F. R. Johnston (Ref 34) and describes the stock control aspect of a computerised order-processing system, developed for a number of builders' and plumbers' merchants.

The approach is one in which the strategic stocking policy of entire groups of stock-items is set by an interactive process between management and the system itself. This is achieved by the system presenting (amongst other information) stock capital investment data and potential 'lost sales' figures for various service level options. Similar data are also presented on an individual stock-item basis for use in the buying department. Demand for each group is assumed to be adequately described by the Gamma frequency distribution.

Although interesting, the paper is not very comprehensive in describing the complete stock control system. More precisely, it does not state clearly the circumstances under which individual replenishments of items are raised nor how associated order quantities are calculated.

Finally, grouping of data, particularly when each group contains as many as 1,000 diversified items as quoted in the paper, is considered unlikely to provide suitable accuracy for efficient control of individual stock-items.

The second practical paper is by P. V. Mallya and M. K. Widnall (Ref 35) and deals with the problem of calculating economic batch quantities for manufactured parts. The company in question is Chubb & Sons Lock & Safe Company Limited.

The paper commences by pointing out the various assumptions made by much of the research literature on scientific stock control and suggests that the underlying assumption, in nearly all cases, is one of independence of demand between products. The paper goes on to say that since the majority of British manufacturing industry is involved in assembly operation, most inventory models developed are of little use. The reason given by the authors is that demands for components of an assembly are mainly generated by the demand for the parent assembly itself. Consequently, component-demands cannot be considered independent of one another. As a result, the paper recommends the use of Materials Requirements Planning (MRP), in conjunction with a forecasting routine to forecast demand for the parent assemblies. The authors continue by proposing that calculation of economic production batch sizes may be achieved through the use of a 'Least Total Cost' algorithm, which they describe.

For cases where dependency between stock-items holds true, the argument put forward by the authors is logically sound and in keeping with that generally offered in support of MRP. However, Mallya and Widnall fail to point out that such relationships between stock-items do not always exist.

A further criticism of the work under discussion relates to the fact that, in an initial case-study within Chubb & Sons, forecasts of parent assemblies were made on a month-by-month basis. Moreover, following the examination of results, consideration was given to a week-by-week forecasting arrangement. Despite claims of success in both instances by the two authors, it cannot be seen how MRP could work efficiently over such short time scales (see sub-section 2.3.3). Unfortunately, no information was given about the market environment nor the exact method of forecasting.

Moving on to the third paper, this is written by W. L. Berry et al. (Ref 36) and deals with the use of biased sampling techniques in analysing what sizes of steel coils should be kept by a company manufacturing 300 plastic-coated steel products.

The paper describes an unusual mathematical approach to the subject of holding stocks and is not scientific stock control as it is commonly recognised. This is because it does not concern itself with the continuous control of stocks but rather the strategic decisions of what sizes of steel coils to hold.

Briefly, biased sampling provides a means of determining an optimal or (more frequently) a near optimal solution, to problems of the type considered, without having to explore all possible solutions (in this instance: stock holding combinations).

Although falling somewhat outside the boundary of 'conventional' scientific stock control, this paper is very interesting and the techniques described could quite easily be applied to industries with a similar raw material-to-finished product relationship.

It is the fourth and final paper by D. Gross et al. (Ref 37): "Bridging the gap between mathematical inventory theory and the construction of a workable model - a case study", that was found to be the most interesting of all the research literature examined. The paper is unique, in that it describes a positive approach to providing practical scientific stock control within an organisation (name not given), without over-simplifying the true inventory problem. Further, it is the only paper that recognises the fact that, because demand within many businesses/organisations actually fluctuates markedly, values of reorder level (when using a reorder level policy) and replenishment quantity must 'float' for efficient control of stocks to be achieved (see sub-section 3.1). The authors also realise that, for the same reason, a forecasting routine must be included as an integral part of the total control methodology.

Since the basic approach used in formulating the stock control model presented in this thesis is similar to that used by D. Gross et al., further comments on the paper's content and the merits of the model described are reserved for sub-section 3.1 and final discussion in Chapter 7. It should be noted at this point, however, that the methodology presented by the authors was found to be unacceptable for use in controlling stocks within Edgar Vaughan.

2.4.4 Surveys of Literature

Those surveys deserving reference again number four in total but, between them, they provide a comprehensive survey and reference source on literature published over the previous twenty-seven years. Although each is dealt with separately in this sub-section, in chronological order, certain statements within these papers will be referenced and commented upon in Chapters 3 and 7.

The first of the surveys is written by W. Lamkin in 1967 (Ref 17) and is not strictly a literature survey but a review of the prime aspects of the inventory modelling problem, with occasional reference to certain research papers as and when necessary.

This may be regarded as being a useful paper, in that it provides a better understanding of the various problems/considerations associated with the formulation of an efficient stock control model. Moreover, one is soon made to realise the inbuilt weaknesses of a stock control model developed on assumptions that are not well-founded for practical purposes.

Finally, a section on non/quasi-stationary demand provided an insight as to the approach necessary for the stock control methodology ultimately developed, along with a basic idea from which to work (see sub-section 3.2).

The second survey paper, published in 1974, is by S. C. Aggarwal (Ref 38). This confines itself to being a survey of research literature and, in the main, consists of a series of synopses of papers considered worthy of description and falling into one of the following categories:

(1) Models for determining optimum inventory policies.

(2) Lot-size optimisation.

(3) Optimisation of various specific management objectives.

(4) Models for optimising highly specialised inventory situations.

(5) Application of advanced mathematical theories to inventory problems.

(6) Models bridging the gap between theory and practice.

Each of these categories is then broken down into other headings for convenience.

The survey, although a lengthy and comprehensive one, contains few of the author's personal comments. One important comment/observation, however, is that his examination of the research showed the need for stock control values to be calculated periodically, when necessary, for efficient control of individual stock-items to be achieved. This finding supports the philosophy put forward in sub-section 3.1, in discussing the approach of the stock control methodology developed for use by Edgar Vaughan.

Primarily, the above paper is considered a convenient reference source for research carried out up until 1973.

The third survey of literature, by L. Fortuin (Ref 14), covers both research literature and that provided in text-book form. Once more the approach is different to the previous two surveys, in that it concerns itself with comparing the literature and the merits of Materials Requirements Planning (MRP) against those of 'Statistical Inventory Control' (SIC) in relation to controlling 'Production Inventories'.

His coverage of individual literature is much shorter than that of Aggarwal and it becomes clear very quickly that Fortuin is an ardent supporter of MRP. Comments on his reasoning for the universal use of MRP are made in Chapter 7.

The paper is rather 'sketchy' in content but, nevertheless, useful for providing a background to some of the literature available on both inventory control topics. The largest criticism is that the case made for MRP could easily encourage a naïve potential practitioner (manager, project engineer, analyst, etc.) to choose MRP regardless of its suitability for the business or organisation concerned (see sub-section 2.3.3).

The final paper in this sub-section is written by H. M. Wagner (Ref 15). Wagner describes the paper as being a nontechnical survey of the status of inventory management, with special attention being given to the practical problems that still need research and analytic attention. It was, however, found to be unduly lengthy for what it had to say and at times rather vague. Further, Wagner seems to have personal knowledge of several working examples of scientific stock control systems incorporating more refined models than that of the simple EBQ formula. This is contrary to the lack of evidence of such systems in research literature, engineering/business journals and text-books.

Some of Wagner's comments are, though, considered useful in highlighting the weaknesses of many of the stock control models published at the time. Wagner's most important statements/findings, on this aspect, are felt to be those related to stock demand, the one shown overleaf being an important example:

" Typically, inventory models now in the operations research literature assume that at least the parameters of the demand distribution, and often the distribution form itself, are known exactly. In reality, however, the parameters must be estimated from limited data, and the distribution form is usually unrecognisable from the data. "

Statements such as the one given above also clarify the contribution made to scientific stock control by the stock control methodology put forward in this thesis. For this reason, further reference is made to this paper in Chapter 7.

Chapter 3

The Stock Control Methodology Proposed for Use by Edgar Vaughan Ltd.

3 The Stock Control Methodology Proposed for Use by Edgar Vaughan

3.1 Introduction

Examination of the relevant literature showed all scientific stock control models therein to be founded on assumptions that were unacceptable in the case of Edgar Vaughan. This conclusion was based on examination of the company's sales/demand patterns (see Appendix C) that showed demand for finished products often to fluctuate wildly and frequently display trends. Stock control models based on stationarity of demand were additionally dismissed as being impractical for Edgar Vaughan, as it was felt unlikely that one stationary frequency distribution would suffice for all items of stock. Evidence in support of this was felt to be the diverse nature and quantity of finished products and raw materials held. Further, although a small percentage of finished products and raw materials are interchangeable regarding their use (approximately 3% of total finished products and 5% of total raw materials), the majority of stocked items are so dissimilar as to make substitution impossible.

With regard to evidence of prior practical application of scientific stock control models (other than the EBQ formula/various modifications) only that put forward by D. Gross et al. (Ref 37) was found. Upon discovery, the paper was thought at first to hold a solution to Edgar Vaughan's stock control problem, since the synopsis describes perfectly the general approach considered for some time previously as being necessary. To illustrate this point, the following extract from the synopsis is presented:

> " The inventory model chosen is one which approximates optimality and has been modified to accept, as input, demand forecasts from a forecasting model. The inventory control procedure utilised is of the continuous-review trigger-point order-quantity type, where the trigger point and order quantity 'float', that is, are adjusted periodically depending on the demand forecasts issued. "

Unfortunately, in examining closely the actual stock control model employed, this was found to be one developed by H. M. Wagner (p811-821, Ref 3) which, although suitable as a computer operated model, relies on the following assumptions:

(1) Demand during replenishment lead-time may be described by a standard distribution, such as Normal, Poisson or Binomial.

(2) Replenishment lead-time is known and is constant.

Contrary to the evidence presented by the authors favouring the model/methodology, the implied assumption of stationarity by (1) was once more considered to be too unrealistic in the case of Edgar Vaughan for adoption of the model to be justified. Moreover, assumption (2) was regarded as being restrictive as it was known, from discussions with the comany's management, that replenishment lead-times in practice varied.

Finally, the forecast-period used in the D. Gross et al. methodology remains fixed. Even at the literature review stage, this was suspected as being unacceptable regardless of lead-time being constant or otherwise. This aspect is discussed in the following sub-section.

The only option left was that of designing a new scientific stock control methodology to meet the specific needs of Edgar Vaughan. However, it was decided early on that effort would be made to make any new methodology developed more widely applicable.

As already indicated, the 'weaknesses' of all stock control models examined, from the company's point-of-view at least, lay in the assumptions on which they were based. This being the case, it seemed logical that the strength/suitability of any model/methodology produced would lie in the lack of assumptions made. For this reason, it was decided that the major constraint imposed would be as follows:

" No assumptions <u>fundamental</u> to the development of the stock control model/methodology could be used without reasonable evidence of validity. "

It was further decided that the suitability/performance of any new model/methodology, with respect to Edgar Vaughan, must be tested rigorously by means of a computer simulation.

In discussing once more the needs of the company with the Administration and Production Directors, it was stated by them that ideally two stock control models were required:

(A) A 'service level model' for use in controlling all raw materials and major sales products that provide the greatest contribution to gross profit (Note: these products are referred to within Edgar Vaughan as category 1 and 2 products). The objective of this model would be that of ensuring required customer service levels at least cost to the company.

(B) A 'cost-basis model' for use in controlling sales products whose contribution to gross profit is considerably less than that made by categories 1 and 2 defined above (Note: these products are referred to within Edgar Vaughan as category 3 products). The objective of this model would be to minimise the total inventory-system operating cost.

So as to allow each model to calculate near-optimal stock requirement values, needed in each case to satisfy the specified objectives, it was agreed that storage and manufacturing capacity constraints would be ignored. This was felt to be realistically acceptable in view of the increased size of plant associated with the new Barton Site (see Table 1.3) and the simplicity and speed of the company's bulk of manufacture (i.e. approximately 50% of the company's sales are simple blends requiring two to three hours manufacturing time; see Glossary of Terms for other basic product details). Further, the removal of such constraints was in fact regarded by the Directors concerned as providing a means of continually monitoring the suitability of the size of plant operated.

As a starting point to the development work, attention was initially given to the cost-basis stock control model. This was in fact fortunate, as it was subsequently indicated within the company that this model might also be preferred for category 1 and 2 finished products, in view of the prevailing economic climate. Even so, in the early stages of the cost-basis model's formulation, it was recognised that the basic concept could also be used to work as a service level model.

Owing to the lack of raw material demand data in a manageable form within the existing system, analysis and simulation concerns only finished products. This was not considered a serious drawback, as the model developed does not make any assumptions regarding the nature of the stock-items held. It should be noted at this point, however, that demand data for raw materials will ultimately be available, in the appropriate form, upon final completion of implementation of the new order-processing/stock monitoring system. This will also be true for finished products.

Finally, to ease presentation, discussion is confined in the rest of this Chapter and Chapters 5 and 6 to the original development of the cost-basis model. The adaptation of the latter as a service level model is discussed in Chapter 7.

3.2 Development of the Basic Principle

In attempting to formulate a scientific stock control model, the fundamental objectives of the model, together with the environmental operating conditions, were examined in an extremely simple manner as follows:

(A) What was the model expected to do?

(B) What would be known/unknown?

(C) What constraints existed?

The answers were again listed simply, thus:

(1) The model's objective was to be one of minimising the total inventory-system operating cost.

(2) Cost data would be available.

(3) Future demand would be unknown.

(4) Lead-times would vary and therefore must also be considered unknown.

(5) Stock-items could realistically be considered independently of one another.

(6) Storage and manufacturing capacity constraints were to be ignored.

(7) No assumptions fundamental to the development of the stock control model/methodology could be used without reasonable evidence of validity.

Where necessary, each of these areas was then dealt with separately, in such a way that the individual solutions developed fitted together to form a complete scientific stock control model/methodology.

Upon commencing the above process, it was decided initially to consider the problem of providing the model/Edgar Vaughan with accurate forecasts of demand. The logic behind this approach was that if future demand is known in an inventory control problem the problem is greatly reduced. The background to the choice and development of the forecasting model used is given in Chapter 4. However, in examining the literature on forecasting, it was realised that the 'forecast-period' used in describing forecasting routines always remained constant; e.g. graphical plots of most forecasting routines' abilities are shown on a month-by-month basis. At this point, careful consideration was given to the practicality of how a forecast routine, with a pre-set forecast-period of (say) a month, would work in conjunction with a mathematical stock control model. In doing this, it was realised that the forecast-period needed to be calculated on a cost-basis and should not be chosen in an arbitrary fashion.

The reasoning leading to the aforementioned conclusion originates from belief in the argument that the forecast-period should, logically, be the period between stock replenishments (p64, Ref 17). Acceptance of such an argument means, therefore, that calculation of the forecast-period will (theoretically) determine the number of stock replenishments per year. In turn, this will govern the annual stock replenishment cost, the total annual stock-holding cost and, since the number of stock replenishments can be regarded as the number of 'exposures to stockout*' (p813, Ref 3), the annual potential stockout cost. Moreover, because each of these costs can vary between stock-items, it follows that a specific forecast-period is required to be calculated for each stock-item carried.

So as to highlight the cost consideration aspect, the term 'forecast-period' was replaced by the description 'Economical Replenishment Period' (ERP). This terminology is not entirely new and is similar to the term 'Economical Review Period', normally associated with cyclical stock control policies (p83, Ref 1). However, choice of the word 'Replenishment', as opposed to the word 'Review', was quite deliberate since review of stock levels occurs after every stock transaction (see sub-section 7.2.2) and not on a review-period basis.

Continuing, calculation of an optimal ERP that minimises all three of the above costs would be highly intractable. This is because in dealing with widely fluctuating demand, that may also display trends, the probability of stockout occurring cannot be calculated with the same ease as when demand is assumed stationary. As a result, it was decided that provided the risk of stockout could somehow be economically safeguarded

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* see Glossary of Terms

against at each replenishment order decision, stockout cost could be ignored in determining a close approximation of a stock-item's ERP. The exact manner in which this is achieved is described later.

It was soon perceived that in making the above decision, the 'total annual cost to size of forecast-period' relationship was fundamentally the same as the 'total annual cost to size of replenishment batch' relationship witnessed in the development of the EBQ formula. The formula for calculating a stock-item's ERP (henceforth referred to as the 'ERP formula') is, consequently, derived in the same way (see sub-section 4.4).

At this stage, consideration was again given to how the forecast routine (and the ERP) would work as an integral part of the main stock control model yet to be developed. The conclusion reached was that the entire stock control methodology would be needed primarily* only when the quantity of free stock held of an item fell to or below its precalculated reorder level. When this occurred, the forecast routine would be called by the computer and a forecast of demand over the forthcoming ERP for that stock-item calculated. Given this forecast value, the stock control model proper would calculate the size of the stock replenishment order. In addition, it would also be necessary at this point for the model to calculate a new reorder level.

It was realised that if forecasts of demand were correct, calculation of replenishment order quantities would be considerably eased. However, it was also recognised that in practice such accuracy of forecasts was highly unlikely. The decision was made, therefore, that errors in demand forecasts, and thus the associated risk of stockout, must be dealt with by

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* see 'Actual Usage within the Company', sub-section 7.2.2

the provision of 'demand safety stock'. So as to develop a suitable approach/formula for calculating the quantity of safety stock required, the appropriate literature was examined more closely regarding the topic of forecasting-errors. This proved extremely worthwhile, as several items of literature were found that put forward the assumption that forecasting-errors were Normally distributed (p83, Ref 39; p64, Ref 17). The assumption was felt to be more acceptable than most encountered in the field of scientific stock control, particularly if the forecast model continually endeavoured to 'track' the mean value of demand for each ERP. However, so as to comply with the constraint regarding 'fundamental' assumptions, analysis was carried out on the errors produced by the forecasting model ultimately selected (see sub-section 4.2.2). The results show the assumption of Normality to be acceptable for practical application within Edgar Vaughan when using the forecasting model chosen.

By accepting the above assumption, the probability of 'stockout' occurring during a stock-item's ERP can be easily determined (see Figure 3.1 overleaf). This feature was subsequently used in formulating a search routine that calculates the quantity of demand safety stock needed to minimise the sum of the associated holding and stockout costs (see sub-section 5.1).

In determining a method for calculating demand safety stock, it was decided that for the quantity of stock held at the start of an ERP to be entirely adequate, variability in replenishment lead-time would also have to be accommodated. Since the approach for dealing with uncertainty in demand appeared (in theory) to be satisfactory, the same technique was adopted for calculating 'lead-time safety stock'; i.e. a forecasting routine is used in calculating lead-time values and the forecasting-errors

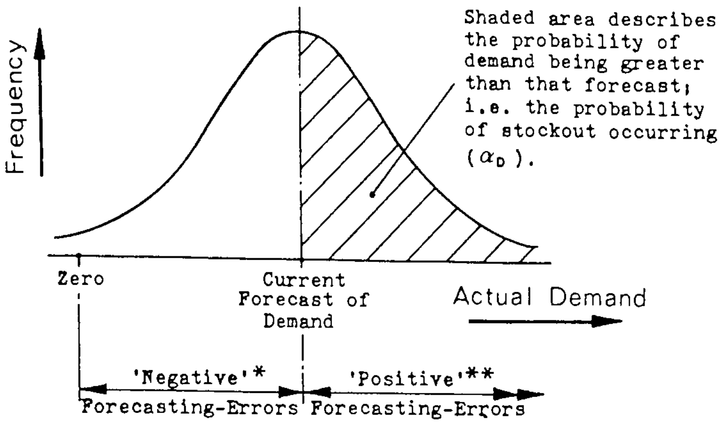

Fig. 3.1 The Normal Probability Distribution of Demand Forecasting-Errors

* Note: Negative errors, for the purpose of this thesis, are considered to be all values of actual demand and actual lead-time found to be less than the respective forecasted values. Whilst recognising that the Normal distribution extends in the 'negative' forecasting-error direction to minus infinity, values less than zero were regarded as being impractical and consequently are ignored (In the case of demand, customer return of goods were felt not to be a constituent of true demand).

** Positive errors, for the purpose of this thesis, are considered to be all values of actual demand and actual lead-time found to be greater than the respective forecasted values. In contrast to the above, whilst it is recognised equally that the Normal distribution extends in the 'positive' forecasting-error direction to plus infinity, no positive limit was set, since it cannot be determined.

For the above reasons, the convention shown in Figure 3.1 was adopted and is used in all other similar diagrams appearing within this thesis.

are considered Normal as before; lead-time safety stock is then calclated using a similar 'minimum cost search routine' to that used in calculating demand safety stock. However, it should be noted that the forecasting technique adopted in the simulation was not the same as that used for demand. Instead, the conventional form of simple exponential smoothing was employed. This was because replenishment lead-times for finished products were known to display little variability and consequently could be regarded as having a stationary mean. Details of simple exponential smoothing are given at the beginning of sub-section 4.1.

Although the added problem of 'overshoot'* (p54, Ref 1; also p61, Ref 17) was in fact recognised, the probability of individual safety stock being required for overshoot, in addition to that needed for excessive demand and excessive lead-time, was anticipated as being so small as to not warrant separate consideration. Validation of this hypothesis was thus felt to lie in the results ultimately to be produced by the simulation.

Finally, the only outstanding control value not provided for at this point was the reorder level. The formula developed for calculating this is described in detail in sub-section 5.5 and basically consists of the appropriate demand-**rate** multiplied by the appropriate lead-time value; both values being those forecast plus their respective safety quantities, calculated as described earlier.

The entire stock control methodology is summarised as a flow-chart in Figure 3.2 with a more detailed description being provided in Chapters 4 and 5.

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* see Glossary of Terms

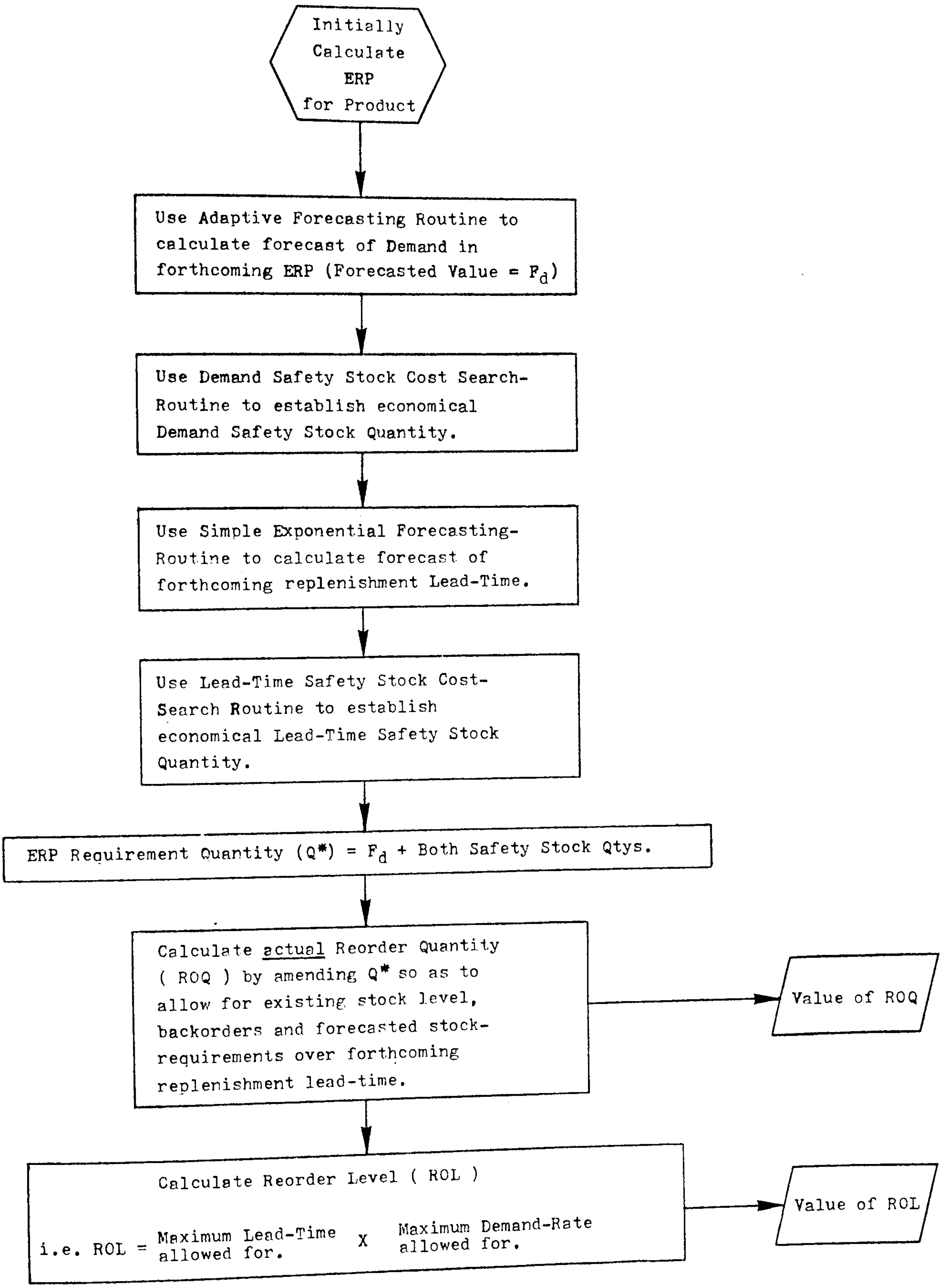

Fig. 3.2 Flow-Chart Illustrating the Basic Operating Principle of the Entire Methodology.

Chapter 4

Forecasting Demand

4 Forecasting Demand

4.1 The Adaptive Forecasting Model

The amount of literature on forecasting is as extensive as that on scientific stock control itself. Moreover, there are also many forecasting techniques available. It was realised early on, however, that any technique to be used in the case of Edgar Vaughan would have to have the following features:

(1) In view of the instability of demand it would, first and foremost, need to be adaptive and so have the ability to respond to significant changes in demand as well as be able to track closely any linear trend.

(2) In addition to (1), it would also need to have the ability to ignore random fluctuations (commonly referred to as 'Noise') or any spurious impulse occurring in demand.

(3) It would need to be easily understood by Edgar Vaughan's management since system programming and implementation would be the responsibility of the company itself.

(4) It would also need to be suitable for computer programming and to form an integral part of the computerised stock control methodology and stock monitoring/order-processing system.

(5) Finally, in view of the number of stock-items required to be controlled, the technique should not depend upon very large

quantities of data being permanently stored.

4.1.1 Forecasting Model 1

It was decided that as a basic approach from which to work, the adaptive forecasting technique put forward by Trigg and Leach (Ref 40) was the most suitable. The reasons for the choice were that the model appeared to comply with each of the constraints listed, yet provided sufficient analytic attention to what is, fundamentally, an imprecise situation. Further, in a limited simulation of four adaptive forecasting techniques, run by Roberts and Whybark (Ref 41), analysis showed the Trigg and Leach model to generally perform the best, from both an accuracy and cost point-of-view.

The actual method used by the Trigg and Leach technique for calculating forecasts is Simple Exponential Smoothing:

i.e. New Forecast, for Period P $= F_P = (D_{P-1} \times \alpha) + (F_{P-1} \times [1-\alpha])$ (4.1)

Where D_{P-1} = Actual Demand in Previous Forecast-Period

F_{P-1} = Forecast of Demand for Previous Forecast-Period

α = The Smoothing Constant, whose value in theory can equal any value between zero and one. In practice though, commonly used values range from 0.01 to 0.3

Note: P-1 at all times refers to the previous forecast-period to that currently being considered, i.e. period P. Similarly, P-2 refers to the previous forecast-period to that of P-1.

However, in this instance, there is also the facility to automatically monitor the stability/accuracy of forecasts made and change the value of α accordingly. This is achieved by generating a 'Tracking Signal', that is defined as the smoothed mean (average) of the forecasting-errors divided by the smoothed Mean Absolute Deviation of errors (MAD). Each of these terms is, in turn, defined/calculated as follows:

Forecasting-Error for Period P $= \mathbf{e_P} = \mathbf{D_P} - \mathbf{F_P}$

Where $\mathbf{D_P}$ = Actual Demand in Period P

and $\mathbf{F_P}$ = Forecast of Demand in Period P

Smoothed Mean Error for Period P $= \bar{e}_P = (e_P \times \delta) + (\bar{e}_{P-1} \times [1 - \delta])$ (4.2)

Where δ = Smoothing Constant, whose value can vary in theory between zero and one. However, the common values used range from 0.1 to 0.3

Smoothed MAD for Period P $= \mathbf{M_P} = (|e_P| \times \delta) + (\mathbf{M_{P-1}} \times [1 - \delta])$ (4.3)

Where $|e_P|$ = Absolute Value of Forecasting-Error

Hence, the Tracking Signal for Period P $= T_P = \dfrac{\bar{e}_P}{M_P}$ (4.4)

If the forecasting technique is in control (i.e. forecasting with reasonable accuracy) the tracking signal will fluctuate around zero. However, if biased errors occur, as a result of a significant change in demand, the signal will move towards plus or minus unity according to the direction of bias. The signal cannot go outside the range [-1,1], however.

Trigg and Leach take advantage of the above characteristic by making the value of α, for each new forecast, equal to the absolute value of the latest tracking signal generated.

i.e. The value of $\alpha = \alpha_P = |T_{P-1}|$ for Period P (4.5)

Thus, when forecasts go out of control the value of α will increase, so as to give more weight to recent data and therefore faster 'homing in' to the new situation. As control is regained by the forecasting model the value of α will decrease, allowing general noise in demand to be filtered out. Summarising, the forecasting formula produced is as shown below:

New Forecast $F_P = (D_{P-1} \times |T_{P-1}|) + (F_{P-1} \times [1 - |T_{P-1}|])$ (4.6)

Although the basic Trigg and Leach technique appeared to perform quite well (Ref Appendix E), three other published variations were tested, with a view to establishing the best for Edgar Vaughan. These are discussed in the following sub-sections along with a new fourth variation (forecasting model 5), that was developed/tested and used as part of the finalised stock control methodology.

4.1.2 Forecasting Model 2

This is virtually identical to model 1. However, the difference is that the value of α_P is only made equal to the absolute value of the latest tracking signal (T_{P-1}) if the signal exceeds/equals a value (L) representing a suitable level of statistical signficance (also often referred to as 'confidence limit'). Where this condition is not met α_P remains fixed at some predetermined value (p30, Ref 1). Upon testing various values of α_P and L, originally computed by Brown (Ref 42), with a programme of finished products sold by Edgar Vaughan, the following parameters were chosen as giving the most efficient performance of the model:

$$\alpha_P = 0.2 \text{ If } |T_{P-1}| < 0.54^*$$

$$\alpha_P = |T_{P-1}| \text{ If } |T_{P-1}| \geqslant 0.54$$

4.1.3 Forecasting Model 3

The main drawback of the Trigg and Leach forecasting technique, in its basic form (models 1 and 2), is that as the forecasting-errors are eventually reduced, simple statistical interpretation of the tracking signal can no longer be made (Refs 40 and 42). As a means of obviating this problem, Lewis (p36, Ref 1) suggests the introduction of an

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* 0.54 equals 80% confidence limit; i.e. should $|T_{P-1}|$ be $\geqslant$ 0.54 then it can be stated with 80% confidence that the change in the tracking signal is statistically significant.

additional simple exponential forecasting model. The principle of operation put forward is that the one forecasting routine has its value of α (α_1) fixed and is used to generate the tracking signal, whilst the second forecasting routine has a value of α (α_{2_P}) that is determined in the same manner as that described for α_P in forecasting model 2. In this way, the first forecasting routine provides a stable 'yardstick' from which to monitor and adjust, when necessary, the effectiveness of the second adaptive model. Again after experimentation, the control parameters considered to produce the most efficient performance of the model were as shown below:

$$\alpha_1 = 0.2 \text{ (Fixed)}$$
$$\alpha_{2_P} = 0.2 \text{ If } |T_{P-1}| < 0.54$$
$$\alpha_{2_P} = |T_{P-1}| \text{ If } |T_{P-1}| \geqslant 0.54$$

where α_1 = Value of Smoothing Constant used in the Non-Adaptive Forecasting Model

α_{2_P} = Value of Smoothing Constant used in the Adaptive Forecasting Model for Period P

[Note: The value of δ remained equal to 0.2]

4.1.4 Forecasting Model 4

This model is an adaptation of Lewis's modification (p35, Ref 1) to model 1, that originally involved the value of α_P always being made equal to $|T_{P-2}|$ (i.e. the tracking signal prior to the latest generated). In this case, though, the idea is applied to model 3, with the same objective of preventing overreaction to large single demand impulses. So as to allow direct comparison between this model and model 3, the following control parameters were once more used:

$$\alpha_1 = 0.2 \quad \text{(Fixed)}$$

$$\alpha_{2_P} = 0.2 \text{ If } |T_{P-2}| < 0.54$$

$$\alpha_{2_P} = |T_{P-2}| \text{ If } |T_{P-2}| \geqslant 0.54$$

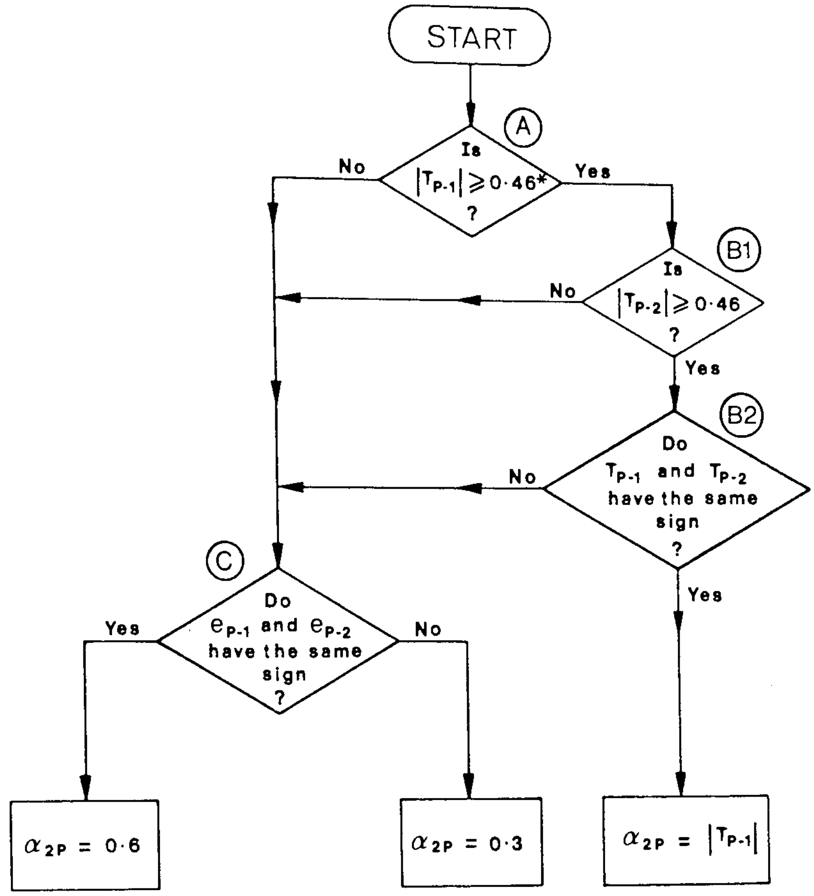
[Note: The value of δ remained equal to 0.2]

4.1.5 Forecasting Model 5

The testing of forecasting models 1, 2, 3 and 4 was followed by an interactive process of testing further possible refinements to the general approach of model 3. As a result, the following model was developed and, after testing, was regarded as that best suited to work as an integral part of the total stock control methodology:

$$\left.\begin{array}{l} \alpha_1 = 0.2 \text{ (Fixed)} \\ \delta = 0.2 \text{ (Fixed)} \end{array}\right\} \text{Used by non-adaptive forecasting routine to calculate the tracking signal}$$

The control parameters for the adaptive part of the total forecasting methodology are best described by means of a flow-chart (See Figure 4.1 overleaf). It should, however, be noted that the values of α_{2_P} of 0.6 and 0.3 were estimates based on subjective assessment of the problem.



*(70% Confidence level)

Fig. 4.1 Flow-Chart Showing the Control Parameters for the Adaptive Part of Forecasting Model 5.

The effect of using 0.46, in controls A and B, is one of reducing the confidence level at which the value of the tracking signal is considered significant. However, control B requires that the new significance level must be exceeded on two consecutive occasions with the same direction of bias. The logic behind the approach is that possible significant changes in demand are recognised at an early stage, yet reaction on the part of the model is restricted until corraborating demand data are presented.

Control C attempts to ensure a balance between positive and negative forecasting-errors, so that the forecasting model may comply more closely with the assumption of errors being Normally distributed. This control feature is thus made effective when consecutive forecasting-errors of the same sign (bias) are encountered.

4.2 Method of Testing

All forecasting models were tested by examining their performance with 1979 sales data recorded against thirty finished products. The phrase 'sales data' refers, in this instance, to data basically comprising a quantity of finished stock delivered to a customer and the respective date on which delivery occurred. Ideally, the actual quantity of finished stock ordered together with the respective actual required date of delivery, i.e. 'actual demand data', would have been preferred in testing the forecasting models. Unfortunately, actual demand data was held only on stock record cards and retrieval would not have been possible in the time available. Further, because the service lead-time offered to customers was often a week or less and rarely greater than two weeks, it was considered that sales data would differ little to that of actual demand data.

Continuing, in an effort to ensure that most demand conditions experienced by Edgar Vaughan were encountered during testing, the thirty finished products were randomly chosen within each demand type, taken overall from the top 180 best selling products, to reflect the range and types of products in the full manufacturing programme.

Actual testing was carried out by programming each of the forecasting models using the language BASIC and then running them separately on a Commodore PET microcomputer. Data were presented in all cases as in real life, i.e. as a series of 'unknown' monthly demand values, covering the entire twelves months of 1979. Model 5 was additionally tested in the same way with sales/demand data for 1980 (see Appendices E and F for graphical results of all models).

4.2.1 Performance Measurement

There are various recognised methods of quantitatively measuring the forecasting ability/efficiency of a forecasting technique. These include:

1) Measurement of Forecast Bias (i.e. mean error, $\bar{e}$)

defined as:

$$\bar{e} = \sum_{P=1}^{N} e_P / N$$

where **N** = No. of Forecast Periods concerned.

2) Measurement of Forecast-Error Variability. This is generally measured in one or more of the following ways:

(a) Actual MAD $= \dfrac{\sum_{P=1}^{N} |e_P|}{N}$

(b) Actual Variance of errors (σ_e^2) $= \dfrac{\sum_{P=1}^{N} (e_P - \bar{e})^2}{N-1}$

(c) Actual Standard Deviation of errors $\sigma_e = \sqrt{\dfrac{\sum_{P=1}^{N} (e_P - \bar{e})^2}{N-1}}$

3) Measurement reflecting the extent of correlation between successive forecasting-errors. This is achieved by calculating the Autocorrelation-Coefficient AC_e as shown below:

$$AC_e = \frac{\left[\sum_{P=1}^{N} e_P \, e_{P-1} - N\bar{e}^2\right]}{\left[\sum_{P=1}^{N} e_P^2 - N\bar{e}^2\right]}$$

An ideal forecasting technique, in terms of accuracy, would be one in which the aforementioned performance measures were as close to zero as possible. However, it is argued that for practical application, it is impossible for any forecasting technique to simultaneously satisfy all criteria fully, as such measures will always conflict (Ref 41).

In view of the fact that both the stock control model and the tracking signal depend upon forecasting-errors being Normally distributed, forecast bias was considered to be the most appropriate overall quantitative measure of performance in this instance. Although such a measure would not confirm possible Normality of the frequency distribution of errors, it would provide an indication of the model's suitability. Actual 'goodness of fit' testing of forecasting-errors to the Normal distribution was confined solely to model 5 and is discussed in detail in the following sub-section.

Finally as a guide to the variability of forecasting-errors, values of actual standard deviation of errors (i.e. σ_e for the purpose of this sub-section) were also recorded. The results for both types of performance measurement are shown at the beginning of Appendix E.

The five forecasting models were, however, primarily appraised in a qualitative way by simply examining their response (graphically) to the various demand conditions encountered. This approach was considered to be more informative and provided a better 'feel' for each model's forecasting ability. It was observed though that the quantitative results matched well with the qualitative conclusions.

Summarising, with both methods of measuring forecasting performance (quantitatively, greater consideration was given to error-bias), model 5 appeared to be the most robust for all conditions of demand considered and was, for this reason, chosen as being the best for Edgar Vaughan.

4.2.2 Analysis of Forecasting-Errors

As stated earlier, both the tracking signal and a fundamental part of the stock control model rely on the assumption that forecasting-errors are Normally distributed. Consequently, so as to comply with the constraint made in sub-section 3.1, restricting the use of assumptions, it was necessary to investigate the validity of the above assumption in the case of forecasting model 5. This was carried out by using an interactive computer package known as 'Disfit' (Ref 43), programmed in BASIC and designed to run on a Hewlett-Packard Access 2000 computer.

Briefly, the package permits 'goodness of fit' testing of data, to those frequency distributions listed below, by employing the Chi-Square, Kolmogorov-Smirnov or Craemor-Von Mises test, depending in the main on the quantity of data available (i.e. the sample size):

Normal
Gamma
Negative Exponential
Uniform
Lognormal
Poisson

The error data used comprised that produced by forecasting model 5, for both 1979 and 1980 sales/demand data, for a random sample of eight of the thirty finished products previously selected (see overleaf for product code numbers used). This provided 23 forecasting-error values for each product and as a result of the package's design, the Kolmogorov - Smirnov test was <u>automatically</u> selected.

The results obtained show that in testing against the critical value of 0.361, measured at 95% significance level, the forecasting-errors for all the products examined could be regarded as being Normally distributed. However, the frequency distributions they best fitted were as follows:

12030	Normal	15010	Gamma
13020	"	20700	"
30113	"	40020	"
58205	"		
80005	"		

4.3 Practical Consideration Required in Operating the Finalised Forecasting Model (Model 5)

Owing entirely to the erratic nature of demand, the period elapsing between replenishment decisions will, in practice, rarely equal precisely the appropriate ERP. This means that the actual value of demand (DA_{p-1}) for the previous period, actual length PA_{p-1}, cannot be used to represent D_{p-1}* in calculating a new forecast of demand. Instead, an estimate of D_{p-1} has to be determined. The way in which this is achieved is by first establishing the Actual Average Demand-Rate ($\overline{DR}_{p-1}$) for the actual length of the previous period (see overleaf).

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* Total demand recorded for the previous forecast period, where the latter is assumed equal to the appropriate ERP; see sub-section 4.1.1.

i.e. Actual Average Demand-Rate for the previous period $=$ $\dfrac{\text{Actual Demand Incurred Since Last Replenish't Decision}}{\text{Actual Period Elapsed (weeks)}}$

i.e.

$$\overline{DR}_{p-1} = \frac{DA_{p-1}}{PA_{p-1}} \qquad (4.7)$$

Using the result of equation (4.7):

$$D_{p-1} \triangleq \overline{DR}_{p-1}\, P_E^* \qquad (4.8)$$

example:-

Let: Length of ERP (P_E) = 4 weeks

Actual Period Elapsed (PA_{p-1}) since the last replenishment decision $= 3\frac{1}{2}$ weeks

Actual Demand incurred (DA_{p-1}) since the last replenishment decision = 60 storage-units

∴ using equation 4.7:

Actual Average Demand-rate ($\overline{DR}_{p-1}$) $= \dfrac{60}{3.5} = 17.14$ storage-units/week

Hence: Estimated Demand (D_{p-1}) during ERP $= 17.14 \times 4 \triangleq$ 69 storage-units

4.4 Calculation of the Economical Replenishment Period

As stated in sub-section 3.2, the approach put forward for calculating the ERP is that used for deriving the EBQ formula. However, acceptance of the approach, on this occasion, is not considered a contradiction of the original criticisms made regarding the use of it in determining ROQ values. The reason, it is argued, is that although a

* Actual value of the ERP in question.

fixed value of ROQ cannot be used where demand is non-stationary, a fixed* forecast-period can, providing the ROQ and ROL values are appropriate for demand in each forecast-period. Given that the aforementioned constraint is met and that:

1) replenishment cost for each product does not vary with replenishment quantity and remains fixed until the size of the ERP is reviewed (this is valid in the case of Edgar Vaughan as there are no set-up costs; manufacturing times vary very little with quantity; and the cost per hour of running each size of mixer is very similar, owing to the simplicity of the basic manufacturing process);

2) holding cost per unit of storage remains fixed until the size of ERP is reviewed; and

3) stockout cost is temporarily ignored;

then it is further argued that the annual stocking-system costs vary with the size of the forecast-period in a manner similar to that shown in Figure 4.2, irrespective of the nature of demand.

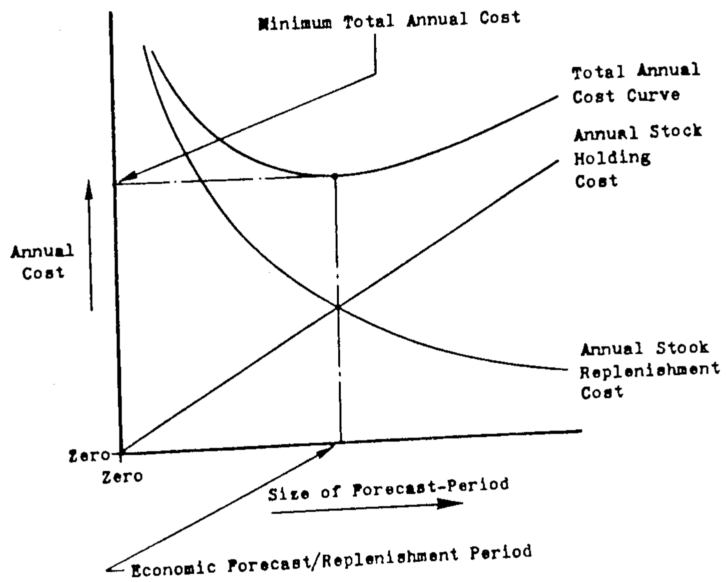

Fig. 4.2 Graph Showing Approximate 'Cost to Forecast-Period' Relationship in the Development of the ERP Formula.

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* Note: It is recognised that the forecast-period (ERP) would most likely require reviewing after some suitable period of time (e.g. a year) or if a substantial change in operating costs or anticipated future annual demand occurred.

It can be seen from the previous diagram that the cost model is fundamentally identical to that used in formulating the EBQ formula (Ref Appendix D). Consequently, it is possible to derive an ERP formula in a similar way by effectively balancing the two costs involved. Moreover, the EBQ basic cost relationship that achieves the latter may be used as a starting point:

$$\text{i.e.} \qquad \frac{A_D C_R}{q^*} = \frac{q^* H_C}{2} \tag{4.9}$$

where $\dfrac{A_D C_R}{q^*}$ = Annual Replenishment Cost

and $\dfrac{q^* H_C}{2}$ = Annual Holding Cost

Definitions of individual terms are given below:

A_D = Forecasted Annual Demand (appropriate units of storage)

C_R = Cost of each replenishment

q^* = EBQ for when demand is constant (appropriate units of storage)

H_C = Holding Cost/per unit of storage/year

However, in order to make the approach entirely suitable for use with non-stationary demand and variable lead-time, it is necessary to modify the assumption that the 'Average Stock Holding Ratio' (R) is 0.5 (i.e. implied by the statement $q^*/2$). The reasons, given that the operating conditions described prevail, are as follows:

1) Safety stocks determined by the stock control model will not always be used up. Thus, stock levels cannot be considered to vary between some upper limit and zero.

2) Owing to the need/existence of safety stocks, the quantity of stock held at the commencement of an ERP is often likely to be <u>much greater</u> than q^*.

As a direct result of (1), alone, the Average Stock Holding Ratio will at least be larger than 0.5. However, the implication of (2) is more profound. This is because in the subsequent derivation of the ERP formula, the average ERP requirement quantity ($\bar{Q}^*$) continues to be represented by q^*. Consequently, the value of R <u>remains</u> a ratio in terms of q^* even though q^* does not appear in the final formula. Hence, if a hypothetical value of $\bar{Q}^*$ is (say) $1\frac{1}{2}$ times larger than that of the respective value of q^*, to account for uncertainty, and the <u>true</u> stock holding ratio in terms of $\bar{Q}^*$ is (say) 0.75, then:

$$\text{The Average Stock Quantity Held} = 0.75(1.5q^*)$$

$$\text{i.e. The Average Stock Holding Ratio (R) (in terms of } q^* \text{)} = 1.125$$

The objective of the above exercise is simply to show that the value of R may well in practice be greater than unity. For the purpose of this sub-section, though, the Average Stock Holding Ratio will not be given a specific value but will continue to be symbolised as R. Continuing:

Since $\frac{A_D}{q^*}$ = Number of Replenishments per Year (N_R)

it follows that: $$q^* = \frac{A_D}{N_R}$$

Thus, substituting for q^* in equation (4.9):

$$\frac{N_R \cancel{A_D} C_R}{\cancel{A_D}} = \frac{R\ A_D H_C}{N_R}$$

∴ by cross-multiplying:

$$N_R^2 C_R = R\ A_D H_C$$

Hence: $$N_R^* = \sqrt{\frac{R\ A_D H_C}{C_R}} \qquad (4.10)$$

[where N_R^* = <u>Economical</u> No. of Replenishments per Year.]

The complete ERP formula for a year is, therefore, as follows:

$$\underset{\text{(weeks)}}{\text{ERP}} = \frac{52}{\sqrt{\dfrac{R\,A_D\,H_C}{C_R}}} \tag{4.11}$$

It should be noted that where the calculated ERP is found to be less than the corresponding <u>average</u> actual replenishment lead-time, then the forecast-period must be made equal to the average lead-time. This is necessary in order to permit <u>practical operation</u> of the Methodology and the avoidance of continuous backorder*situations developing. The results produced by the Methodology under such circumstances, although not optimal from a theoretical point-of-view, would nevertheless approach practical optimality.

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*See Glossary of Terms

Chapter 5

The Stock Control Model

5 The Stock Control Model

This sub-section relates to that part of the total control methodology directly responsible for the following:

1) Calculation of Q^*, the quantity of stock required to be available at the start of an ERP.

2) Calculation of Replenishment Order Quantity (ROQ).

3) Calculation of Reorder Level (ROL).

However, it is the formulae/approach used in determining safety stocks that constitutes the basis of the stock control model proper and on which calculation of quantities (1), (2) and (3) depend. The exact details of the model are, consequently, presented as shown below:

5.1 Calculation of Demand Safety Stock
5.2 Calculation of Lead-Time Safety Stock
5.3 Calculation of ERP Requirement Quantity
5.4 Calculation of Reorder Quantity
5.5 Calculation of Reorder Level

[Note: To ease derivation of the safety stock formulae, variability in replenishment lead-time is ignored when considering demand safety stock.]

5.1 Calculation of Demand Safety Stock

Reference to Figure 5.1 shows that for adequate protection against stockout to be achieved, the quantity of stock held at the start of an ERP must be larger than that of the demand forecasted (i.e. F_D). This additional quantity is represented in Figure 5.2 by moving to the right of F_D by an amount equal to some multiple (K_D) of the distribution's standard deviation (σ_D).

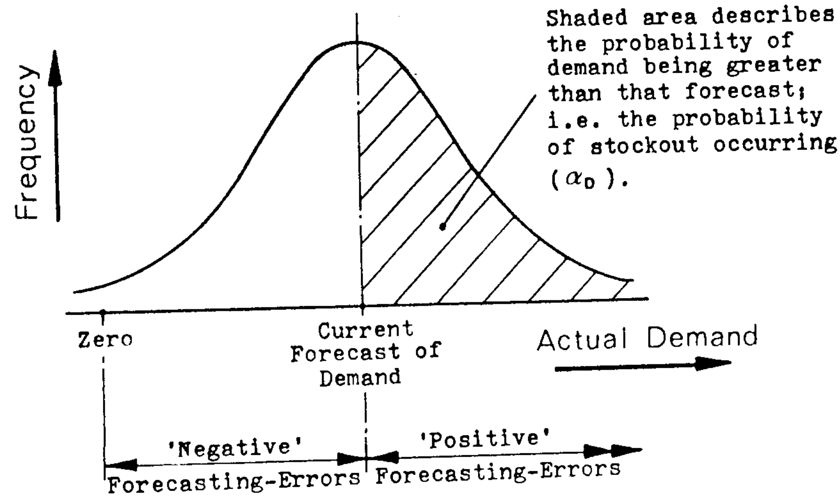

Fig. 5.1 The Normal Probability Distribution of Demand Forecasting-Errors.

The change of subscripts for the forecast of demand from that used in Chapter 4 (i.e. F_P) to that used in this Chapter (i.e. F_D) should be noted and is done for purposes of consistency within the final formulae developed and to later distinguish between forecasts of demand and forecasts of lead-time.

It should also be noted that 'α' takes on a different meaning within this Chapter to that of Chapter 4, and instead of representing a smoothing constant, it is used to represent the probability of stockout occurring. Although possibly confusing initially, the two definitions are retained in order to comply with recognised convention within both the field of forecasting and statistical stock control.

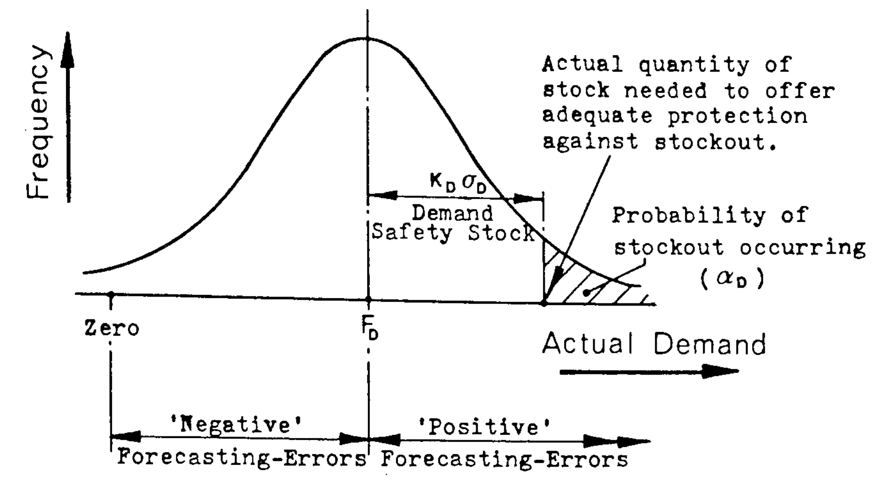

Fig. 5.2 The Normal Probability Distribution of Demand Forecasting-Errors, Showing Demand Safety Stock

So as to reduce the amount of data stored, it is considered practical, as well as providing adequate accuracy, to calculate the distribution's standard deviation thus:

σ_D for period P = 1.25* x Smoothed MAD of demand forecasting-errors for period P-1

* (p26, Ref 1)

The size of the demand safety stock can thus be expressed as follows:

$$\text{Quantity of Demand Safety Stock} = K_D \sigma_D \qquad (5.1)$$

Although holding safety stock reduces stockout-cost, in instances where it is not used, an additional carrying cost is incurred. Since σ_D is fixed, the problem is one of determining the value of K_D that gives the smallest total expected cost, i.e. the sum of the expected holding cost and the expected stockout cost needs to be minimised. In order to achieve this objective, it is first necessary to have a suitable formula for calculating each cost. The derivation of both formulae is, therefore, described next.

5.1.1 Determination of Expected Holding Cost $E(HC_D)$

The term 'expected' refers throughout the remainder of this thesis to the statistical mean (average) value. Thus, during an ERP examined at random, the cost of holding demand safety stock may in practice be smaller, larger or may not be incurred at all.

Accepting that some demand safety stock will be carried so that, in theory, the stock level will be $F_D + K_D\sigma_D$ at the start of an ERP, Figure 5.3 shows that three subsequent demand outcomes are possible.

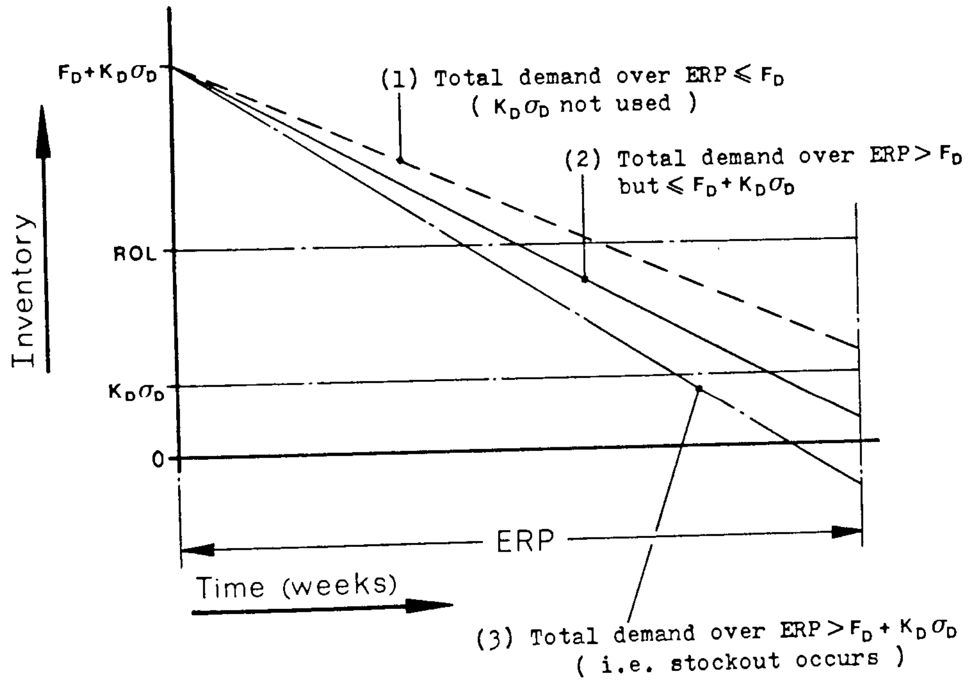

Fig. 5.3 Diagrammatical Representation of the Three Prime Demand Outcomes, for the Purpose of Analysing Demand Safety Stock.

Each demand outcome is represented by a straight line purely for convenience and must not be taken to imply that demand-rate is assumed constant in practice. Moreover, rejection of the assumption is upheld throughout the rest of this Chapter, again contrary to instances where linearity is implied when calculating/using average demand-rates, i.e. pages 92 and 94, in particular equations 5.4 and 5.7. In all such cases, the approach is taken as a simplified means of providing a suitable estimate of demand-rate/usage, for demand conditions that are otherwise inexact.

The expected holding cost equation for each demand outcome may be expressed in general terms as shown below:

$$\text{Expected Holding Cost} = \begin{array}{c}\text{Quantity of}\\ \text{Demand Safety}\\ \text{Stock Carried}\end{array} \times \begin{array}{c}\text{Period}\\ \text{Concerned}\end{array} \times \begin{array}{c}\text{Per Unit}\\ \text{Holding}\\ \text{Cost Per}\\ \text{Unit of Time}\end{array} \times \begin{array}{c}\text{Probability of}\\ \text{Demand Outcome}\\ \text{Occurring}\end{array}$$

Equation (5.2)

For the purpose of determining an explicit total expected holding cost formula, each of the demand outcomes shown in Figure 5.3 is first considered separately:

Demand Outcome (1): Demand over the ERP does not exceed forecasted demand F_D.

Therefore, demand safety stock $K_D\sigma_D$ is held for the entire ERP (Note: length of ERP is henceforth expressed as P_E for the purpose of formulae development).

Referring to Figure 5.4, the probability of demand outcome (1) = 0.5.

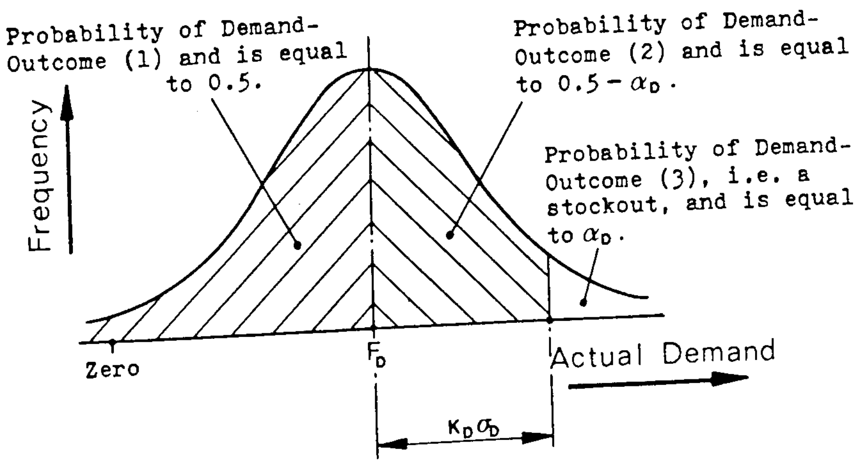

Fig. 5.4 The Normal Probability Distribution of Demand Forecasting-Errors, Showing the Probabilities of the Three Prime Demand Outcomes.

Thus, by substituting the appropriate terms into equation 5.2, the expected holding cost for demand outcome (1) is:

$$\underline{\underline{\text{Expected Holding Cost for Demand Outcome (1)}}} = K_D\sigma_D \times P_E \times C_H \times 0.5 \qquad (5.3)$$

Demand Outcome (2): Demand over the ERP exceeds forecasted demand F_D by an amount no greater than the safety stock held.

Therefore, demand safety stock $K_D\sigma_D$ is partly/totally used.

Reference to Figure 5.4, shows the probability of demand outcome (2) occurring = $(0.5 - \alpha_D)$.

So as to derive the expected holding cost expression, the average quantity of safety stock used is assumed to be $K_D\sigma_D/2$. This was chosen in preference to determining the statistical average quantity*, as it is a much simpler expression to calculate with very little difference in accuracy. In addition, it will be seen further on that the choice of value has no effect on the final formula proposed.

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* Normally termed 'partial expectation' (see Appendix G).

As a result, demand over $P_E = F_D + (K_D\sigma_D/2)$

$$\therefore \text{ average demand-rate } = \frac{F_D + (K_D\sigma_D/2)}{P_E} = D' \text{ units/week} \qquad (5.4)$$

Thus, $K_D\sigma_D$ is held for approximately $\frac{F_D}{D'}$ weeks ———— (A)

(i.e. the time taken for F_D to be used completely).

In addition, in the remaining time of the ERP the safety stock level falls from $K_D\sigma_D$ to $K_D\sigma_D/2$.

$\therefore$ The average quantity of stock carried for the remaining time of the ERP $= \dfrac{K_D\sigma_D + \dfrac{K_D\sigma_D}{2}}{2}$

i.e. 0.75 $K_D\sigma_D$ is held for approximately $\left(P_E - \frac{F_D}{D'}\right)$ weeks ———— (B)

Statements (A) and (B) show that the quantity of safety stock $K_D\sigma_D$ remains virtually intact for the whole of the ERP. Thus, the expected holding cost expression for demand outcome (2) approximates to:

$$\text{Expected Holding Cost for Demand Outcome (2)} = K_D\sigma_D \times P_E \times C_H \times (0.5 - \alpha_D) \qquad (5.5)$$

By combining equations 5.3 and 5.5, the total expected holding cost expression for demand outcomes (1) and (2) reduces to:

$$\text{Total Expected Holding Cost for Demand Outcomes (1) and (2)} = K_D \sigma_D P_E C_H \beta_D \qquad (5.6)$$

(where $\beta_D = 1 - \alpha_D$)

Demand Outcome (3): Demand over the FRP exceeds forecasted demand F_D by an amount greater than $K_D \sigma_D$, the safety stock quantity held.

Thus, the safety stock quantity $K_D \sigma_D$ is totally used.

Reference to Figure 5.4 shows the probability of demand outcome (3) occurring = α_D.

In this case, so that the expected holding cost expression can be determined, it is first necessary to know the actual size of the demand incurred. It is known that it is greater than $F_D + K_D \sigma_D$, what is not known is by how much. However, it is possible to calculate the average quantity by which demand exceeds $F_D + K_D \sigma_D$, given that demand outcome (3) (i.e. a 'stockout') occurs. This quantity is more commonly referred to as the 'partial expectation' and is symbolised for a (0,1) Normal distribution thus:

$$E(K)$$

or in this instance $E(K_D)$. For a more detailed explanation of partial expectation, see Appendix G.

Thus, using partial expectation:

The average total demand for Demand Outcome (3) $= F_D + K_D\sigma_D + E(K_D)\sigma_D$

$\therefore$ The 'Average Excess Demand-Rate', D'' units/week, for Demand Outcome (3)

$$= \frac{F_D + K_D\sigma_D + E(K_D)\sigma_D}{P_E} \tag{5.7}$$

$\therefore$ It may be considered that the demand safety stock $K_D\sigma_D$ is carried for approximately F_D/D'' weeks.

(i.e. the time taken for the quantity F_D to be used completely).

and that on average, $K_D\sigma_D/2$ is carried for approximately $K_D\sigma_D/D''$ weeks.

(i.e. the time taken for the quantity $K_D\sigma_D$ to be used completely).

Hence:

Expected Holding Cost for Demand Outcome (3)

$$= \left[\left(K_D\sigma_D \times \frac{F_D}{D''}\right) + \left(\frac{K_D\sigma_D}{2} \times \frac{K_D\sigma_D}{D''}\right)\right] \times C_H \times \alpha_D$$

The above equation reduces to:

Expected Holding Cost for Demand Outcome (3)

$$= \frac{K_D\sigma_D C_H \alpha_D}{2}\left[\frac{2F_D + K_D\sigma_D}{D''}\right] \tag{5.8}$$

Therefore, by adding equation (5.6) to equation (5.8), the total expected holding cost for all three demand outcomes is obtained:

Total Expected Holding Cost for Demand Outcomes (1), (2) and (3) $= \dfrac{K_D \sigma_D C_H \alpha_D}{2} \left[\dfrac{2F_D + K_D \sigma_D}{D''} \right] + K_D \sigma_D P_E C_H \beta_D$

This reduces to:

The Total Expected Holding Cost for Demand Safety Stock $E(HC_D) = K_D \sigma_D C_H \left[\dfrac{\alpha_D}{2} \left(\dfrac{2F_D + K_D \sigma_D}{D''} \right) + P_E \beta_D \right]$

Equation (5.9)

5.1.2 Determination of Expected Stockout Cost $E(SC_D)$

The cost incurred as a result of a stockout is considered throughout this thesis as being the lost contribution to overheads and gross profit:

i.e. Stockout Cost = Selling Price − Prime Costs of Raw Materials and Manufacture (excluding labour*) and packaging where applicable.

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* Regarded as being a fixed cost

It was shown earlier that the average sales quantity lost may be represented by the partial expectation associated with the value of K_D, used in setting the level of demand safety stock, and may be expressed as follows:

$$\underline{\text{Average Stockout Quantity} = E(K_D)\sigma_D}$$

Therfore, given that the basic expected stockout cost equation is as shown:

Expected Stockout Cost	=	Stockout Quantity	x	Per Unit Stockout Cost	x	Probability of Occurrence

Then $$E(SC_D) = E(K_D)\sigma_D C_{SO}\alpha_D \qquad (5.10)$$

The expected total cost $E(TC_D)$, related to carrying demand safety stock $(K_D\sigma_D)$, can now be obtained:

$$E(TC_D) = E(HC_D) + E(SC_D) \qquad (5.11)$$

The minimum expected total cost, $E(TC_D)^*$, is obtained through the use of a simple search process that calculates $E(TC_D)$ (using equations 5.9, 5.10 and 5.11) for different values of $K_D \geqslant 0$, chosen in such a way as to ensure a gradual decrease in the value of α_D. The value of K_D associated with the smallest value of $E(TC_D)$ determines the actual value of demand safety stock to be carried (see equation 5.1).

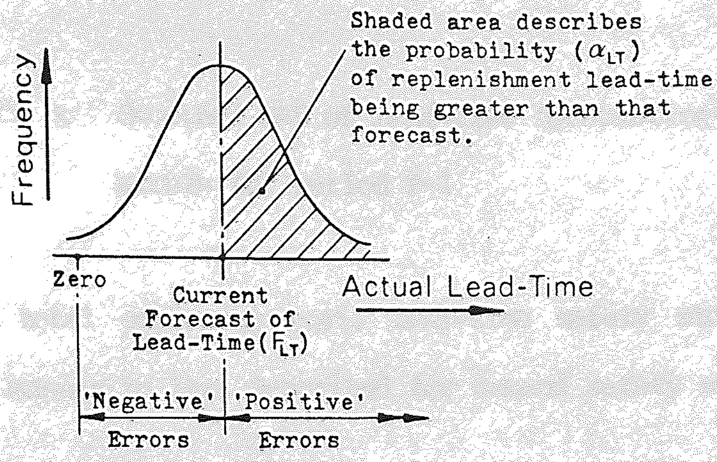

Fig. 5.5 The Normal Probability Distribution of Lead-Time Forecasting-Errors.

Examination of Figure 5.5 indicates that in addition to requiring demand safety stock, it is also necessary to provide some safeguard against positive forecasting-errors of replenishment lead-time. This is achieved by carrying lead-time safety stock and requires initially calculating a lead-time safety value (see Figure 5.6).

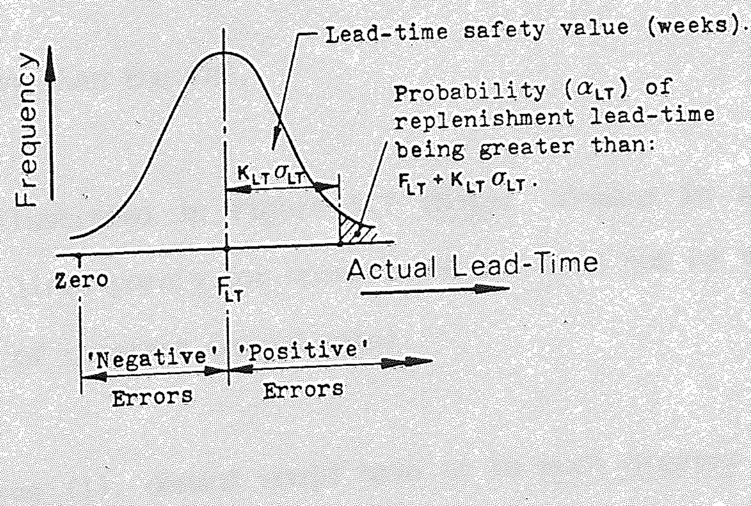

Fig. 5.6 The Normal Probability Distribution of Lead-Time Forecasting-Errors, Showing the Lead-Time Safety Value.

It should be noted that σ_{LT} is calculated in the same way as is σ_D, i.e.:

σ_{LT} for period p = 1.25 x Smoothed MAD of lead-time forecasting-errors for period P-1

So as to minimise total operating cost, lead-time safety stock is determined in a similar manner to that described for demand safety stock:

5.2.1 Determination of Expected Holding Cost $E(HC_{LT})$

The value of $E(HC_{LT})$ is made up of three individual expected holding costs, resulting from the possibility of lead-time safety stock being carried for:

1) a period less than the ERP;

2) a period equal to the ERP;

and 3) a period greater than the ERP.

All three cases are illustrated in Figure 5.7 (Note: demand is again represented by straight lines purely for convenience and must not be taken to imply the assumption of constant demand-rate).

With respect to case (1), demand would have to be much greater than that of $F_D + K_D\sigma_D$ **plus** lead-time safety stock for the period to be substantially less than the ERP (variability in lead-time would have little effect on the period involved). Further, the occurrence of such a sizeable demand would have to be very infrequent, if it were to be unprovided for by the quantity of demand safety stock calculated/held. The probability of case (1) occurring was thus considered as being extremely small. Instead, a more realistic representation of such a demand outcome was felt to be the case (1A), Figure 5.7.

On the basis of the above hypothesis being correct, the period for which lead-time safety stock is carried will for case (1A) differ little from the ERP. For this reason, separate analysis of case (1)/(1A) is not included in the derivation of a formula for $E(HC_{LT})$.

The results of the simulation show the dismissal of case (1)/(1A), in retrospect, to be acceptable.

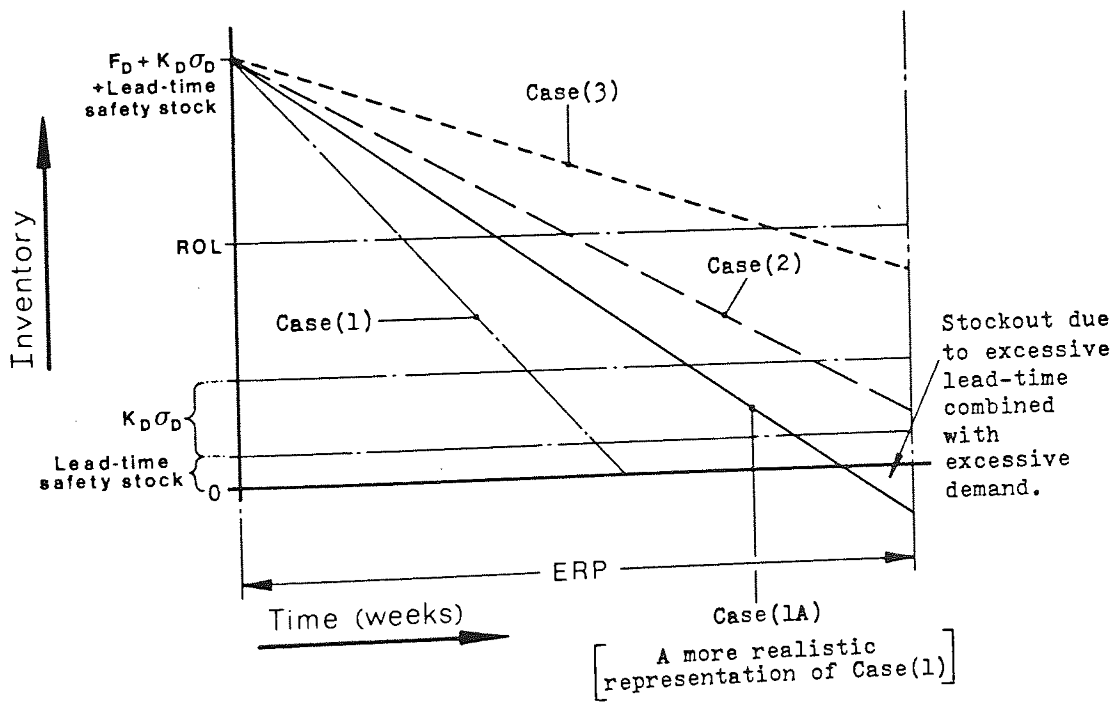

Fig. 5.7 Diagrammatical Representation of Possible Demand Outcomes, for the Purpose of Analysing Lead-Time Safety Stock.

Since the total stock control methodology is designed to examine only what occurs within each ERP, consideration of case (3) is also avoided. It will be seen later that, because of the method used in calculating the actual Replenishment Order Quantity, this approach for practical purposes is quite valid.

Analysis is thus reduced to case (2), for which the general holding cost equation is as follows:

$$\text{Expected Holding Cost} = \text{Quantity of Lead-Time Safety Stock} \times \text{ERP} \times \text{Per Unit Holding Cost Per Unit of Time} \times \text{Probability of Occurrence} \qquad (5.12)$$

Consider each of the following terms, used on the right-hand side of equation 5.12:

i) <u>Quantity of lead-time safety stock</u>

In converting the lead-time safety value, $K_{LT}\sigma_{LT}$ weeks, into actual units of stock, it is felt that the maximum rate of demand allowed for $\left(\text{i.e. } \frac{F_D + K_D\sigma_D}{P_E}\right)$ must be considered. This is regarded as justifiable by the fact that the safety stock must, under such circumstances, continue to provide adequate coverage against extended lead-time (see Figure 5.7).

Hence, $$\text{Quantity of Lead-Time Safety Stock} = K_{LT}\,\sigma_{LT}\left(\frac{F_D + K_D\sigma_D}{P_E}\right) \qquad (5.13)$$

ii) Probability of Occurrence

This is defined as follows:

Probability of Occurrence = Probability of lead-time safety stock being held for a period equal to the stock-item's ERP

Bearing in mind that a period greater than a stock-item's ERP is regarded as falling outside the bounds of the stock control model/methodology, the above equation can be rewritten thus:

Probability of Case (2) Occurring = 1 - Probability of lead-time safety stock being totally used within a period less than the stock-item's ERP

The prime circumstances under which lead-time safety stock would be totally used within a period less than a stock-item's ERP are felt to be if demand and lead-time exceeded their respective forecasted values plus the safety stock quantities held; i.e. case (1A), Figure 5.7 (probability of occurrence: $\alpha_D \alpha_{LT}$).

Therefore:

$$\text{The probability of case (2) occurring} = 1 - (\alpha_D \alpha_{LT}) \tag{5.14}$$

Therefore, substituting into equation 5.12:

$$E(HC_{LT}) = K_{LT}\sigma_{LT}\left(\frac{F_D + K_D\sigma_D}{P_E}\right) \times P_E \times C_H \times \left[1 - (\alpha_D \alpha_{LT})\right]$$

i.e. $$E(HC_{LT}) = K_{LT}\sigma_{LT}(F_D + K_D\sigma_D)C_H\left[1 - (\alpha_D \alpha_{LT})\right] \tag{5.15}$$

5.2.2 Determination of Expected Stockout Cost $E(SC_{LT})$

The basic formula for determining $E(SC_{LT})$ is identical to that used in calculating demand stockout cost:

i.e. $E(SC_{LT})$ = Stockout Quantity x Per Unit Stockout Cost x Probability of Occurrence (5.16)

With regard to the stockout quantity, this is the result of excessive demand (i.e. demand $> F_D + K_D\sigma_D$) combined with excessive lead-time (i.e. lead-time $> F_{LT} + K_{LT}\sigma_{LT}$); i.e. case (1A), Figure 5.7.

Therefore:

$$\text{Stockout quantity} = D'' \times E(K_{LT})\sigma_{LT}$$

where D'' = Average Excessive Demand-rate per ERP (see equation 5.7)

and $E(K_{LT})\sigma_{LT}$ = partial expectation (i.e. the average length of time by which $F_{LT} + K_{LT}\sigma_{LT}$ is exceeded).

Hence, substituting the appropriate terms into equation 5.16 gives:

$$E(SC_{LT}) = D'' E(K_{LT})\sigma_{LT} C_{SO}\,\alpha_D \alpha_{LT} \qquad (5.17)$$

The expected total cost $E(TC_{LT})$, associated with the lead-time safety value $K_{LT}\sigma_{LT}$, can now be obtained:

i.e. $$E(TC_{LT}) = E(HC_{LT}) + E(SC_{LT}) \qquad (5.18)$$

The minimum value of expected total cost $E(TC_{LT})^*$, is obtained in the same manner as that described for determining $E(TC_D)^*$. This being achieved, the value of K_{LT} associated with $E(TC_{LT})^*$ is then used in calculating the quantity of lead-time safety stock needed (Ref equation 5.13).

5.3 Calculation of ERP Requirement Quantity

Calculation of the quantity of stock required to be held at the start of an ERP, i.e. the ERP Requirement Quantity (Q^*), simply consists of adding demand and lead-time safety stock values to the forecast of demand. Consequently, the formula for calculating Q^* is as follows:

$$Q^* = F_D + K_D\sigma_D + \left[K_{LT}\sigma_{LT} \left(\frac{F_D + K_D\sigma_D}{P_E} \right) \right] \qquad (5.19)$$

5.4 Calculation of Reorder Quantity

Although the ERP Requirement Quantity can now be calculated, it is not necessarily the quantity that is required to be ordered, i.e. the Reorder Quantity (ROQ). The reason is that Q^* is purely that quantity required to be in stock at the start of an ERP. How much stock needs to be ordered will depend upon the following:

1) How much free stock currently exists (SL).

2) Whether any backorders exist (B).

3) Anticipated usage during the stock replenishment lead-time (U).

Note: Each of the above variables: SL (Stock Level), B (Backorders) and U (Usage) are measured in appropriate units of storage.

When applying the stock control methodology in practice, values for SL and B (for the stock-item in question) will be available from the computer data base. The value of U, however, will always have to be calculated. This is achieved by the stock control model first recalling the value of Actual Average Demand Rate ($\overline{DR}_{p-1}$), calculated originally for use in forecasting demand (Ref equation 4.7). Having obtained this value, anticipated usage during the forthcoming lead-time is then calculated as shown overleaf:

Anticipated Usage
During Forthcoming Lead-Time

$$\underline{U = \overline{DR}_{p-1} \times F_{LT}} \quad (5.20)$$

The recommended Reorder Quantity that the stock control model/computer then generates is as follows:

$$\underline{\underline{ROQ = Q^* - (SL - (B + U))}} \quad (5.21)$$

It should be noted that the quantity (SL - (B + U)) can be a minus value, i.e. the backorder quantity may be large, or/and anticipated usage during the replenishment lead-time may be larger than the current stock quantity. The result will be that the reorder quantity will be larger than the value of Q^*. The logic is that, where such circumstances prevail, it would be inefficient to commence the next ERP with a stock level less than the requirement quantity Q^*, calculated.

It should be noted also that the value of (SL - (B + U)) can, occasionally, be greater than the requirement quantity Q^*. A negative value of ROQ would thus be generated. This may, for example, be the result of a fall-off in demand and shows that the existing (old) reorder level is now, under current demand circumstances, too high. The new reorder level, subsequently calculated, will be lower and the negative replenishment quantity (which also means more stock exists for the forthcoming ERP than is required) can be ignored, or considered as an indication as to a possible general fall-off in demand.

5.5 Calculation of Reorder Level

In deciding the size of Reorder Level (ROL), it is basically necessary to calculate the quantity required to satisfy demand during replenishment lead-time. However, it is suggested that, in this case, it is also necessary to recognise the variations in demand and lead-time allowed for (i.e. $K_D\sigma_D$ and $K_{LT}\sigma_{LT}$ respectively) in order that the coverage for demand during the lead-time is sufficient. For this reason, the following formula for calculating ROL was proposed:

$$ROL = \left[\frac{F_D + K_D\sigma_D}{P_E}\right] \times \left[F_{LT} + K_{LT}\sigma_{LT}\right] \qquad (5.22)$$

i.e. $\frac{F_D + K_D\sigma_D}{P_E}$ = Maximum Demand-Rate allowed for;

and $F_{LT} + K_{LT}\sigma_{LT}$ = Maximum Lead-Time allowed for.

Chapter 6

Test-Simulation

6 Test-Simulation

6.1 Description

The purpose of the simulation (see Appendix H), as stated in sub-section 3.1, was to test the efficiency of the entire stock control methodology rigorously in relationship to Edgar Vaughan. As a result, the simulation was designed to present the Methodology with various demand/replenishment delivery conditions, reproduced mathematically, that were similar to those encountered by the company in its normal operating environment.

In the tests carried out, sales/demand data for 26 finished products were used, recorded for the year 1980 and comprising 12 monthly values for each finished product. Each simulation-run related to one product only.

So as to allow the performance results from the simulation testing to be interpreted as direct measures of efficiency of the Methodology, the simulation ignored supportive manual functions such as physically raising purchase orders, receiving goods into stock, barrel filling, etc.

Actual operation of the simulation is best described, in the main, by the use of a flow-chart (see Figure 6.1). However, there are certain points about the simulation that require separate explanation. These are shown numbered on Figure 6.1 and are dealt with in the following paragraphs.

1 So as to permit the demand forecasting routine to commence its role in the Methodology/simulation in a reasonably stable state, it was first

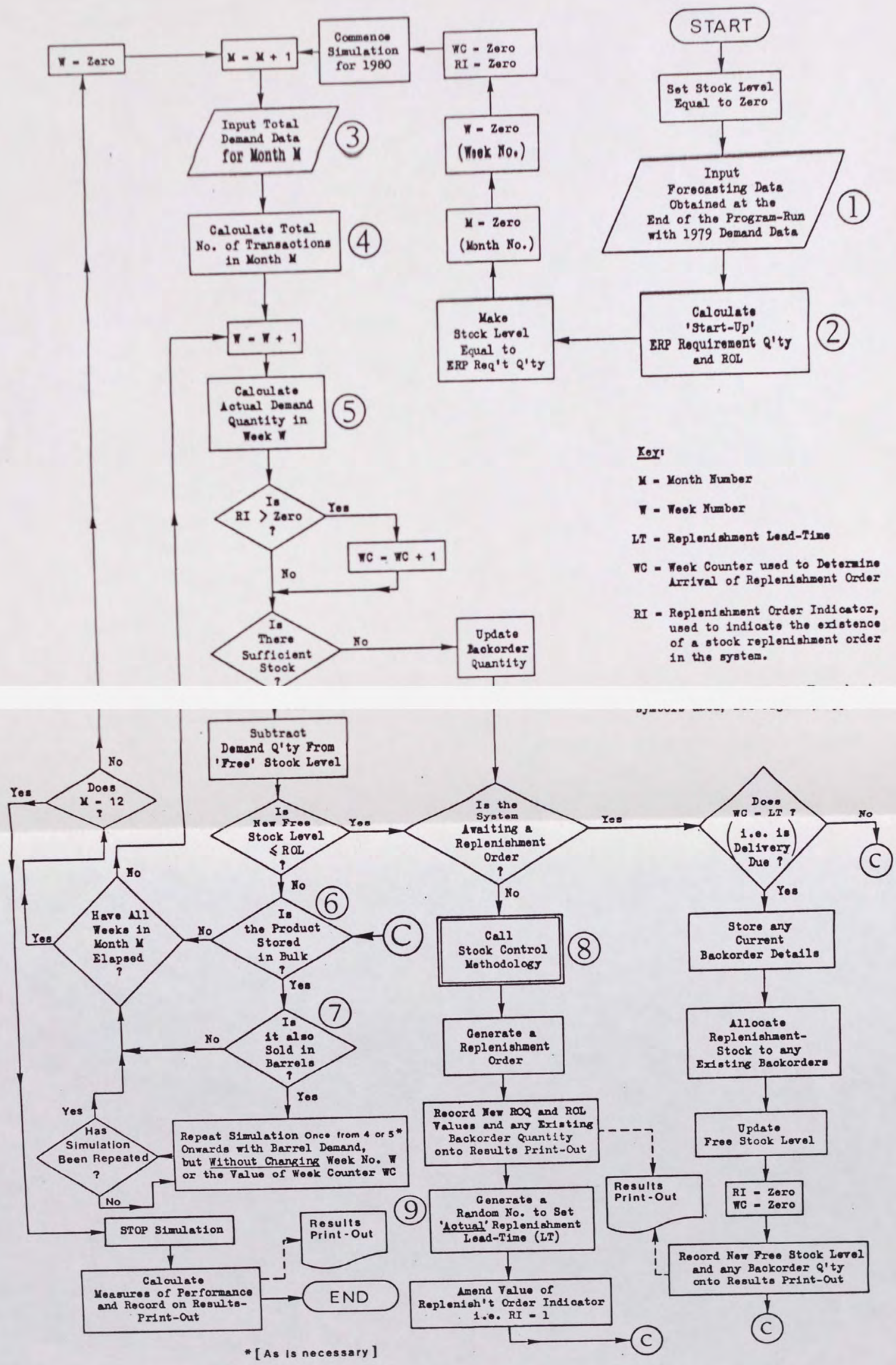

Fig. 6.1 Flow-Chart Summarising the Logic of the Test-Simulation Program Used for Examining the Performance Capability of the Stock Control Methodology.

run on its own with data recorded for 1979. In this instance, though, the original monthly sales/demand data were used to produce estimates of actual demand for a series of periods each equal to the respective ERP and spanning in total the full 12 months of 1979. This allowed the forecasting-period on each occasion also to equal the respective ERP, as it would in practice. By doing this, the final forecasting parameters developed were suitable as commencement values in the simulation involving 1980 data. These parameters comprised those listed below and were recorded at the end of each 1979 program-run for use as input data to the main simulation.

(i) Non-adaptive forecast of demand for final ERP of 1979 (i.e. that value relating to period P).

(ii) Last value of smoothed mean of non-adaptive forecasting-errors (i.e. that value relating to period P-1).

(iii) Last value of smoothed MAD of non-adaptive forecasting-errors (i.e. that value relating to period P-1).

(iv) Value of last tracking signal (i.e. that value relating to period P-1).

(v) Adaptive forecast of demand for final ERP of 1979 (i.e. that value relating to period P).

(vi) Value of last adaptive forecasting-error (i.e. that value relating to period P-1).

(vii) Actual demand for final ERP of 1979 (i.e. that value relating to period P).

2 So as to begin the simulation proper with the system in a similar condition to that if it were established and working perfectly, the above variables were also used to calculate the theoretical 'start-up' values of ERP Requirement Quantity and ROL. The simulation was then commenced with a stock level and ROL respectively equal to the two values calculated. In this way, transient effects of changing over to the new stock control policy were avoided thus making simulation and performance measurement more meaningful.

3 The units of demand used in the simulation varied with product and depended upon the main method of storage employed:

Bulk Storage	:	Demand Units	:	Tonnes
Barrel Storage (warehouse)	:	Demand Units	:	Barrels

4 and 5 Since the ERP/forecast-period was measured in weeks, it was also necessary to present demand data and monitor stock levels on a weekly basis at least. Unfortunately, sales/demand data could not be obtained as a series of weekly values in the time available. To overcome this problem, the simulation was designed to accept individual monthly sales/demand values as initial input data at the start of each four week

cycle*. These values were, in turn, then used to generate weekly demand figures as follows:

(i) Prior to commencing the simulation for the month in question an estimate of the number of transactions involved was first calculated. This was achieved through the use of an Average Transaction Quantity, formulated as shown below.

$$\text{Average Bulk Transaction Quantity} = \frac{\text{Total Bulk Demand for 1980}}{\text{Known No. of Actual Bulk Transactions}} \qquad (6.1)$$

Note: Bulk demand, in the context of this thesis, relates to customer demand requesting delivery in bulk and necessitating the use of a road tanker wagon (RTW) for delivery.

$$\text{Average Barrel Transaction Quantity} = \frac{\text{Total Barrel Demand for 1980}}{\text{Known No. of Actual Barrel Transactions}} \qquad (6.2)$$

$\therefore$ by using equation 6.1:

$$\text{Approximate No. of Bulk Transactions in Month } M = \frac{\text{Bulk Demand for Month } M}{\text{Average Bulk Transaction Quantity}} \qquad (6.3)$$

---

* Taken to represent one month M

Similarly, by using equation 6.2:

$$\text{Approximate No. of Barrel Transactions in Month M} = \frac{\text{Barrel Demand for Month M}}{\text{Average Barrel Transaction Quantity}} \qquad (6.4)$$

(ii) So as finally to obtain a weekly value of demand, yet still ensure approximation to real-life conditions, a proportion of the month's transactions was allocated randomly to each of the four weeks involved. This was achieved by using the standard facility contained within the computer for generating 'pseudo-random numbers'. These are drawn from a uniform distribution and thus all numbers in the series have, theoretically, an equal probability of occuring. Such a series of random numbers is termed 'pseudo' because the numbers are generated artifically, each one being derived from the one before.

The basic methodology by which the random numbers were used is summarised below:

$$\text{No. of Transactions in Week 1, Month M} = \text{Total No. of Transactions Calculated for Month M} \times \text{Random No. for Week 1} \times \tfrac{1}{2} \qquad (6.5)$$

$$\text{No. of Transactions in Week 2, Month M} = \text{No. of Transactions Remaining for Month M} \times \text{Random No. for Week 2} \times \tfrac{2}{3} \qquad (6.6)$$

$$\text{No. of Transactions in Week 3, Month M} = \text{No. of Transactions Remaining for Month M} \times \text{Random No. for Week 3} \qquad (6.7)$$

$$\text{No. of Transactions in Week 4, Month M} = \text{No. of Transactions Remaining for Month M} \qquad (6.8)$$

The reason for the inclusion of the third term in the first two equations was to prevent the majority of transactions <u>frequently</u> occurring in the early part of the month. Instead, the approach used results in the <u>average</u> percentage of transactions per week per month remaining the same (i.e. 25% of the total for the month in question), whilst allowing the exact pattern of transactions to vary from week to week.

Concluding, a weekly demand value was obtained for each of the four weeks thus:

$$\text{Demand during week W, month M} = \text{No. of transactions during week W, month M} \times \text{Appropriate average transaction quantity} \qquad (6.9)$$

6 and 7 In cases where finished products were stored and sold primarily in bulk yet also sold in barrels, it was stated by Edgar Vaughan that in the future, manufacture would be governed solely by the level of stock within the bulk storage tank and would not be actioned by a drop in barrel stock. Further, barrel stock would be replenished when necessary by filling barrels from bulk storage.

As a modification to the above, with a view to easing the design and use of the simulation, it was assumed that barrel stock was not kept but that demand was met when possible by filling barrels directly from bulk storage. This assumption permitted bulk and barrel demands to be presented in the simulation in the same units of quantity, against one stock figure. Duplication of performance measurements was also avoided in this way. Nevertheless, in order to retain a substantial degree of realism, each type of demand (bulk and barrel) was presented/simulated separately on a weekly basis; i.e. for each week, two simulation cycles were completed where required.

8 This comprised three sub-routines representing the following:

(i) Demand Forecasting Routine

(ii) Lead-Time Forecasting Routine

(iii) Stock Control Model Proper

9 Simulated 'actual' replenishment lead-times were generated, using once more the pseudo-random number facility within the computer, in such a way as to be effectively chosen from a uniform distribution with a minimum of one week and a maximum of three weeks, rounded to a whole number of weeks (see Appendix J).

The equipment used for programming and running the simulation was the Commodore Pet series 8000 microcomputer, in conjunction with a dual floppy-disk drive and printer. The programming language used was BASIC.

Choice of the above computer was simply to speed up the initial program-testing and reduce the time spent in refining the simulation. This was achieved quite easily with the Pet, as it is an interactive machine.

6.2 Finished Products Considered

The finished products used in conjunction with the simulation were once more those selected for use in testing the forecasting models described in Chapter 4 (see 4.2, p. 72). In foreseeing their use with the simulation, products whose number of transactions for the year was nine or less were not included. The reason for this was that it had been previously agreed by all concerned that such products would in practice be dealt with on a 'make-to-order' basis. Originally, as stated in Chapter 4, the number of products picked was 30; unfortunately four had to be omitted owing to insufficiently detailed data regarding costs and the total number of transactions in 1980.

The finished products ultimately used for simulation test purposes, along with the characteristics considered important, are given in Table 6.1. The range of demand characteristics encountered is presented graphically in Appendix C.

Product Code	Sales Category	End of 1980 Sales Rank No.	Nature of Product	Prime Units of Storage	1980 Demand for Prime Units of Storage	Total* Simulated No. of Transactions	1980 Sales Price(£s) per Tonne	Category of Manufacture	Manufacturing Site
01010	1	171		Tonnes	36 Tonnes	15	413.75	Simple Blend	Barton
01050	2	105		Barrels	304 Barrels	42	510.83	"	"
01260	3	19		Tonnes	202 Tonnes	64	456.31	"	"
03010	1	101		Barrels	242 Barrels	99	652.63	"	"
03020	1	80		"	264 "	60	601.37	"	"
04060	2	147		"	155 "	53	540.45	"	"
06050	2	123	Neat Cutting Oils	Tonnes	53 Tonnes	34	425.04	"	"
06080	1	62		"	69 "	20	526.52	"	"
06610	3	131		Barrels	221 Barrels	24	513.04	"	"
07030	1	42		"	254 "	91	676.14	"	"
07110	2	97		"	126 "	45	622.00	"	"
08910	3	14		Tonnes	205 Tonnes	43	486.21	"	"
08915	3	50		Barrels	238 Barrels	92	596.73	"	"
12030	1	7		Tonnes	312 Tonnes	268	558.87	Blend	"
14010	1	2		"	437 "	486	771.11	Mixer*	Trafford Park
14020	1	86	Soluble Cutting Oils and Fluids	Barrels	134 Barrels	52	887.96	"	"
15010	2	120		"	256 "	125	303.35	Blend	"
15030	2	75		"	339 "	89	371.55	"	"
20700	1	92	Drawing Oil	"	182 "	60	763.56	Mixer	"
30160	1	115	Lubricating Oils	"	78 "	37	461.89	Blend	Barton
30909	3	74		"	293 "	34	595.70	"	Trafford Park
40020	1	1	Fire Resistant - Hydraulic Fluid.	Tonnes	1002 Tonnes	731	697.55	Mixer	Barton
52200	1	22	Quenching Oil	"	126 "	61	566.39	Blend	"
67061	2	54	Rust Preventive	Barrels	266 Barrels	109	735.26	Spirit Blend	Trafford Park
70028	1	6	Paper Defoamers	Tonnes	233 Tonnes	76	790.49	Blend	Barton
70029	2	133		Barrels	121 Barrels	13	916.64	"	"

(**Note:** One barrel on average = 0.18 tonnes)

* For products held primarily in bulk storage, the values shown also include barrel transactions; all values are based on actual sales/demand data for 1980.

* Use of a mixer impies a complex blend.

Table 6.1 Characteristics of Products Used in Conjunction with the Test-Simulation.

Although Table 6.1 shows the choice of products to comprise several simple blends*; this was not deliberate, but resulted naturally owing to the majority of the company's 'best sellers' being of this type. The fact that they appear in succession is simply the result of the method of product-coding.

As a follow-on to the above, it so happens that the actual percentages of the different categories of manufacture are, as a whole, naturally represented quite accurately by the percentages of each included in the simulation analysis, i.e. in practice:

Simple Blends	represent approx. 50% of total manufacture
Ordinary Blends	represent approx. 25% of total manufacture
Complex Blends	represent approx. 20% of total manufacture
Spirit Blends	represent approx. 5% of total manufacture

A similar analysis of the products used in the simulation shows:

Simple Blends	represent 50%
Ordinary Blends	represent 31%
Complex Blends	represent 15%
Spirit Blends	represent 4%

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* For definitions of the 4 types of blends produced by Edgar Vaughan see Glossary of Terms

6.3 Data

6.3.1 Stock Control Model Data (K, α and E(K))

This sub-section relates to the fixed statistical parameters required in the two safety stock cost-search routines of the stock control model. Since the same parameters are employed in both cases, only one range of values for each is necessary. The actual values of K, α and E(K) used during the simulation testing are shown in Table 6.2. Although the choice and range of the parameters used in practice can differ, the values given are considered a minimum requirement if both cost algorithms are to function efficiently.

K	α	E(K)
0.000	0.500	0.400
0.500	0.310	0.200
1.040	0.150	0.078
1.282	0.100	0.047
1.645	0.050	0.021
2.000	0.023	0.008
2.250	0.012	0.005
2.750	0.003	0.001
3.000	0.001	0.000

Table 6.2 Fixed Statistical Parameters Used in the Stock Control Model/Simulation.

[Note For a more comprehensive range of values, see Appendix G.]

6.3.2 The Average Stock Holding Ratio (R)

In initially developing the ERP formula an actual value of the Average Stock Holding Ratio was not determined. Instead, a value for this parameter was obtained later by using the simulation to test various values of R (0.5 upwards) in conjunction with actual cost and actual historic demand data for the 26 finished products concerned. The performance of each value was partly assessed by examining the effect on the sum of the annual stock holding, stock replenishment and stockout costs rsulting. To complete the assessment, the actual number of replenishments recorded was also compared to that of the economical number of replenishments (N_R^*, calculated using equation 4.10). The value of R chosen was that which produced, as a compromise, a near optimisation of total system-operating cost and an actual number of replenishments not too far removed from N_R^*.

Summarising, the results of the tests showed the best value of R, for the products examined, to be 1.3*.

Further reference to the Average Stock Holding Ratio is made in Chapter 7.

6.3.3 Basic Product Data

All data described in this sub-section were, for the purpose of the simulation, actual data relating to Edgar Vaughan and where necessary were obtained on an individual product basis (for details, see overleaf).

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* See sub-section 4.2 as to why the ratio may be greater than unity

(i) Holding Cost (£/unit of storage/week; symbol: C_H)

This was considered as being equal to the following:

fixed storage cost + variable storage cost

and varied according to the method of storage employed:

A) Bulk (units of storage : tonnes)

fixed storage cost = Lost opportunity cost of renting* the storage tank in question to another company; units : £/tonne/week (actual figure used: £0.25/tonne/week).

variable storage cost = Interest paid/lost on capital spent ('tied-up') as a direct result of pursuing stocking policy, i.e. cost of materials and manufacture (production labour cost was considered a fixed overhead cost and was not included); units : £/tonne/week.

With regard to variable storage cost, in both the cases of bulk and barrel storage, the costs associated with research and development,

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* This was not an unusual practice for Edgar Vaughan.

marketing, sales, administration, etc., were considered as general overheads and unaffected by the exact stocking policy pursued. As a result, such costs were not included in calculating variable storage cost.

B) Barrels (units of storage : barrels)

fixed storage cost = Proportion of write-off cost of new warehouse + proportion of cost of running warehouse (costs included insurance, rates, labour, security, stacker trucks, computer facilities, etc.); units : £/barrel/week (actual figure used : £0.37/barrel/week).

variable storage cost = Interest paid/lost on capital spent ('tied-up') as a direct result of pursuing stocking policy, i.e. cost of materials, manufacture and packaging; units : £/barrel/week.

(ii) Replenishment Cost (£/replenishment; **symbol:** C_R)

Owing to the fact that no bought-out items were considered, the individual replenishment cost for each product constituted simply the fixed cost incurred when actually running the equipment needed for manufacture. Since manufacturing time for a product does not differ with the quantity required, all such running costs were independent of quantity and varied only with equipment type.

(iii) Stockout Cost (£/unit of storage of lost sales; **symbol**: C_{SO})

This was defined as shown below:

Stockout Cost = lost contribution to overheads and gross profit

i.e. Stockout cost = Selling Price - Prime costs of Raw Materials and Manufacture (excluding labour) and packaging where applicable

(iv) Economical Replenishment Period (weeks)

All ERP values were calculated separately prior to using the simulation and thus were provided as part of the input data.

(v) Demand Data (appropriate units of storage)

It is important once more to note that the units used to measure demand varied according to the method of storage employed (see earlier note against 3, sub-section 6.1).

(vi) Actual data used for (i), (ii), (iii) and (iv)

See Table below.

Product Code	Holding Cost (£ /unit of/week) storage	Replenishment Cost (£ /replenishment)	Stockout Cost (£ /unit of storage) of lost sales	ERP (weeks)
01010	1.06	26.50	97.52	5
01050	0.51	"	24.90	2
01260	1.23	"	77.39	2
03010	0.53	"	40.77	3
03020	0.51	"	44.73	3
04060	0.51	"	35.66	3
06050	1.07	"	102.19	4
06080	1.11	"	184.31	3
06610	0.51	"	33.15	3
07030	0.56	"	53.25	3
07110	0.59	"	38.00	4
08910	1.25	"	95.52	2
08915	0.53	"	35.43	3
12030	1.10	41.50	216.63	2
14010	1.21	147.50	376.63	3
14020	0.67	"	77.77	8
15010	0.46	41.50	33.94	3
15030	0.47	"	46.62	3
20700	0.60	147.50	55.10	7
30160	0.51	41.50	132.42	6
30909	0.54	"	37.00	3
40020	1.26	147.50	289.39	2
52200	1.28	41.50	161.46	3
67061	0.53	45.50	51.07	3
70028	1.43	41.50	317.45	2
70029	0.58	"	80.10	5

Table 6.3 Basic Product Data Used in Conjunction with the Test-Simulation.

6.4 Performance Measurement

Reference to Appendix K shows that the results print-out, obtained from each simulation-run, presented a comprehensive range of data relating to the stock control methodology's behaviour/performance. However, so as to ease the final overall assessment of the Methodology's ability, analysis was ultimately confined to the following performance measures:

- Total Inventory Holding Cost for Year
- Total Replenishment Cost for Year
- True Total Stockout Cost for Year
- Total Inventory Operating Cost for Year

  (summation of the first three performance measures listed above)
- Service level*
- Total number of Stockouts for Year
- Maximum Stockout Duration
- Average Backorder Quantity per Stockout
- Total number of Stock Replenishments for Year
- Average Weekly Stock Level (Note: In each case, this measurement was compared to company's June 1981 stock-take figure).

At a late stage in the development of the simulation, Edgar Vaughan's management stated that generally a stockout of one or two weeks' duration would not, in practice, result in the loss of the customers' orders involved. It was, nonetheless, agreed by them that stockouts greater than two weeks would not be tolerated by customers. Hence, so as to ensure that the simulation results would be viewed as being entirely realistic by the company, the measure 'True Total Stockout Cost' relates to the total cost arising only from stockouts in excess of two weeks' duration.

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* Percentage of customer demand transactions satisfied ex stock.

In order that the Methodology might also be assessed against some form of yardstick, the basic simulation program was modified slightly (see Appendix L) so as to test a stock control policy put forward by Edgar Vaughan. This policy comprised a simple 'rule-of-thumb' approach and was devised in June 1981 as an interim means of drastically reducing the amount of capital tied-up in stocks. The need for this action was brought about by the continuing detrimental effects of the general business recession. The policy's control parameters for each product were as follows:

Maximum Stock Level = 10% of Annual Sales Figure [measured in units of storage]

Reorder Level = 10% of Maximum Stock Level

Reorder Quantity = That quantity of Stock needed to bring the Stock Level up to Maximum Stock Level

In carrying out the simulation tests on the '10% Policy' (see Appendix M), the product sales/demand data used were those ultimately employed in testing the stock control methodology (i.e. product sales/demand data for 1980).

Finally it was also felt necessary to examine the Methodology's ability to 'tune' its performance, with time, to the particular demand characteristics of a product. This was achieved by comparing the <u>total quantity of stock ordered</u> by the stock control model against the <u>total actual demand quantity</u>; first at the end of six months and then at the end of 12 months.

All results are summarised in the following chapter.

Chapter 7

Discussion

7 Discussion

7.1 Test-Simulation Results

Product Code	1980 Sales Rank No.	Inventory Holding Cost for Year 1	Replenish't Cost for Year 2	True * Stockout Cost for Year 3	Total Operating Cost (1)+(2)+(3)	Number of Transactions	Service Level	Total No. of Stockouts for Year	Maximum Stockout Duration	Average Stockout Quantity	Total No. of Stock Replenish'ts	Average Weekly Stock Level	June 1981 Stock Level
01010	171	£272.95	£159.00	£Zero	£431.95	16	87.5%	2	1 week	3.2T'ns	6	5.4 T'ns	12.1 T'ns
01050	105	£514.07	£450.50	"	£964.57	39	84.6%	2	2 weeks	21Br'ls	17	21 Br'ls	21 Br'ls
01260	19	£810.41	£503.50	"	£1313.91	63	90.4%	4	1 week	5.0T'ns	19	13.7 T'ns	16.3 T'ns
03010	101	£541.47	£291.50	"	£832.97	124	90.3%	1	2 weeks	10Br'ls	11	21 Br'ls	36 Br'ls
03020	80	£712.04	£265.00	"	£977.04	68	83.8%	1	1 week	28 "	10	29 "	79 "
04060	147	£525.29	£212.00	"	£737.29	52	100%	None	-----	-----	8	21 "	24 "
06050	123	£283.81	£238.50	"	£522.31	43	100%	"	-----	-----	9	5.5 T'ns	28.4 T'ns
06080	62	£486.97	£265.00	"	£751.97	23	91.3%	1	2 weeks	5.5T'ns	10	9.1 T'ns	1.6 T'ns
06610	131	£458.49	£318.00	"	£776.49	23	91.3%	1	1 week	9Br'ls	12	19 Br'ls	No Stock
07030	42	£568.40	£371.00	"	£939.40	86	84.8%	2	2 weeks	17 "	14	21 "	33 Br'ls
07110	97	£377.60	£291.50	"	£669.10	41	100%	None	-----	-----	11	13 "	8 "
08910	14	£868.44	£397.50	"	£1265.94	41	87.8%	4	2 weeks	10.4T'ns	15	14.4 T'ns	1.0 T'n
08915	50	£700.91	£265.00	"	£965.91	81	86.4%	1	1 week	21Br'ls	10	28 Br'ls	48 Br'ls
12030	7	£1148.48	£705.50	"	£1853.98	266	89.4%	3	2 weeks	9.3T'ns	17	21.7 T'ns	10.2 T'ns
14010	2	£2178.73	£2065.00	"	£4243.73	490	100%	None	-----	-----	14	37.6 "	20.8 "
14020	86	£773.17	£737.50	"	£1510.67	71	83.0%	1	2 weeks	24Br'ls	5	24 Br'ls	43 Br'ls
15010	120	£462.60	£498.00	"	£960.60	131	94.6%	1	1 week	14 "	12	21 "	69 "
15030	75	£587.97	£581.00	"	£1168.97	88	80.6%	3	1 "	19 "	14	26 "	15 "
20700	92	£818.40	£737.50	"	£1555.90	62	95.1%	1	1 "	9 "	5	28 "	34 "
30160	115	£301.75	£249.00	"	£550.75	42	100%	None	-----	-----	6	12 "	20 "
30909	74	£686.71	£539.50	"	£1226.21	33	84.8%	1	1 week	18Br'ls	13	26 "	No Stock
40020	1	£3131.89	£3097.50	"	£6229.39	731	96.5%	4	1 "	11.7T'ns	21	51.8 T'ns	263.1 T'ns
52200	22	£879.84	£415.00	£1519.82	£2814.66	60	91.6%	1	4 weeks	9.4T'ns	10	14.3 "	13.9 "
67061	54	£677.64	£637.00	£Zero	£1314.64	137	99.2%	1	<1 week	2Br'ls	14	26 Br'ls	No Stock
70028	6	£1246.88	£705.50	"	£1952.38	74	93.2%	1	1 week	2.5T'ns	17	18.2 T'ns	37.1 T'ns
70029	133	£687.20	£249.00	"	£936.20	14	85.7%	2	2 weeks	18Br'ls	6	25 Br'ls	2 Br'ls
	Totals:	£20,702.11	£15,411.00	£1,519.82	£37,632.94	Average:	91.2%			Total:	310		

* [Stockout costs associated with stockouts equal to/less than 2 weeks duration are ignored from a cost point-of-view; see sub-section 6.4.]

Table 7.1 Simulation Results Obtained in Testing the Stock Control Methodology Proposed.

Product Code	1980 Sales Rank No	Inventory Holding Cost for Year 1	Replenish't Cost for Year 2	True* Stockout Cost for Year 3	Total Operating Cost (1)+(2)+(3)	Number of Transactions	Service Level	Total No. of Stockouts for Year	Maximum Stockout Duration	Average Stockout Quantity	Total No. of Stock Replenish'ts	Average Weekly Stock Level	June 1981 Stock Level
01010	171	£129.22	£318.00	£1022.98	£1470.20	16	50.0%	6	4 weeks	3.9T'ns	12	2.5 T'ns	12.1 T'ns
01050	105	£298.86	£291.50	£1220.10	£1810.46	39	64.1%	6	5 "	16Br'ls	11	12 Br'ls	21 Br'ls
01260	19	£494.42	£397.50	£2686.20	£3578.12	63	55.5%	8	4 "	11.5T'ns	15	8.4 T'ns	16.3 T'ns
03010	101	£263.79	£424.00	£Zero	£687.79	124	79.0%	6	2 "	9Br'ls	16	10 Br'ls	36 Br'ls
03020	80	£301.64	£318.00	£3399.48	£4019.12	68	51.4%	6	3 "	22 "	12	12 "	79 "
04060	147	£205.01	£371.00	£855.84	£1431.85	52	61.5%	7	3 "	9 "	14	8 "	24 "
06050	123	£146.93	£450.43	£1644.23	£2241.59	43	72.0%	8	6 "	4.0T'ns	17	2.8 T'ns	28.4 T'ns
06080	62	£224.39	£318.00	£1021.07	£1563.46	23	73.9%	6	3 "	5.5 "	12	4.2 "	1.6 "
06610	131	£249.38	£318.00	£1491.75	£2059.13	23	56.5%	6	4 "	15 Br'ls	12	10 Br'ls	No Stock
07030	42	£297.36	£397.50	£1278.00	£1972.86	86	75.5%	7	3 "	9 "	15	11 "	33 Br'ls
07110	97	£173.46	£450.50	£684.00	£1307.96	41	68.2%	5	3 "	8 "	17	6 "	8 "
08910	14	£546.83	£344.50	£3183.68	£4075.01	41	73.1%	7	6 "	13.1T'ns	13	9.1 T'ns	1.0 T'n
08915	50	£289.92	£344.50	£2657.25	£3291.67	81	48.1%	6	3 "	21Br'ls	13	11 Br'ls	48 Br'ls
12030	7	£591.98	£705.50	£Zero	£1297.48	266	84.9%	8	2 "	6.7T'ns	17	11.2 T'ns	10.2 T'ns
14010	2	£969.23	£2507.50	"	£3476.73	490	85.9%	7	2 "	9.7 "	17	16.7 "	20.8 "
14020	86	£182.24	£1917.50	£3888.50	£5988.24	71	50.7%	7	5 "	10 Br'ls	13	6 Br'ls	43 Br'ls
15010	120	£256.12	£664.00	£Zero	£920.12	131	84.7%	8	1 week	5 "	16	12 "	69 "
15030	75	£330.87	£622.50	£1864.80	£2818.17	88	71.5%	6	4 weeks	17 "	15	15 "	15 "
20700	92	£282.60	£2212.50	£Zero	£2495.10	62	72.5%	6	1 week	9 "	15	10 "	34 "
30160	115	£89.40	£664.00	£794.52	£1547.92	42	76.1%	5	3 weeks	4 "	16	4 "	20 "
30909	74	£403.24	£622.50	£Zero	£1025.74	33	81.8%	4	1 week	14 "	15	16 "	No Stock
40020	1	£2850.93	£2360.00	"	£5210.93	731	93.0%	3	2 weeks	25.5T'ns	16	47.1 T'ns	263.1 T'ns
52200	22	£476.70	£456.50	£3038.67	£3971.87	60	81.6%	4	3 "	14.9 "	11	7.7 T'ns	13.9 T'ns
67061	54	£291.56	£728.00	£Zero	£1019.56	137	73.7%	8	2 "	9Br'ls	16	11 Br'ls	No Stock
70028	6	£700.27	£622.50	£4444.30	£5767.07	74	82.9%	7	3 "	10.2T'ns	15	10.2 T'ns	37.1 T'ns
70029	133	£192.14	£581.00	£1441.80	£2214.94	14	42.8%	7	3 "	10Br'ls	14	7 Br'ls	2 Br'ls
	Totals:	£11,238.49	£19,407.43	£36,617.17	£67,263.09	Average:	69.6%			Total:	375		

* [Stockout costs associated with stockouts equal to/less than 2 weeks duration are ignored from a cost point-of-view; see sub-section 6.4]

Table 7.2 Simulation Results Obtained in Testing Edgar Vaughan's '10% Policy' Approach to Controlling Stocks.

Product Code	1st Six Months		Difference: (2) minus (1)	2nd Six Months		Difference: (4) minus (3)
	Total Customer Demand 1	Qty Ordered by Stock Model* 2		Total Customer Demand 3	Qty Ordered by Stock Model 4	
01010	21.83 tonnes	29.00 tonnes	+7.17	17.78 tonnes	19.00 tonnes	+1.22
01050	161 barrels	193 barrels	+32	112 barrels	90 barrels	-22
01260	133.26 tonnes	152.00 tonnes	+18.74	64.96 tonnes	62.00 tonnes	-2.96
03010	126 barrels	154 barrels	+28	122 barrels	127 barrels	+5
03020	144 "	181 "	+37	128 "	134 "	+6
04060	120 "	145 "	+25	36 "	21 "	-15
06050	31.68 tonnes	37.00 tonnes	+5.32	23.63 tonnes	24.00 tonnes	+0.37
06080	34.73 "	40.00 "	+5.27	28.46 "	32.00 "	+3.54
06610	108 barrels	120 barrels	+12	99 barrels	106 barrels	+7
07030	153 "	166 "	+13	105 "	107 "	+2
07110	57 "	63 "	+6	66 "	74 "	+8
08910	105.00 tonnes	127.00 tonnes	+12.00	83.34 tonnes	86.00 tonnes	+2.66
08915	171 barrels	227 barrels	+56	72 barrels	37 barrels	-35
12030	178.63 tonnes	206.00 tonnes	+27.37	127.30 tonnes	126.00 tonnes	-1.3
14010	267.74 "	354.00 "	+86.26	176.82 "	130.00 "	-46.82
14020	100 barrels	125 barrels	+25	42 barrels	57 barrels	+15
15010	148 "	172 "	+24	114 "	108 "	-6
15030	212 "	254 "	+42	140 "	131 "	-9
20700	81 "	122 "	+41	105 "	86 "	-19
30160	46 "	63 "	+17	38 "	33 "	-5
30909	189 "	232 "	+43	108 "	95 "	-13
40020	618.61 tonnes	735.00 tonnes	+116.39	383.23 tonnes	325.00 tonnes	-58.23
52200	54.31 "	72.00 tonnes	+17.69	61.87 "	94.00 "	+32.13
67061	146 barrels	180 barrels	+34	128 barrels	134 barrels	+6
70028	133.84 tonnes	148.00 tonnes	+14.16	96.85 tonnes	99.00 tonnes	+2.15
70029	72 barrels	102 barrels	+30	54 barrels	43 barrels	-11

* [Including 'Start-up' Quantity]

Table 7.3 'Six Month Check' Analysis Showing the Tuning/Adaptive Response Ability of the Stock Control Methodology, in Each of the Simulation Tests Completed.

7.1.1 General Comments

Examination of Tables 7.1 and 7.2, comprising the results of the two stock control policies tested, shows the Stock Control Methodology to have performed overall with a high degree of efficiency. This conclusion is further substantiated by the evidence presented in Table 7.3, containing the results of the Six Month Check analysis. The latter will, however, be discussed in more detail towards the end of this sub-section.

With specific regard to the Methodology's ability to function as a cost-basis model, for which it was fundamentally designed/tested, the associated results show the total annual operating costs summed for all products considered to be approximately 44% lower than the equivalent figure recorded for the 10% Policy. In this instance, the 'cost-saving' is made up primarily of a 95.85% reduction in total annual stockout cost, along with a 20.60% reduction in total annual replenishment cost. No cost-saving was made by the Methodology on total annual holding cost, since the 10% Policy was specifically formulated to reduce stock levels well below those normally held (see end two columns of Table 7.2). However, this inbuilt characteristic of the 10% Policy, although producing a total annual stock holding cost that is just over half that incurred with the Methodology, nevertheless results in service levels being less than 65% for 35% of the products considered. In contrast, the lowest service level value recorded for the Methodology is 80.6%. The results for the two policies show, therefore, that uncontrolled lowering of stock levels does not in itself provide a satisfactory solution to the capital investment problem, if an efficient off-the-shelf service to customers is also desired.

Management within Edgar Vaughan began to appreciate the aforementioned fact in examining the results, but were still not convinced about the realism of the stockout cost measure (see page 126) and hence the stockout costs/savings represented by the results of the two policies. They felt that, on reflection, stockouts would not in practice result in the loss of any customers' orders, as some form of remedial action would be quickly taken. Such reasoning was eventually accepted and it was suggested that the use of an overtime working/contingency cost might provide a more accurate stockout cost, when implementing the Methodology within the company. This suggestion was considered by Edgar Vaughan's management to be far more acceptable.

In view of the management's feelings towards the original stockout cost measure employed, together with the fact that the 10% Policy was never introduced, the figure of 44% saving in total operating cost was not used to estimate any real cost benefits of the Methodology to Edgar Vaughan. It was, instead, noted that for 14 of the 26 products considered, the average weekly stock levels produced by the Methodology were less than the respective real/actual stock levels recorded at the end of the June 1981 stock-take; of these, 10 (38.5% of the total tested) were markedly less. For this reason, it was believed that real sizeable cost-savings would be possible in practice, as a result of a reduction in the quantities of stock carried. The method used in obtaining an estimate of the saving is described in sub-section 7.1.2.

As already mentioned, one noticeable feature of the Methodology's performance is that the service levels never fall lower than 80.6%. Although pleasing, it must be realised that the Methodology was operating first and foremost as a cost-basis model, its objective being solely to minimise the total inventory system-operating cost for each product with which it was tested. High service levels, therefore, were not intentional but occurred instead for the following reasons:

(i) First, the stockout cost was taken to equal the loss of contribution normally made by a product to overheads and profit and was in all cases far higher than that of associated inventory holding costs.

(ii) Secondly, demand for all products was so variable as to provide a high risk of stockout if only that quantity forecasted was carried at the commencement of an ERP.

Consequently, in order to avoid high stockout costs, substantial demand and lead-time safety stocks were calculated by the stock control model proper, on nearly all occasions that the Methodology was employed.

A further point, related to the results of the Methodology (Table 7.1), that may possibly require explanation is the general imbalance between holding costs and the respective replenishment costs, contrary to the attempt to balance both when calculating the ERP for a product. The results are not, however, in error as the imbalance is brought about by the continual need to carry safety stocks. The difference in the two costs is thus the cost of carrying additional stock to the forecasted requirement and is separately cost-justified by the saving achieved in avoided stockout costs.

Final analysis of the results in Tables 7.1 and 7.2 reveals instances where there are considerable differences in customer service levels between products in spite of the number of associated stockouts being the same (e.g. see product codes: 03010 and 03020, Table 7.1; also product codes: 70028 and 70029, Table 7.2). It is suggested that such evidence of inconsistency offers support to the argument put forward by Lewis and Lamkin (p 53, Ref 1; p 58, Ref 17). Both consider 'the probability of there not being a stockout' a poor customer service measurement, as it does not describe the total stockout quantity over a period of, for example, a year, nor does it give any indication of stockout duration(s) or frequency of stockout. This is in fact because all three measures vary with replenishment-rate (i.e. the number of stock replenishment orders placed per unit of time).

In contrast, 'the percentage of customer demand transactions satisfied ex stock' when recorded/stated for a specified period is explicit and consequently far more purposeful.

Moving on to Table 7.3, comprising the Six Month Check results, examination shows the Methodology's ability to 'tune' itself to demand to be markedly good. This is evidenced by the reduction/compensation seen in the customer demand/replenishment quantity differences, occurring at the end of the final six months. The fact that there are as many positive differences as there are negative differences indicates no built-in bias within the Methodology.

These results are, however, considered those best suited to highlighting the efficiency/advantage of an adaptive stock control model/methodology. The reason is that they illustrate the Methodology's ability to recognise a trend in demand and modify replenishment ordering accordingly. This can be seen very clearly with products 01050, 01260, 04060, 07030, 14010, 15010, 15030, 30909 and 40020. Such results are primarly due to the demand forecasting routine and reflect in particular its efficiency of operation.

Finally, by comparing the customer demand/replenishment quantities at the end of the year alongside the respective service level values and average weekly stock levels shown in Table 7.1, it can be further deduced that:

(1) adaptation to demand is achieved without any detrimental effects to service levels, and

(2) the stock control model (proper) of the Methodology is operating efficiently by calculating adequate safety stocks <u>without overstocking</u>.

7.1.2 <u>Potential Cost-Savings to Edgar Vaughan</u>

Examination of Table 7.4 shows the ratio of 'average stock level' to 'annual demand', for each stock-item used in the simulation testing, to have been on average approximately 10.6% when controlled by the cost-basis version of the stock control methodology. Since the simulation results contained in Table 7.1 show this version of the Methodology to have performed in a similar manner to that expected of the service level version, it is assumed that the ratio of 10.6% is equally valid for the latter. Thus, application of this ratio, to the total annual demand figure embracing all finished products, is felt to provide a realistic <u>estimate</u> of the <u>average total quantity</u> of finished product stock held at any one time when controlling stocks by either of the two versions of the

Product Code	Relevant Prime Cost (£s/tonne)	Annual Demand (units of prime storage)	Average Weekly Stock Level Recorded	(2)/(1) %
01010	286.03	36.39 tonnes	5.4 tonnes	14.84
01050	340.89	304 barrels	21 barrels	6.91
01260	345.61	201.63 tonnes	13.7 tonnes	6.81
03010	383.92	242 barrels	21 barrels	8.67
03020	324.73	264 "	29 "	10.98
04060	319.26	155 "	21 "	13.55
06050	291.82	52.62 tonnes	5.5 tonnes	10.45
06080	303.77	68.75 "	9.1 "	13.31
06610	311.91	221 barrels	19 barrels	8.60
07030	376.43	254 "	21 "	8.26
07110	408.65	126 "	13 "	10.32
08910	355.20	205.07 tonnes	14.4 tonnes	7.02
08915	368.38	238 barrels	28 barrels	11.76
12030	301.44	312.13 tonnes	21.75 tonnes	6.97
14010	338.10	436.50 "	37.60 "	8.61
14020	502.50	134 barrels	24 barrels	17.91
15010	159.52	256 "	21 "	8.20
15030	171.36	339 "	26 "	7.67
20700	447.28	182 "	28 "	15.38
30160	310.53	78 "	12 "	15.38
30909	369.82	293 "	26 "	8.87
40020	357.24	1001.68 tonnes	51.78 tonnes	5.17
52200	363.58	125.59 "	14.30 "	11.38
67061	393.69	266 barrels	26 barrels	9.77
70028	415.33	233.46 tonnes	18.19 tonnes	7.79
70029	439.42	121 barrels	25 barrels	20.66
Average:	£345.63		Average:	10.58

Table 7.4 Results from the Test-Simulation of the Stock Control Methodology, Showing the Relationship Between Average Stock Level and Annual Demand for the Finished Products Considered.

Methodology. The potential cost savings to Edgar Vaughan may, therefore, be calculated as follows:

Total 1980 Sales Figure by weight = 18,764* tonnes

$\therefore$ the estimated Average Total Quantity of Finished Product Stock held at any one time using the Stock Control Methodology = 18,764 x 10.6%

$\simeq$ 2,000 tonnes

Taking the average relevant prime cost per product to equal £346.00 per tonne (see Table 7.4), it follows that:

The Average Amount of Capital Invested in Finished Product Stocks at any one time using the Stock Control Methodology = 2,000 x 346 = £692,000

So as to estimate whether the above figure was an improvement or not, the end of June 1981 stock-take total figures were obtained and considered as representing the actual total amount of capital invested (tied-up) in finished product stocks at any one time. The breakdown of the stock-take figures is given overleaf.

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* Including bought-out products

£608,000 held at the Barton site	(1)
£438,000 held at the Burntwood site	(2)
£27,000 held at the Paisley site	(3)
£15,000 Taps*	(4)
£16,000 Stock Depletion✱	(5)
£23,000 Voided Products	(6)

Since it was difficult to foresee the effect of the Methodology on stock categories (4), (5) and (6), only categories (1), (2) and (3) were considerd in the analysis. Thus, summing the invested capital associated with (1), (2) and (3):

Actual Amount of Capital invested in Finished Product Stocks at the end of June 1981 = £1,073,000

∴ The Estimated Potential Reduction in Capital Invested in Finished Product Stocks offered by the Stock Control Methodology = £1,073,000 - £692,000

= £381,000

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* Partially filled barrels

✱ see Glossary of Terms

At a Minimum Interest-rate of 10% per year, the Estimated Potential Cost-Saving per year for Finished Product Stocks $\simeq$ £38,000

As a guide to the savings on raw material stocks, this was calculated as shown below:

Total Annual Demand for Raw Materials in 1980 = Total Annual Demand for Finished Product Stock requiring manufacture by Edgar Vaughan in 1980 = 16,000* tonnes

$\therefore$ The Estimated Average Total Quantity of Raw Material Stock held at any one time using the Stock Control Methodology = 16,000 x 10.6%

$\simeq$ 1,700 tonnes

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* i.e. Excluding bought-out products

Since raw materials constitute approximately 70% of the relevant prime-cost of finished products, then:

The Average Amount of Capital Invested in Raw Material Stocks at any one time using the Stock Control Methodology = 1,700 x 346 x 0.7 = £411,740

The recorded end of June, 1981 stock-take figure for raw materials was £1,220,253.

∴ The Estimated Potential Reduction in Capital Invested in Raw Materials Stocks offered by the Stock Control Methodology = £1,220,253 - £411,740

= £808,513

At a Minimum Interest-Rate of 10% per year, the Estimated Potential Cost-Saving per year for Raw Material Stocks ≏ £81,000

∴ The Overall Potential Cost Saving to Edgar Vaughan each year = £38,000 + £81,000

i.e. £119,000

In view of the way that the company operates, i.e. primarily on a make-to-order basis, it is logical that the greatest saving should be obtained from a reduction in raw material stocks, i.e. a make-to-order approach without adequate stock control on raw materials is likely to result in overstocking, arising from their importance as a prerequisite to manufacture. However, it was recognised that the ratio of 'average stock level' to 'annual demand' may well in practice be larger than 10.6% for raw material stocks, owing to larger safety stocks being carried to cater for generally larger replenishment lead-times to those associated with finished product stocks. Nevertheless, even if the ratio was as high, for example, as 20%, the estimated potential cost-saving per year for raw material stocks would still be approximately £44,000.

As a final comment on the calculations made, the fact that a sizeable saving is shown to be possible for finished product stocks, despite the make-to-order policy pursued, is strong evidence of poor production control in the past.

7.2 The Stock Control Methodology

7.2.1 As a Service Level Stock Control Model

The only difference between the service level version of the Methodology and the cost-basis version, described so far, is the method of establishing the values of K used in calculating demand and replenishment lead-time safety stocks. The way in which this is achieved with the service level version is fundamentally by first specifying the service level desired. However, as the approach involves using once more the distrubution of forecasting-errors of demand in such calculations, the original interpretation of the measure 'service level' (i.e. that percentage of total demand transactions satisfied from stock) can no longer be used as it cannot be pre-specified (i.e. the distribution in question does not provide a measure of demand in terms of numbers or percentages of associated transactions).

A revised definition of 'service level' is therefore necessary in the case of the service level version of the stock control methodology. As a direct consequence, service level is defined in this instance as follows:

"The probability of a stockout not occurring over a period of 12 months".

The exact approach used for calculating values of K/safety stocks is considered best explained by use of an example:

Suppose the desired customer service level for a stock-item is 95%. Bearing in mind that each replenishment may be considered an exposure to stockout, the actual service level for each ERP must be higher than that required for the year (p 8, Ref 44). Consequently, assuming the service level per ERP equals 'Y' and, as a result of the ERP calculated for the stock-item, the number of replenishments per year equals 4 (say), then expressed in terms of probability:

$$Y \times Y \times Y \times Y = 0.95$$

$$\text{i.e.} \quad Y^4 = 0.95$$

$$\underline{Y \simeq 0.9872}$$

i.e. The service level offered for each ERP must equal 98.72%

However, in each ERP, the service level comprises two components:

1) The 'service level' provided by demand safety stock

2) The 'service level' provided by lead-time safety stock

Further, in accordance with the approach taken in sub-section 5.2.1, the total risk of stockout per ERP is defined as follows:

Total Risk of Stockout per ERP $= \alpha_D \alpha_{LT}$

i.e.: $(1 - 0.9872) = \alpha_D \times \alpha_{LT} = 0.0128$

By assuming, for practical purposes, $\alpha_D = \alpha_{LT}$ then:

$$\alpha^2 = 0.0128$$

$$\text{i.e.} \quad \underline{\alpha_D = \alpha_{LT} = 0.113}$$

(See Fig. 7.1)

The actual values of K_D and K_{LT} are finally found by using standard statistical tables (e.g. p 13, Ref 45):

$$\text{i.e.} \quad \underline{\underline{K_D = K_{LT} = 1.21}}$$

(for $\alpha_D = \alpha_{LT} = 0.113$)

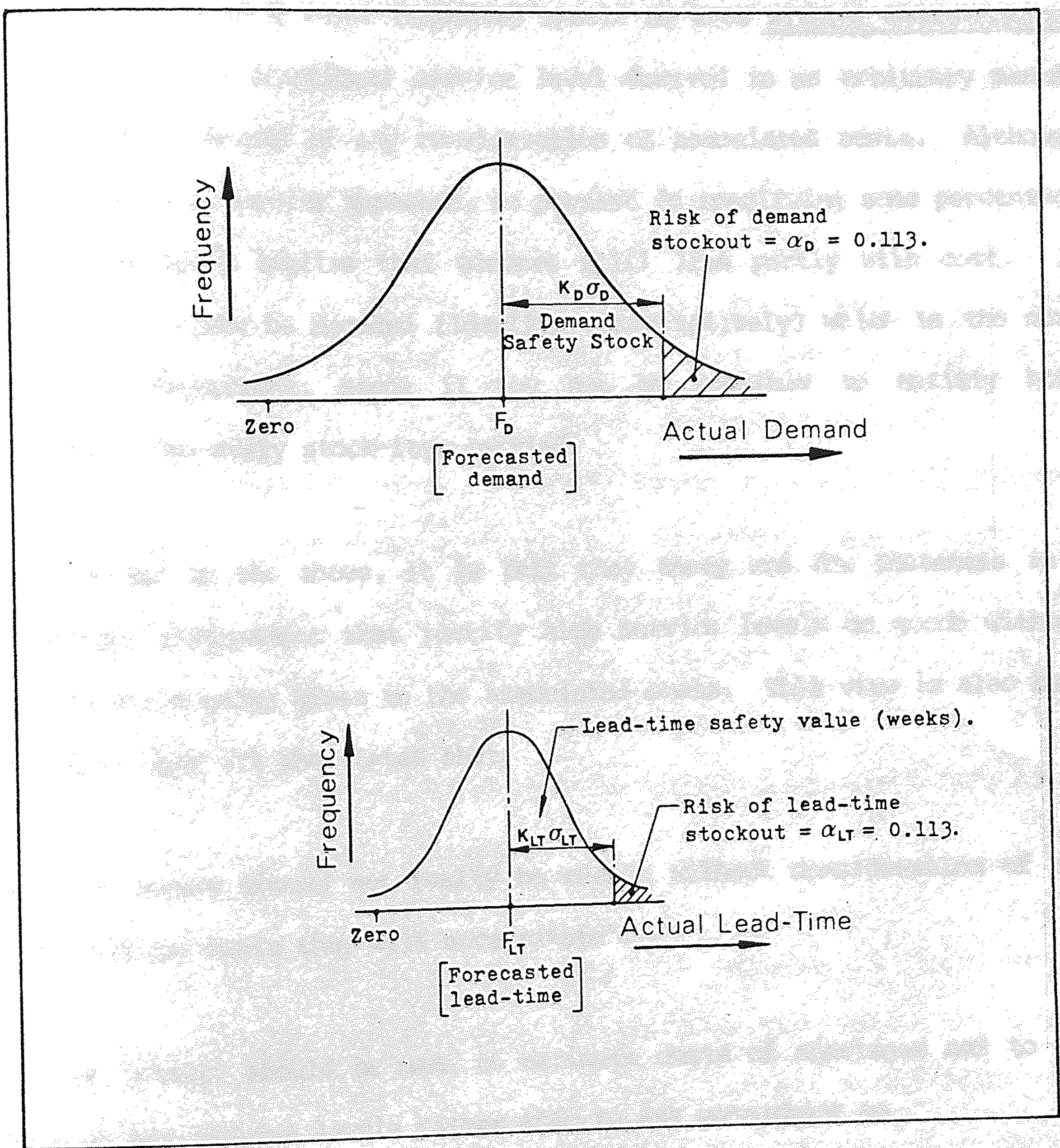

Fig. 7.1 Diagrams Illustrating the Result of the Calculations Used in Describing the Service Level Version of the Stock Control Methodology.

In practice, it is believed that if a user wishes to employ a service level model/methodology for the control of stocks, then the user should be genuinely concerned with service and not cost. Further, in cases where this concern for service holds true, it is suggested that wherever possible the service level requested should be 100% without overstocking, rather than some fractional service level derived in an arbitrary manner and therefore devoid of any consideration of associated costs. Although the latter is a popular approach, to persist in specifying some percentage of service level implies that concern still lies partly with cost. It must at all times be decided (ideally, quantitatively) which is the more important constraint, since it may not be possible to satisfy both adequately for every stock-item carried.

Further to the above, it is felt that there are few instances in a commercial environment that justify high service levels on goods without consideration being given to the associated costs. This view is also held by Lamkin (ref 17) who states that:

"Service levels should not really be chosen without consideration of the stock holding costs they will necessitate".

"... an attempt should be made to estimate costs of shortages and to use these to set service levels rather than to ask management to choose them ..."

If using holding costs and shortage costs in the way described produces unacceptably low service levels in practice, and examination of the importance of the product(s) to the company's welfare still shows high service levels as being necessary, then a re-costing exercise should ideally be carried out in order to cost-justify the service levels desired.

7.2.2 The Stock Control Methodology in Relationship to Edgar Vaughan

The Company's Response

Initially, upon explaining the principle and actual method of operation of the stock control methodology to the management of Edgar Vaughan, there was a reluctance to accept the fact that ROQ values would vary in size and that a fixed EBQ (Economic Batch Quantity) could not be established for each stock-item. Contradictory to this attitude, however, the need for a demand forecasting routine was readily appreciated. To overcome the problem, a separate 9 page write-up was produced discussing EBQs and the circumstances under which they could or could not be determined. It was also explained that calculation of the ERP for a stock-item obviated the need to analyse the economics of the ROQ requested at each stock replenishment decision.

The write-up served its purpose very well and once the logic behind the Methodology was accepted, the results from the simulation tests, together with the estimate of the real cost savings, were viewed with considerable enthusiasm. The Data Processing Manager was, as a result, authorised to start program-writing for eventual implementation as soon as possible. Work in this direction was commenced at the end of April, 1982.

Actual Usage within the Company

When implemented fully within Edgar Vaughan, the Methodology will, as indicated in Chapter 1, work as an integral part of the computerised order-processing/stock monitoring system. The manner in which use of it will be triggered will primarily be through the stock monitoring function of the order-processing system. This will be achieved by the following check being carried out, subsequent to every demand transaction placed in the order-processing system:

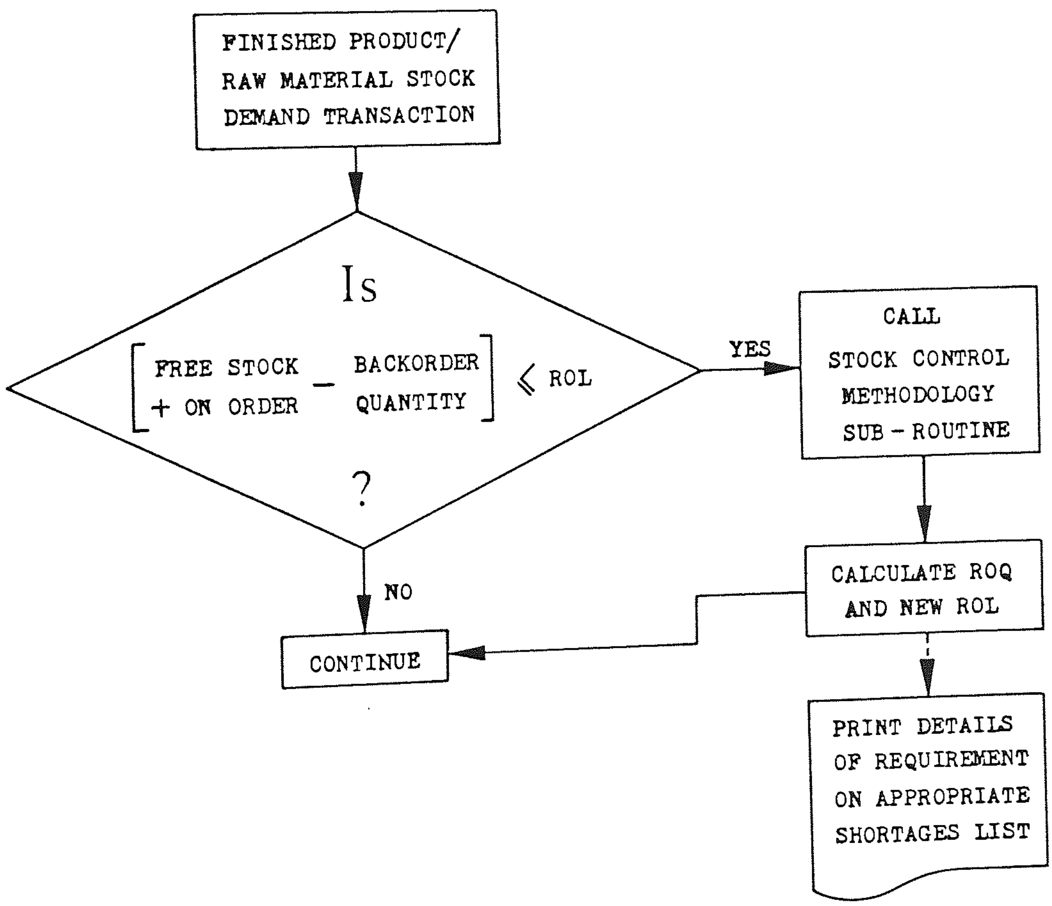

Fig. 7.2 Replenishment Requirement Check, Used to Action the Stock Control Methodology.

Depending upon whether the stock in question is finished stock or raw material/bought-out stock, the system will generate either:

(a) a production order that will appear on the Finished Product Shortages List, subsequently passed to the Production Manager for scheduling and manufacture; or

(b) a requisition to the Purchasing Department that will appear on the Raw Material/Bought-out Shortages List.

All decision variables considered when analysing the need to call the stock control methodology sub-routine (i.e. free stock, on-order and back-order quantity) are continually up-dated on a 'real time'* basis, again by means of the stock monitoring function of the order-processing system.

On the remote chance that there may arise the need to have two (or more) replenishment orders in the system at the same time, it must be noted that in using equation 5.21 of the stock control model proper, i.e.:

$$ROQ = Q^* - (SL - (B + U))$$

SL (free stock) must at <u>all times</u> comprise not only the actual free stock quantity existing but also any quantity 'on-order'.

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* see Glossary of Terms

Finally, although usage of the Methodology will be actioned in the main automatically, as part of the overall computerised system, there will also exist the facility to call the Methodology manually through the use of a VDU. This will permit the Methodology to be used in initiating a new product into the system and as a general management tool.

Basic Stocking Policy

Prior to actually implementing the Methodology, it will first be necessary to establish the basic stocking policy required. By this, it is meant determination of:

i) the stock-items for which the stock control methodology must be used;

ii) the prime method of storage in the case of each stock-item;

iii) the objective of the Methodology on an individual stock-item basis (i.e. choice of cost-basis or service level version of Methodology).

With regard to (i), it was agreed that for finished products some form of the Methodology (i.e. either the cost-basis version or the service level version) would be applied wherever possible. Those products for which it would not be used would be determined through examination of:

- first, the number of customer demand transactions per year; generally use of the Methodology would <u>not</u> be made for products where the number of transactions per year was less than or equal to 6 (see sub-section 6.2);

- second, any storage problems; any product that deteriorated <u>quickly</u>* through storage would <u>not</u> be considered by the Methodology.

All finished products falling outside the scope of the Methodology would be supplied to customers on a 'make-to-order' basis.

In the case of raw materials, because availability is nearly always critical, <u>all</u> such stock-items would be controlled by the stock control methodology.

Moving on to aspect (ii), the type of storage used for holding finished products would depend largely on the nature of demand, i.e.:

A) If demand for a product were primarily bulk (i.e. demand requiring delivery in a road tanker wagon) then, providing it could be stored successfully in bulk form, a bulk storage tank would be employed as the <u>main</u> method of storage. Barrel demand would be met by filling barrels from the storage tank, as and when necessary. Demand input data to the demand forecasting routine would thus need to comprise both bulk and barrel demand, presented in the prime units of storage, i.e. tonnes.

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*in comparison to the stock-item's latest calculated ERP (few products are likely to be effected by this constraint).

B) If demand were primarily for delivery in barrels then the product would generally be stored in barrels in the warehouse and bulk demand would be met on a make-to-order basis. Under such circumstances, demand input data to the demand forecasting routine would need to comprise barrel demand only. Exceptions to this storage rule would be those products whose barrel demand was so large that to store them in barrels would require using a very large section of the warehouse. Products of this type would be considered in the same way as those discussed against (A).

C) If demand were divided fairly evenly between bulk and barrel requirements then, providing no storage problems existed, the product would be stored in both barrels and bulk. In this instance, the Methodology would have to be applied <u>separately</u> to bulk and barrel demand in order to permit both types of storage to be controlled efficiently.

The exact control parameters for deciding whether a product fell into category (A), (B) or (C) were not agreed upon at the time of writing.

Finally, it was recognised that the basic nature of demand for each product would have to be reviewed periodically (e.g. every 6 or 12 months) in order to maintain the best method of storage and control of stocks.

The approach to the storage of raw materials would not require to be as complex and it is believed that the stocking policy operated by the company, at the time, would remain suitable; i.e. bulk storage of raw materials where demand justified large quantities of stock and barrelled raw materials where demand was considerably smaller (Note: a raw material is never held both in bulk and in barrels at the same time).

In considering aspect (iii), it was originally requested that the objectives of the stock control methodology must be as follows:

1) Finished products, sales categories 1 and 2: The objective must be one of maintaining high service levels without overstocking (i.e. at least cost to the company).

2) Finished products, sales category 3: The objective must be one of minimising total supply operating costs (excluding costs associated with distribution).

3) Raw materials: The objective must be one of maintaining high service levels without overstocking.

The objectives for (2) and (3) remained unchanged. However, in the case of (1), it was stated that although high service levels were still required, attention to the cost of carrying safety stocks would now also be necessary, in view of the fall-off in sales caused by the general business recession. As a compromise solution, based on the simulation results, it was suggested to the company that the cost-basis version of the Methodology be employed, using once more the loss of contribution to overheads and profit as the stockout cost. Although such a stockout cost may be somewhat meaningless as an actual cost incurred, it would nevertheless result in reasonably high service levels for those products for which sales and service were critical to the welfare of the company. This suggestion was ultimately accepted by the company's management, however, it was also agreed that it would only be retained whilst stock turnover remained comparatively low. As soon as business returned to normal, the service level version of the Methodology would be used to control finished product categories 1 and 2, as originally required.

General Benefits

The potential benefits to Edgar Vaughan, resulting from the use of both versions of the Stock Control Methodology, may be summarised as follows:

1) As shown in sub-section 7.1.2, the potential reduction in capital tied-up in stocks is considerable, as is the associated cost-saving.

2) The majority of customers' orders would be satisfied 'ex stock', thereby speeding-up the supply service to customers and improving customer goodwill.

3) The manufacture of finished products would be sufficiently divorced from customer demand (by the finished product stocks held) to permit better production scheduling, as well as better utilisation of manufacturing equipment and delivery transport.

4) As a consequence of (3), the total work-load awaiting blending facilities could be presented clearly, thereby allowing any production problems pertaining to manning levels, requirements for overtime working, etc., to be quickly recognised.

5) Discipline to maintain the control of stocks would be automatically imposed, by the very nature of operation of the entire computerised stock control system.

7.3 Significance of the Completed Research, in the General Field of Scientific Stock Control

It is believed that the development of the stock control methodology put forward in this thesis, together with the associated testing, is as a whole very significant in the field of scientific stock control. Based on the evidence of published work on the subject area, the reasons offered in support of the above statement are as listed below:

1) First and foremost the Methodology appears to be entirely new in its actual structure and method of operation.

2) It appears to be the only scientific stock control model/methodology tested with real data to the extent described within this thesis and for which the results show quite strongly its ability to work in practice.

3) It appears to be the only scientific stock control model/methodology designed specifically for non-stationary demand.

4) As a consequence of (3), it appears to be the only scientific stock control model/methodology that does not rely upon the assumptions that demand is either constant or forms a stationary distribution.

5) As a consequence of (4), it should operate successfully in any demand environment. However, it must be noted that where demand quantities and timing are known with substantial accuracy for 'parent' stock-items the use of MRP is likely to be more appropriate/efficient.

6) It appears to be the only scientific stock control model/methodology designed specifically for use as an integral part of a computerised stock monitoring/control system.

7) The adaptive demand forecasting routine, although operating on the basic principle formulated by Trigg and Leach, appears to be unique in its actual method of operation.

Wagner (ref 15) also makes several comments based on his survey of scientific stock control, that reinforce the significance of the Methodology developed. These are summarised in the following extracts:

"Multi-echelon probabilistic models now in the operations research literature are only a start toward the needed understanding. Many assume a single item, make restrictive demand and cost postulates, and focus on computing a decision rule".

"A definitive work is required on effective approaches to demand forecasting for the purpose of providing input to planning models".

"Most planning models do not attempt intrinsically to account for uncertainties, such as the range of variability in future demand".

"... tractable and practical analytic approaches need further attention, especially for more advanced replenishment rules and realistic dynamic settings".

"Although it is possible to adapt many replenishment formulas to handle the impact of lead time uncertainty... , how to provide a numerical estimate of lead time variability is still an art".

In short, many of the statements by Wagner show the Methodology developed as being one that fills a substantial number of gaps left by other researchers in the field of scientific stock control. In particular, his observations clarify the importance of the realistic/ practical approach of the Methdology to controlling stock levels. Similar and equally supportive evidence, for this aspect of the Methodology, can also be found in Fortuin's survey of the literature (Ref 14).

7.4 Final Comments on Existing Scientific Stock Control Methods

7.4.1 Similar Research Work

As indicated in sub-section 2.4.3, the only research considered to be similar to that described in this thesis was the work completed by D. Gross et al. (Ref 37). This work is worthy of much praise, as it is the only published evidence of researchers/practitioners recognising the need, given certain demand conditions, for ROQ and ROL values that 'float'. It is also the only paper that describes an attempt to adapt a true scientific stock control model (other than the EBQ formula) for practical application. Unfortunately, although the basic logic put forward by D. Gross et al. is sound, as well as being the first of its kind, the actual details of the methodology formulated are open to much debate. The main criticisms are given overleaf:

i) The assumption that demand during replenishment lead-time is normally distributed and that lead-time remains fixed, severely restricts application of the methodology to those circumstances where such conditions do in fact hold true.

ii) Since the stock control model itself does not consider any specific time horizon, but instead relies upon forecasts of demand ultimately being input as forecasts of demand-rate, it is believed that use of replenishment cost and holding cost in calculating values of Q serves no practical purpose. Consequently, although values of Q will be partially geared to actual demand and therefore will vary accordingly, from a cost effectiveness point-of-view results are likely to be poor.

iii) The forecast-period should not be fixed in an arbitrary manner but should be calculated on a cost-basis, for the reasons given in sub-section 3.2

iv) The statement:

"Forecasting-errors generally tend to be normally distributed thus giving credence to the normality assumption for demand"

used by D. Gross et al. is fundamentally untrue. The reason is that forecasting-errors are solely dependent on the forecasting routine's performance. Hence, evidence of forecasting-errors forming a Normal distribution does not automatically signify that demand is also Normally distributed. It should also be noted that forecasting-errors will only tend towards a Normal distribution if the forecasting routine is efficient at tracking the mean demand (i.e. trend) for all demand conditions.

The above criticism must not be taken to imply, however, that the assumption of lead-time demand being considered a Normally distributed random variable is not permissible on this occasion. For the stock control methodology/model put forward by D. Gross et al. the assumption is reasonably acceptable, though it is important to note why:

Basically, the authors validate the assumption, as well as meet their client's demand conditions, by assuming that the demand pattern (the probability distribution of demand) is constant within a month but varies from month to month. Validification is completed and the methodology/model made workable by the replenishment lead-time and the forecast-period, in practice, being also equal to one month.

Later on in the paper D. Gross et al. go on to say:

"... the model can be easily adapted to reflect different lead-times".

The accuracy of this statement is somewhat suspect and is felt at best to be rather optimistic.

v) According to D. Gross et al., the replenishment cost was "... directly derived from data obtained from the client's Supply and Fiscal Divisions, incorporating record keeping, purchasing, accounting, receiving, handling and inspection". By their description, it is likely that all of these costs relate to areas of the company where human resources and equipment are continuously employed and are, therefore, independent of any stocking policy pursued against a specific stock-item. They are, in short, fixed costs/overhead costs. If the true operating cost of pursuing a stocking policy for a stock-item is to be minimised, the replenishment cost must instead comprise real actual costs occurring directly as a result of raising an individual stock replenishment order, e.g. in the case of certain raw materials used by Edgar Vaughan, brought in from abroad, one should include the cost of shipment, the cost of a third party assessor needed upon delivery, Manchester Ship Canal dues and the real total cost of handling.

vi) As a follow-on from (v), the replenishment cost used was a fixed average value. For efficient control of stocks on a cost-basis, all costs must ideally be specific to the stock-item under consideration. The importance of this statement is highlighted by the authors themselves, when referring to part of their findings:

"The results showed the models to be relatively insensitive to perturbations in all parameters except the lead-time and fixed ordering costs".

It is worth noting that the inclusion of lead-time in the above statement also reinforces the comment made against (i) and the latter part of (iv).

vii) The final criticism relates to the simulation testing carried out by the authors:

- First, the use of 5 line-items to test the ability of the stock control methodology is considered too small a sample for realistic conclusions to be made about its performance in practice.

- Second, the measures of performance presented in the paper are also considered insufficient to permit a proper assessment of the efficiency of the stock control methodology. Since the methodology is concerned with maintaining specified service levels as well as supposedly being cost-conscious, it is suggested that service measures such as those used in this thesis would have completed the analysis of the methodology's capabilities.

7.4.2 Materials Requirements Planning (MRP)

In spite of the evidence put forward in this thesis supporting the Methodology, it is nevertheless recognised that there are certain inventory environments where the use of MRP would be considerably more accurate in determining exact stock requirements (quantities and timing). Examples of suitable areas of application are given in sub-section 2.3.3. However, the essential prerequisite for MRP is that a Master Production Schedule can be produced, i.e. "an authoritative statement of how many end-items are to be produced and when" (p 38, Ref 46).

Contrary to the last sentence above, Fortuin (Ref 14) displays clearly the opinion that MRP has no limitations whatsoever. This is shown strongly in the following extracts:

"Manufacturing inventories* .... are most efficiently controlled by means of Materials Requirements Planning (MRP) ...."

"Strictly speaking, MRP is the only efficient way for carrying out the replenishment task".

" ... the fact that MRP, although superior to SIC* for manufacturing inventories ..."

This arrogant form of support for MRP is completely misplaced and extremely misleading, particularly so to the naïve practitioner. Although MRP has an important place in the field of stock control, it is <u>not</u> a panacea for all inventory control situations, and should not, therefore, be presented as such.

Fortuin attempts to qualify most of his statements about MRP by continually relating its use to the control of manufacturing inventories, as opposed to 'distribution inventories'*. What Fortuin fails to realise, or at least explain, is that manufacturing inventories are not all the

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* Note: the term 'Manufacturing Inventories' is defined by Fortuin as inventories comprising dependent demand items. These are taken to include raw materials, component parts and sub-assemblies.

* Statistical Inventory Control ≡ Scientific Inventory Control.

* Stock-items for which there is no demand dependency on other stock-items, i.e. 'finished Products'.

same and certainly do not always lend themselves to being controlled by MRP. The first and third extracts would, consequently, read more accurately if the word 'certain' were placed before the phrase 'manufacturing inventories'. Although quoting a list of prerequisites and assumptions required to be valid when introducing MRP (extracted from a book on the subject by Orlicky (Ref 46)), Fortuin does not linger on their importance.

In defence of the criticism made against the validity of Fortuin's claims, Orlicky states that in examining companies for whom MRP was successful, what was common to all such companies and what, in Orlicky's view, represented the "principal criterion of materials requirements planning applicability" was the existence of a Master Production Schedule. Without this form of advance knowledge of demand and timing MRP cannot be used as a means of efficiently controlling stocks.

Finally, it is also felt that many of the criticisms made of SIC are quite unfair generally and certainly the majority do not apply to the stock control methodology described in this thesis. Those criticisms that do hold true, even for the Methodology, relate to situations where the inventory problem is best suited to control by MRP. Two examples of what are considered unfair criticisms are given overleaf, along with appropriate comments:

(1) "In SIC models, inventory investment can only be lowered at the cost of lower service levels; MRP achieves a reduction of inventory investments without reducing the service level".

This statement is completely false, since much of SIC concerns itself with the objective of reducing stock investment, whilst providing high service levels. The inaccuracy of the statement is especially highlighted by the service levels and potential cost-savings produced by the Stock Control Methodology. As for the latter part of statement (1), once more this is only true in cases suited to the use of MRP.

(2) "SIC methods tend to devote most attention to vital items; MRP gives all items the same attention".

The above statement is, in the strict sense, quite true. However, when read in context with the rest of the paper, it is felt to be misleading as it implies that SIC methods <u>cannot</u> easily provide adequate attention/control to <u>all</u> stock-items carried, whereas MRP can and does. Contrary to this, the Methodology developed in this thesis, as well as any other SIC methods that can be successfully computerised, can be applied to the same extent to as many stock-items as is required. The reason why they are not is that often not all stock-items command the same level of attention/control. Fortuin, himself, states in the same paper that:

"An MRP system user may feel that not all inventory items warrant such elaborate treatment".

In analysing Fortuin's comments carefully, it is believed that his lack of respect for SIC models results from those weaknesses of existing models described earlier in this thesis. In particular, there is no sound published evidence of any SIC models (excluding the EBQ formula/extensions of the EBQ formula) working successfully in practice. Even so, this does not excuse Fortuin's overwhelming and, at times, unjust praise of MRP, nor his indiscriminate criticism of scientific inventory control.

7.5 Areas for Further Work

The following aspects of scientific stock control are considered particularly worthwhile areas for research, both from an academic and practical application point-of-view. Those relating specifically to the stock control methodology described in this thesis are presented first, followed by those relating to scientific stock control in general.

(A) The Stock Control Methodology Developed

1) Although the Average Stock Holding Ratio (R) was found to produce good results when set at 1.3 (see sub-section 6.3.2), it is felt that more investigation/understanding in this area is necessary. Further research should ideally culminate in a concise and simple method for quickly determining the best value of the ratio for each stock-item/type of demand.

2) It would be interesting to establish the extent (on average) to which the cost-basis version of the Methodology approaches its objective. In carrying out such an investigation, it is suggested that results should be recorded for different types of demand condition.

3) Actual measurement of the performance (of the type used in this thesis) of both versions of the Methodology when operating specifically with seasonal/cyclical demand would prove interesting and useful.

4) Measurement of the performance of the service level version of the Methodology should, ideally, also be pursued for a range of demand conditions.

5) All parameters crucial to the efficient operation of both forms of the Methodology (these are considered to be the stock-items ERP and hence R, A_D, H_C, and C_R used in its calculation; and F_D, F_{LT}, C_{SO}, C_H, σ_D and σ_{LT} used in the calculation of safety stocks in the stock control model proper) should be determined by means of analysis of variance and should, in addition, be examined as to the effect that changes in their value have on the results produced.

(B) Scientific Stock Control in General

1) It is felt that the practical suitability of existing stock control models should be examined in great detail. This should at least involve the rigorous testing of such models using computer simulation, in conjunction with realistic demand data of different types and replenishment lead-time data reflecting that found in practice.

2) Comparison of 'workable'* scientific stock control models (including the Methodology developed within this thesis), by testing each in turn with identical data and in the manner described against (1), would also provide invaluable information, especially to potential practitioners.

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* Scientific stock control models that could be physically used in practice, regardless of problems concerning the validity of the assumptions made in their development.

Chapter 8

Conclusions

8 Conclusions

In reviewing the work presented in this thesis alongside that of previous recorded research relating to scientific stock control, it is felt that the following conclusions may be drawn:

Primary Conclusions

1) A new scientific stock control methodology has been devised.

2) The test simulation results show the Methodology to work successfully when applied as the cost-basis (cost conscious) version with demand and cost data such as that used.

3) Since the demand and cost data used caused the Methodology to perform in virtually the same way as if it had been applied as the service level version, it is concluded that the service level version of the Methodology would also work successfully in practice, if presented with similar data.

4) Since the Methodology was tested with a wide range of demand data, it is further concluded from the test-simulation results that the Methodology is capable of working equally as well in any demand environment.

5) The stock control methodology along with the thesis write-up fill two important gaps in scientific stock control:

i) First, the Methodology is specifically designed to operate with non-stationary demand; from this point-of-view alone, the Methodology appears to be unique.

ii) Second, the Methodology together with the contents of this thesis provide a vital bridge, that is well documented, between pure analytical* scientific stock control and practical application.

Secondary Conclusions

1) The entire simulation results show the logic and assumptions used in formulating the stock control methodology to be valid for practical purposes within Edgar Vaughan, at least.

2) The final adaptive forecasting routine used in forecasting demand works successfully.

3) A substantial cost-saving is possible from a reduction in the quantities of finished product and raw material stock carried by Edgar Vaughan whilst ensuring high service levels to customers.

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* See sub-section 2.4.2

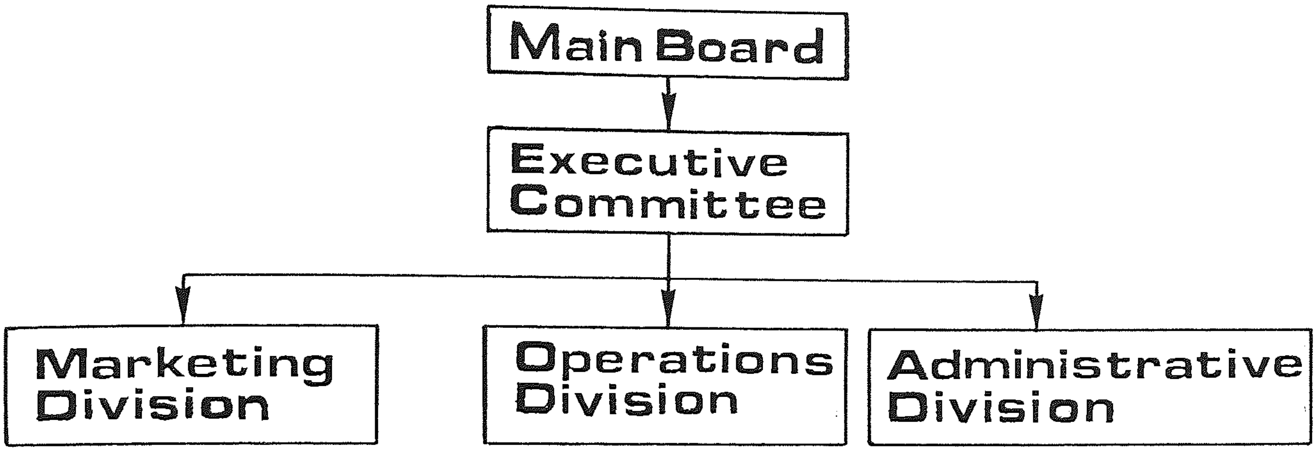
4) The simulation test results relating to the Edgar Vaughan 10% Policy show that uncontrolled reduction in stock levels can produce a detrimental effect on service levels to customers.

Appendices

List of Appendices

Appendix A

Edgar Vaughan's Basic Operations-Control Structure



1. Operations Division: under the control of the Managing Director, this division covers purchasing, manufacture and finance.

2. Administration Division: under the control of the Administration Director, this division covers services to the other two divisions and includes such responsibilities as personnel, office services, accounts, data processing, etc.

3. Marketing Division: under the control of the Marketing Director/Assistant Managing Director, this division covers those functions associated with obtaining and maintaining the company's business and includes sales, product management and technical, publicity and marketing services.

Appendix B

The Order-Processing/Stock Monitoring System

Contents of Appendix B

B.1 System Objectives

The three main objectives of the computerised order-processing system were:

i) to improve the speed and efficiency of processing customers' orders;

ii) to provide a finished product and raw material stock monitoring facility, specifically designed to function with a scientific stock control model/methodology, the latter operating as an integral part and providing the control parameters necessary;

iii) to provide a comprehensive management information system for efficient control of the entire system.

In an attempt to make the overall system as efficient as possible, physical system procedures were tailored to operation with a computer/computer facilities and as a result are, in the main, entirely new from Edgar Vaughan's point-of-view. However, all procedures, including the VDU facilities available, were specified with the aim of also providing:

(a) ease of understanding and operation by the personnel concerned;

(b) maximum assistance to personnel when performing order-processing duties.

It is believed that the effort made in fulfilling (a) and (b) together with regular close/informal liaison with all levels of users helped considerably in the speedy and successful implementation of the computerised system at the Barton site. Further, these aspects of computerised system design are felt to be key factors generally in ensuring successful implementation with minimum conflict from the personnel involved/affected.

Finally, it should be noted that the system was designed so that it would also be compatible with the computerised sytems at the company's Head Office and would, as a whole, function as an integral part of the entire Edgar Vaughan business operation.

B.2 The Basic Order-Processing/Stock Monitoring System

(Flow-Chart)

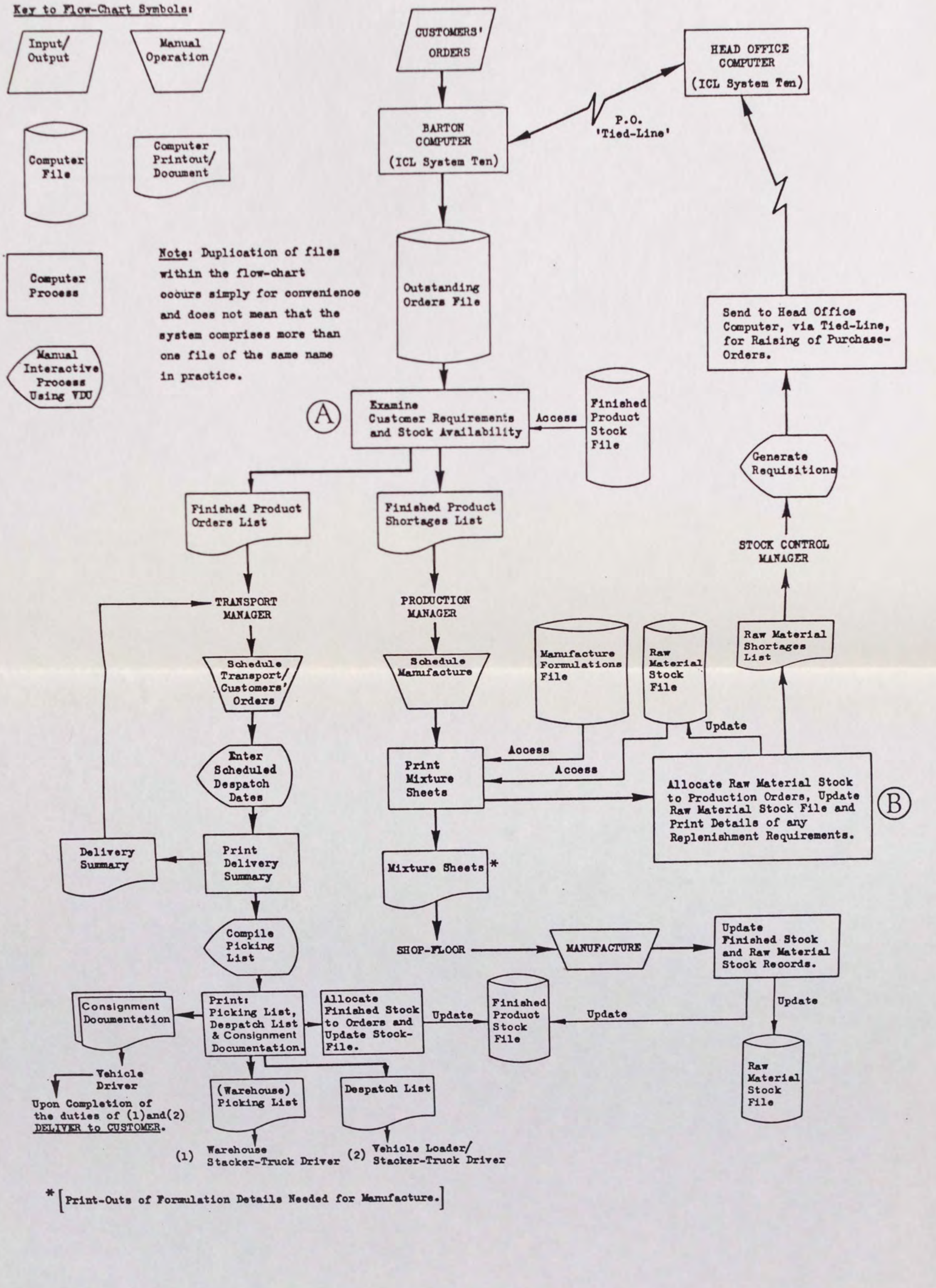


Fig. B.1 Flow-Chart Showing the Basic Principles of Operation of the Computerised Order Processing/Stock Monitoring System Installed at Edgar Vaughan's Main Manufacturing Site.

B.4 System Summary

The system:

i) records and processes, automatically, customers' orders as well as distribution sites' requisitions;

ii) maintains a record of the quantity and location of all stock held (i.e. finished products and raw materials);

iii) monitors total requirement quantity per finished product, per package-type, against appropriate 'Free' stock quantity;

iv) summarises production and barrelling needs, determined at (iii) and prints details on 'Finished Product Shortages List ';

v) maintains a record of formulation details and provides a facility for calculating specific raw material requirements for a predetermined batch size;

vi) monitors total requirement quantity per raw material, against 'Free' stock quantity;

vii) produces 'Raw Material/Bought-out Shortages List' along with inter-site requisition documentation, where necessary;

viii) produces 'Mixture Sheets';

ix) maintains a record of actual raw material usage and any wastage-details;

x) updates raw material and finished product stock records;

record of manufacturing times;

xii) lists all orders placed on the factory/warehouse in the form of a 'Finished Product Orders List', primarily for despatch-scheduling purposes;

xiii) produces a 'Delivery Summary' listing those customers' orders (and their basic details) for which despatch dates have been determined;

xiv) records the status* of all customers' orders within the system;

xv) produces 'Picking List ', 'Despatch List' and consignment documentation;

xvi) maintains an historical record of all stock transactions;

xvii) provides management information retrieval facilities;

xviii) provides a suitable print-out to enable regular periodical stock checks to be carried out;

xix) provides a direct link, via a 'Tied Line', with Head Office thus enabling entry of orders at Head Office and providing two-way access to information and communication between Head Office and Barton.

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* The status of a customer's order may be one of the following:

'Un-processed';
'Awaiting Raw Materials';
'Awaiting Manufacture';
'Manufacture' (in the process of);
'Awaiting Despatch';
'On Consignment';
'Order Completed'.

B.5 System Benefits

The prime system benefits that have/will be gained by the company through the introduction of the computerised order-processing/stock monitoring system are as follows:

1) Faster processing of customers' orders upon arrival at the Barton site.

2) Automatic facility for checking finished product and raw material stock availability at a very early stage. This allows both types of stock to be replenished, where required, far more quickly than in the past, avoiding what were unnecessary and sometimes serious delays.

3) Stock and production statistics considered important will be stored and summarised in print-out form (in an immediately usable format) for management analysis.

4) Improved management/control resulting from a better information system in general, provided in the form of print-outs and VDU interrogation facilities.

5) Greater accuracy regarding all information.

6) Better utilisation of transport, owing to comprehensive despatch information, pertaining to outstanding customers' orders, being presented concisely in a suitable format.

7) Integration of overall factory and warehouse systems with existing and new computerised systems operated at Head Office.

B.6 System Hardware

The Barton Site

1) One ICL System Ten, 120 Series Computer comprising 90 K bytes main memory.

2) Four disc-drives, constituting 46 Mbytes support memory, the breakdown being as follows:

   1 disc-drive : 20 Mbytes

   1 disc-drive : 10 Mbytes

   2 disc-drives : 8 Mbytes each

3) Four VDUs (ICL 82 Series), located as follows:

   2 VDUs : General Office

   [Used principally for manufacture and stock control purposes.]

   1 VDU : Transport Office

   1 VDU : Warehouse

4) One line-printer; output speed : 300 lines/minute.

5) One serial printer (bi-directional); output speed : 180 characters/second.

6) One 'Tied' Post Office telephone line, connecting the Barton computer to the computer housed at the company's Head Office; transmission capability : 300 characters/second.

Head Office (details of main hardware only)

1) One ICL System Ten Computer comprising 120 K bytes 'core' memory.

2) Five disc-drives, constituting 104 Mbytes support memory, the breakdown being as follows:

2 disc-drives : 40 Mbytes each

3 disc-drives : 8 Mbytes each

B.7 System Procedures

1 Initial Order Processing

1.1 Customers' Orders and Incoming Requisitions

Whether entered on site or via Head Office, these orders are stored complete on the Outstanding Orders File. An indicator is then set to show that these orders have not yet been processed by the computer system.

1.2 Process Incoming Orders

Twice a day and/or when required, the computer system examines the Outstanding Orders File for unprocessed orders. Every unprocessed order found is then split by product and a record is generated in the data base for each. These records are chained to the Customer File and the Product File for later access. The quantity required of each product is then added to the overall total requirement for that product and to the total requirement for that product in the package-type requested. At this point the need to replenish finished product stock is examined.

2 Finished Product Replenishment Processing

2.1 Produce 'Finished Product Shortages List'

This is a list of finished products for which customer requirements have caused the Free Stock quantity to fall to or below the respective reorder level. The list shows old and new stock control parameters and is used to generate manufacturing-orders and inter-works requisitions.

2.2 Enter/Amend Manufacture Requirements

Using the Finished Product Shortages List, the Production Manager enters into the computer system details of intended manufacture. Raw material requirements are automatically calculated, using fixed information held in the Manufacture Formulations File. Any raw material shortage is shown on the VDU together with any purchase orders that may have been placed for the raw material(s). Manufacture requirements can also be entered quite independently of the Finished Product Shortages List.

2.3 Produce Mixture Sheets

It is at the above stage that Mixture Sheets are produced by the computer system,under the control of the Production Manager. At this point raw materials are allocated precisely and the quantity of raw material Free Stock, for each, amended and examined from a replenishment point-of-view. Manufacture requirements not dealt with in this way continue to appear on the Finished Product Shortages List. However, the system functions more smoothly regarding raw material replenishment if requirements are entered immediately, even if manufacture is not planned for some time or there is a shortage of one or more raw materials.

2.4 Amend/Confirm Manufacture Output and Usage

Following manufacture, details of output and actual raw material usage are entered into the computer, whereupon finished product and raw material stock records are updated. Production times, actual specific gravity and any wastage are also entered.

2.5 Enter/Amend Filling Requirements

Included on the Finished Product Shortages List, as part of finished stock replenishment requirement details, are the package-type and the replenishment source. This highlights whether the need is to to replenish barrel stock from bulk storage or whether manufacture is necessary. Where replenishment of barrel stock simply involves filling, the Production Manager enters the associated details per product into the computer system. Such action automatically involves the printing of a 'Filling Instruction Sheet' and, as a whole, constitutes a stock movement request. Movement details are recorded on the Filling Instruction Sheet together with the batch number allocated.

3 Raw Material Replenishment Processing

3.1 Produce Raw Material Shortages List*

This will be a list of raw materials for which manufacture requirements have caused the Free Stock quantity to fall to or below the

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* This document was not available at the time of writing.

respective reorder level. This list will show old and new stock control parameters and will be used to generate requisitions, which may require to be sent to Head Office direct or printed to be sent to other works. Actual requisition details will be subsequently entered into the computer system.

3.2 Process Purchase Orders and Goods Inwards

In response to requisitions, Head Office generates purchase orders. Details of these are transmitted from Head Office to the Barton system and are recorded against the requisition, on file. A hard copy of the purchase order is also sent to the factory for use in checking goods inwards. When receipt has been confirmed, details of delivery are entered into the computer and stock levels are updated. Details of receipt are both stored within the computer system and are transmitted to Head Office for use by the Purchasing Department.

4 Warehouse and Despatch Processing

4.1 Produce 'Finished Product Orders List'

Each day/when requested, the computer system produces the Finished Product Orders List. This shows details of all orders that have not been despatched and is printed in consignment area sequence. All orders for an area are, therefore, grouped and show possible load formation for ease of transport scheduling. Stock availability is indicated by use of a code, so as to complete the information required for despatch scheduling.

4.2 Enter/Amend Schedule Despatch Date

Using the Finished Product Orders List, the Transport Manager enters into the computer system scheduled despatch dates against an individual order or against a consignment area, the dates being recorded on the Outstanding Orders File. In addition, a promised or required date can also be entered against an order; this is printed separately on any print-outs. A vehicle load identifier number is also entered at this stage (see 4.4).

4.3 Produce 'Delivery Summary'*

Following the above, the computer system will produce each day a Delivery Summary. This will contain all orders that have been scheduled for despatch, listed within area in date sequence, and will form the basis of a diary.

4.4 Produce 'Picking List' and 'Despatch List'

The warehouse Picking List and Despatch List are printed out each day by the computer system, under the control of the Transport Clerk and contain, fundamentally, finished product requirements for customers' orders scheduled for delivery the following day. Details on the Picking List are printed in warehouse storage location sequence, so as to optimise the movements of the high-reach stacker truck used within the warehouse. Stock removed is subsequently placed in a sectioned despatch area, according to the vehicle load identifier number allocated. Details on the Despatch List are in vehicle load number sequence, permitting vehicles to be loaded later efficiently. Production of the Picking List also causes finished product stock to be allocated to specific orders and 'physical stock' quantities held on file to be amended.

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* This document was not available at the time of writing.

4.5 Produce Consignment Documents

As well as the warehouse Picking List and Despatch List, the computer system also produces consignment documents for the customers' orders due for delivery.

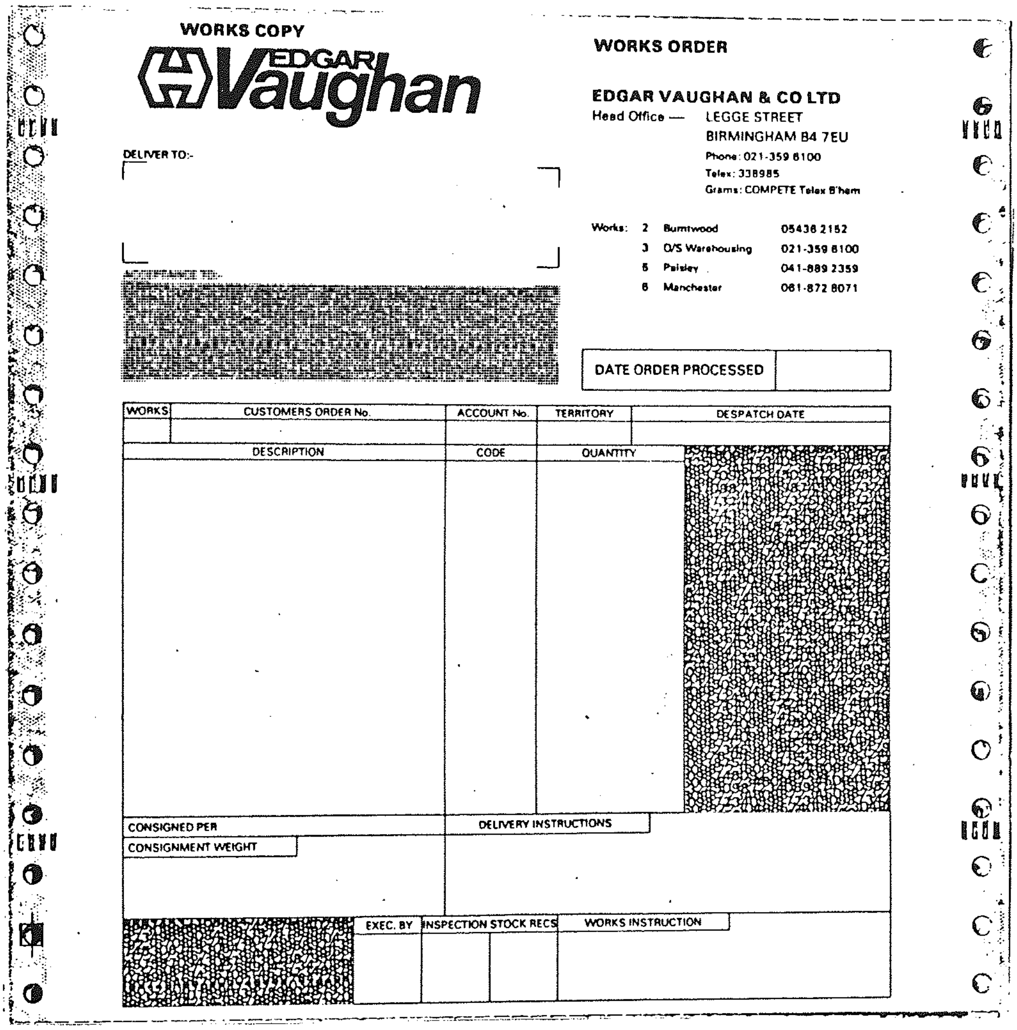
4.6 Confirm/Amend Consignment Details

The warehouse Picking List is subsequently used as input to the computer system to confirm or amend stock allocation details for goods awaiting consignment.

4.7 Confirm/Amend Delivery Details

When receipt notes are returned, following delivery, these are used as input to the computer system to confirm or amend delivery details. Such details are also transmitted to Head Office for further processing. A record of each delivery is retained by the computer system in a History File for the purposes of any subsequent access or analysis.

B.8 Examples of Computer Print-outs



WORKS COPY

EDGAR Vaughan

WORKS ORDER

EDGAR VAUGHAN & CO LTD
Head Office — LEGGE STREET
BIRMINGHAM B4 7EU
Phone: 021-359 6100
Telex: 338985
Grams: COMPETE Telex B'ham

Works:			
2	Burntwood	05438 2152
3	O/S Warehousing	021-359 6100
5	Paisley	041-889 2359
6	Manchester	061-872 8071

DELIVER TO:-

DATE ORDER PROCESSED

WORKS	CUSTOMERS ORDER No.	ACCOUNT No.	TERRITORY	DESPATCH DATE

DESCRIPTION	CODE	QUANTITY

CONSIGNED PER

CONSIGNMENT WEIGHT

DELIVERY INSTRUCTIONS

EXEC. BY	INSPECTION	STOCK RECS	WORKS INSTRUCTION

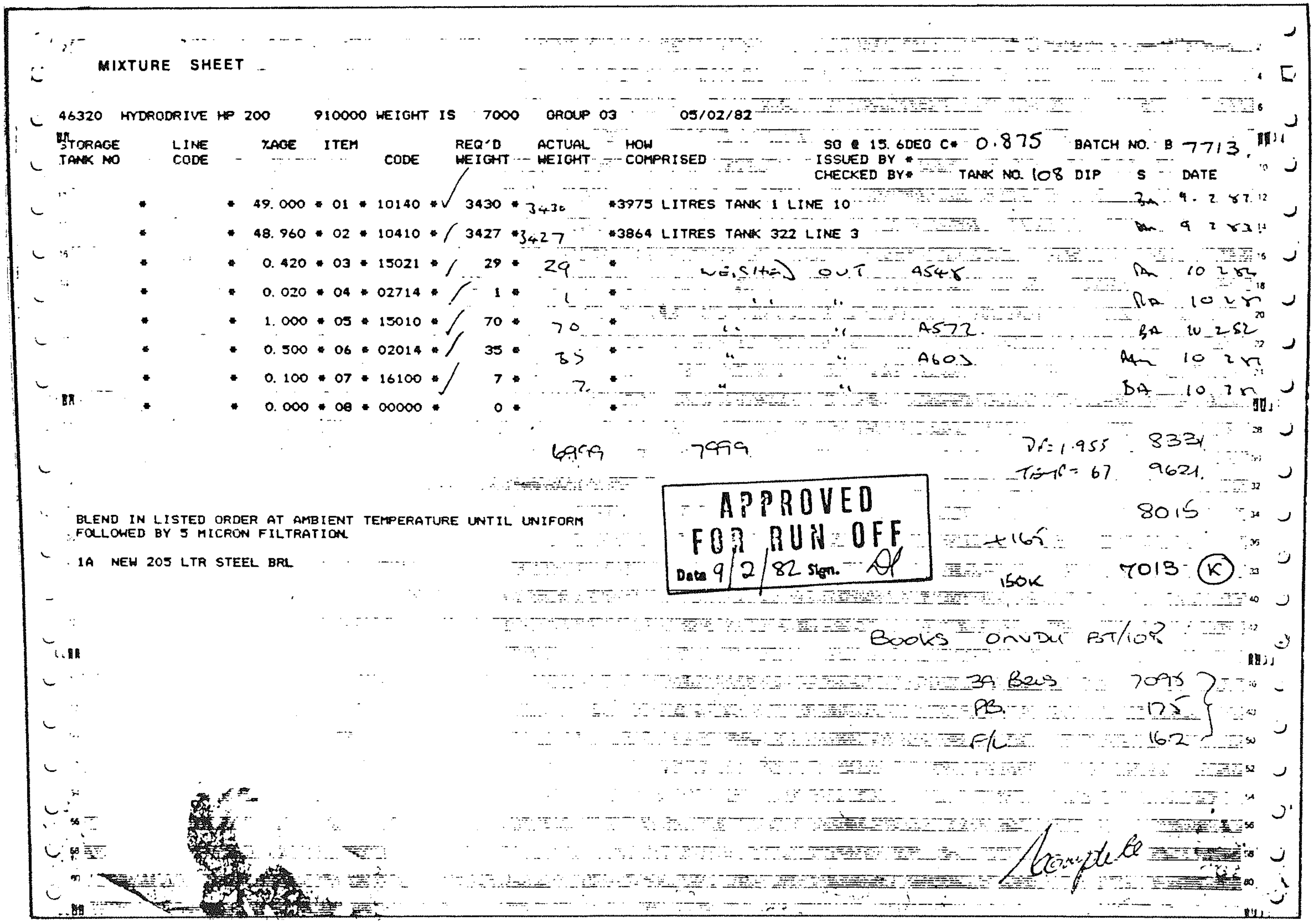
Fig. B.2 Photo-Reduction of Works Order Document.

FINISHED PRODUCT SHORTAGES LIST

17/02/82 PAGE 0002 EDGAR VAUGHAN & CO. LTD.

PROD CODE	DESCRIPTION	PACK TYPE	CUSTOMER REQ'T	PHYSICAL STOCK QTY	REORDER LEVEL	REORDER QUANTITY	DATE REQUESTED		RE-BRAND OF
		12	5.0	0.0	0.0	4.8	82/01/06	INCREASED	
12235	SOLCUT 84	DRUMS	0.0	0.0	1230.0	4983.5	82/01/06		
12555	FILEINE 84N	DRUMS	0.0	0.0	2460.0	4674.0	82/01/25		
		BULK	4600.0	0.0	0.0	4370.0	82/01/06		
12905	L 83	DRUMS	4100.0	205.0	0.0	3680.7	82/02/11		12030
13010	SOLCUT XX	DRUMS	8405.0	0.0	3280.0	14606.2	82/01/25		
		BULK	2729.0	0.0	0.0	2592.5	82/01/06	INCREASED	
13015	HOCUT 799	12	5.0	5.0	0.0	0.0	82/02/17		
13020	HOCUT 3210 A	DRUMS	5535.0	615.0	6560.0	17859.6	82/01/06		
		11	200.0	150.0	200.0	841.5	82/01/12	INCREASED	
		BULK	5000.0	0.0	0.0	4950.0	82/01/06		
13022	HOCUT 3210	DRUMS	5125.0	0.0	0.0	5073.7	82/01/06		13020
13030	HOCUT 3210 SWEDEN	DRUMS	11275.0	5535.0	0.0	5682.6	82/01/06		13031
13031	HOCUT 3210 T	DRUMS	1025.0	0.0	2050.0	7103.2	82/02/17		
		12	10.0	5.0	0.0	4.9	82/02/17		
13100	SOLCUT HD 25	DRUMS	410.0	0.0	0.0	422.3	82/02/11		
14010	HOCUT 237	DRUMS	13530.0	0.0	9840.0	31518.7	82/01/25		
		11	175.0	0.0	400.0	1204.3	82/01/25	INCREASED	
		BULK	2300.0	0.0	0.0	2357.5	82/02/15		
14015	HOCUT 238	DRUMS	0.0	205.0	1640.0	3972.9	82/01/25		
14020	EVCOL 70	11	0.0	125.0	200.0	735.7	82/01/25	INCREASED	
14040	TO 36	DRUMS	205.0	0.0	0.0	225.5	82/02/15		
14200	HOCUT 711	DRUMS	3280.0	0.0	2050.0	9543.1	82/01/16		
		11	125.0	50.0	0.0	75.9	82/02/16	INCREASED	
14300	HOCUT 569	BULK	26000.0	0.0	0.0	25740.0	82/01/06		
14510	HOCUT 237 UNDYED	DRUMS	2050.0	0.0	0.0	2091.0	82/02/11		14015
14600	HOCUT 70	DRUMS	615.0	410.0	0.0	223.4	82/01/29		13020
14650	EVCOL V	DRUMS	205.0	205.0	0.0	0.0	82/02/17		
15030	HOUGHTOGRIND 35 PM	DRUMS	2050.0	0.0	3280.0	13881.7	82/02/05		
15040	HOUGHTOGRIND 45	DRUMS	820.0	1845.0	4100.0	13110.5	82/01/25	INCREASED	
		11	100.0	0.0	0.0	125.4	82/02/17	INCREASED	
15050	HOUGHTOGRIND 55	11	200.0	250.0	400.0	906.7	82/01/06	INCREASED	
		BULK	2500.0	0.0	0.0	3022.5	82/01/06		
15321	HOUGHTOGRIND 78 UND/D	DRUMS	410.0	820.0	820.0	2234.5	82/01/21		
15326	RC 5/77L	DRUMS	410.0	0.0	0.0	430.5	82/02/11		
16010	CINDOLUBE 3214	DRUMS	23165.0	4305.0	1640.0	26461.4	82/01/06	INCREASED	
		11	800.0	100.0	200.0	1198.6	82/01/21	INCREASED	
		12	5.0	0.0	0.0	4.6	82/02/03	INCREASED	
17030	GLASS GRIND 960	DRUMS	4100.0	0.0	410.0	6334.5	82/01/25		
20310	HOUGHTODRAW TD50	17	300.0	0.0	0.0	345.0	82/02/17	INCREASED	25110
20315	HOUGHTODRAW TD51	11	50.0	75.0	400.0	837.0	82/01/25	INCREASED	25115
20320	HOUGHTODRAW TD52	12	10.0	0.0	0.0	11.2	82/02/16	INCREASED	25120
20325	HOUGHTODRAW 431	DRUMS	400.0	400.0	0.0	0.0	82/02/17		
20335	HOUGHTODRAW 433	DRUMS	0.0	410.0	1640.0	3346.8	82/01/14		
20360	HOUGHTODRAW 454	DRUMS	205.0	0.0	0.0	184.5	82/01/27		30202
20370	EVCODRAW F	DRUMS	4100.0	2255.0	0.0	1677.1	82/02/16		
20415	CS 50H DRAWING	DRUMS	615.0	205.0	0.0	362.8	82/02/05		
20420	CINDOLUBE 3103	DRUMS	0.0	2050.0	2460.0	2537.0	82/01/25		
		12	5.0	5.0	0.0	0.0	82/02/17		
20424	CINDOLUBE 3411 S	DRUMS	0.0	0.0	1640.0	4574.7	82/01/06		
20430	CINDOLUBE 4699	11	200.0	125.0	200.0	682.5	82/01/25	INCREASED	
20502	EVCODRAW 12	DRUMS	0.0	615.0	820.0	1854.2	82/01/25		
20505	PT DRAWING COMPOUND	17	300.0	0.0	0.0	300.0	82/02/05	INCREASED	
20506	S DRAWING PASTE	17	600.0	0.0	0.0	600.0	82/02/11	INCREASED	17020
		20	3.0	0.0	0.0	3.0	82/02/17		17020

Fig. B.3 Example of the Finished Product Shortages List (Photo-Reduction)


MIXTURE SHEET

46320 HYDRODRIVE HP 200 910000 WEIGHT IS 7000 GROUP 03 05/02/82

SG @ 15.6DEG C* 0.875 BATCH NO. B 7713

ISSUED BY *

CHECKED BY* TANK NO. 108 DIP S DATE

STORAGE TANK NO	LINE CODE	%AGE	ITEM	CODE	REQ'D WEIGHT	ACTUAL WEIGHT	HOW COMPRISED		DATE
*	*	49.000	01	10140	3430	3430	*3975 LITRES TANK 1 LINE 10		9.2.82
*	*	48.960	02	10410	3427	3427	*3864 LITRES TANK 322 LINE 3		9.2.82
*	*	0.420	03	15021	29	29	WEIGHED OUT	4548	10.2.82
*	*	0.020	04	02714	1	1	"		10.2.82
*	*	1.000	05	15010	70	70	"	A572	10.2.82
*	*	0.500	06	02014	35	35	"	A603	10.2.82
*	*	0.100	07	16100	7	7	"		10.2.82
*	*	0.000	08	00000	0				

6999 7999

DF: 1.955 8331

TARE = 67 9621

8015

+165

BLEND IN LISTED ORDER AT AMBIENT TEMPERATURE UNTIL UNIFORM
FOLLOWED BY 5 MICRON FILTRATION.

1A NEW 205 LTR STEEL BRL

APPROVED
FOR RUN OFF
Date 9/2/82 Sign.

150K 7013 K

Books ONVDU BT/102

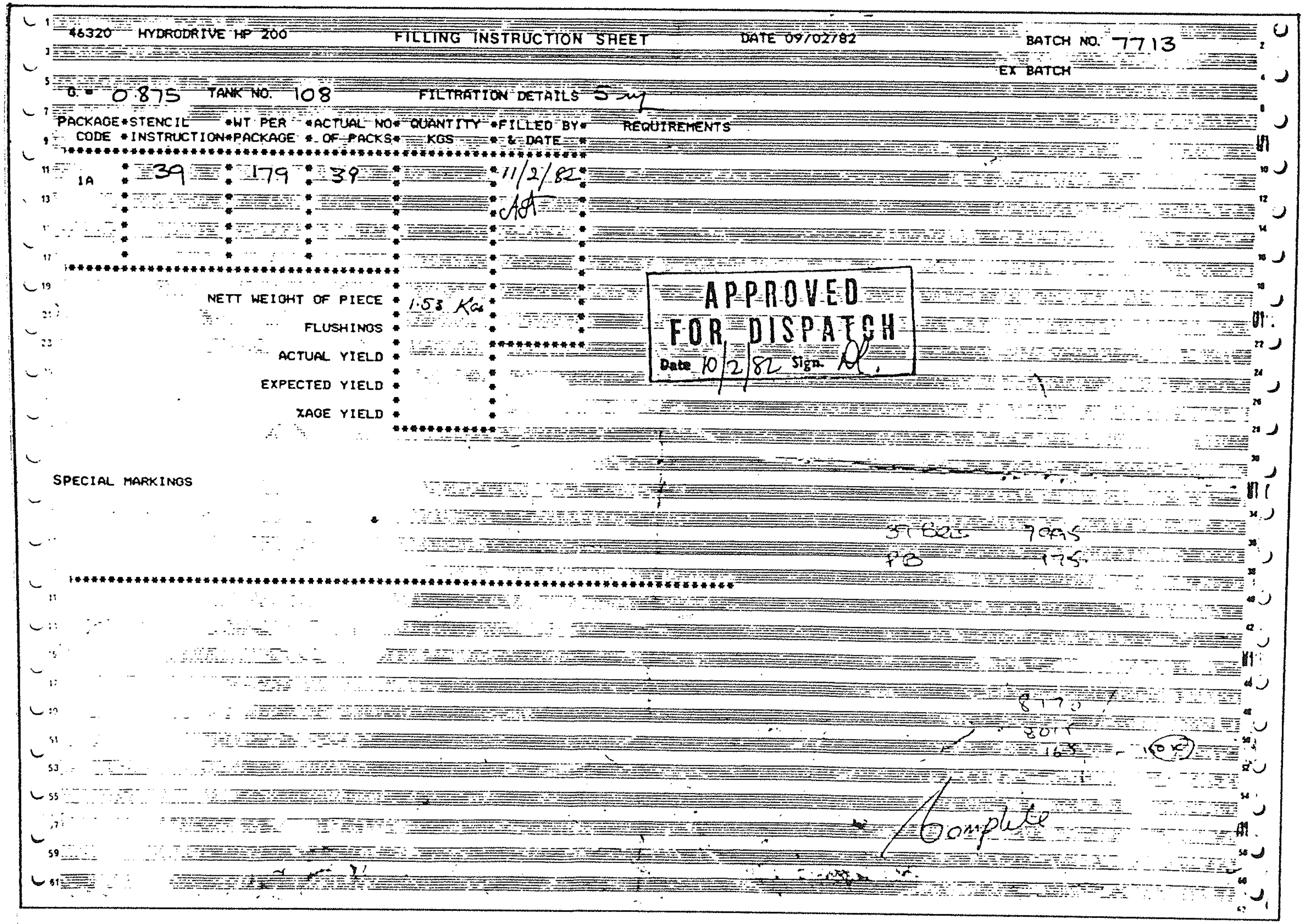
3A Bars 7095

PB 175

F/L 162

Complete

Fig. B.4 Example of a Completed Mixture Sheet
(Photo-Reduction)


46320 HYDRODRIVE HP 200 FILLING INSTRUCTION SHEET DATE 09/02/82 BATCH NO. 7713

EX BATCH

G.* 0.875 TANK NO. 108 FILTRATION DETAILS 5 μ

PACKAGE CODE	STENCIL INSTRUCTION	WT PER PACKAGE	ACTUAL NO OF PACKS	QUANTITY KGS	FILLED BY & DATE	REQUIREMENTS
1A	39	179	39		11/2/82 AA	

NETT WEIGHT OF PIECE 1.53 Kg

FLUSHINGS

ACTUAL YIELD

EXPECTED YIELD

%AGE YIELD

APPROVED FOR DISPATCH Date 10/2/82 Sign.

SPECIAL MARKINGS

37 BBLS 7095
PB 175

8770
8011
163 OK

Complete

Fig. B.5 Example of a Completed Filling Instruction Sheet

(Photo-Reduction)

FINISHED PRODUCT ORDERS LIST

EDGAR VAUGHAN & CO LTD ORDERS FOR AREA 202 DATE 22/01/82 TIME 08.17.37 PAGE 006

WORKS NUMBER	ACCOUNT NUMBER	CUSTOMER	DATE OF ORDER / REQUIRED DATE	PRODUCT	QUANTITY ORDERED	PACK CODE	STOCK QUANTITY	ORDER STATUS	DAYS O/DUE
129534	V76138	VOWLES FOUNDRIES LTD HALE & HALE, TRADING ESTATE LOWER CHURCH LANE TIPTON	82/01/21 EXTREMELY URGENT	27220 MOULDLUBRIC DF20 GROSS WEIGHT	410.0 793.1	01	3280.0	112	
129337	F0037A	FIRTH CLEVELAND STEEL STRIP LD LOCARNO ROAD TIPTON STAFFS, DY4 9SE	82/01/19 AS SOON AS POSSIBLE	23220 EVCO EL ROLLING OIL GROSS WEIGHT	615.0 1169.3	01	205.0	111	
128759	H7567	HAMMOND HEAT TREATMENTS HEATH ROAD DARLASTON WEST MIDLANDS	82/01/06 CONFIRM ALREADY DEL	54007 AQUAQUENCH 251(HOME) GROSS WEIGHT	820.0 1733.8	01	1230.0	-113	16
129279	L0101B	PRESSINGS OF BROWNHILLS LTD LICHFIELD ROAD BROWNHILLS WEST MIDLANDS WS8 6LH	82/01/18 AS SOON AS POSSIBLE	30258 VITAL H D 40 GROSS WEIGHT	410.0 784.9	01	205.0	101	
129451	B7410	B S C (DIECASTING) LTD FRYERS CLOSE BLOXWICH STAFFS	82/01/20 DEL 1.2.82 PLS NOT BEFORE	40020 HOUGHTOSAFE 620 GROSS WEIGHT	410.0 854.6	01	7790.0	-101	
127353	B0041A	BL COMPONENTS-SU BUTEC PLANT 215 BEANS ENGINEERING P O BOX 2 HURST LANE TIPTON STAFFS DY4	81/11/27 03/00/00 AS SOON AS POSSIBLE	15030 HOUGHTOGRIND 35 PM GROSS WEIGHT	205.0 467.0	01	205.0	101	
129548	B0172B	BRIDGE CROSS ENGINEERING CO BRIDGE CROSS CHASE TERACE NR WALSALL WS7 8DD	82/01/21 URGENT	46315 HYDRODRIVE HP 150 46315 HYDRODRIVE HP 150 GROSS WEIGHT	205.0 125.0 502.0	01 11	410.0 250.0	-111 112	
129347	L7706	L & F WILLENHALL LTD CHURCH STREET WILLENHALL WEST MIDLANDS WV13 1QW	82/01/19 AS SOON AS POSSIBLE	40020 HOUGHTOSAFE 620 GROSS WEIGHT	205.0 427.3	01	7790.0	-101	
128961	C0240	CONEX-SANBRA LTD CONEX WORKS, WHITEHALL ROAD GREAT BRIDGE, TIPTON STAFFS, DY4 7JU	82/01/11	30205 STAPUT 360 GROSS WEIGHT	75.0 67.5	11	0.0	103	11

Fig. B.6 Example of the Finished Product Orders List
(Photo-Reduction)

PICKING LIST 19/02/82 PAGE 0005 EDGAR VAUGHAN & CO. LTD.

WAREHOUSE LOCATION		PRODUCT		QUANTITY REQUIRED	NUMBER OF PACKAGES		PACK CODE	
S4/1A1	05150	FRAPOL S-15	131158	25.0	1	11	B7274	139
S4/1A4	16010	CINDOLUBE 3214	130287	5.0	1	12	M7653	139
S4/1A4	16010	CINDOLUBE 3214	130816	500.0	20	11	M7653	139
S4/1A4	16010	CINDOLUBE 3214	131058	50.0	2	11	M7653	139
B4/1D1	09080	EVCO 115	130936	25.0	1	11	B7529	139
B4/1D1	68205	RUST VETO 45	130882	25.0	1	11	M7670	139
B4/1D4	15050	HOUGHTOGRIND 55	131150	50.0	2	11	M7567	139

Fig. B.7 Example of the Picking List
(Photo-Reduction)

DESPATCH LIST 19/02/82 PAGE 0004 EDGAR VAUGHAN & CO. LTD.

DELIVERY AREA	PRODUCT	WORKS NUMBER	CUSTOMER	QUANTITY REQUIRED	NUMBER OF PACKAGES	PACK CODE	BATCH NUMBER	SOURCE LOCATION
REQUIRED FOR LOAD 139								
210	04020 FRAPOL 44	130900	W7720 WESTLINE MACHINED PARTS	615.0	3	01	B7817	W71
203	04060 FRAPOL 88	131129	H0179 M H HURST (ENG) LTD	410.0	2	01	B7372	WA6F5
212	05140 FRAPOL S-200	131059	T0017A TAYLOR INSTRUMENT COS (EUROPE)	615.0	3	01	B7642	W71
219	05150 FRAPOL S-15	131158	G0053 FISHER CONTROLS LTD	25.0	1	11	P/C	WA9K1
219	05150 FRAPOL S-15	131158	G0053 FISHER CONTROLS LTD	25.0	1	11	B7274	S41A1
205	08140 NAGEL HONING OIL	130398	L7620L BL CARS LTD-LAND ROVER	820.0	4	01	B7219	WA2P5
205	08140 NAGEL HONING OIL	130398	L7620L BL CARS LTD-LAND ROVER	820.0	4	01	B7772	WA2H7
210	09080 EVCO 115	130936	P7776A PENNY & GILES TRANSDUCERS LTD	25.0	1	11	B7529	S41D1
217	12120 HOCUT G	131147	P7555C PIRELLI GENERAL CABLE WORKS LD	410.0	2	01	M7627	WA8P6
218	14010 HOCUT 237	130809	G0026B GESTETNER LIMITED	50.0	2	11	M7630	TP1
217	14010 HOCUT 237	130842	P7555A PIRELLI GENERAL CABLE WORKS LT	25.0	1	11	M7630	TP1
220	14010 HOCUT 237	130952	W0347A WOODS OF COLCHESTER LTD	50.0	2	11	M7630	TP1
212	14010 HOCUT 237	130989	W0571 D WICKHAM & CO LTD	410.0	2	01	M7693	TP1
212	14010 HOCUT 237	131000	R8113 RICHMOND PRECISION ENGRG LTD	205.0	1	01	M7693	TP1
204	14010 HOCUT 237	131008	M0017A MANSILL BOOTH & CO LTD	205.0	1	01	M7693	TP1
207	14010 HOCUT 237	131113	L7671C LONGFORD TOOLS&DISTRIBUTION LD	205.0	1	01	M7693	TP1
206	14650 EVCOL V	131141	W0006A WADKIN LTD	205.0	1	01	M7597	WA2K5
215	15050 HOUGHTOGRIND 55	131150	I0220 I M I SANTON LTD	50.0	2	11	M7567	S41D4
206	16010 CINDOLUBE 3214	130287	S8189 EDGAR VAUGHAN & CO LTD	5.0	1	12	M7653	S41A4
215	16010 CINDOLUBE 3214	130816	R0255A RANK XEROX LTD	500.0	20	11	M7653	S41A4
205	16010 CINDOLUBE 3214	131058	T0269A TANGYE-EPCO LIMITED	50.0	2	11	M7653	S41A4
207	20750 EVCODRAW 713	131096	L7671C LONGFORD TOOLS&DISTRIBUTION LD	200.0	4	17	M7572	WA6H1
215	27365 HOT STAMPING OIL	131142	S0139A SOUTH WALES FORGEMASTERS LTD	410.0	2	01	B7743	W71
209	30228 VITAL E P 610	129497	T0084 TOWER MANUFACTURING	615.0	3	01	B7775	W71
218	30323 WAYLUBRICANT 297	131161	S0092 STERLING PATTERN CO LTD	205.0	1	01	M7455	WA3C7
206	40017 HOUGHTOSAFE 520	130663	R0138 S RUSSELL & SONS LTD	410.0	2	01	B7781	W71
204	40020 HOUGHTOSAFE 620	130731	V0039 VOWLES FOUNDRIES LTD	205.0	1	01	B7756	W71
211	46325 HYDRODRIVE HP 300	130478	L0210A LLOYDS (BURTON) LTD	205.0	1	01	B7771	W71
203	46325 HYDRODRIVE HP 300	131011	G0100B GEC TELECOMMUNICATIONS LTD	1230.0	6	01	B7771	W71
209	54007 AQUAQUENCH 251(HOME)	130907	R0101 ROCKWELL MAUDSLAY LTD	100.0	4	11	M7649	TP1
213	54007 AQUAQUENCH 251(HOME)	131124	P0056A PERKINS ENGINES LTD	410.0	2	01	M7649	WA5M2
213	54007 AQUAQUENCH 251(HOME)	131124	P0056A PERKINS ENGINES LTD	820.0	4	01	M7649	WA5S5
204	67105 RUST VETO C 3	131050	T7661A T 1 ACCLES & POLLOCK LTD	615.0	3	01	B7554	WA6J7
204	67105 RUST VETO C 3	131050	T7661A T I ACCLES & POLLOCK LTD	410.0	2	01	B7658	WA6N3
204	67105 RUST VETO C 3	131050	T7661A T I ACCLES & POLLOCK LTD	205.0	1	01	B7554	WA6K7
2	68205 RUST VETO 45	130882	X7679 MR T P J PARSONS	25.0	1	11	M7670	S41D1

I)FINISHED 00042 MF, 00000 DF

<u>Fig. B.8</u> Example of the Despatch List
(Photo-Reduction)

Appendix C

Graphs Showing Random Nature of Demands for the Finished Products Used in the Test-Simulation, for the Years 1979 and 1980.

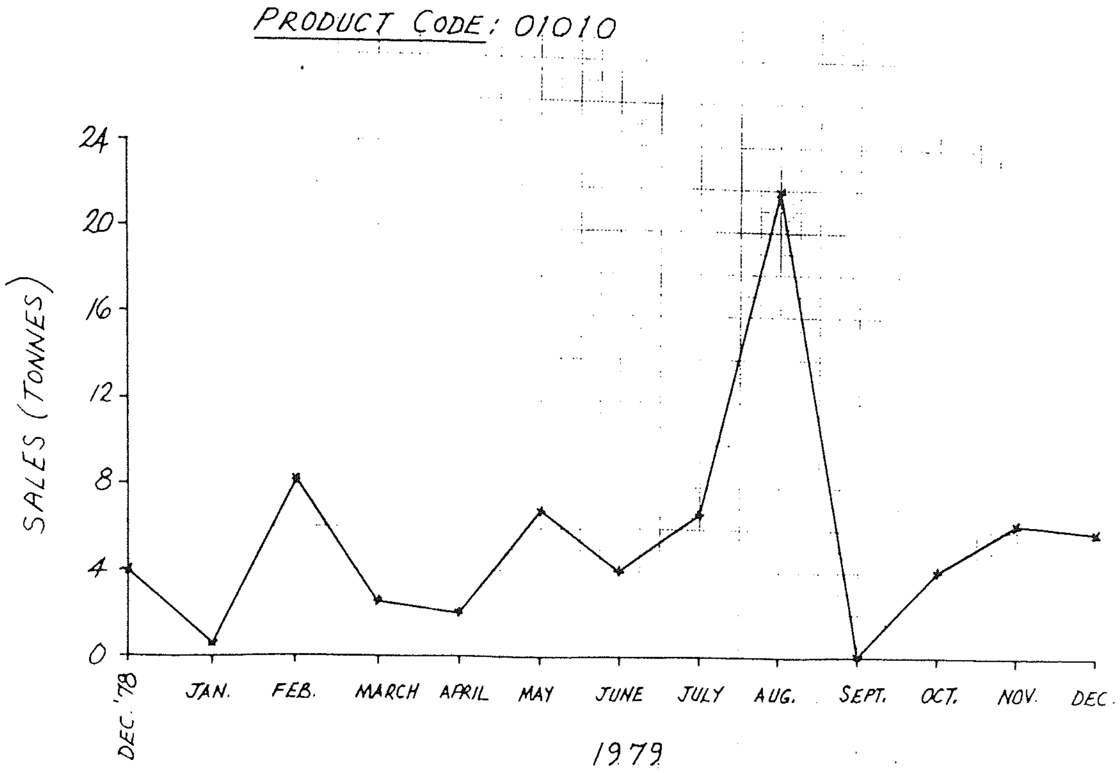


Fig. C 1. Graph Showing the Nature of Demand, during 1979, for Finished Product 01010 Used in Simulation

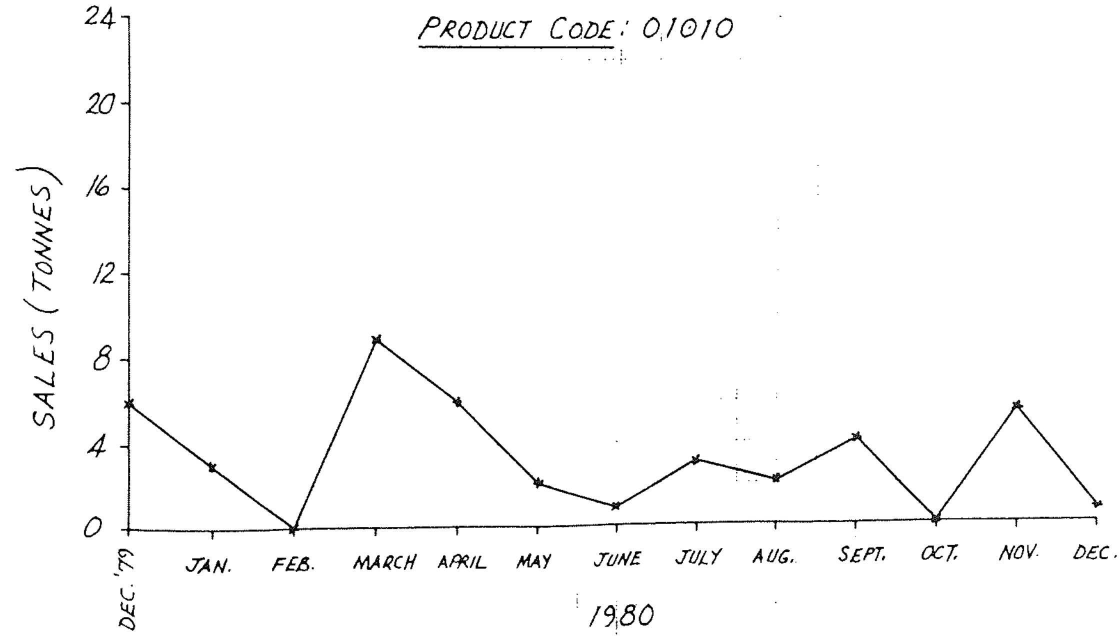


Fig. C2. Graph Showing the Nature of Demand, during 1980, for Finished Product 01010 Used in Simulation

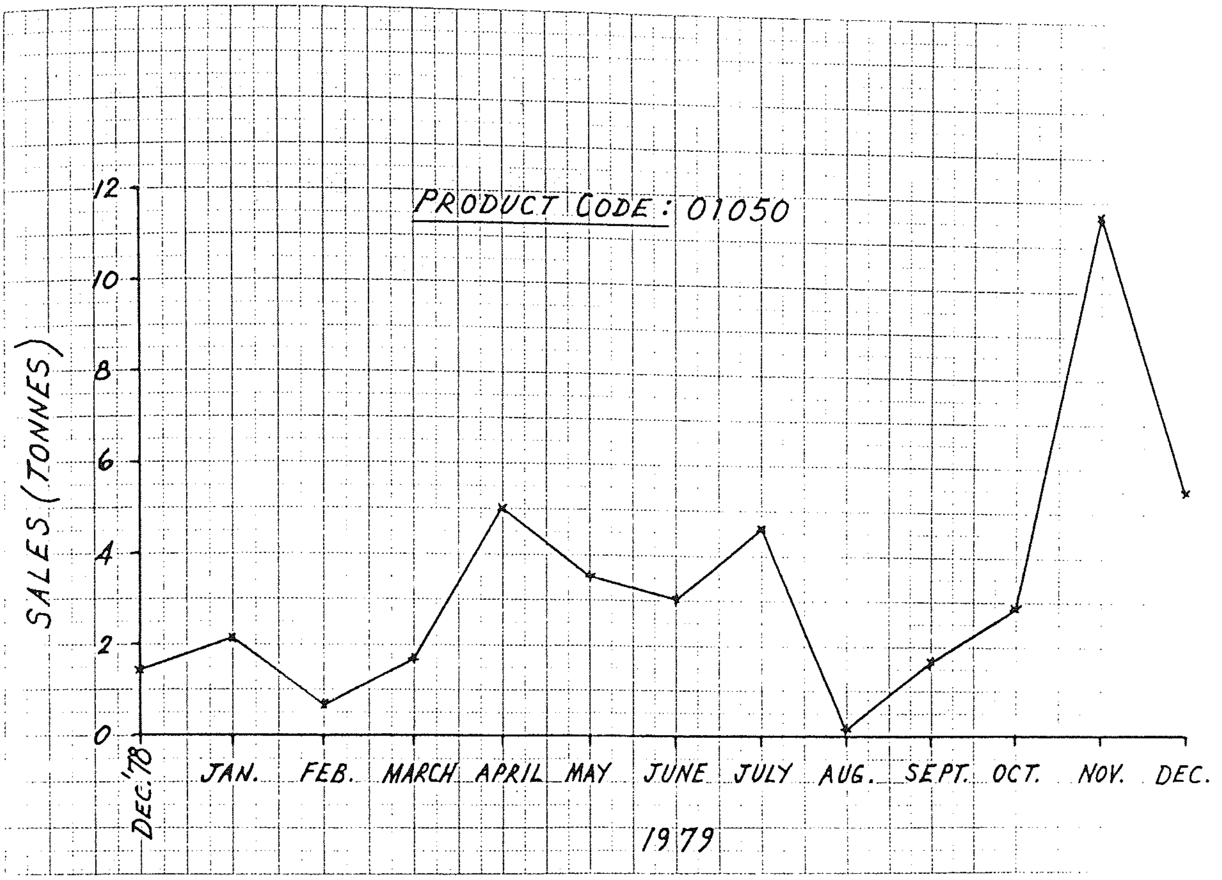


Fig. C3. Graph Showing the Nature of Demand, during 1979, for Finished Product 01050 Used in Simulation

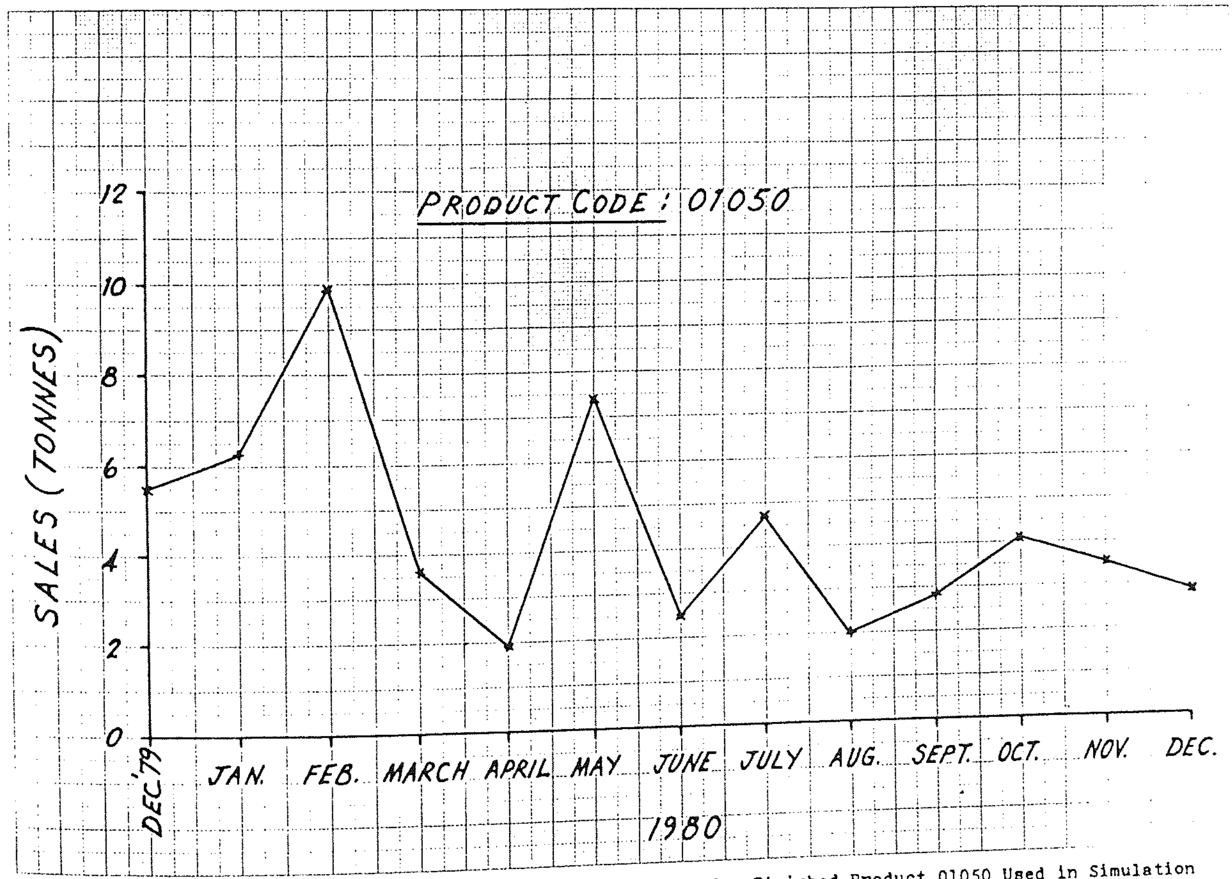


Fig. C4. Graph Showing the Nature of Demand, during 1980, for Finished Product 01050 Used in Simulation

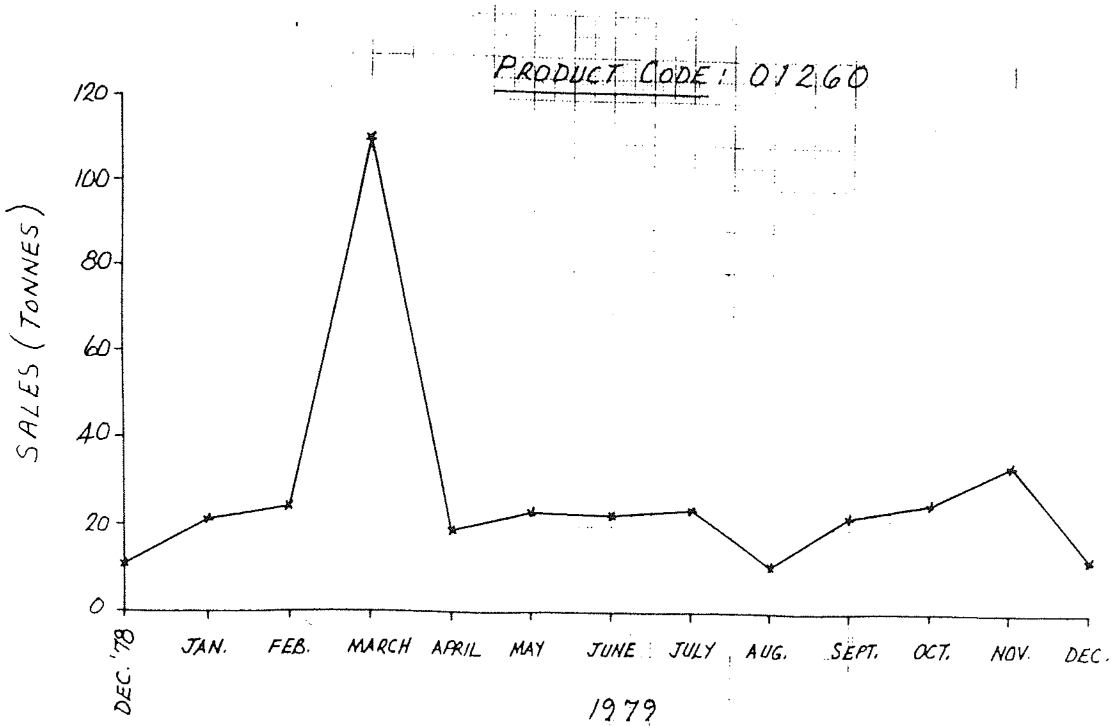


Fig. C5. Graph Showing the Nature of Demand, during 1979, for Finished Product 01260 Used in Simulation

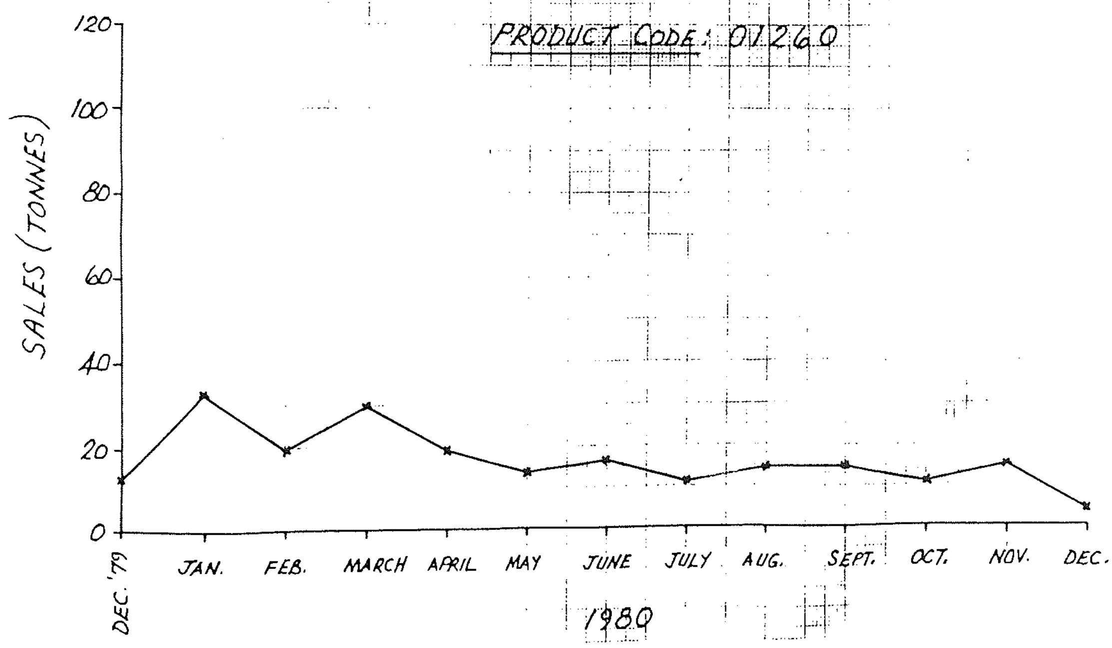


Fig. C6. Graph Showing the Nature of Demand, during 1980, for Finished Product 01260 Used in Simulation

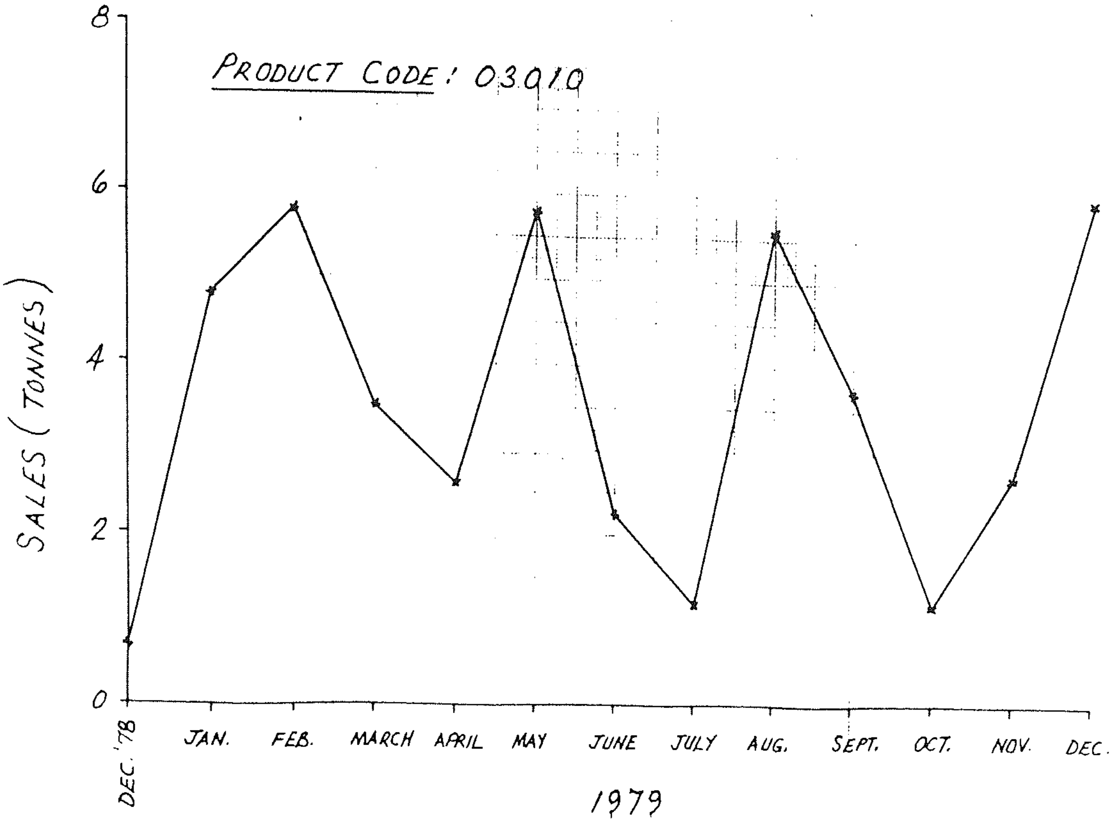


Fig. C7. Graph Showing the Nature of Demand, during 1979, for Finished Product 03010 Used in Simulation

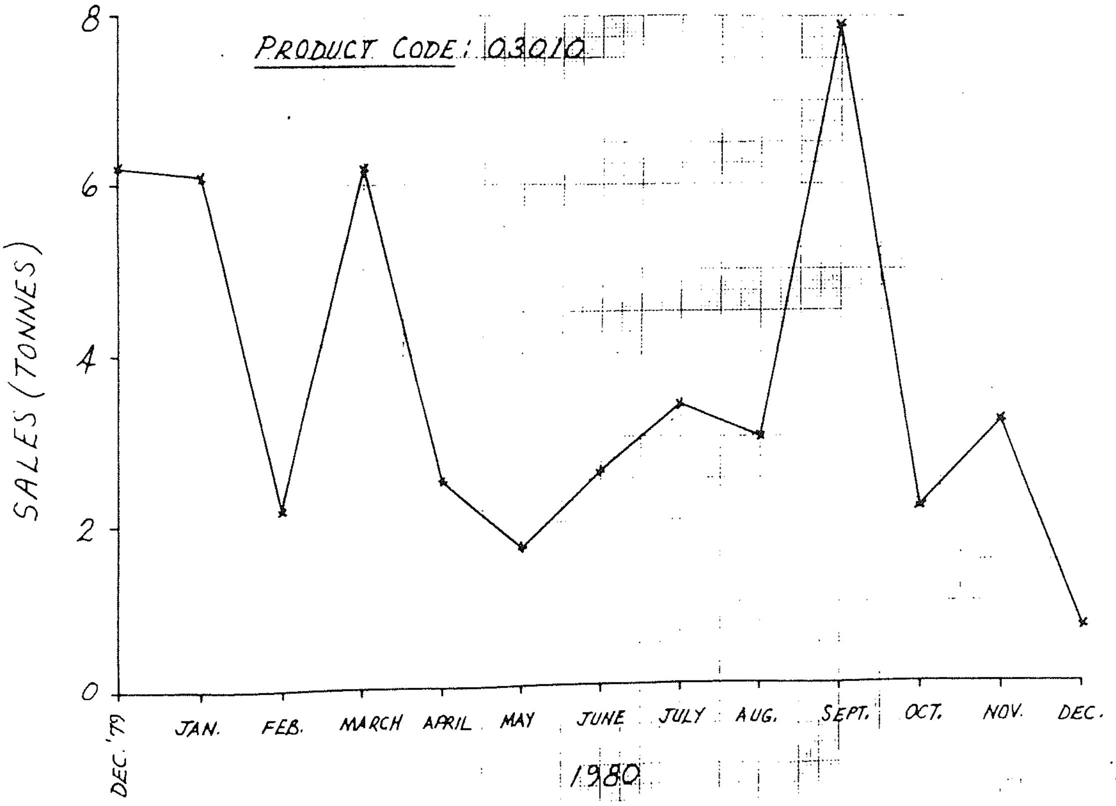


Fig. C8. Graph Showing the Nature of Demand, during 1980, for Finished Product 03010 Used in Simulation

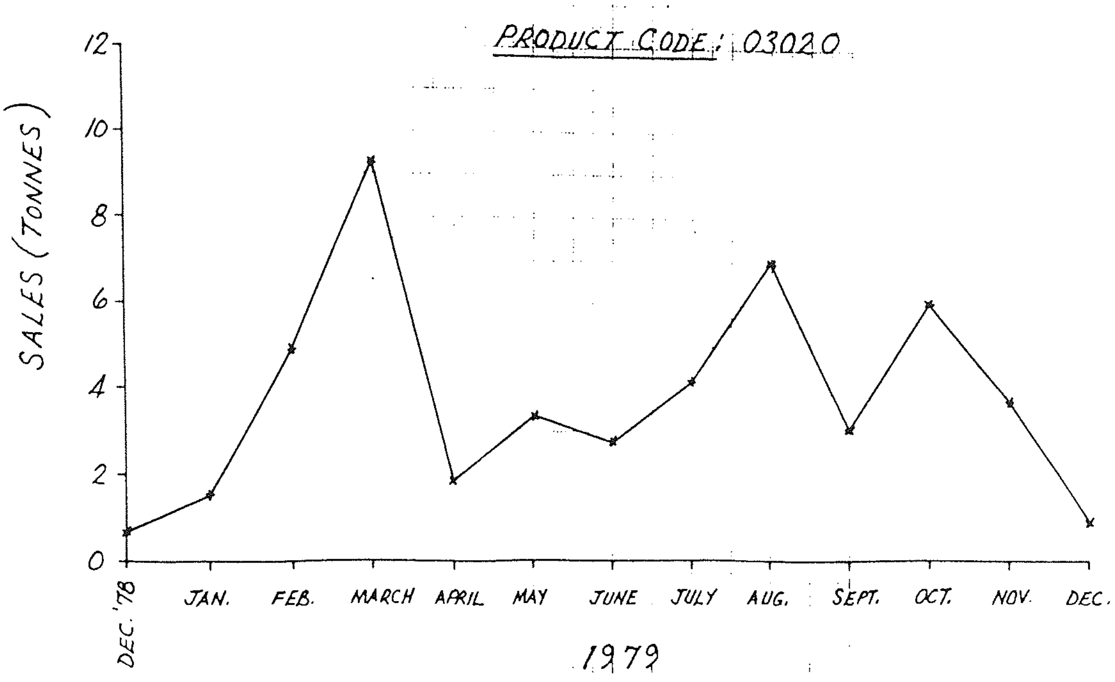


Fig. C9. Graph Showing the Nature of Demand, during 1979, for Finished Product 03020 Used in Simulation

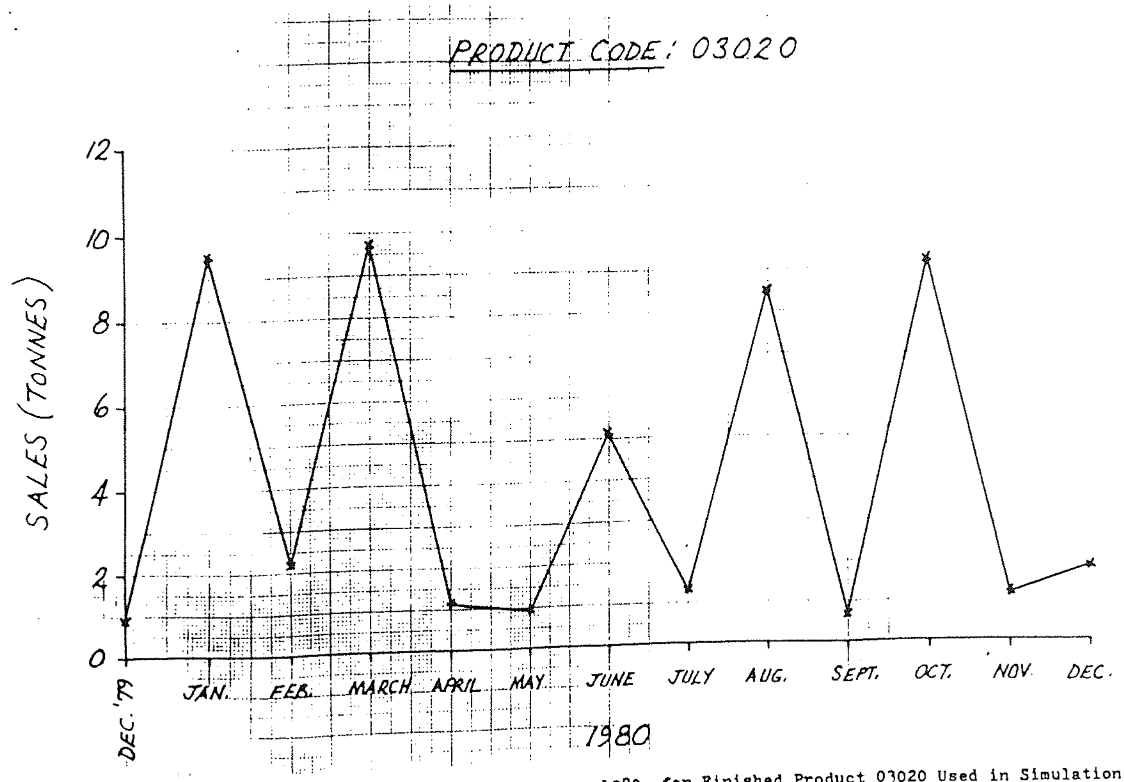


Fig. C10. Graph Showing the Nature of Demand, during 1980, for Finished Product 03020 Used in Simulation

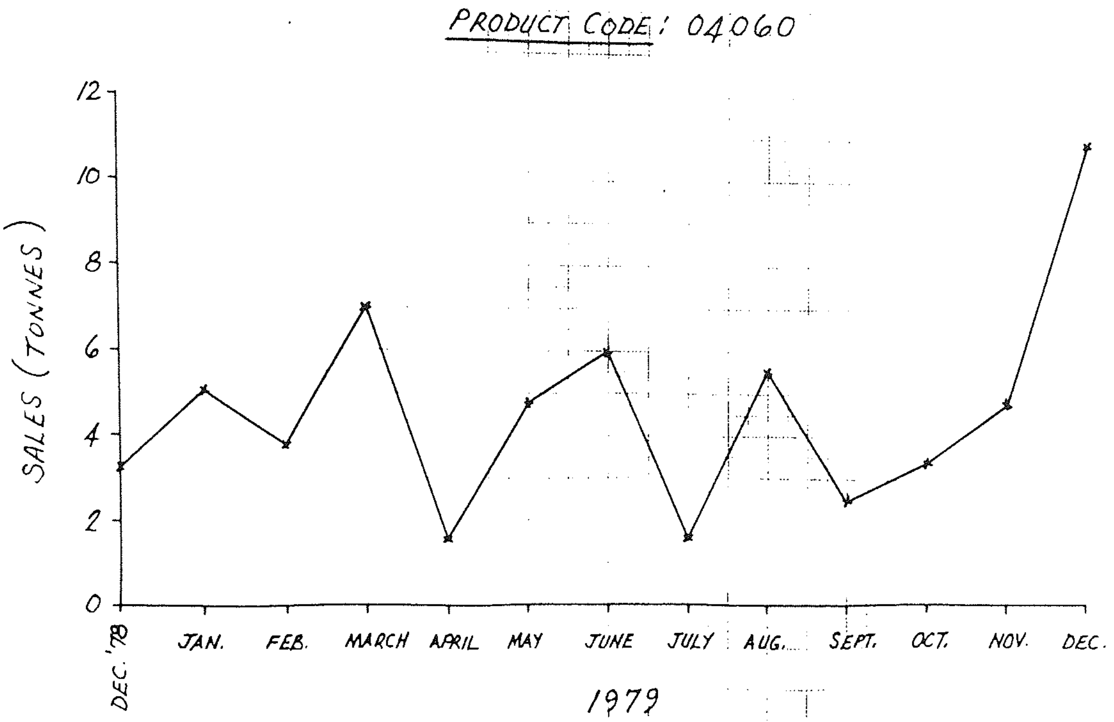


Fig. C11. Graph Showing the Nature of Demand, during 1979, for Finished Product 04060 Used in Simulation

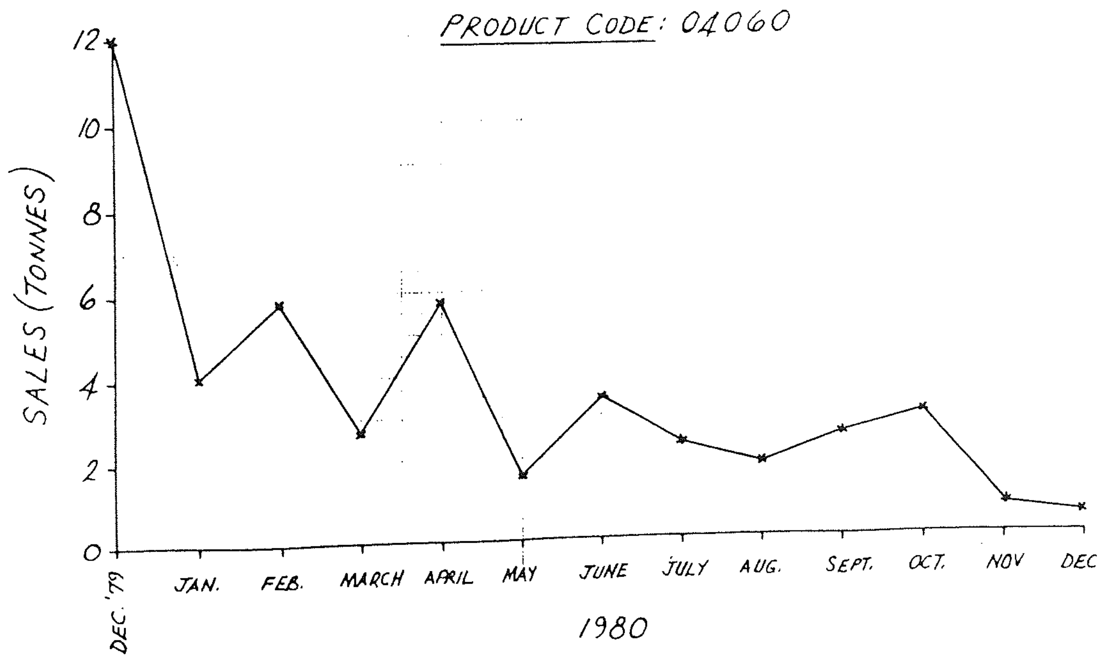


Fig. C12. Graph Showing the Nature of Demand, during 1980, for Finished Product 04060 Used in Simulation

PRODUCT CODE: 06050

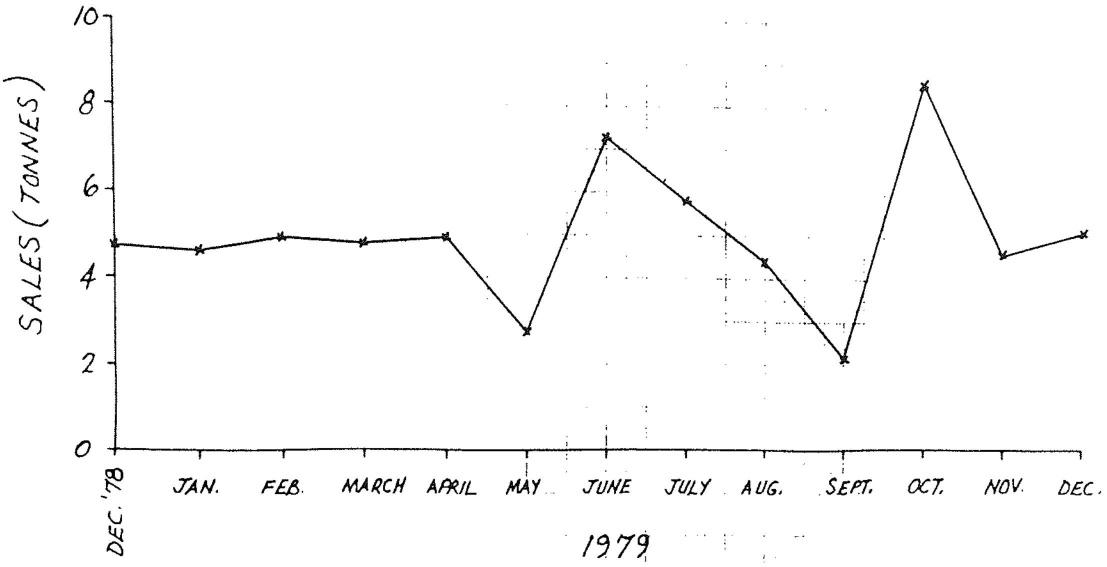


Fig. C13. Graph Showing the Nature of Demand, during 1979, for Finished Product 06050 Used in Simulation

PRODUCT CODE: 06050

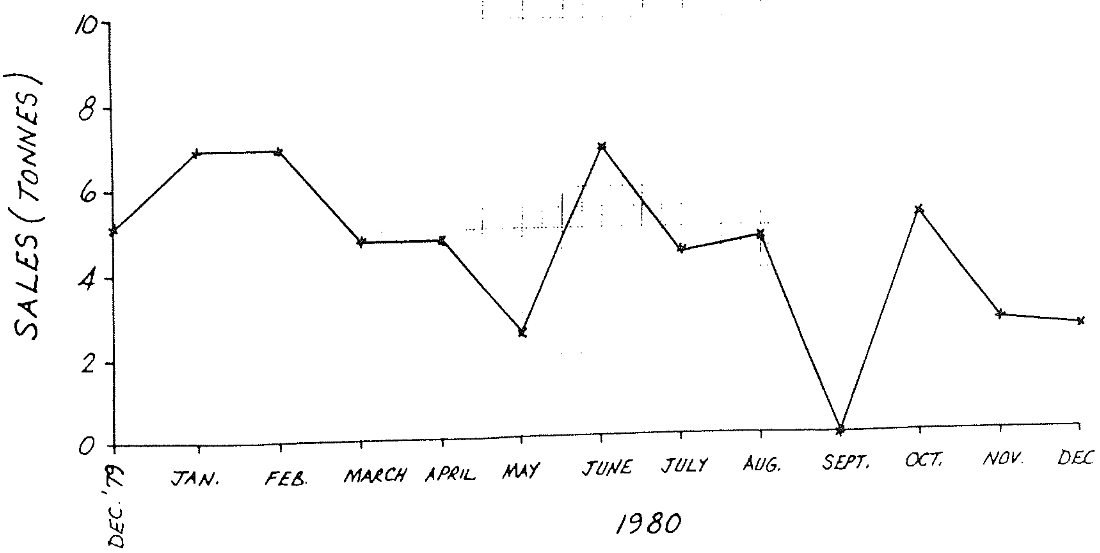


Fig. C14. Graph Showing the Nature of Demand, during 1980, for Finished Product 06050 Used in Simulation

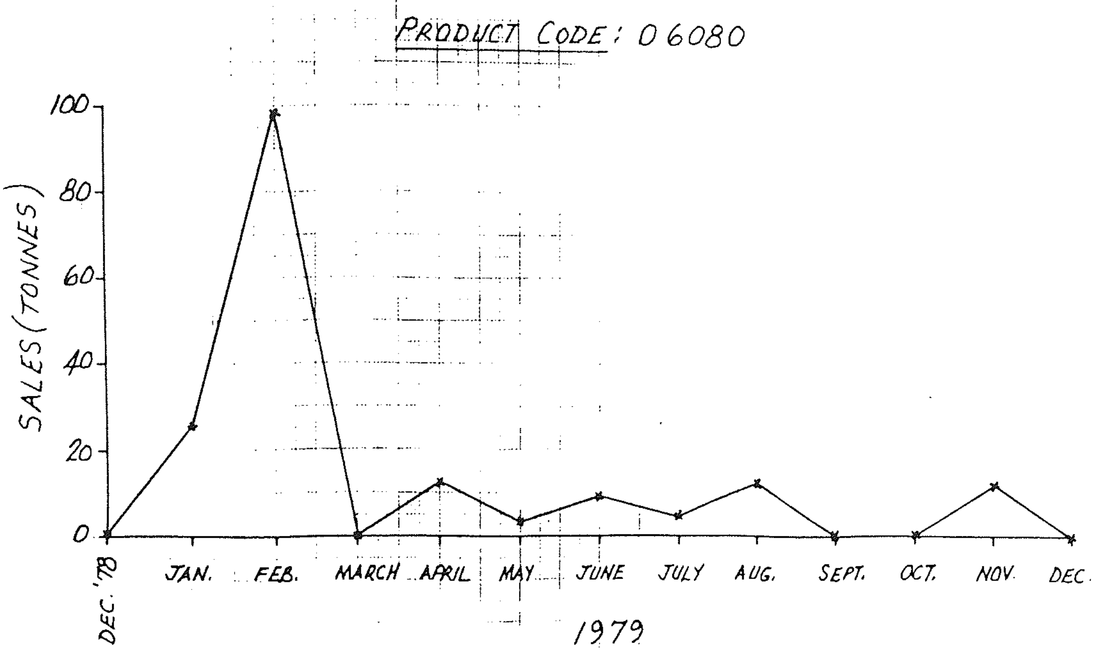


Fig. C15, Graph Showing the Nature of Demand, during 1979, for Finished Product 06080 Used in Simulation

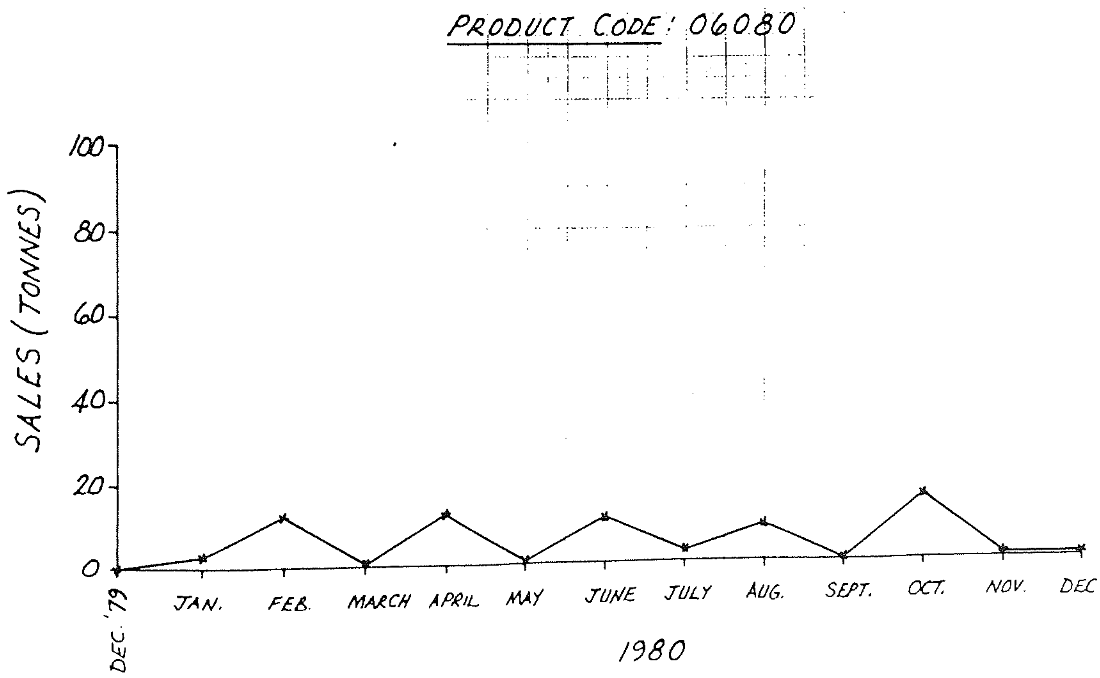


Fig. C16. Graph Showing the Nature of Demand, during 1980, for Finished Product 06080 Used in Simulation

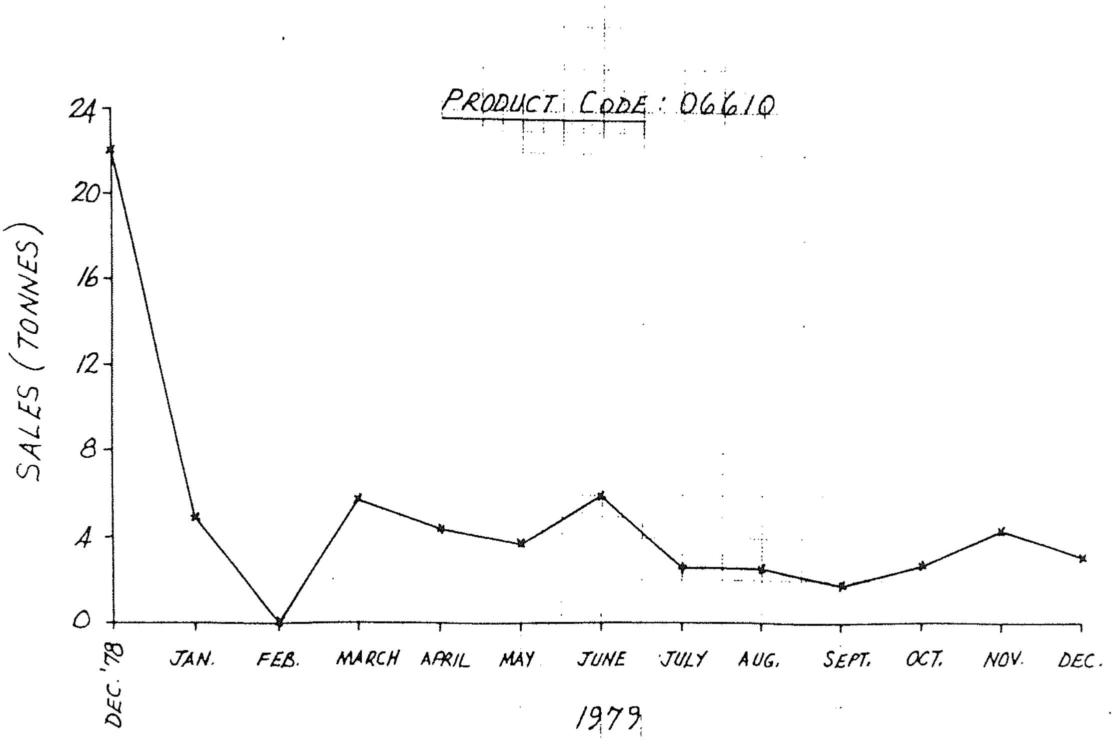


Fig. C17. Graph Showing the Nature of Demand, during 1979, for Finished Product 06610 Used in Simulation

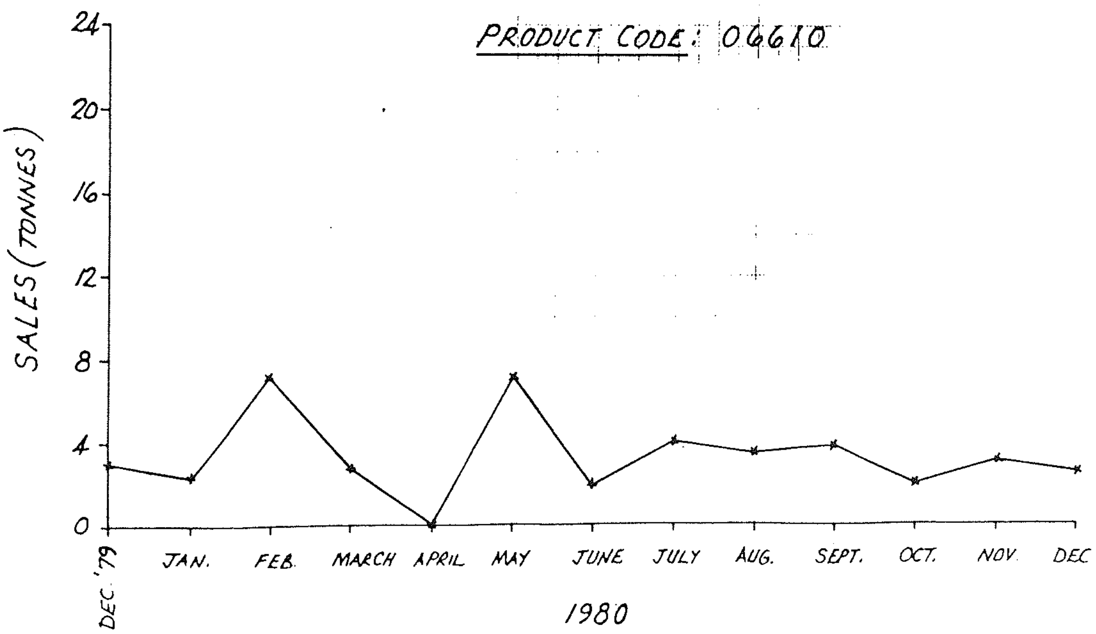


Fig. C18. Graph Showing the Nature of Demand, during 1980, for Finished Product 06610 Used in Simulation

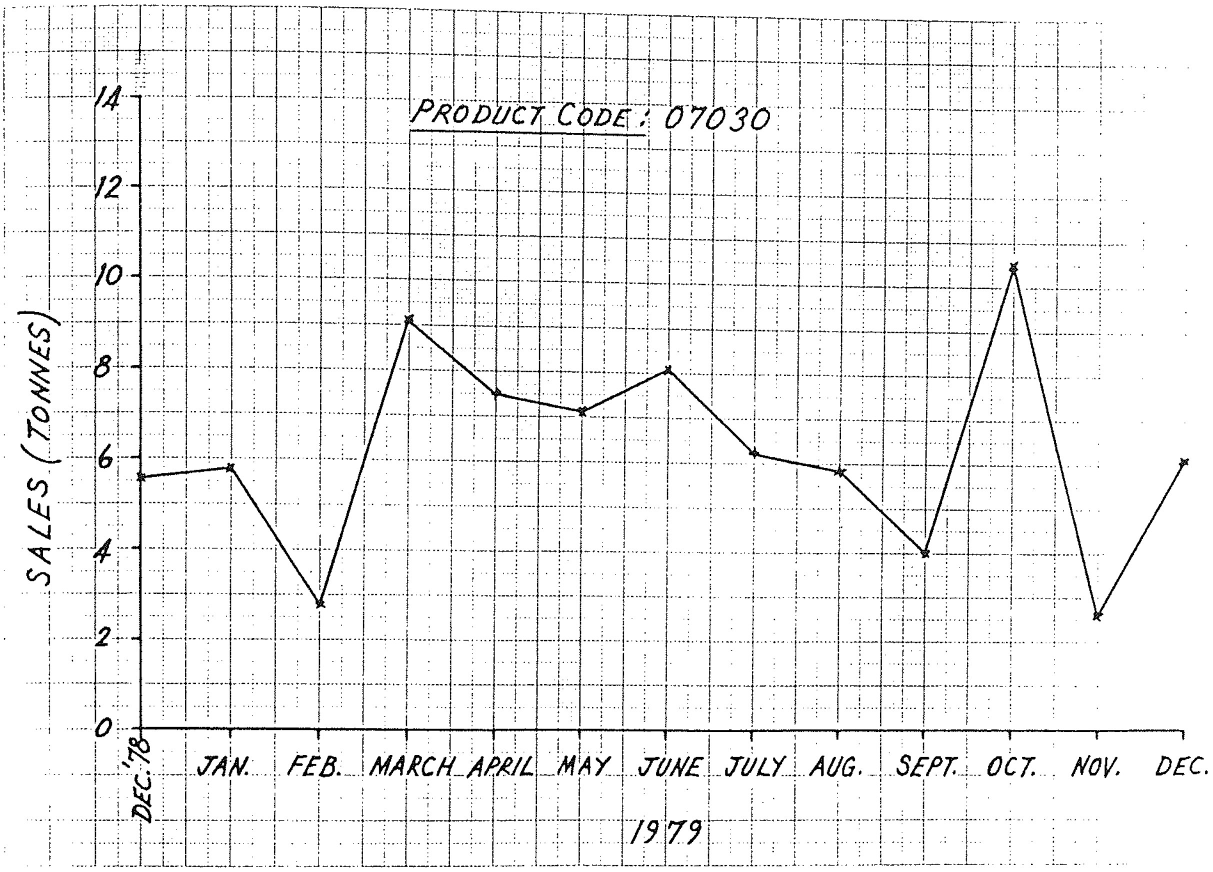


Fig. C19. Graph Showing the Nature of Demand, during 1979, for Finished Product 07030 Used in Simulation

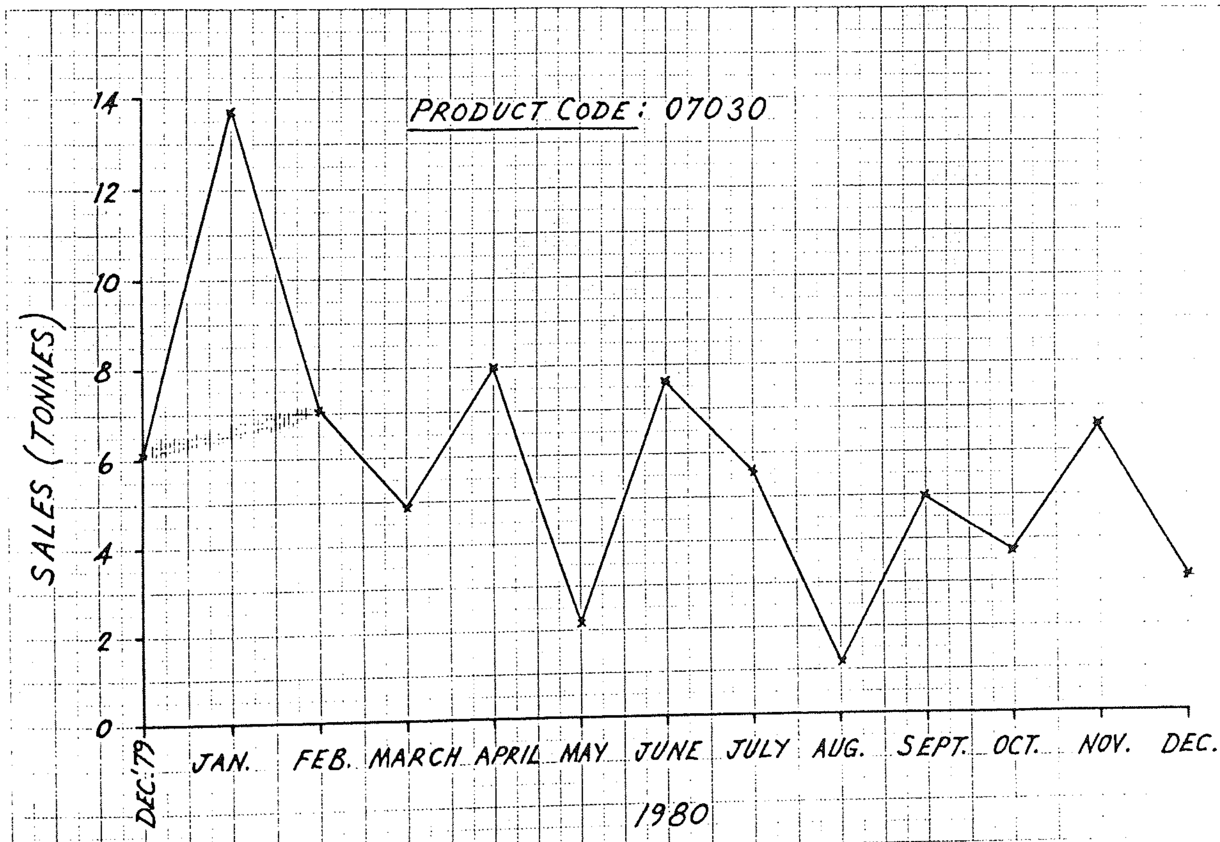


Fig. C20. Graph Showing the Nature of Demand, during 1980, for Finished Product 07030 Used in Simulation

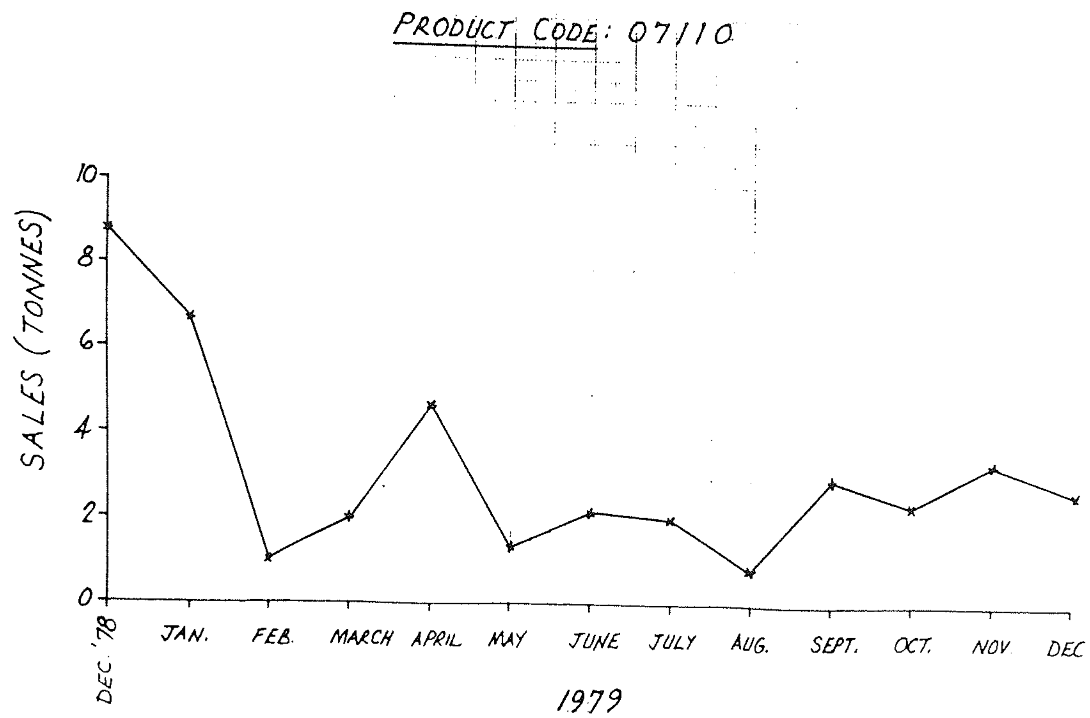


Fig. C21, Graph Showing the Nature of Demand, during 1979, for Finished Product 07110 Used in Simulation

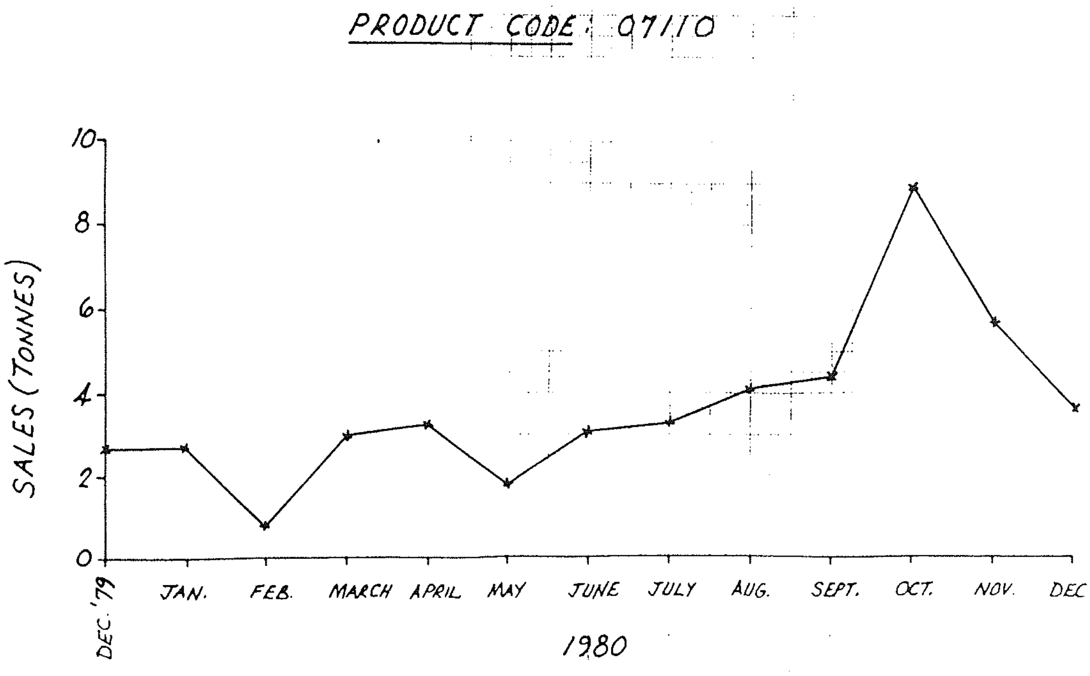


Fig. C22, Graph Showing the Nature of Demand, during 1980, for Finished Product 07110 Used in Simulation

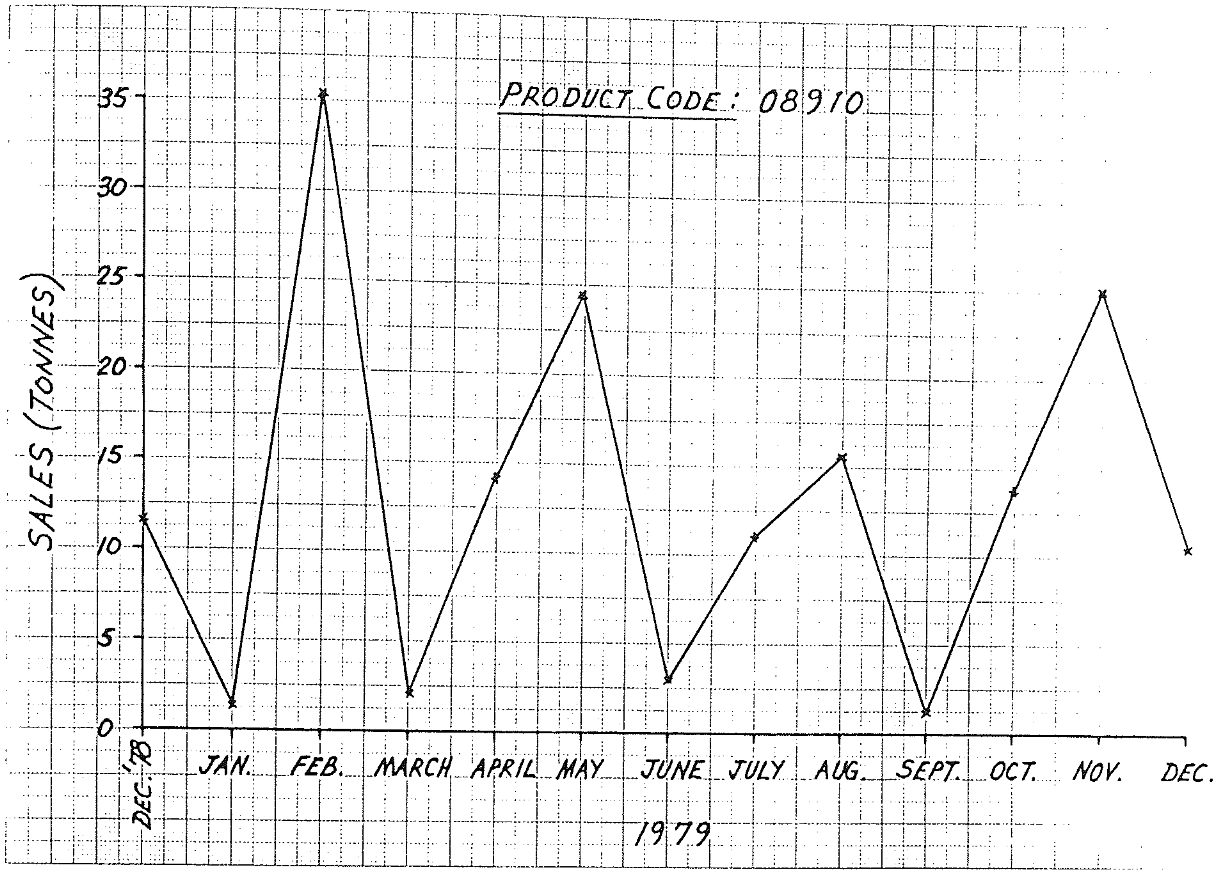


Fig. C23. Graph Showing the Nature of Demand, during 1979, for Finished Product 08910 Used in Simulation

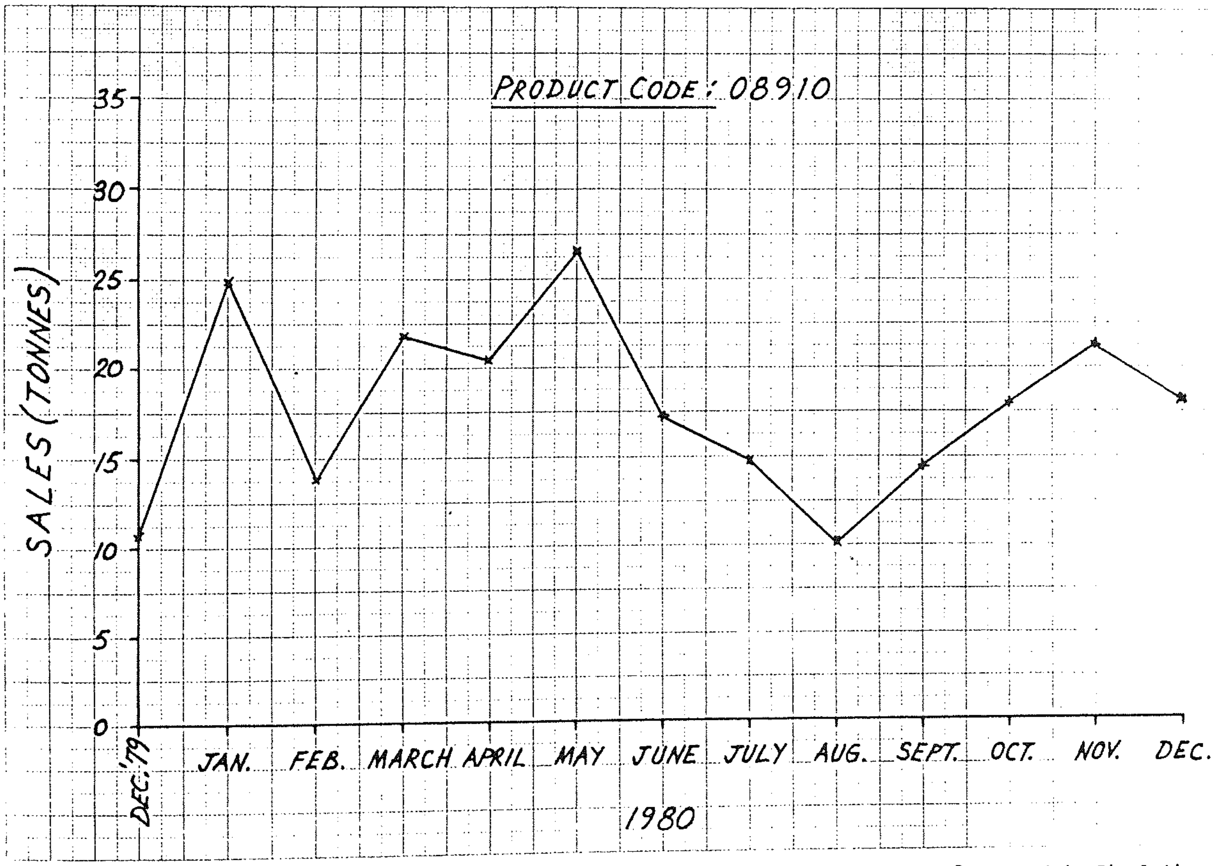


Fig. C24. Graph Showing the Nature of Demand, during 1980, for Finished Product 08910 Used in Simulation

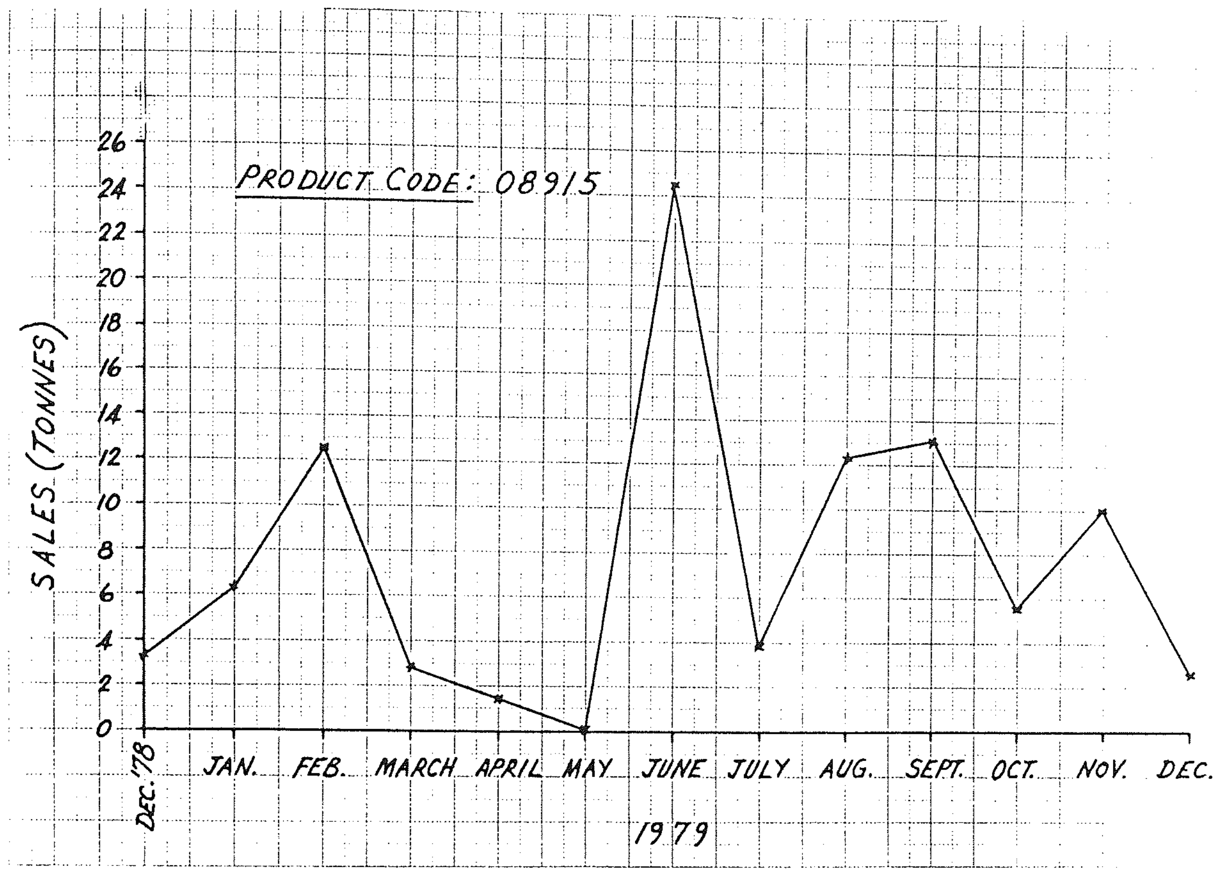


Fig. C25. Graph Showing the Nature of Demand, during 1979, for Finished Product 08915 Used in Simulation

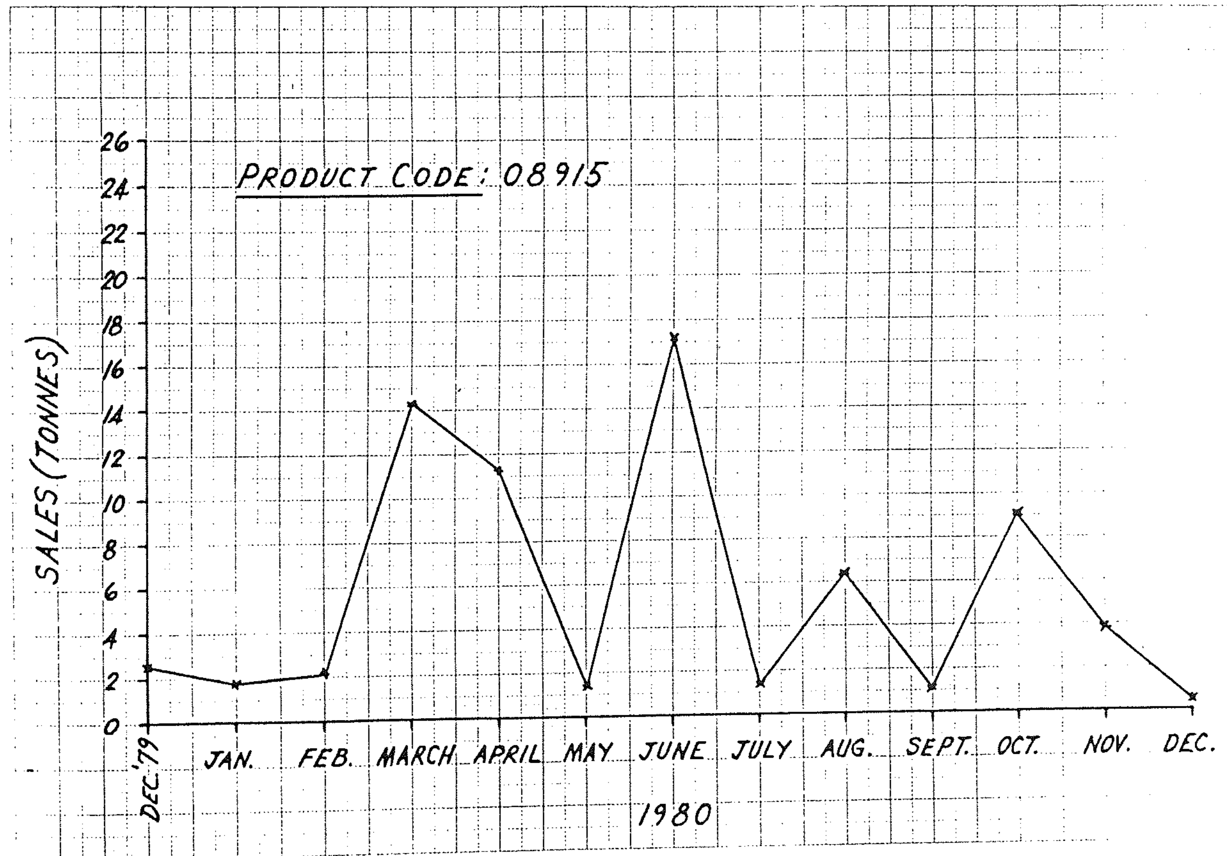


Fig. C26. Graph Showing the Nature of Demand, during 1980, for Finished Product 08915 Used in Simulation

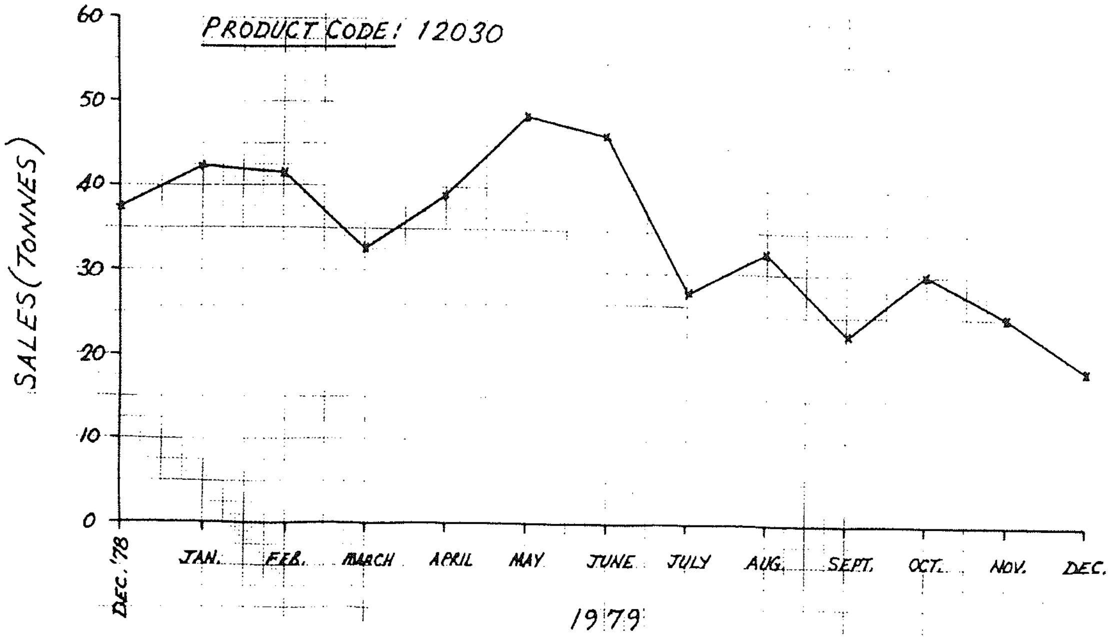


Fig. C27. Graph Showing the Nature of Demand, during 1979, for Finished Product 12030 Used in Simulation

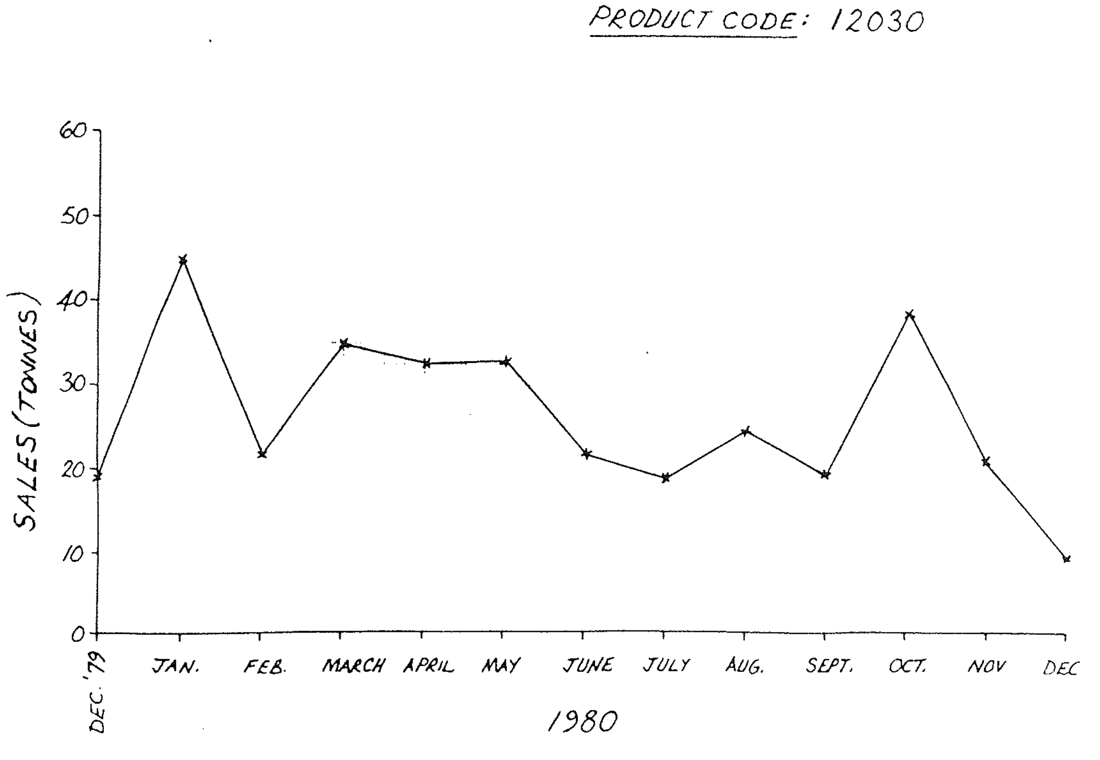


Fig. C 28. Graph Showing the Nature of Demand, during 1980, for Finished Product 12030 Used in Simulation

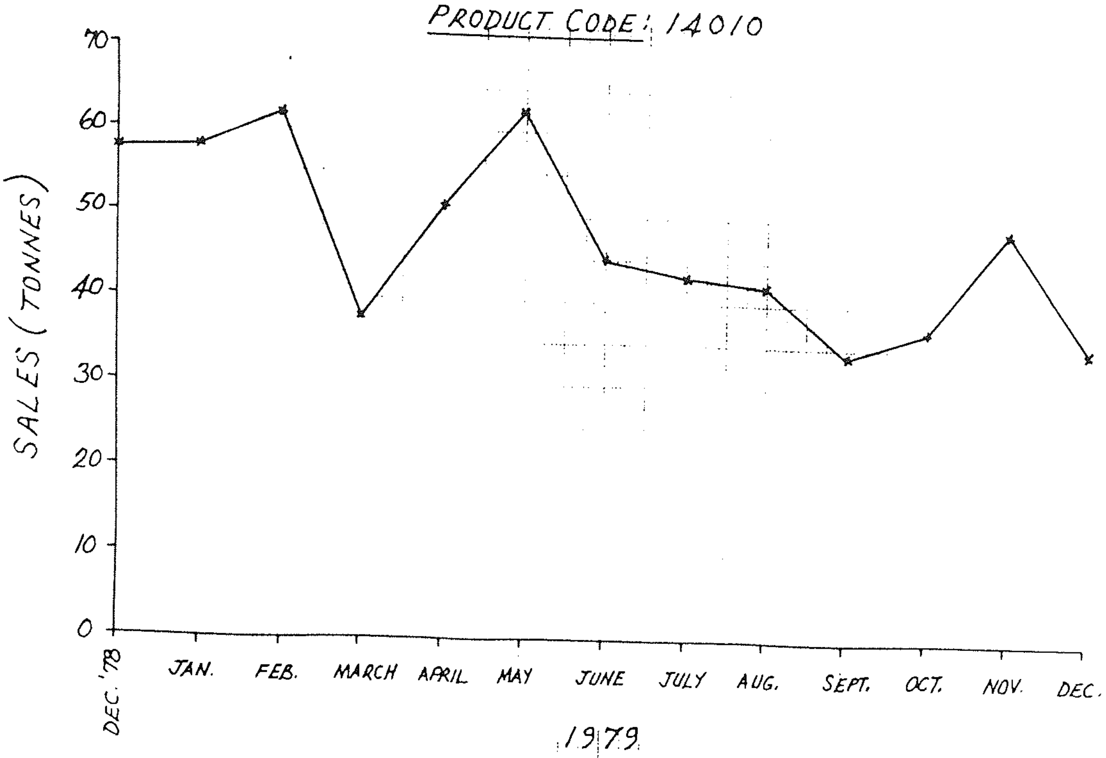


Fig. C29. Graph Showing the Nature of Demand, during 1979, for Finished Product 14010 Used in Simulation

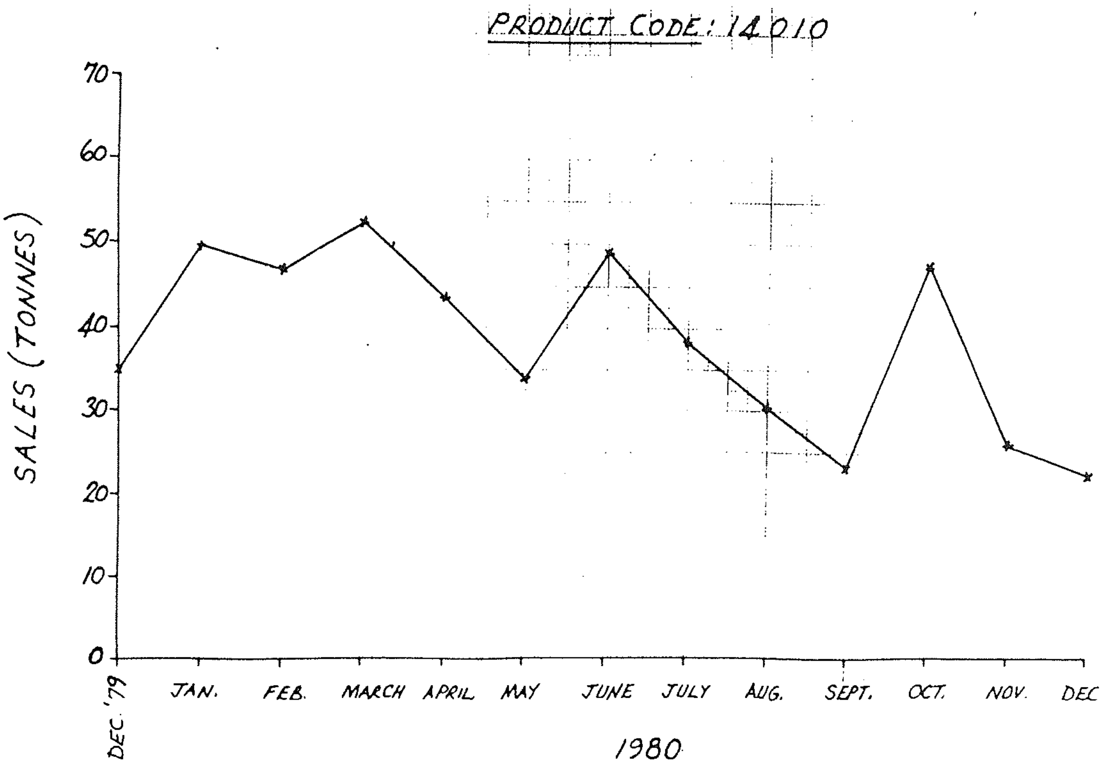


Fig. C30. Graph Showing the Nature of Demand, during 1980, for Finished Product 14010 Used in Simulation

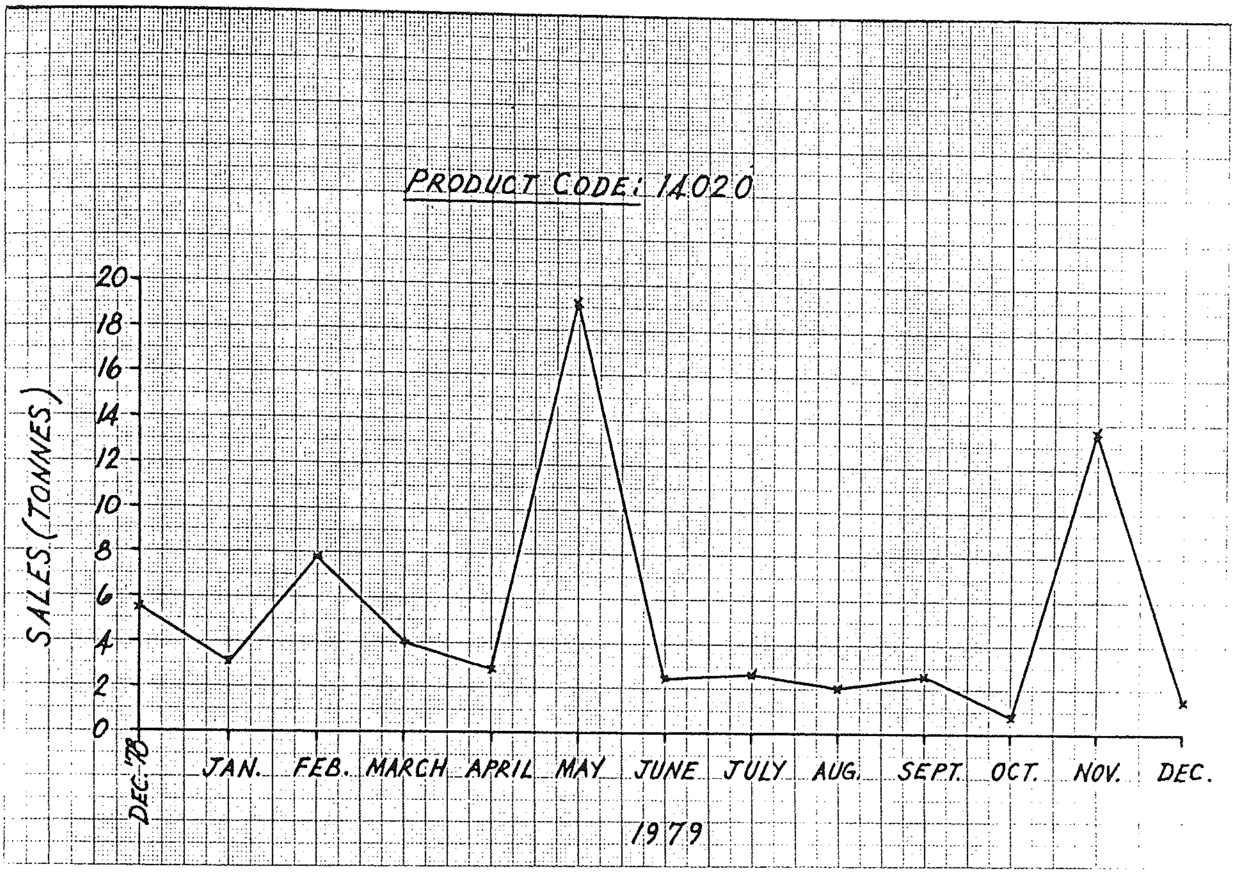


Fig. C31. Graph Showing the Nature of Demand, during 1979, for Finished Product 14020 Used in Simulation

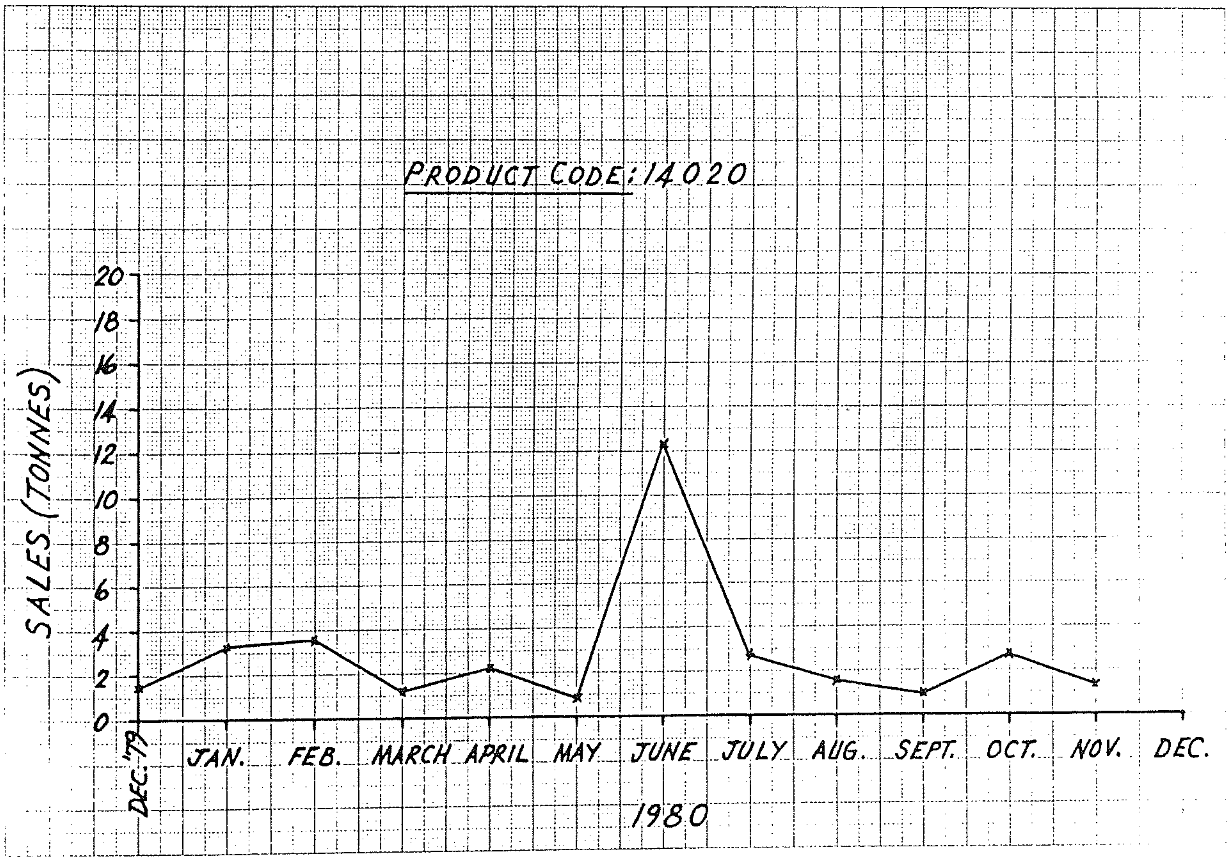


Fig. C32. Graph Showing the Nature of Demand, during 1980, for Finished Product 14020 Used in Simulation

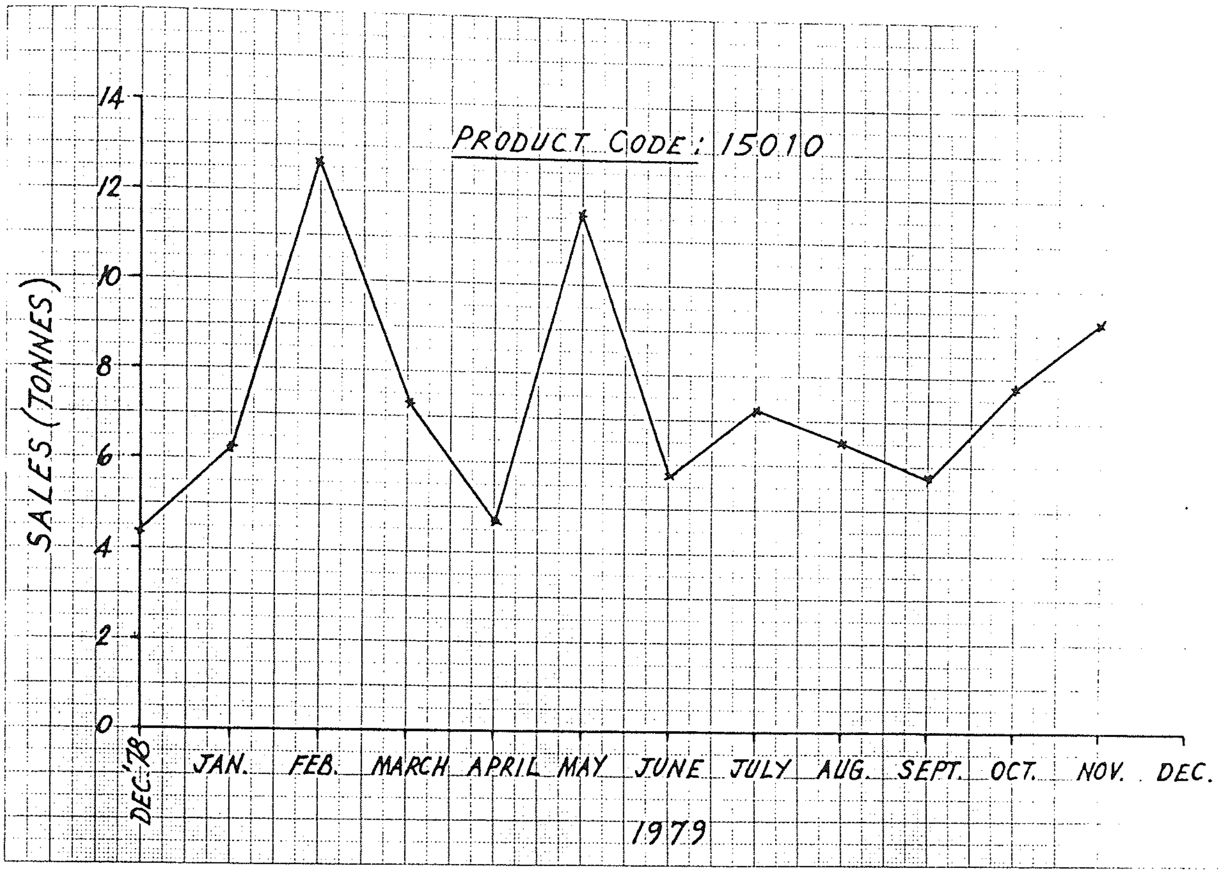


Fig. C33. Graph Showing the Nature of Demand, during 1979, for Finished Product 15010 Used in Simulation

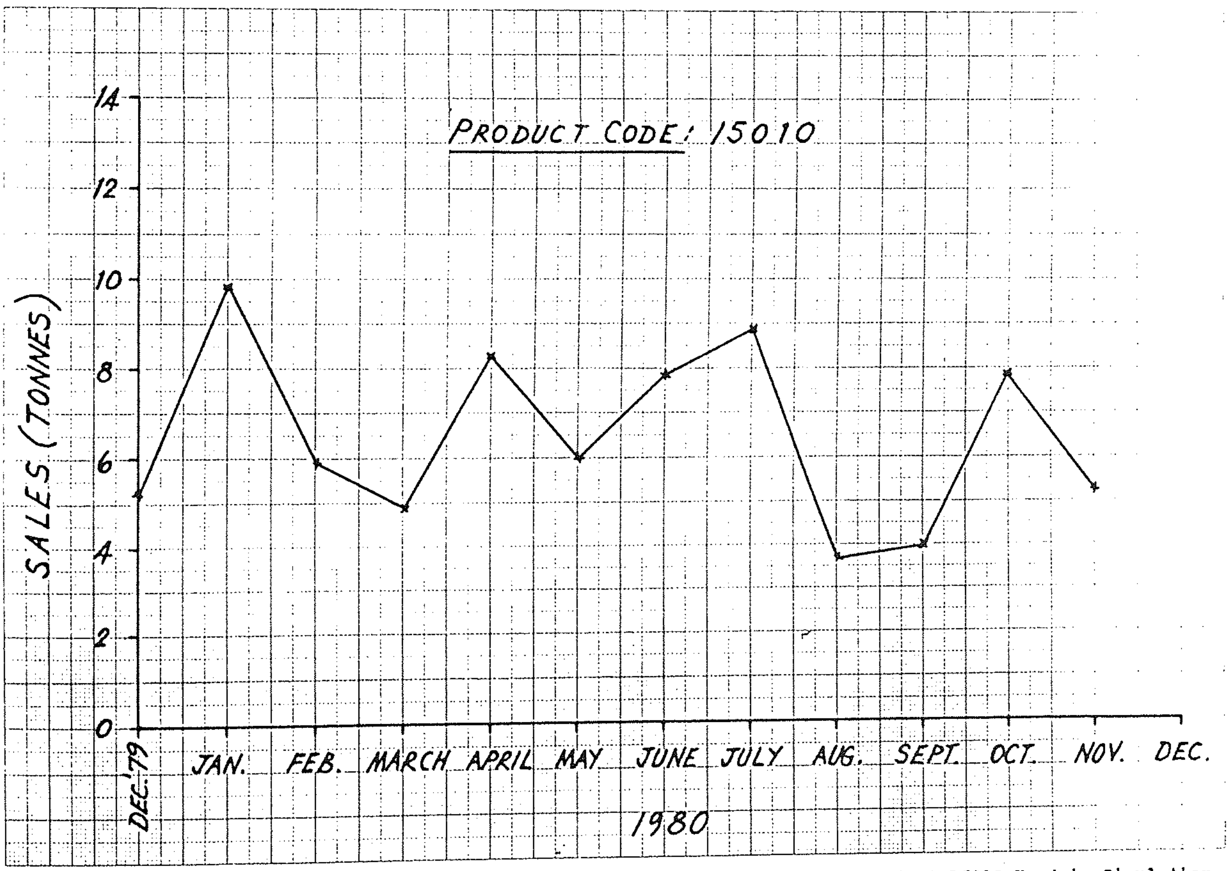


Fig. C34. Graph Showing the Nature of Demand, during 1980, for Finished Product 15010 Used in Simulation

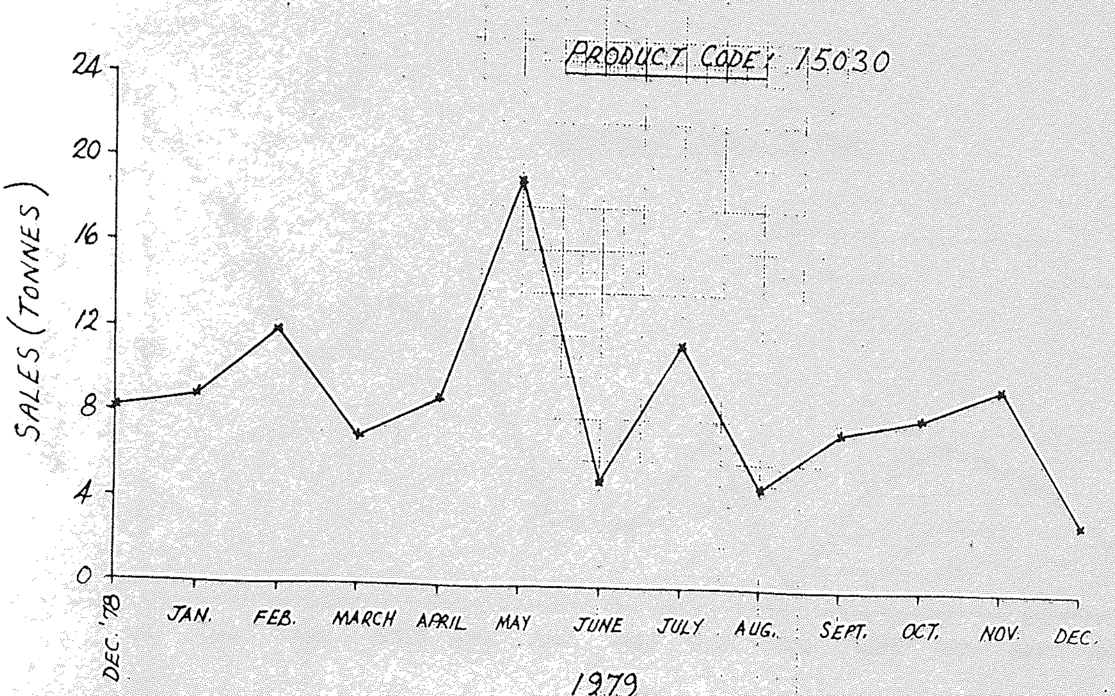


Fig. C35. Graph Showing the Nature of Demand, during 1979, for Finished Product 15030 Used in Simulation

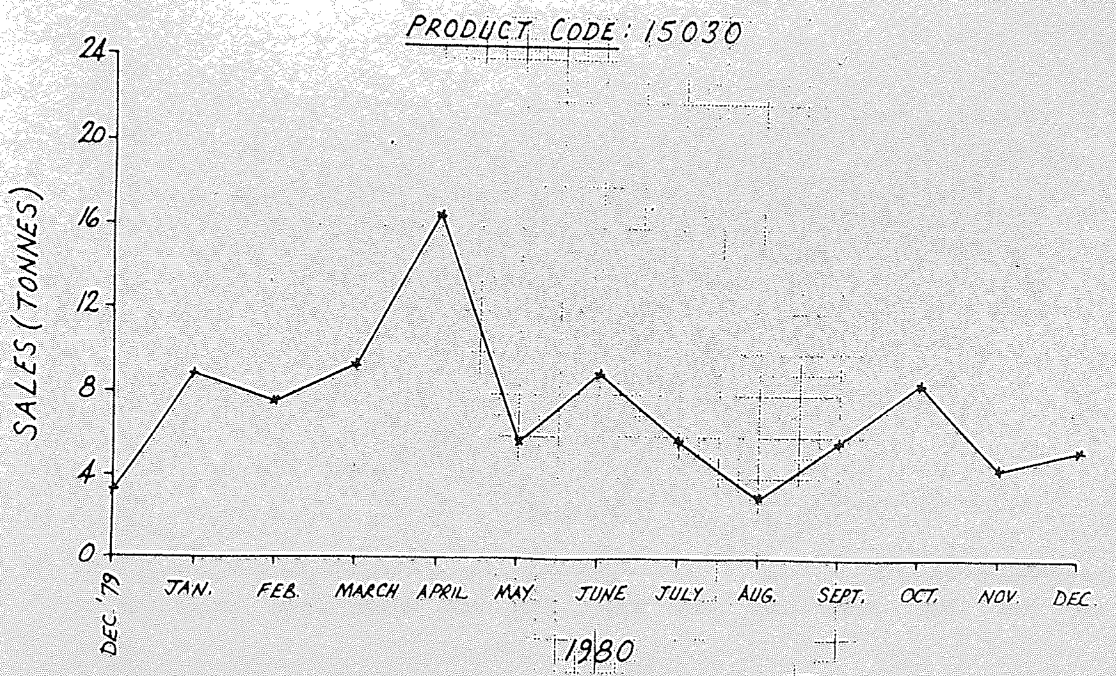


Fig. C36. Graph Showing the Nature of Demand, during 1980, for Finished Product 15030 Used in Simulation

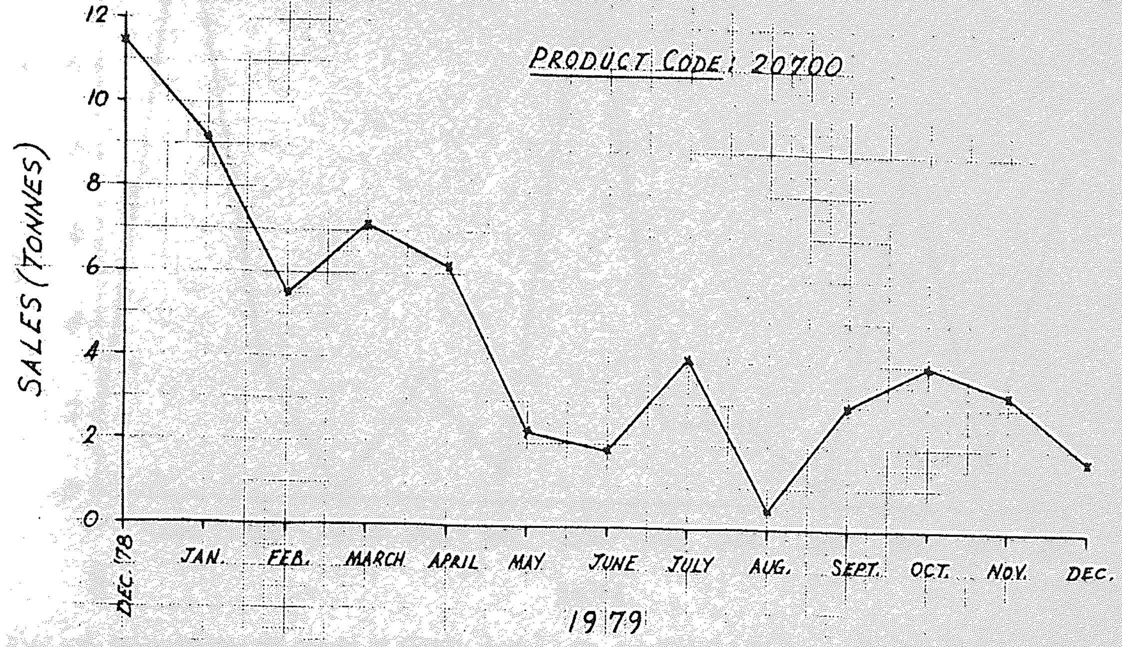


Fig. C37. Graph Showing the Nature of Demand, during 1979, for Finished Product 20700 Used in Simulation

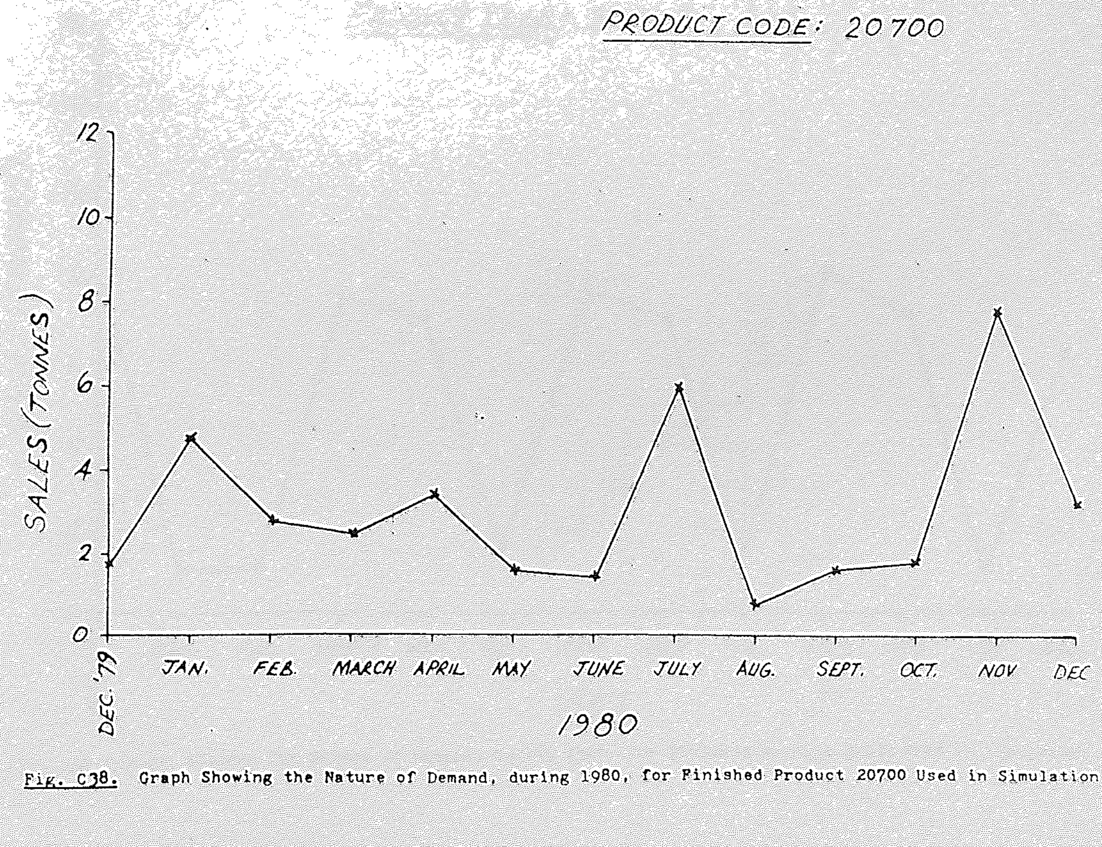


Fig. C38. Graph Showing the Nature of Demand, during 1980, for Finished Product 20700 Used in Simulation

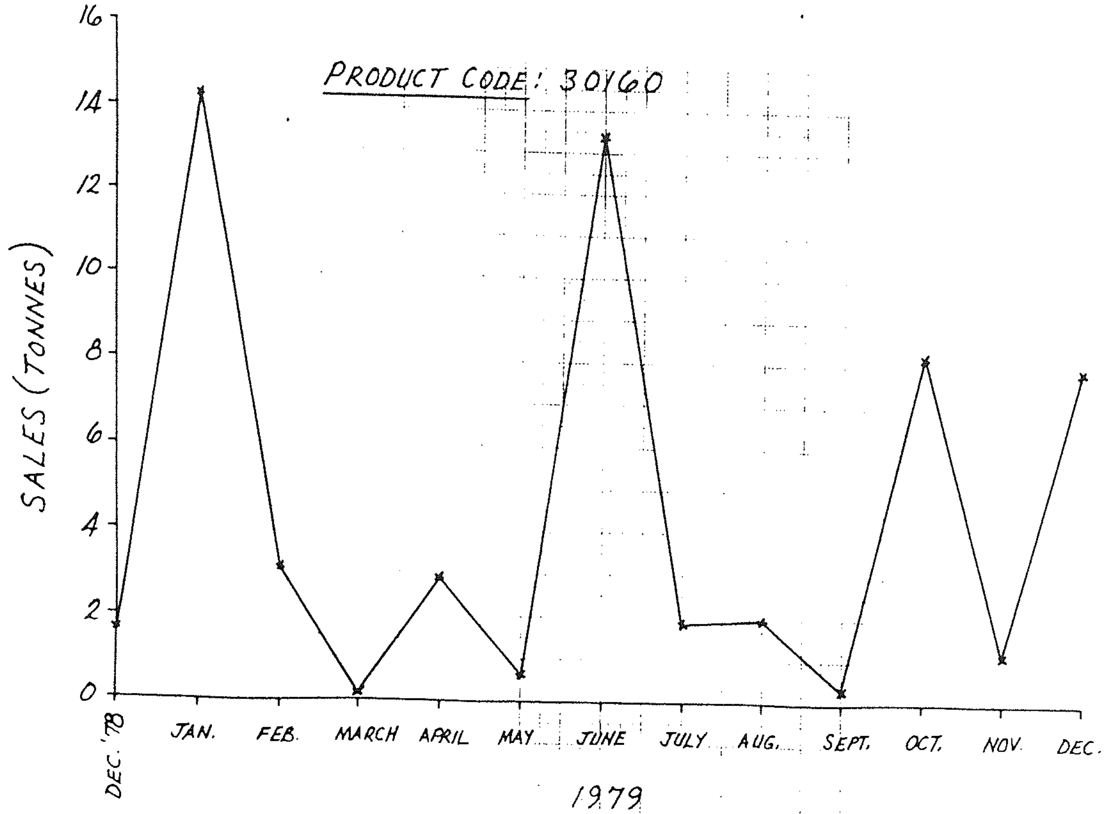


Fig. C39. Graph Showing the Nature of Demand, during 1979, for Finished Product 30160 Used in Simulation

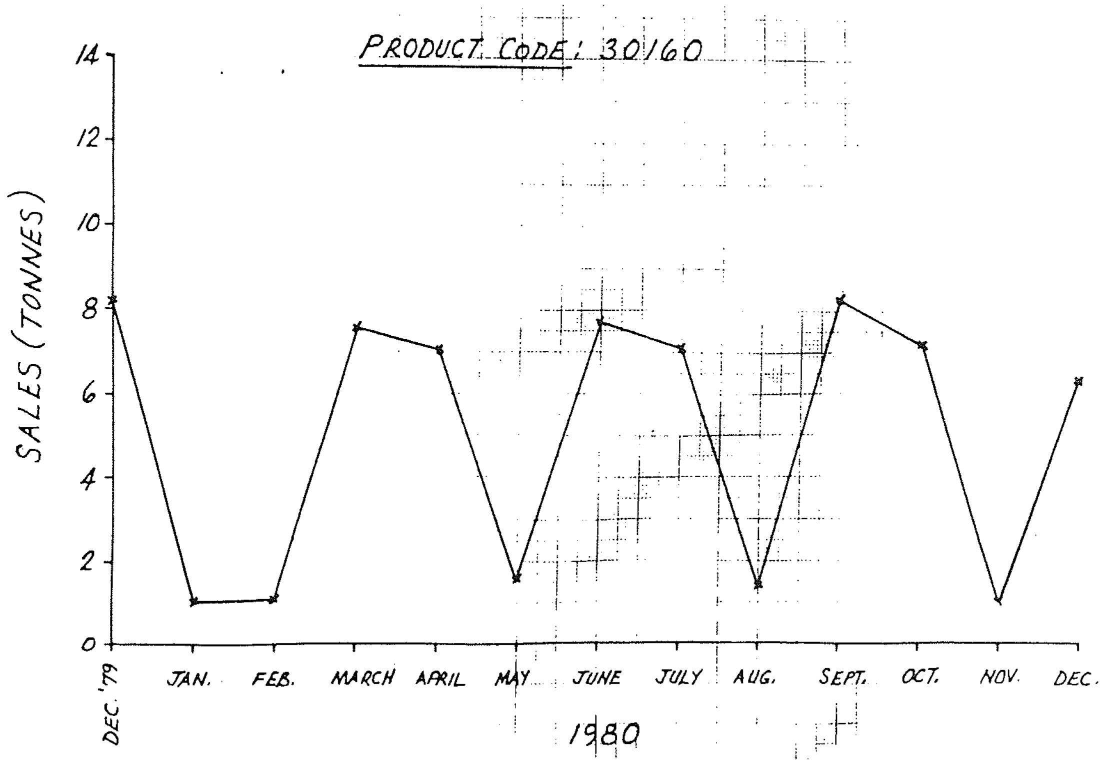


Fig. C40. Graph Showing the Nature of Demand, during 1980, for Finished Product 30160 Used in Simulation

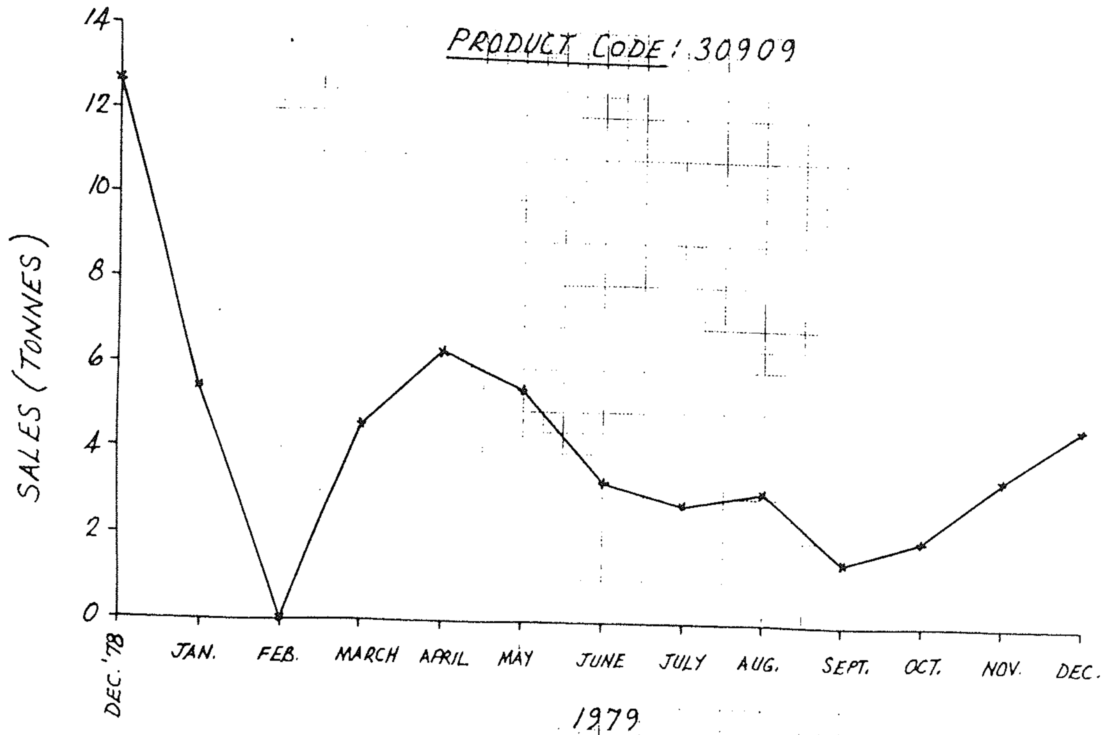


Fig. C41. Graph Showing the Nature of Demand, during 1979, for Finished Product 30909 Used in Simulation

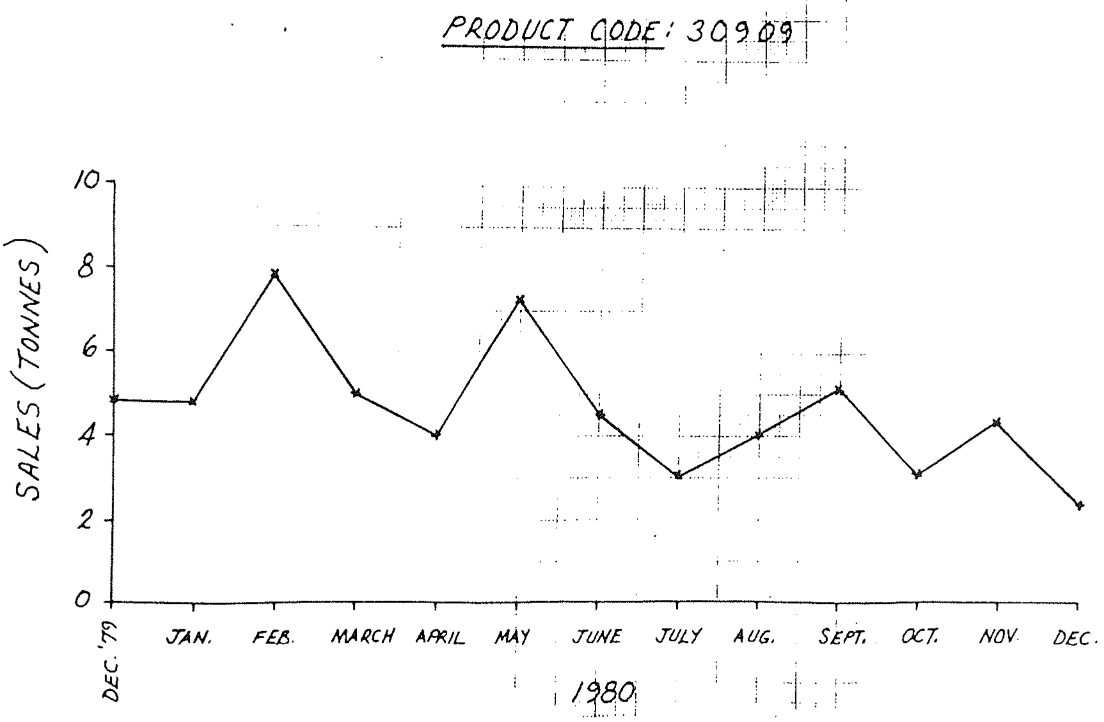


Fig. C42. Graph Showing the Nature of Demand, during 1980, for Finished Product 30909 Used in Simulation

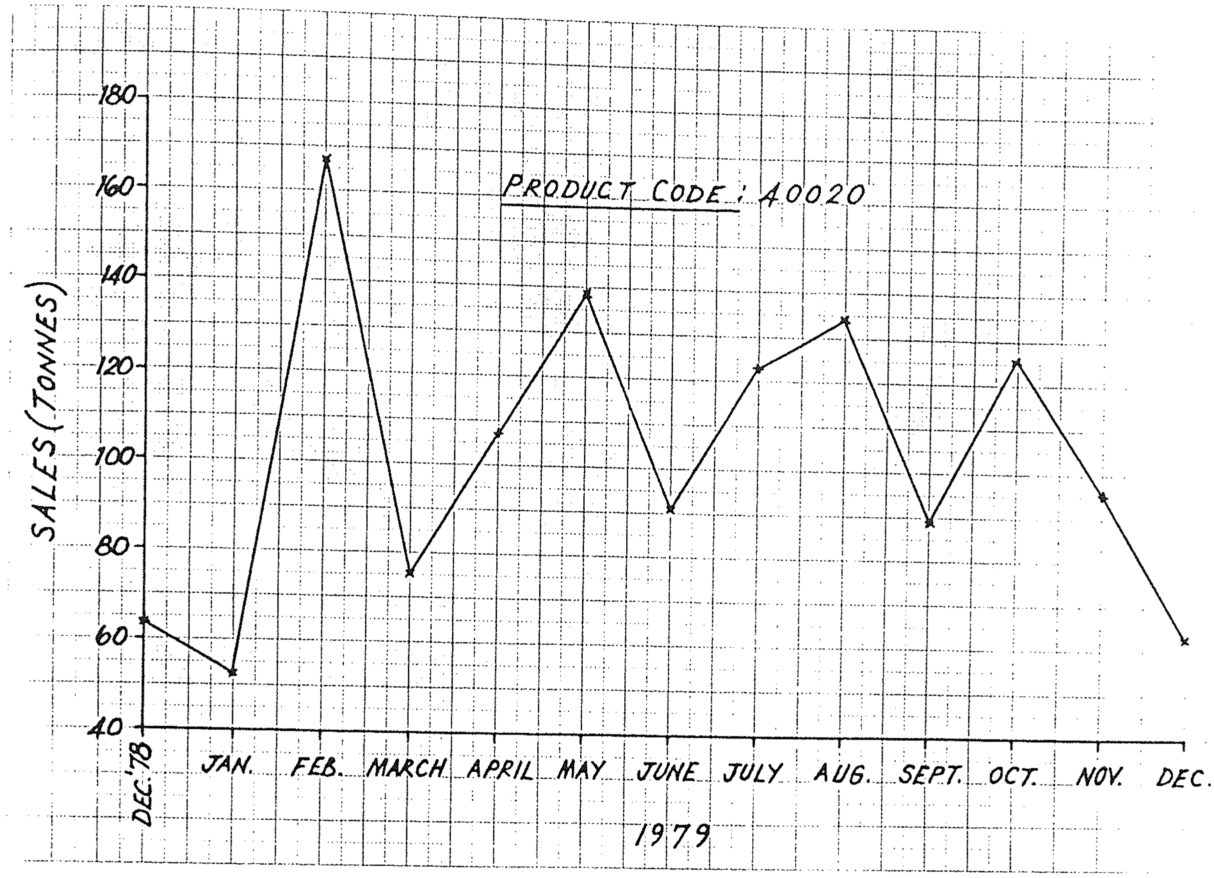


Fig. C43. Graph Showing the Nature of Demand, during 1979, for Finished Product 40020 Used in Simulation

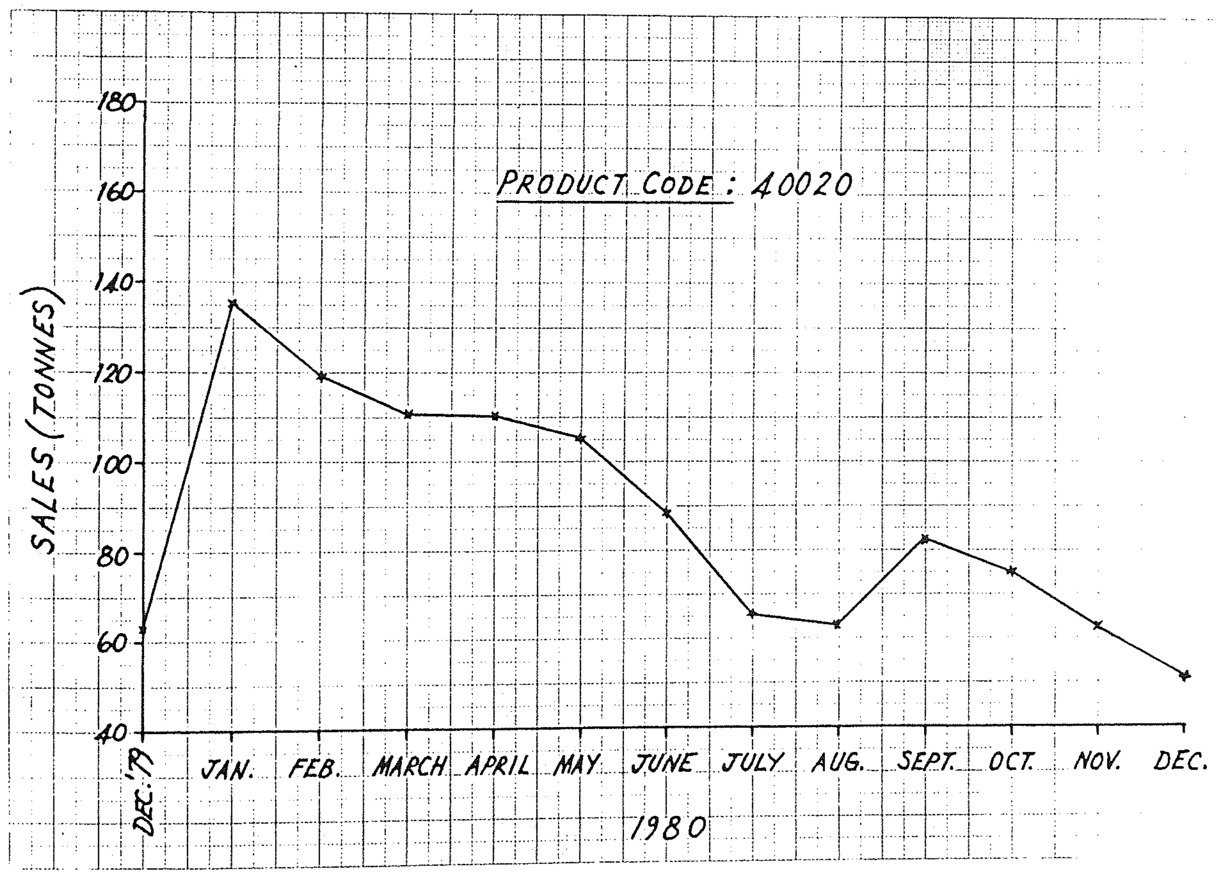


Fig. C44. Graph Showing the Nature of Demand, during 1980, for Finished Product 40020 Used in Simulation

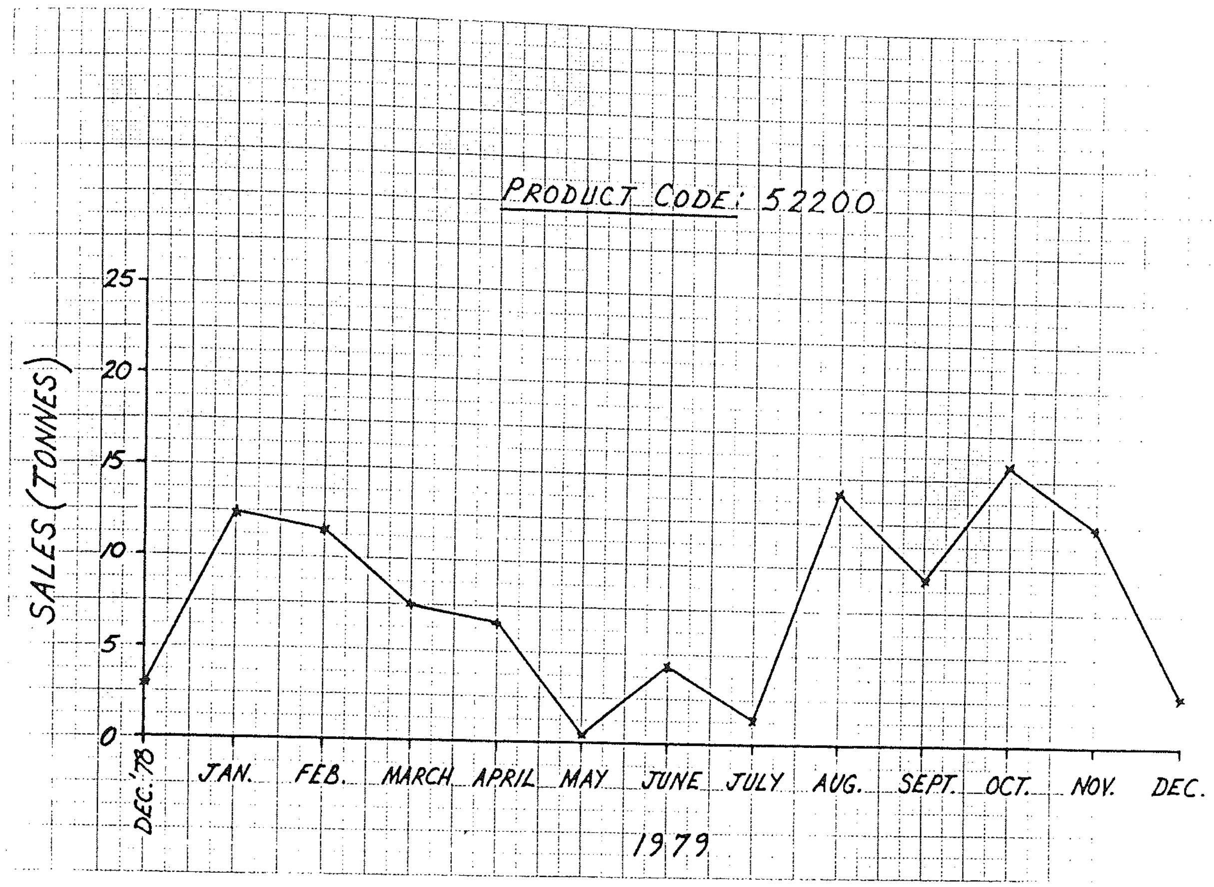


Fig. C45. Graph Showing the Nature of Demand, during 1979, for Finished Product 52200 Used in Simulation

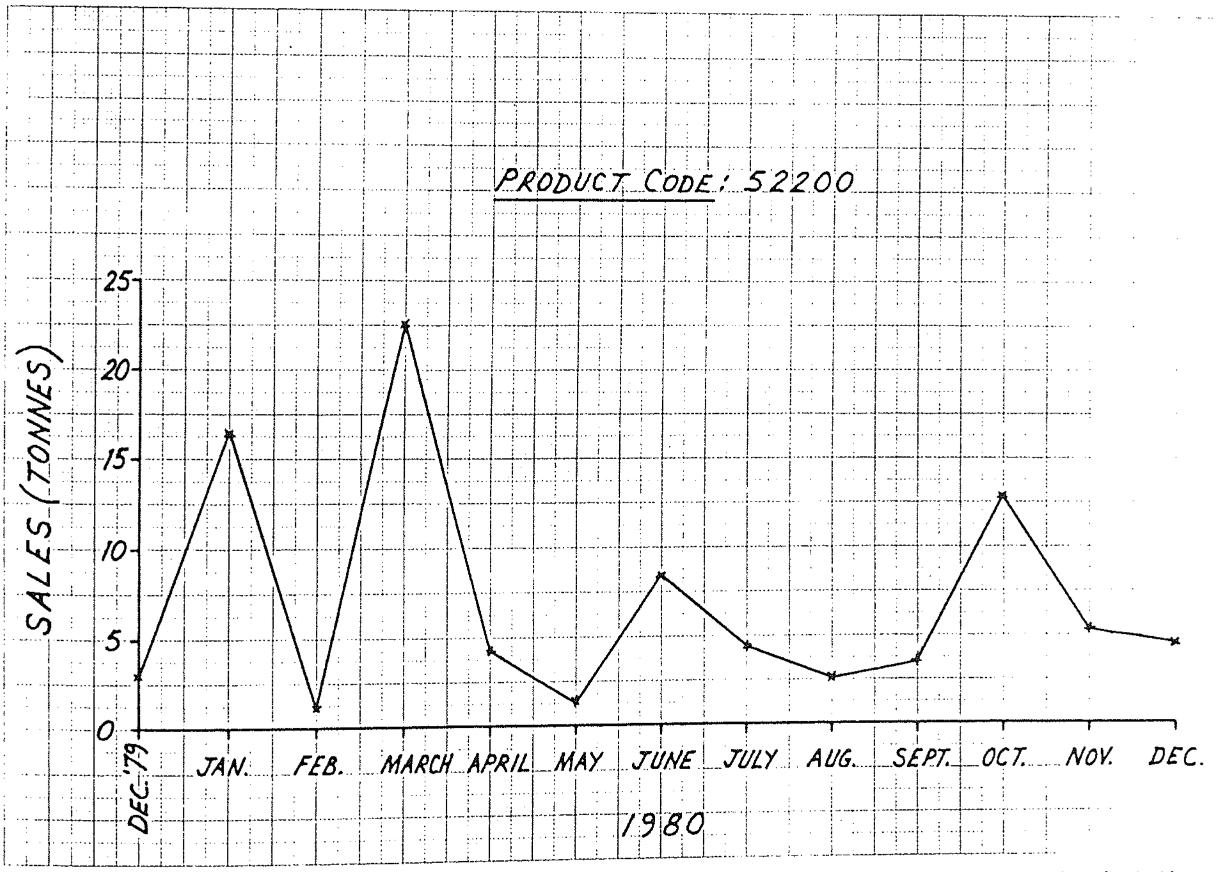


Fig. C46. Graph Showing the Nature of Demand, during 1980, for Finished Product 52200 Used in Simulation

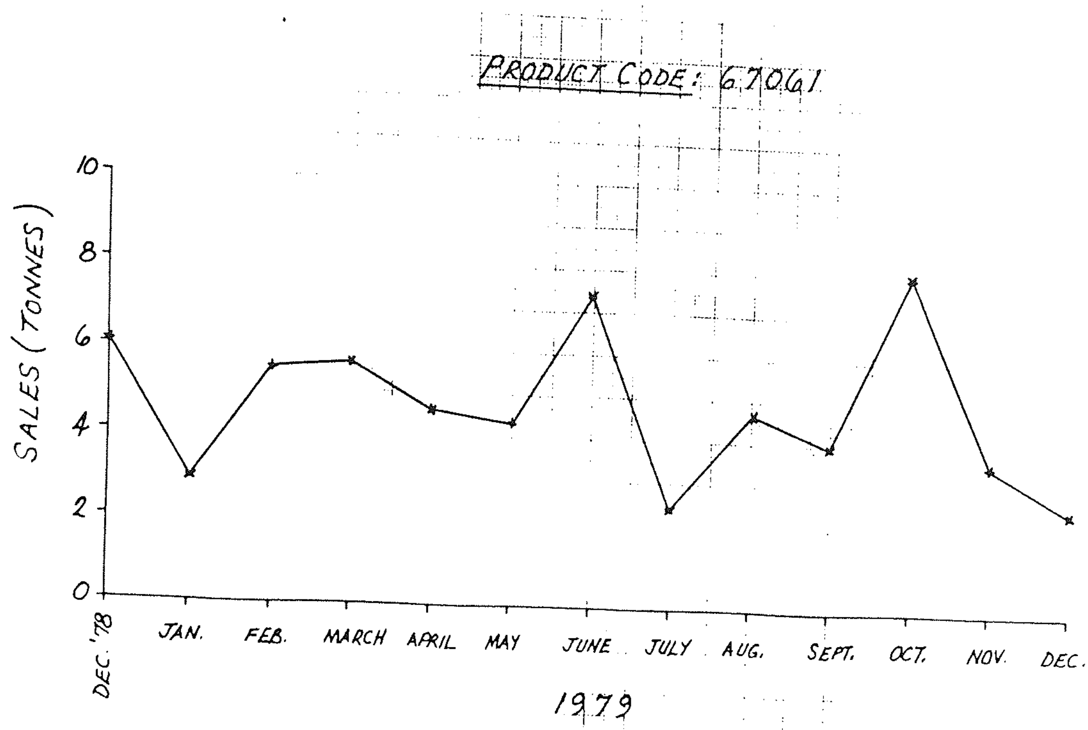


Fig. C47. Graph Showing the Nature of Demand, during 1979, for Finished Product 67061 Used in Simulation

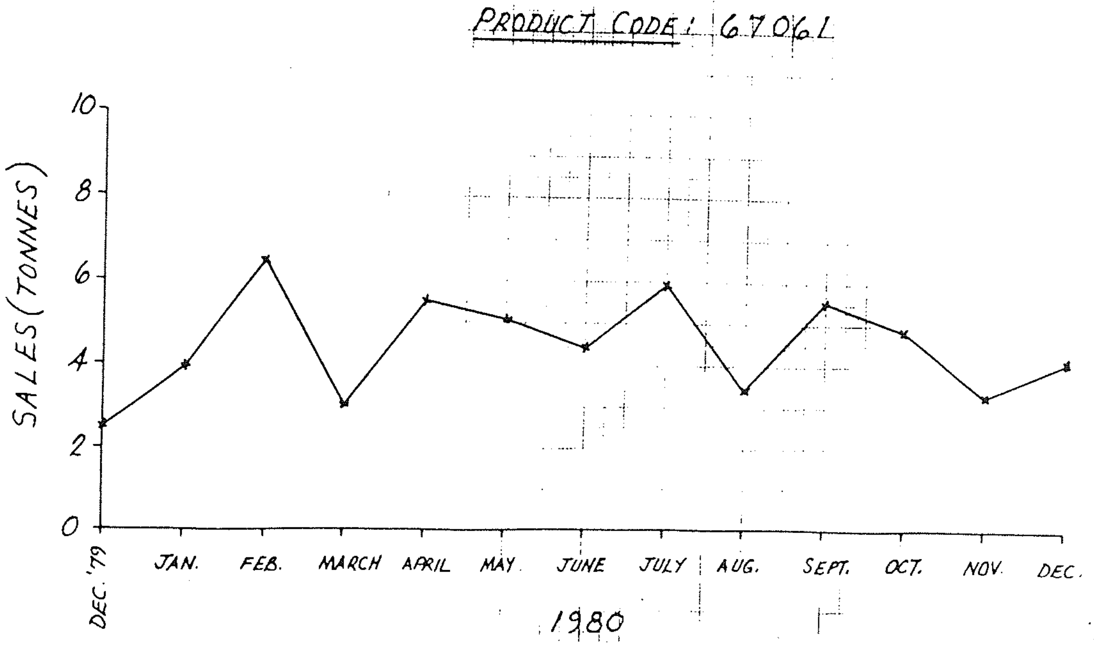


Fig. C48. Graph Showing the Nature of Demand, during 1980, for Finished Product 67061 Used in Simulation

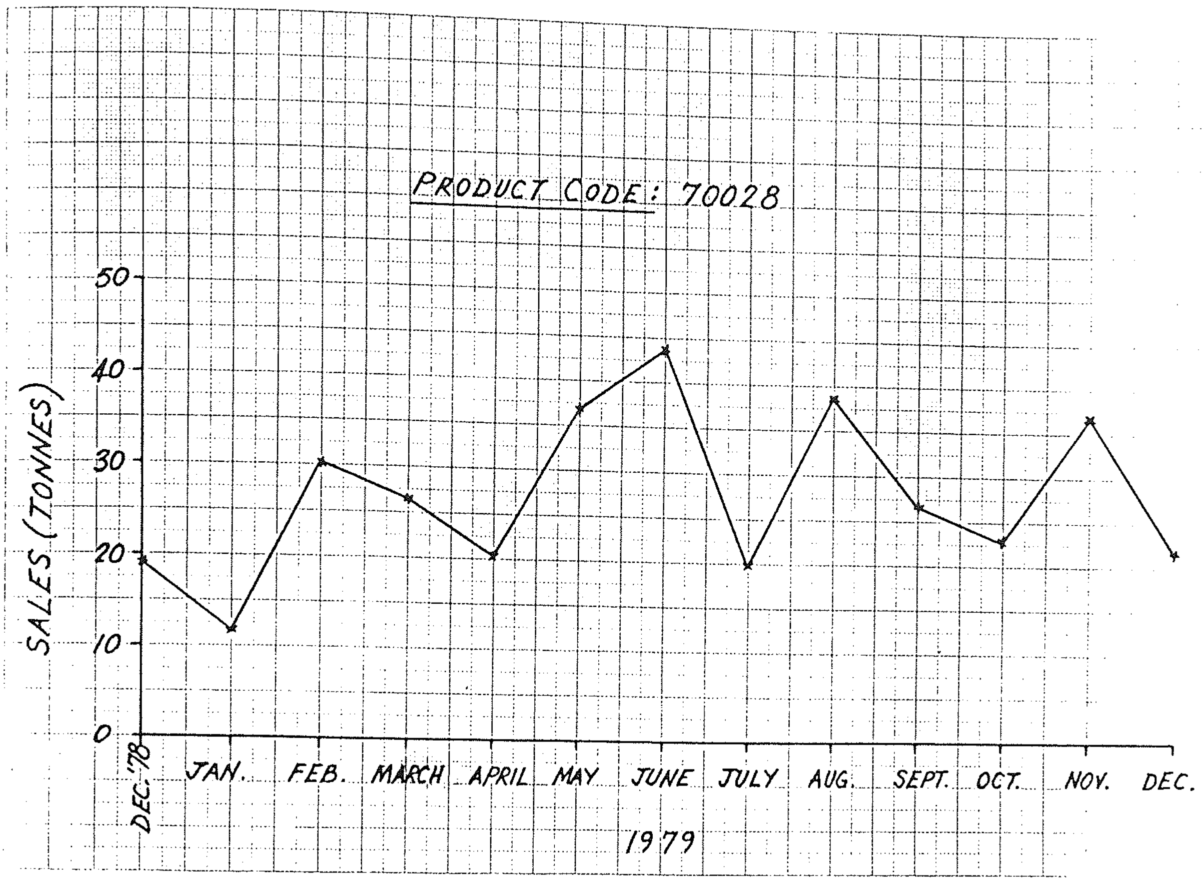


Fig. C49. Graph Showing the Nature of Demand, during 1979, for Finished Product 70028 Used in Simulation

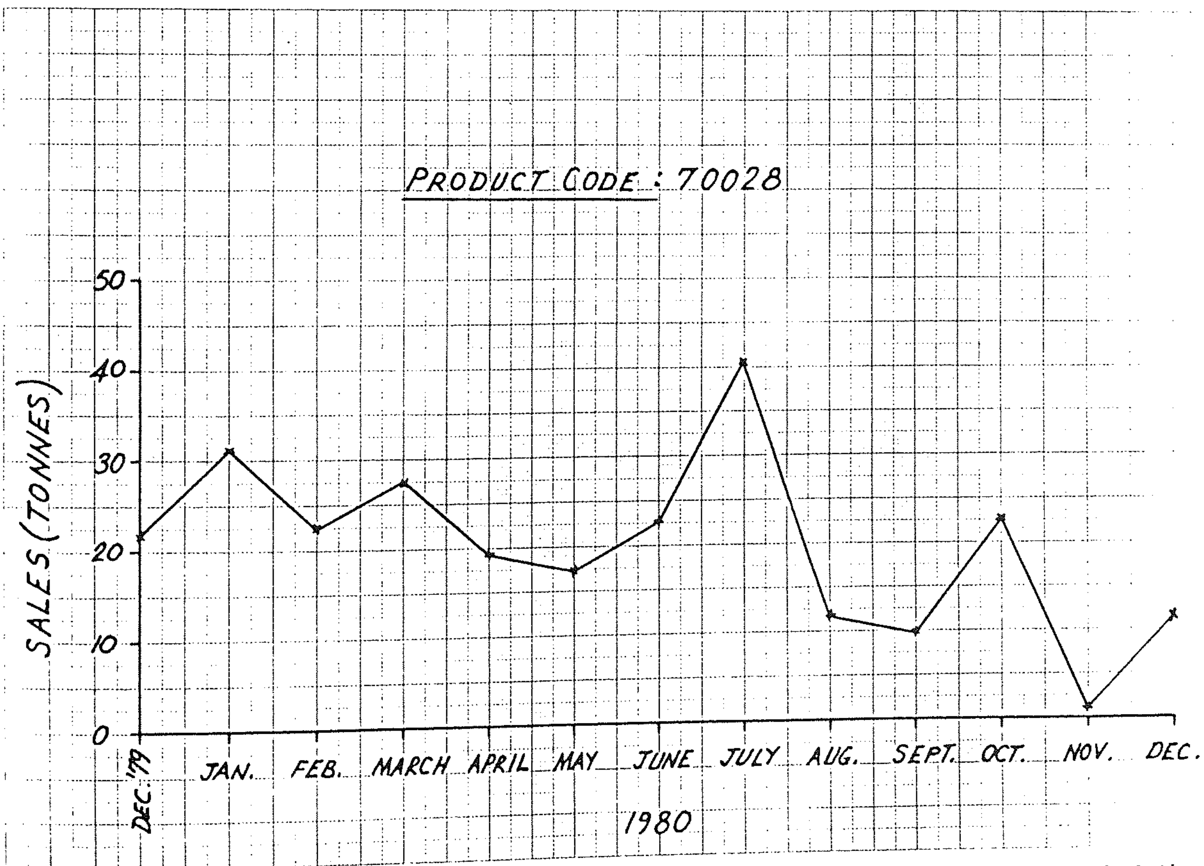


Fig. C50. Graph Showing the Nature of Demand, during 1980, for Finished Product 70028 Used in Simulation

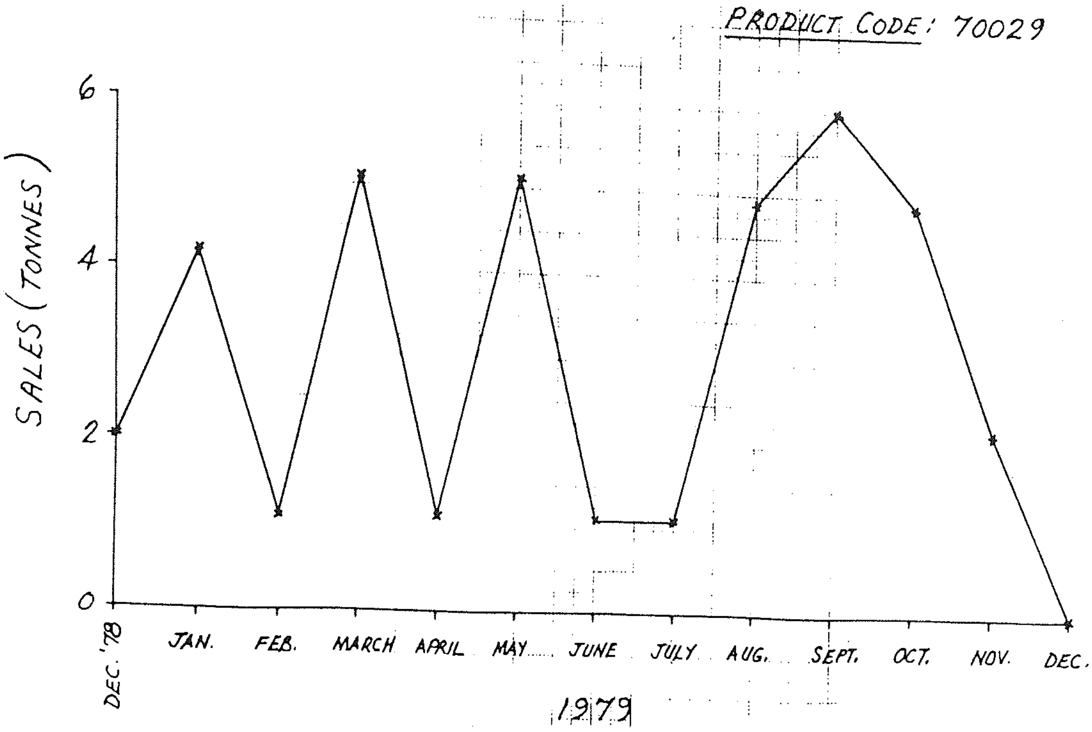


Fig. C51. Graph Showing the Nature of Demand, during 1979, for Finished Product 70029 Used in Simulation

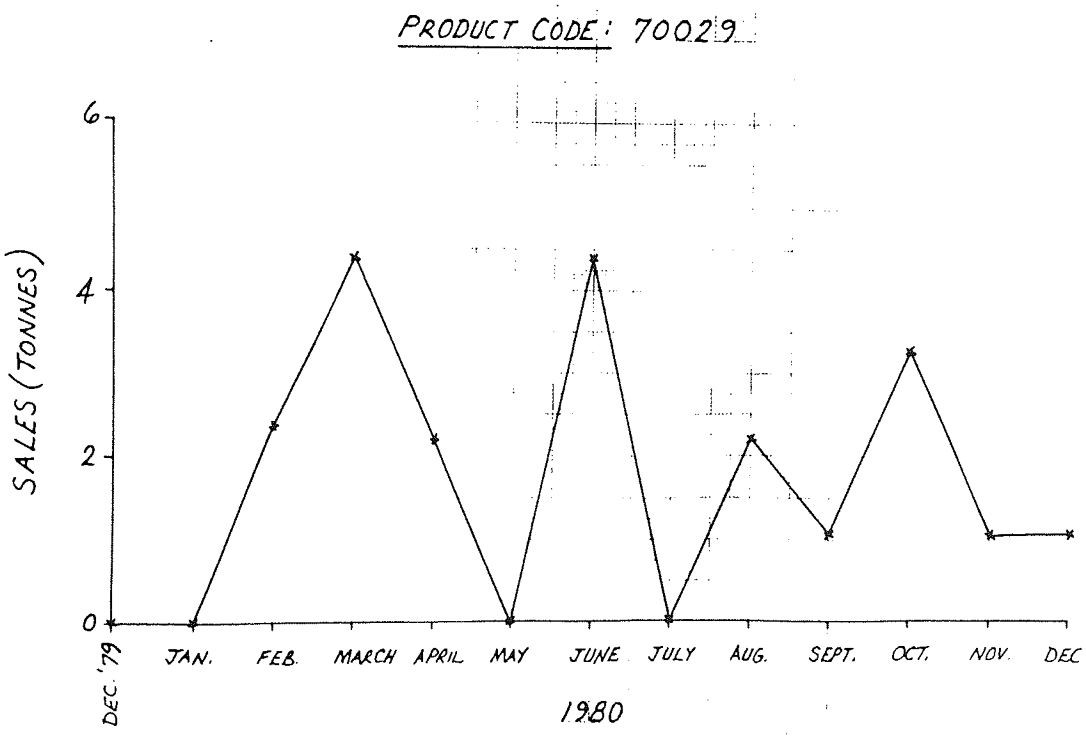


Fig. C52. Graph Showing the Nature of Demand, during 1980, for Finished Product 70029 Used in Simulation

Appendix D

EBQ Formula Development

The development of the Economic Batch Quantity (EBQ) formula assumes:

(1) Constant demand-rate; or at least that the average demand is continuous and constant.

(2) Instantaneous replenishment of stock when the current stock level reaches zero.

(3) Assumption (2) implies constant lead-time.

(4) All costs incurred through stock replenishment are independent of replenishment/batch quantity and are thus constant. Such costs include the actual cost of each stock-item and associated costs of raising a replenishment order. Inclusion of the former costs means that variation in manufacture or purchasing cost (depending upon whether it is a 'made-in' or 'bought-out' item) is not permissible. In the case of bought-out stock-items the implication of such a constraint is that quantity discounts ('price-breaks') are not recognised.

(5) Inventory carrying cost per unit of time is directly proportional to the quantity of stock carried (i.e. the holding cost/unit of storage/unit time is fixed).

(6) Independence between inventory items (i.e. it is assumed that the replenishment of one stock-item has no effect on the replenishment of any other stock-item).

As a result of assumptions (1) and (2), stock movement can be represented as shown in Figure D.1 overleaf.

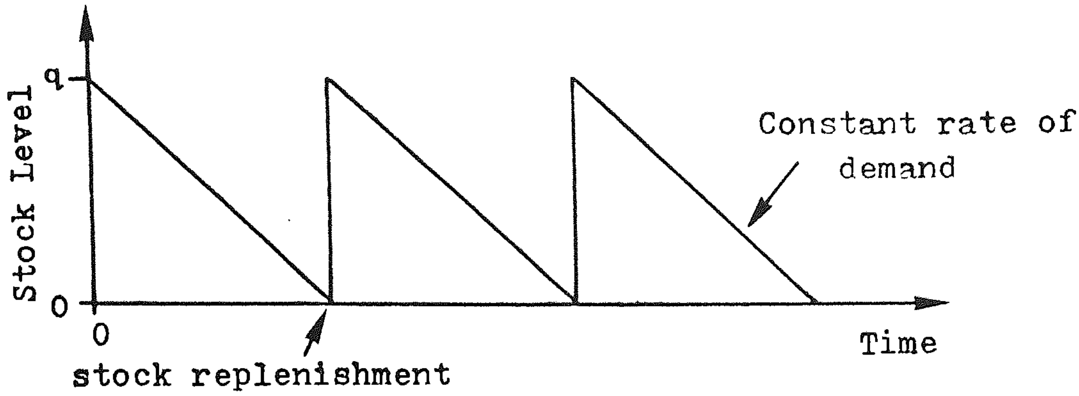


Fig. D.1 Stock Movement as Implied by the Assumptions Made in the Development of the EBQ Formula.

A further consequence of assumptions (1) and (2) is that stockout cost(s) does not require consideration, hence:

$$\text{Total Annual System Operating Cost} = \text{Total Annual Stock-Holding Cost} + \text{Total Annual Replenishment Cost}$$

where:

$$\text{Total Annual Stock-Holding Cost} = \text{Average Stock Quantity Held } ({}^{q}/_{2}) \times \text{Holding Cost/Unit of Storage/}\underline{\text{Year}}\ (H_C)$$

$$= \frac{q}{2} H_C$$

Total Annual Replenishment Cost = Number of Replenishments (Batches) per Year x Individual Replenishment Cost

$$= \frac{\text{Annual Demand } (A_D)}{\text{Replenishment (Batch) Quantity } (q)} \times C_R$$

$$= \underline{\underline{\frac{A_D C_R}{q}}}$$

When plotted for a stock-item, the relationship of each annual cost to that of the replenishment/batch quantity 'q' is as shown in Figure D.2.

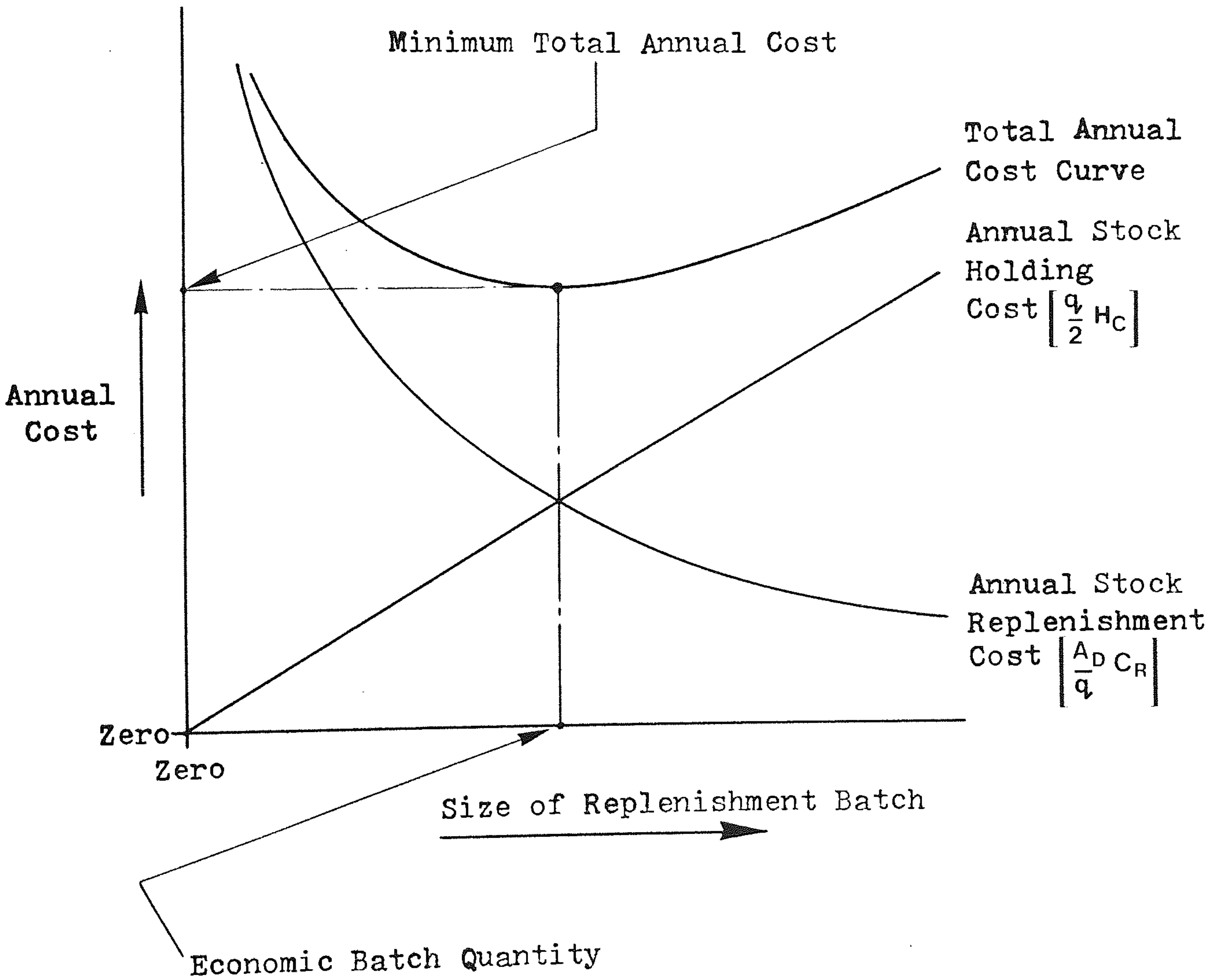


Fig. D.2 Graph Showing Approximate 'Cost to Size of Replenishment Batch' Relationship in the Development of the EBQ Formula.

Since the total annual cost curve in Figure D.2 is described mathematically as follows:

$$\text{Total Annual System-Operating Cost} = \frac{q H_C}{2} + \frac{A_D C_R}{q} \qquad \text{(D.1)}$$

the <u>minimum</u> total annual system-operating cost can be found by differentiating the whole of equation D.1 with respect to q and placing it equal to zero, thus giving:

$$\frac{H_C}{2} - \frac{A_D C_R}{q^2} = 0 \qquad \text{(D.2)}$$

This is generally rewritten as follows:

$$\frac{q H_C}{2} = \frac{A_D C_R}{q} \qquad \text{(D.3)}$$

and shows that the minimum total annual system-operating cost is achieved when, effectively, the total annual holding cost equals the total annual replenishment cost. As the replenishment/batch quantity in equation D.3 is the economical replenishment/batch quantity, this value of q is normally denoted by q^*.

Rearranging equation D.3, the EBQ formula reduces to the following:

$$q^* = \sqrt{\frac{2 A_D C_R}{H_C}}$$

Appendix E

Tables and Graphs Showing the Results of Testing Forecasting Models 1,2,3,4 and 5 with 1979 Sales/Demand Data.

Product Code \ Forecasting Model		Model 1	Model 2	Model 3	Model 4	Model 5
01010	Bias σ_e	-1.37 9.59	-1.31 9.40	-0.30 8.60	+0.35 6.68	-0.34 7.93
01050	Bias σ_e	+0.51 3.53	+0.82 3.42	+0.53 3.50	-0.06 3.86	+0.06 3.91
01260	Bias σ_e	-9.30 40.34	-10.21 39.87	-16.02 39.80	+4.95 27.43	-1.91 36.33
03010	Bias σ_e	+0.44 2.18	+0.15 2.06	+0.44 2.32	-0.34 2.51	+0.31 2.43
03020	Bias σ_e	+0.02 3.19	+0.47 3.06	+0.79 2.88	-0.24 2.71	-0.18 3.41
04060	Bias σ_e	+0.45 3.38	+0.12 3.23	-0.11 3.46	+1.58 3.50	+0.35 3.64
06050	Bias σ_e	+0.10 2.07	+0.25 1.95	+0.19 2.11	+0.67 2.41	+0.39 2.42
06080	Bias σ_e	-10.28 42.78	-10.64 41.11	-17.72 40.53	+2.36 26.04	-3.10 36.03
06610	Bias σ_e	-3.26 5.76	-3.36 5.37	-3.45 5.34	-1.43 4.02	-1.94 5.01
07030	Bias σ_e	+0.26 3.50	+0.61 3.52	-0.01 3.48	-0.88 3.99	-0.34 3.89
07110	Bias σ_e	-0.67 2.19	-0.82 2.32	-0.89 2.19	-0.42 2.09	-0.59 2.24
08910	Bias σ_e	+3.11 14.90	+2.93 14.47	+3.16 14.71	-5.17 18.04	-1.90 13.94
08915	Bias σ_e	-0.16 8.49	+1.41 8.17	+1.39 8.16	-3.58 8.72	+0.45 9.14
12030	Bias σ_e	-2.69 8.64	-2.35 8.54	-2.59 7.62	-4.98 8.90	-3.18 8.33
13020	Bias σ_e	+0.27 5.58	-0.20 5.29	-0.20 5.29	+1.18 4.31	-0.44 5.24

(**Note:** All units of measurements are in TONNES)

Table E.1(a) Performance Results for Forecasting Models 1 to 5.

Forecasting Model / Product Code		Model 1	Model 2	Model 3	Model 4	Model 5
14010	Bias σ_e	-1.83 10.95	-2.19 11.35	-2.78 11.84	-3.16 12.14	-3.24 12.14
14020	Bias σ_e	-1.03 8.30	-1.42 7.96	+0.39 6.49	-3.04 8.24	+0.35 7.04
15010	Bias σ_e	+0.32 2.94	+0.28 2.87	+0.27 2.87	-1.64 3.61	+0.33 3.25
15030	Bias σ_e	-1.35 5.52	-1.47 5.24	-0.47 4.47	-1.37 4.48	-0.51 4.89
20700	Bias σ_e	-1.29 2.55	-1.53 2.37	-1.32 2.30	-0.45 2.23	-0.48 2.12
30113	Bias σ_e	-0.07 2.18	-0.02 2.08	-0.20 2.42	-0.25 2.44	-0.19 2.48
30160	Bias σ_e	+0.74 5.48	+0.32 5.78	+0.34 5.79	-3.49 7.37	+0.34 6.78
30909	Bias σ_e	-0.96 2.22	-0.99 2.04	-0.91 2.13	+0.37 2.74	-0.47 2.72
40020	Bias σ_e	+11.26 50.39	+10.52 47.56	+14.06 45.28	-20.06 51.26	-4.86 41.58
52200	Bias σ_e	+0.61 7.59	+0.42 7.40	+0.32 6.69	+2.09 7.31	+1.31 7.29
58205	Bias σ_e	-0.60 4.22	-0.63 4.16	-0.89 4.60	-1.58 5.28	-1.02 4.65
67061	Bias σ_e	-0.44 2.13	-0.33 1.99	-0.63 2.24	+0.47 2.38	-0.34 2.46
70028	Bias σ_e	+1.33 14.16	+1.44 14.36	-0.14 14.52	-4.68 14.81	-2.30 13.60
70029	Bias σ_e	-0.21 2.62	-0.36 2.46	-0.82 2.57	+0.85 2.63	-0.10 2.79
80005	Bias σ_e	-5.35 39.31	-6.21 39.54	-5.78 35.68	+1.19 25.78	+0.16 33.48

(Note: All units of measurements are in TONNES)

Table E.1(b) Performance Results for Forecasting Models 1 to 5.

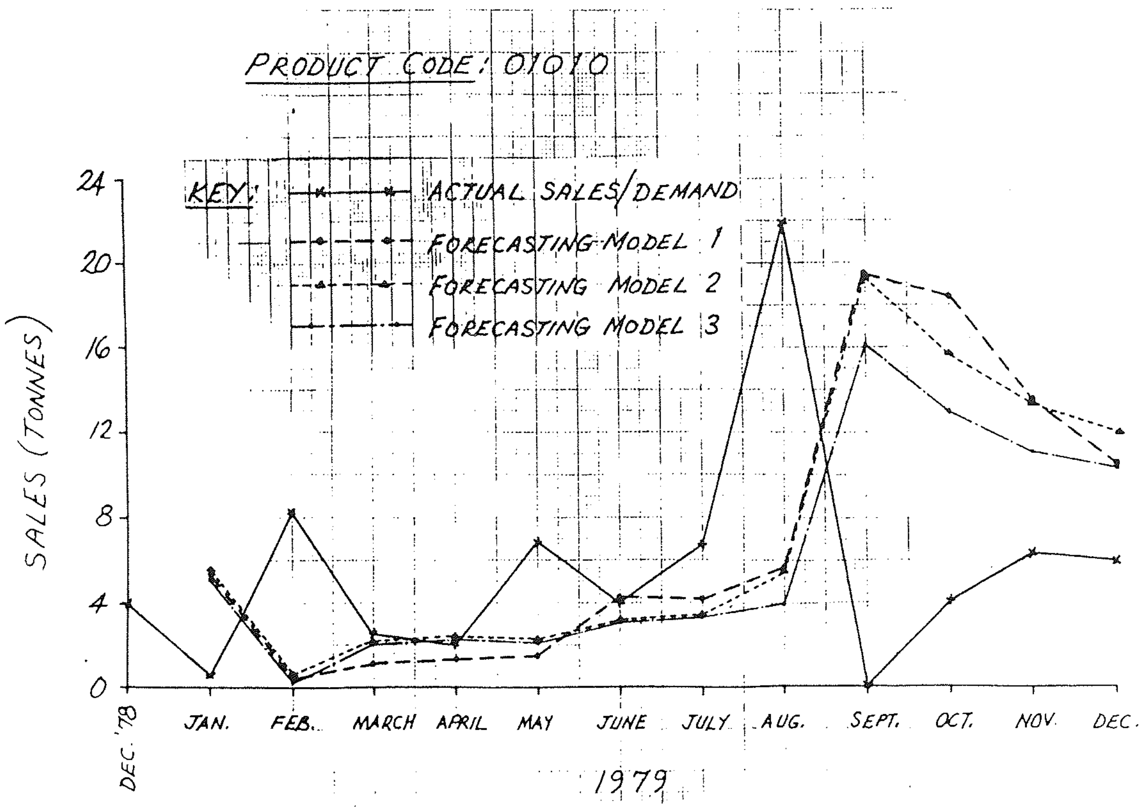


Fig. E1. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 01010

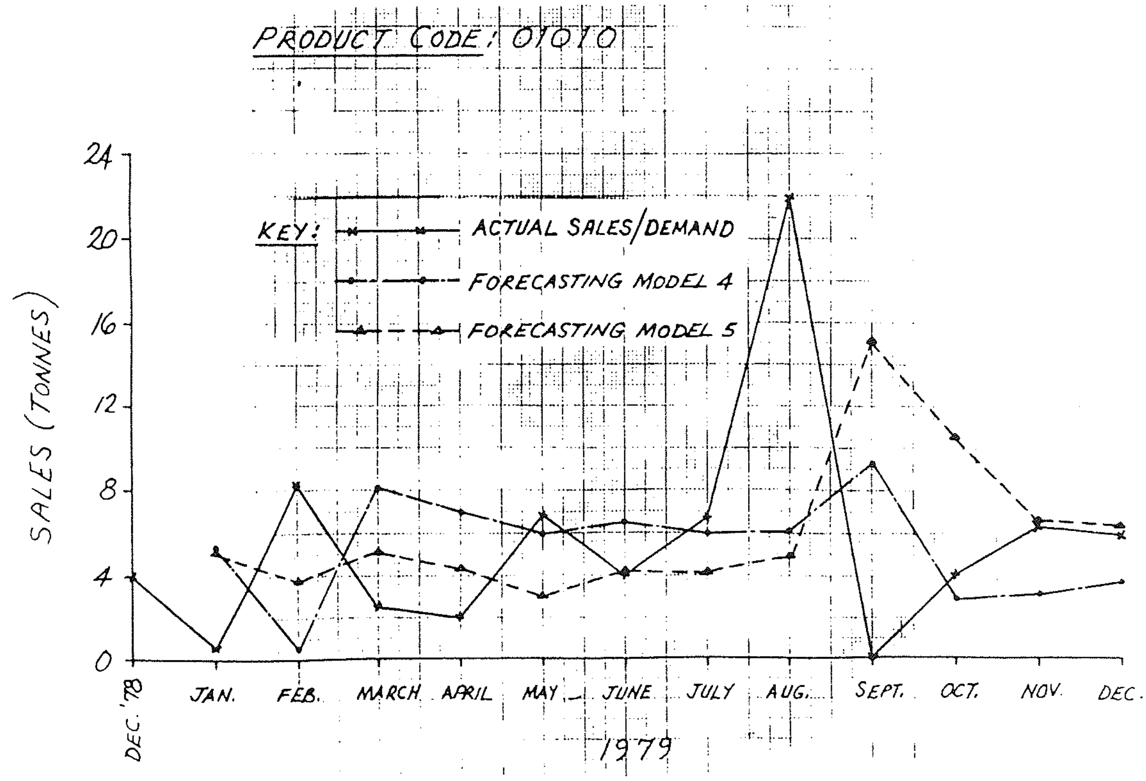


Fig. E2. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 01010

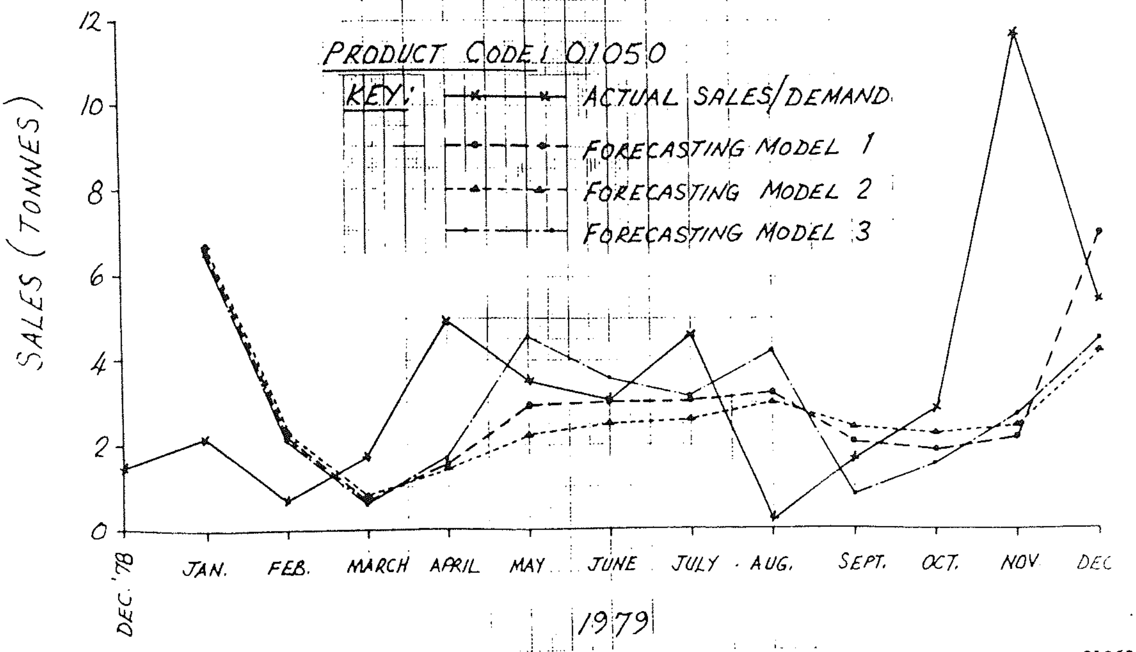


Fig. E3. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 01050

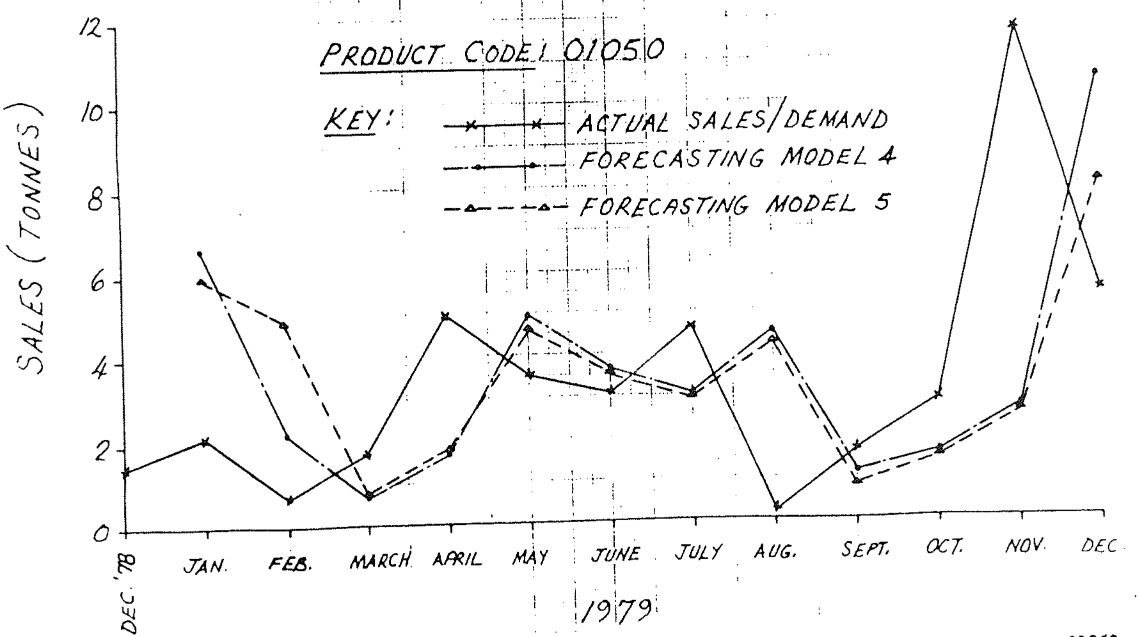


Fig. E4. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 01050

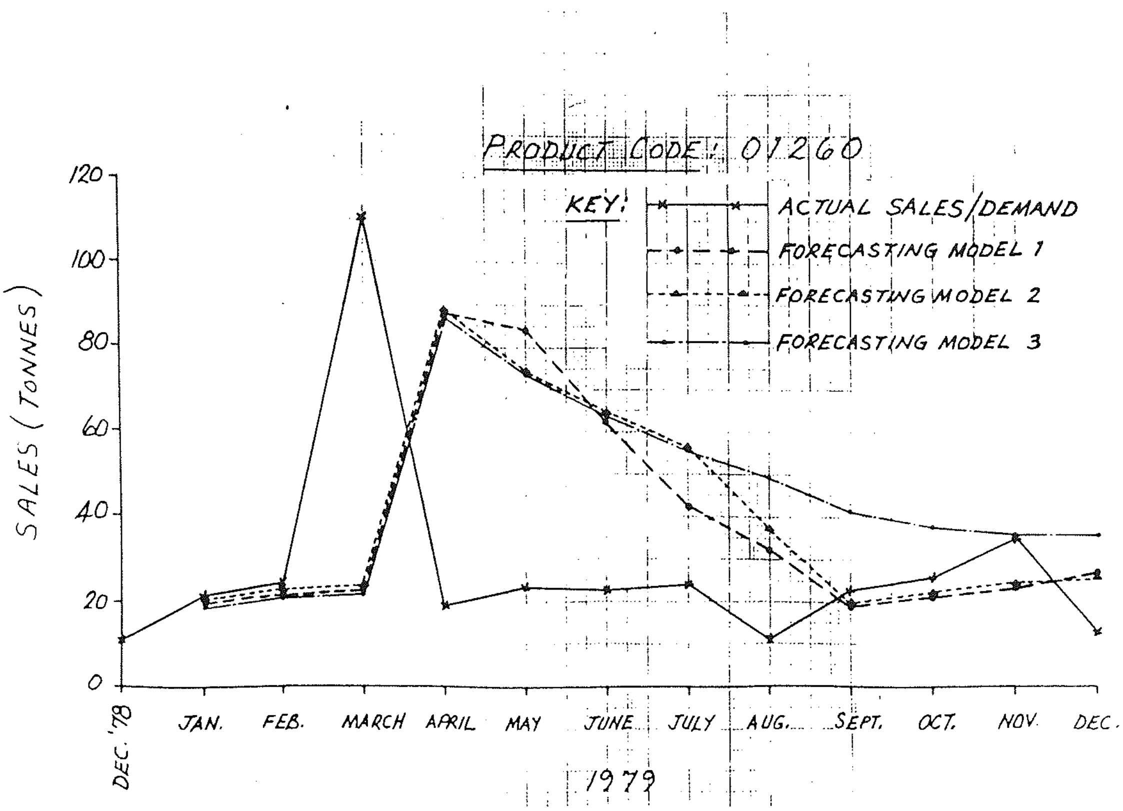


Fig. E5. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 01260

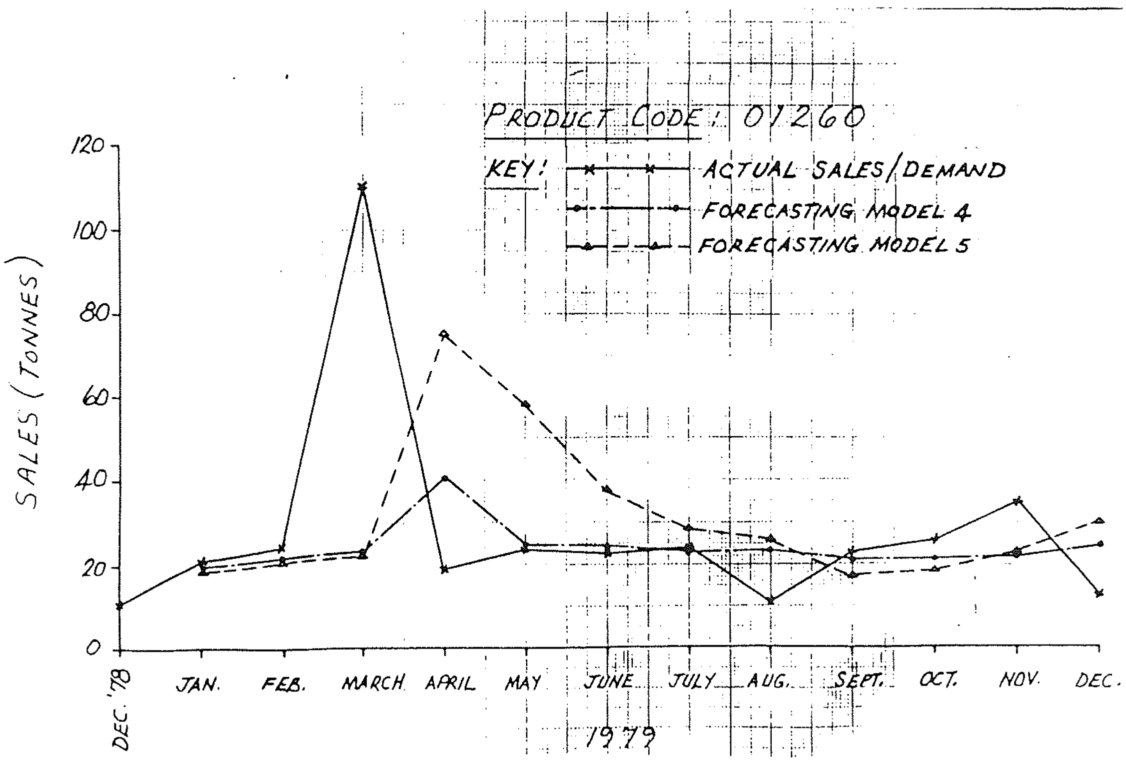


Fig. E6. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 01260

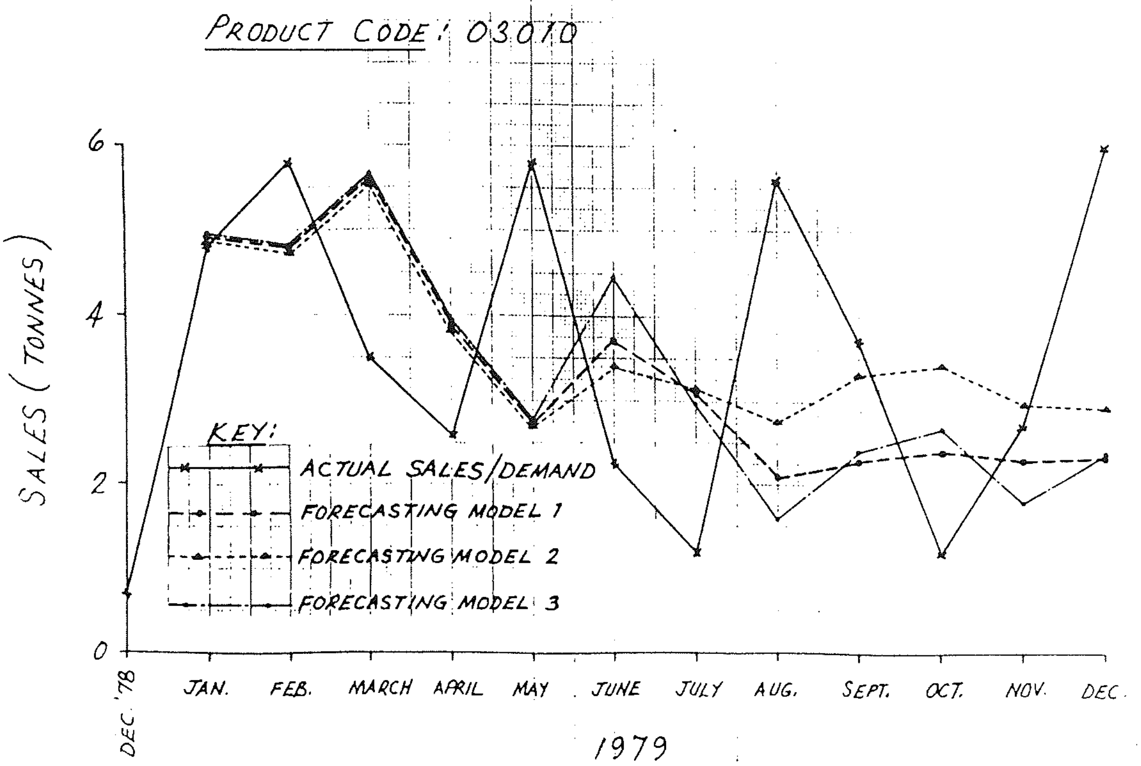


Fig. E7. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 03010

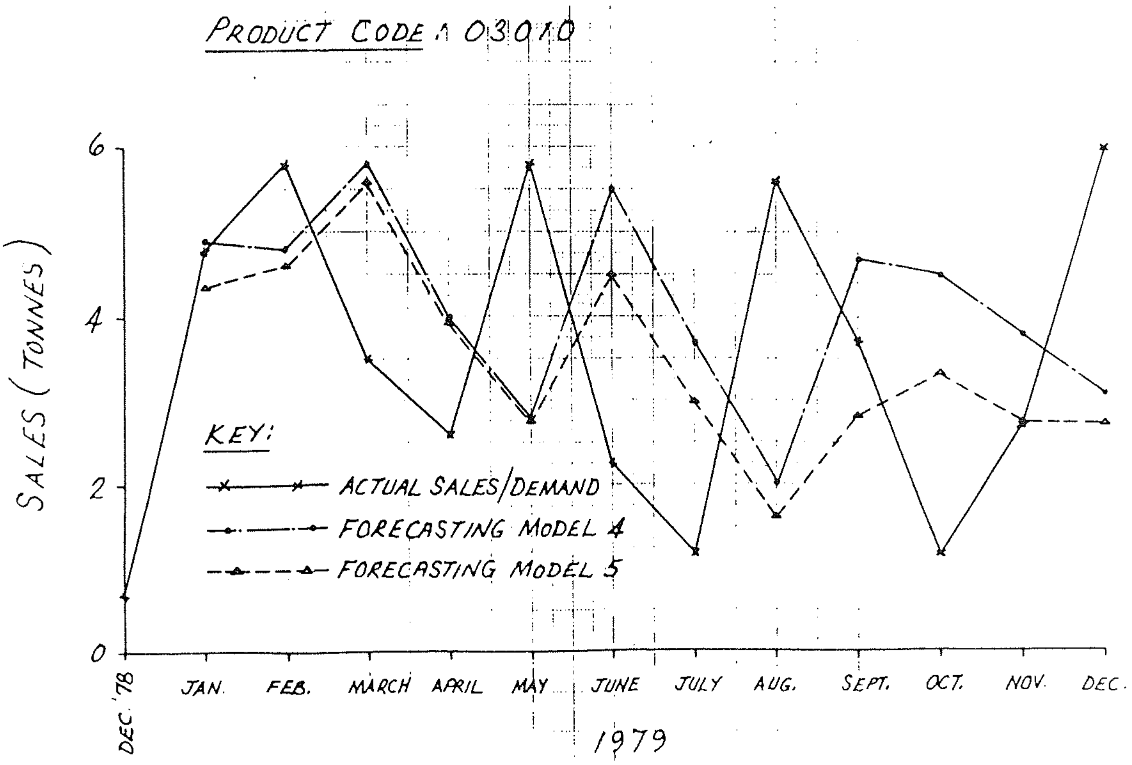


Fig. E8. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 03010

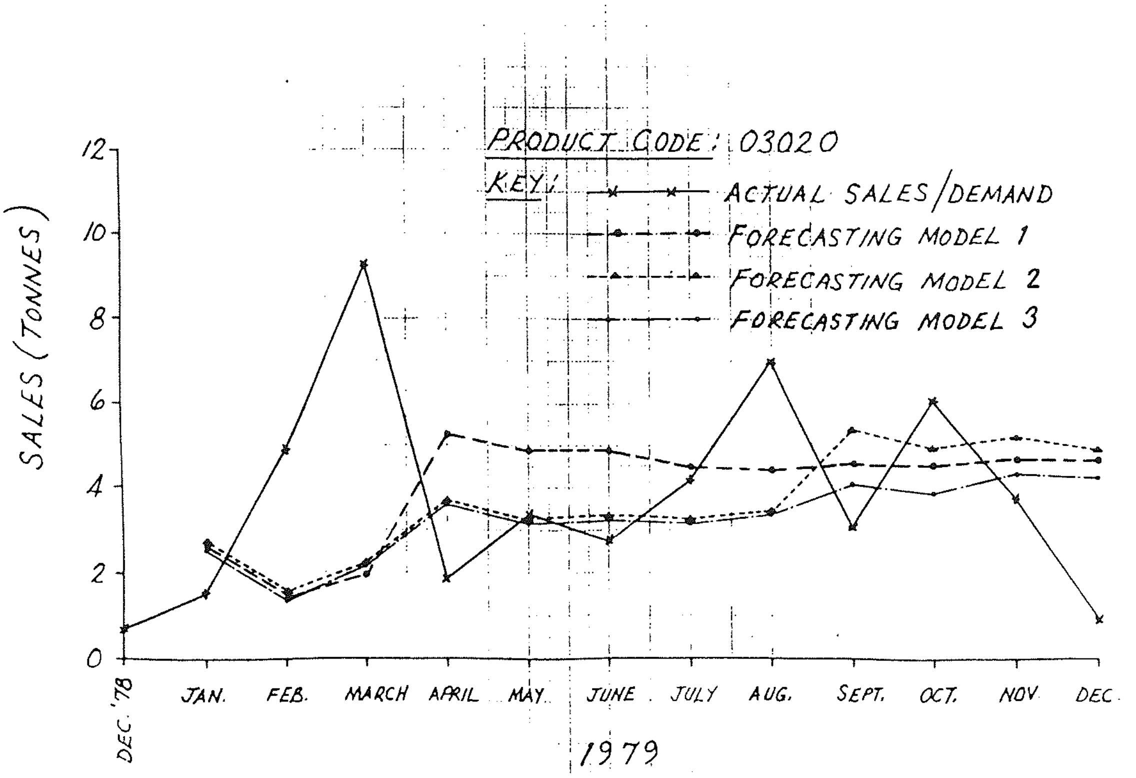


Fig. E9. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 03020

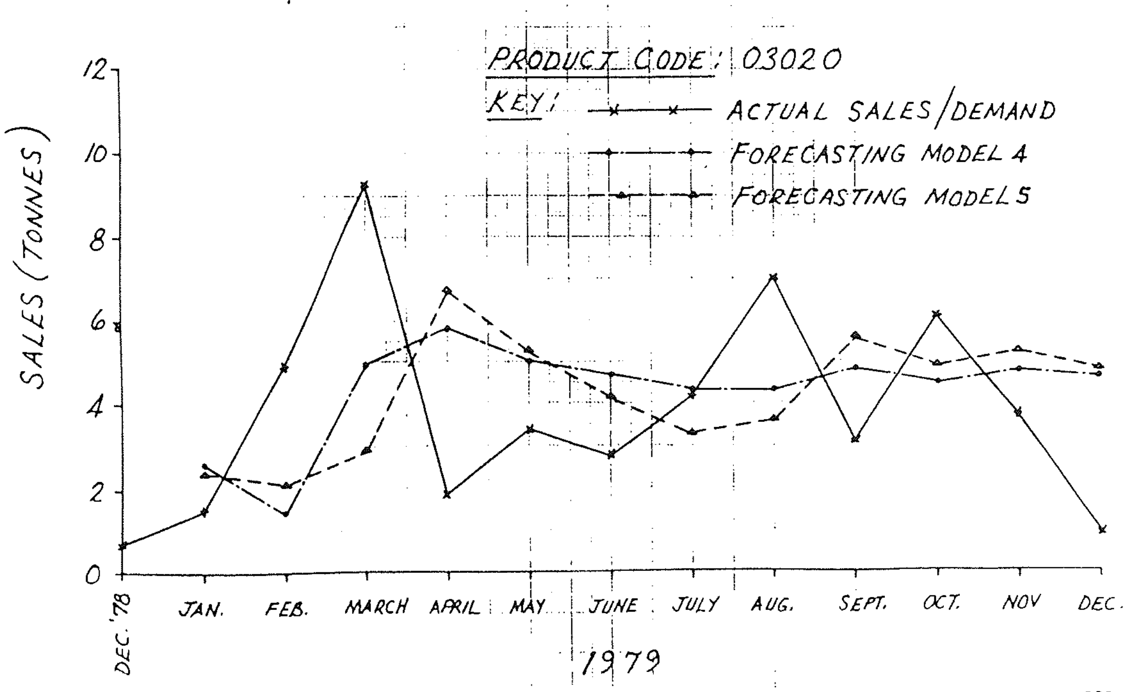


Fig. E10. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 03020

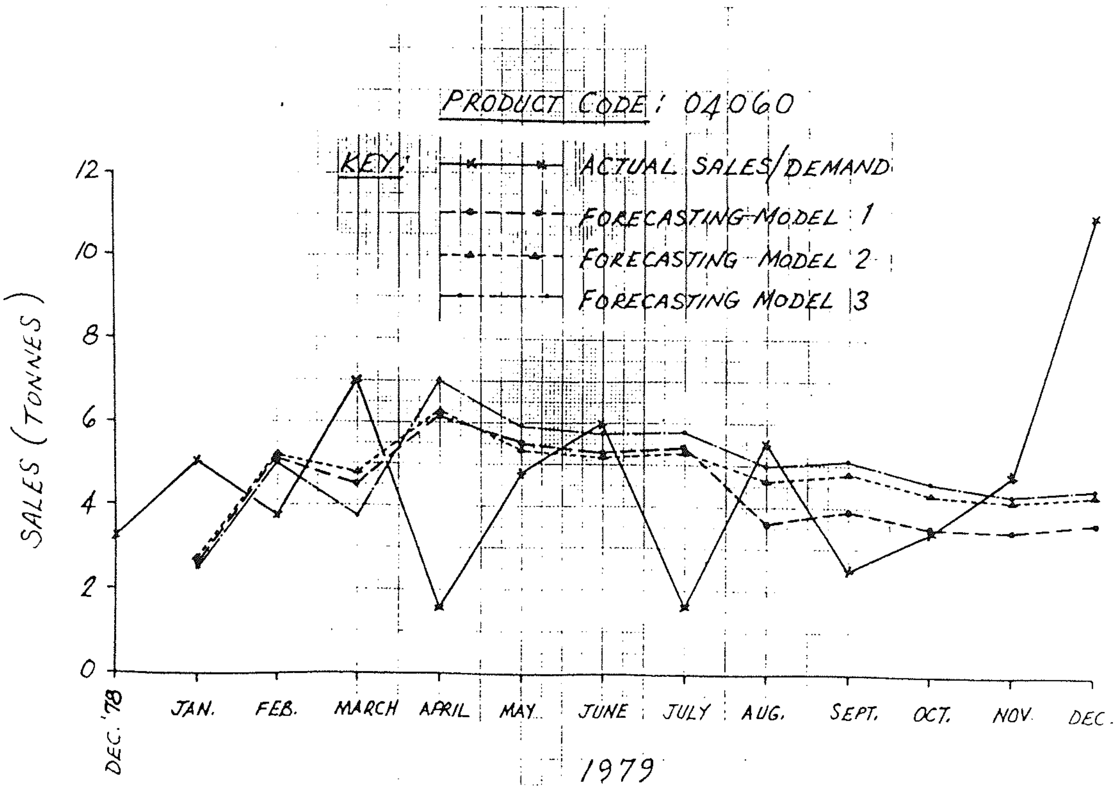


Fig. E11. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 04060

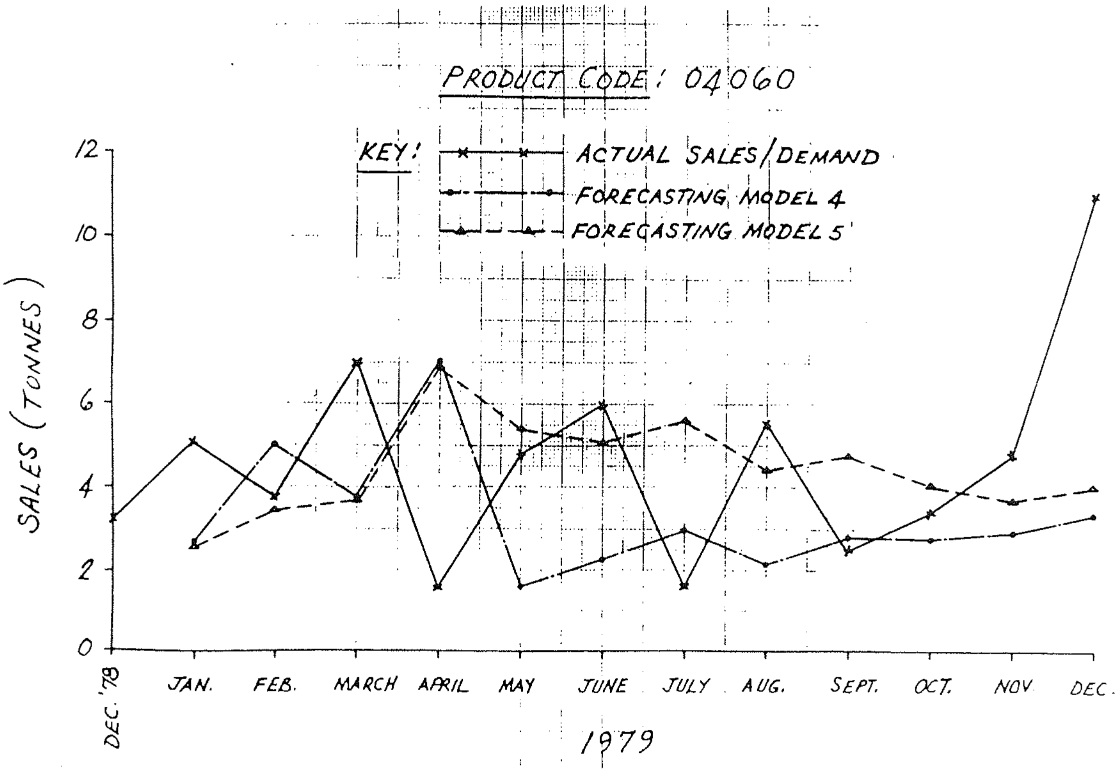


Fig. E12. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 04060

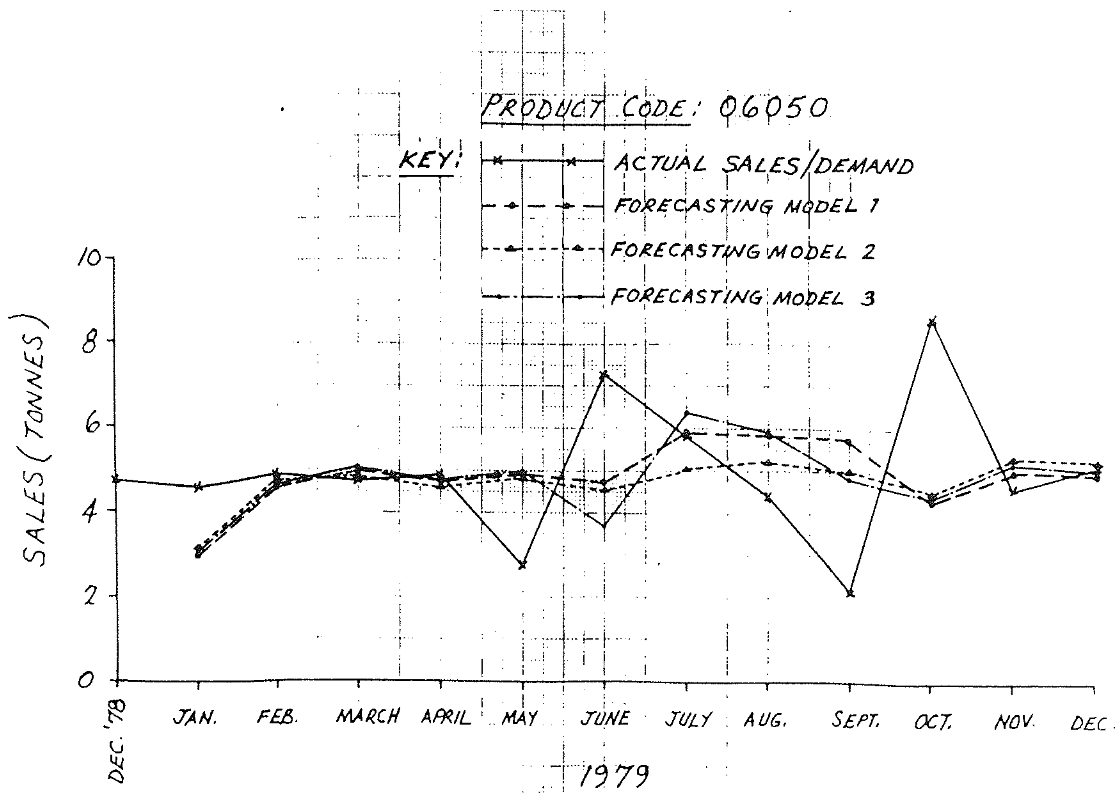


Fig. E13. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 06050

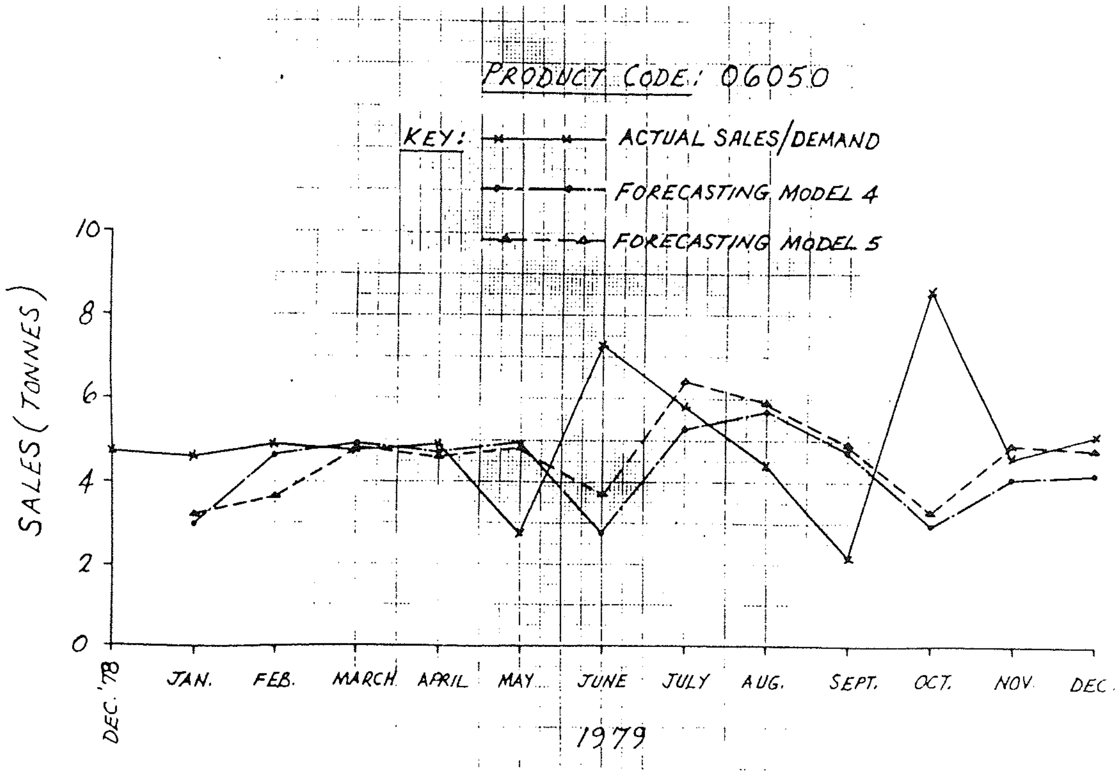


Fig. E14. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 06050

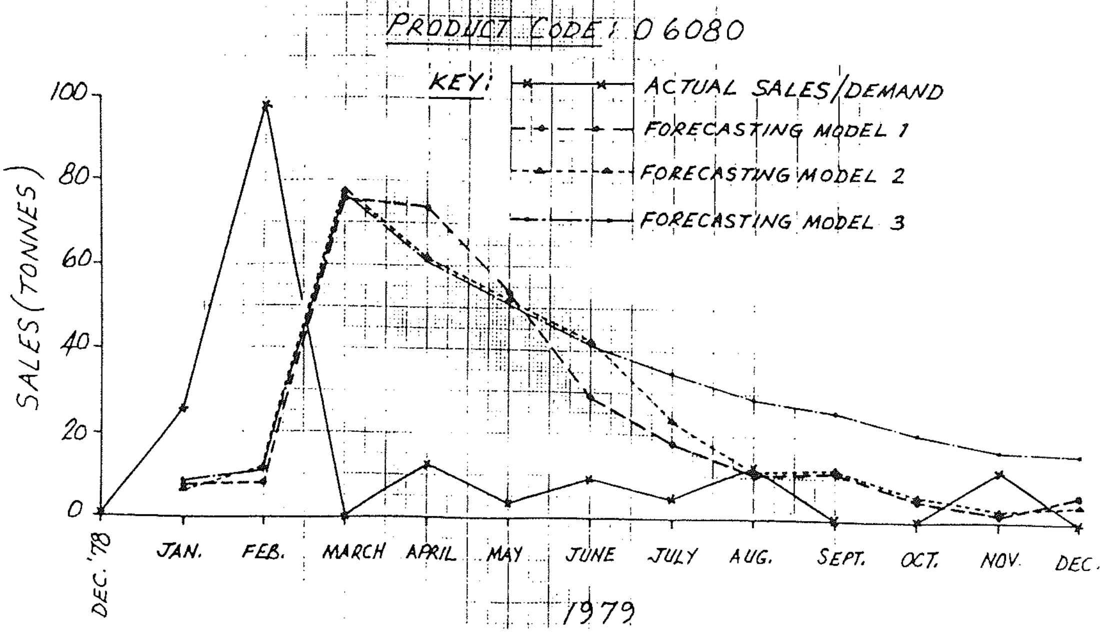


Fig. E15. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 06080

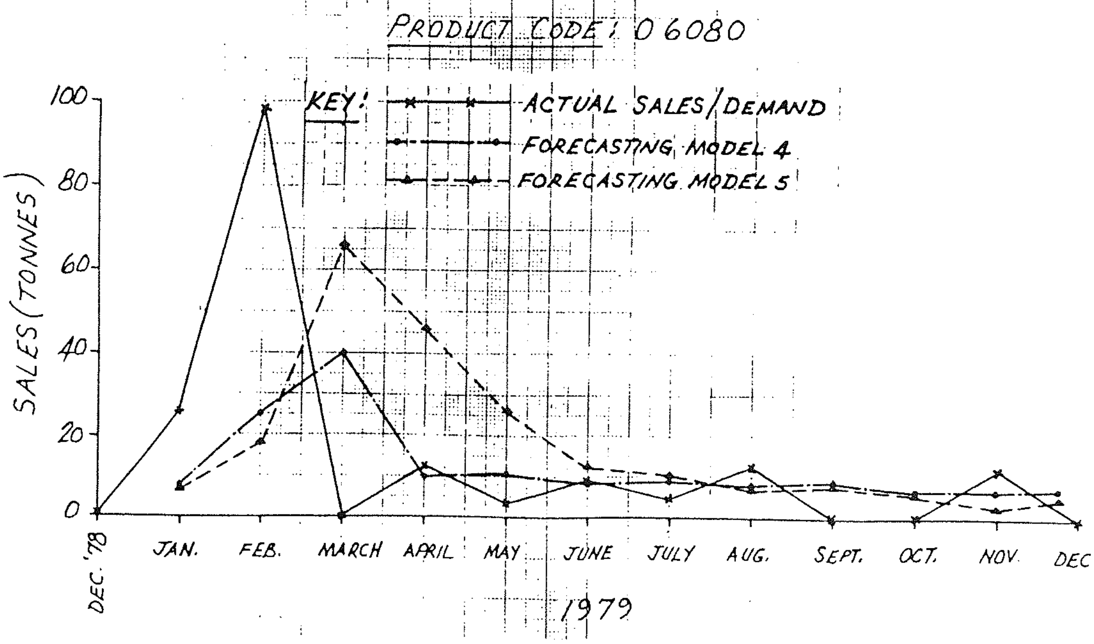


Fig. E16. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 06080

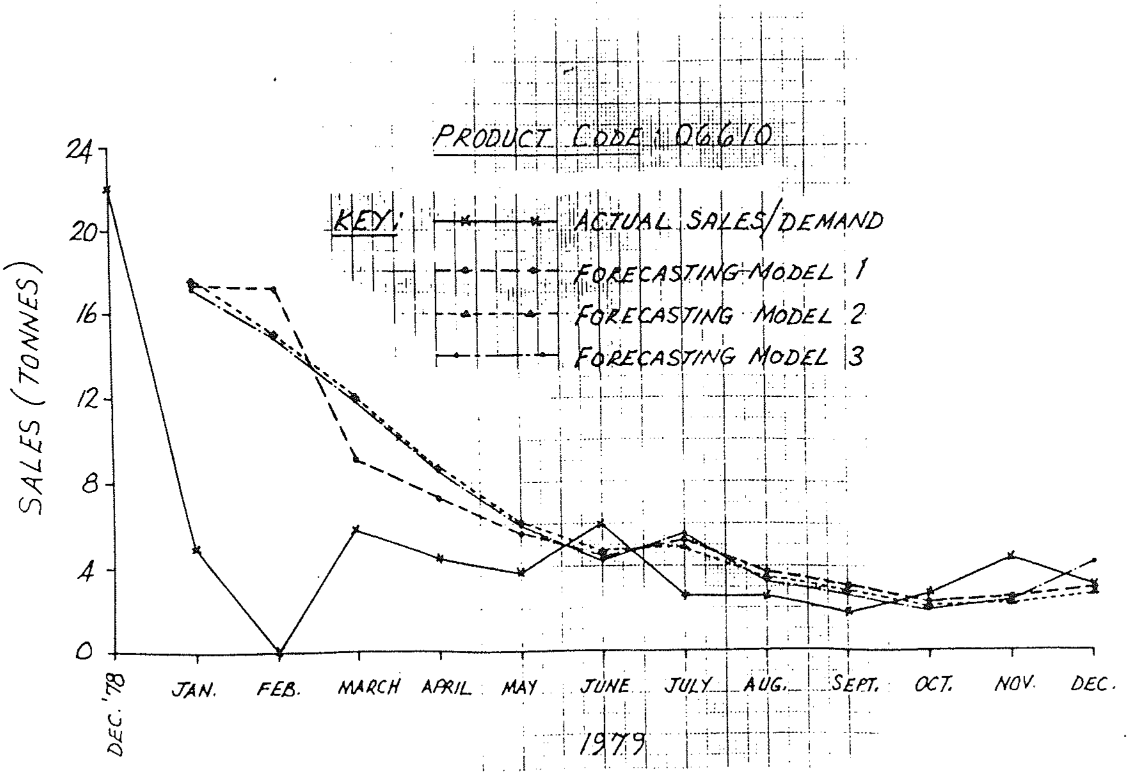


Fig. E17. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 06610

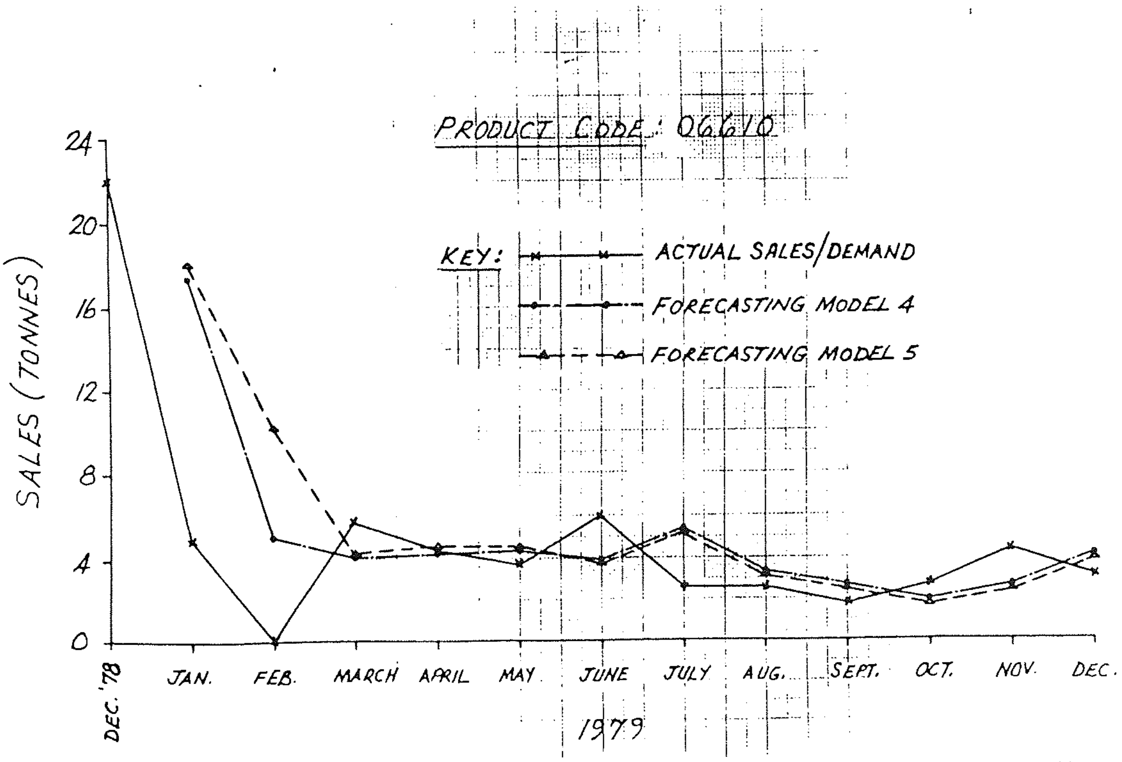


Fig. E18. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 06610

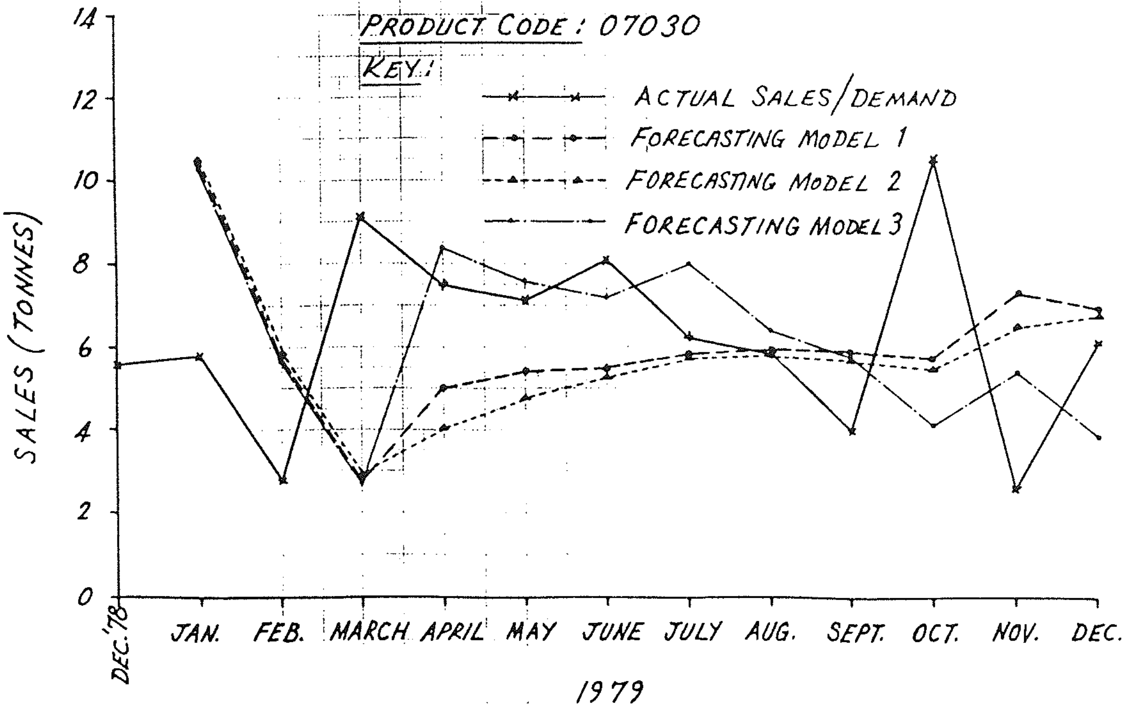


Fig. E19. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 07030

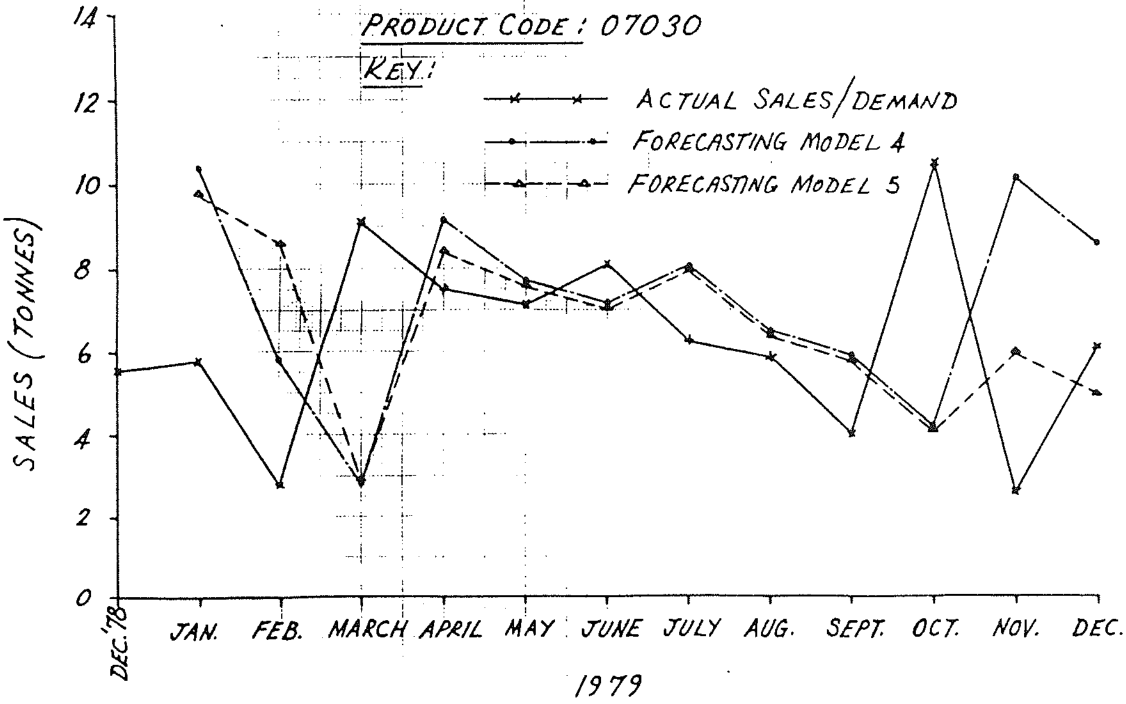


Fig. E20. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 07030

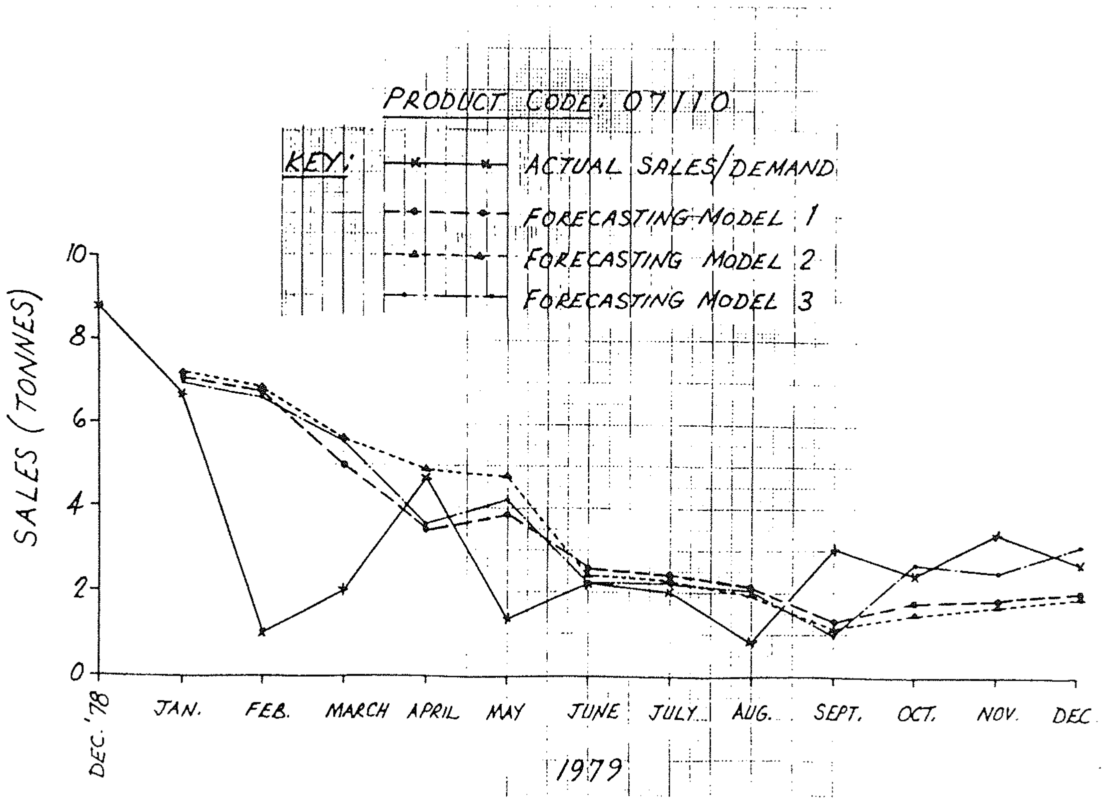


Fig. E21. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 07110

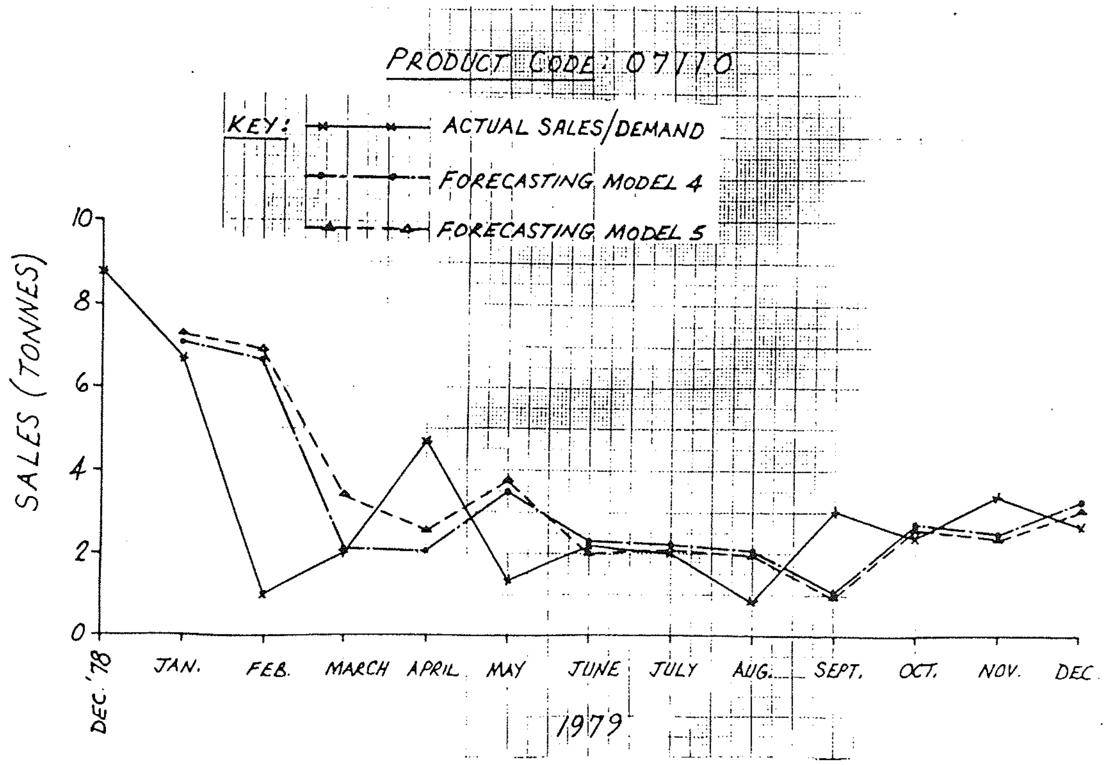


Fig. E22. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 07110

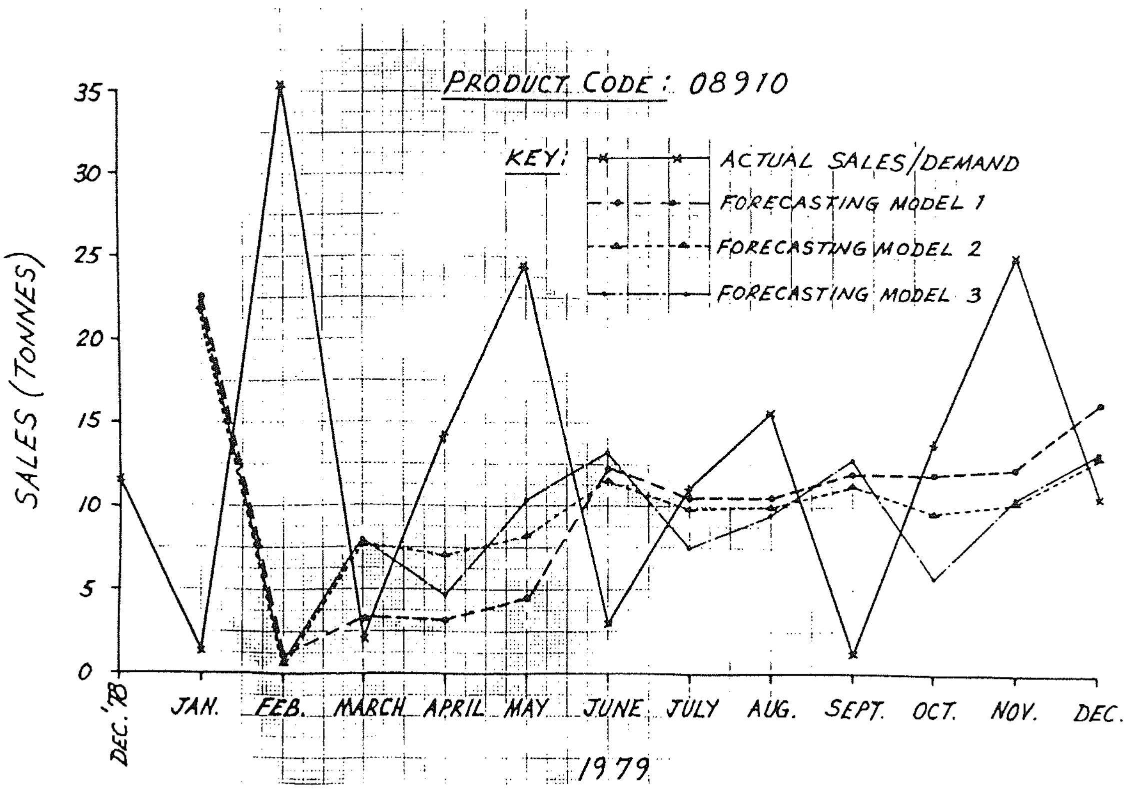


Fig. E23. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 08910

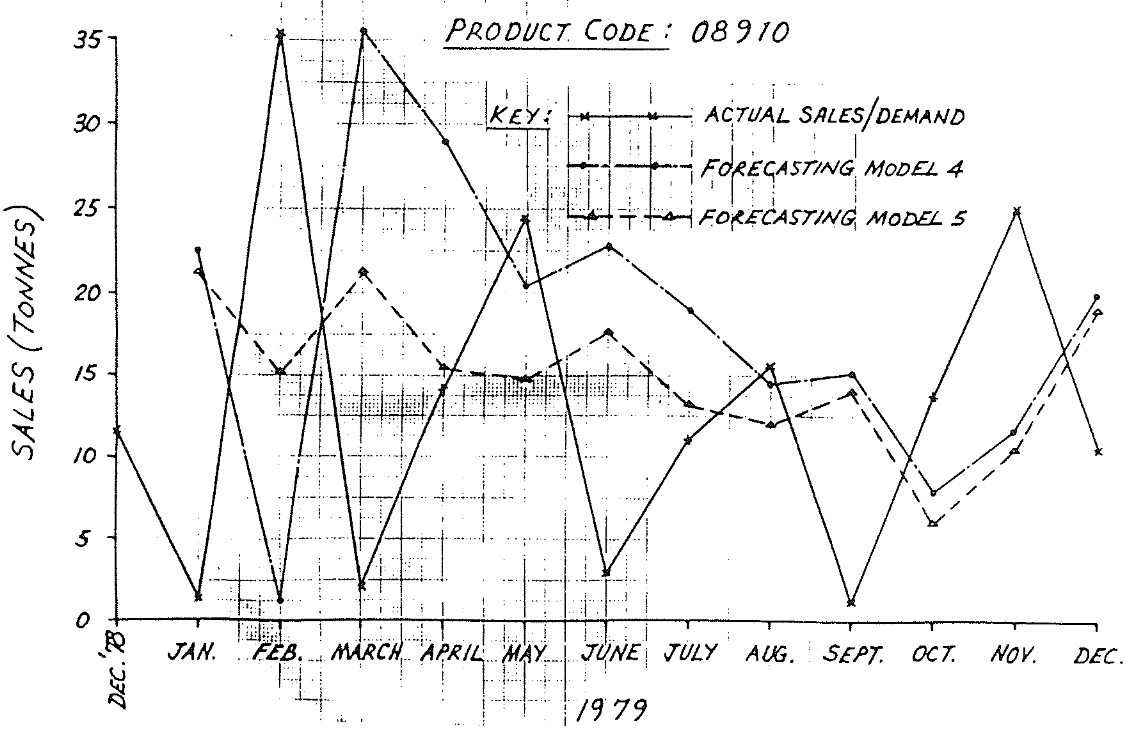


Fig. E24. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 08910

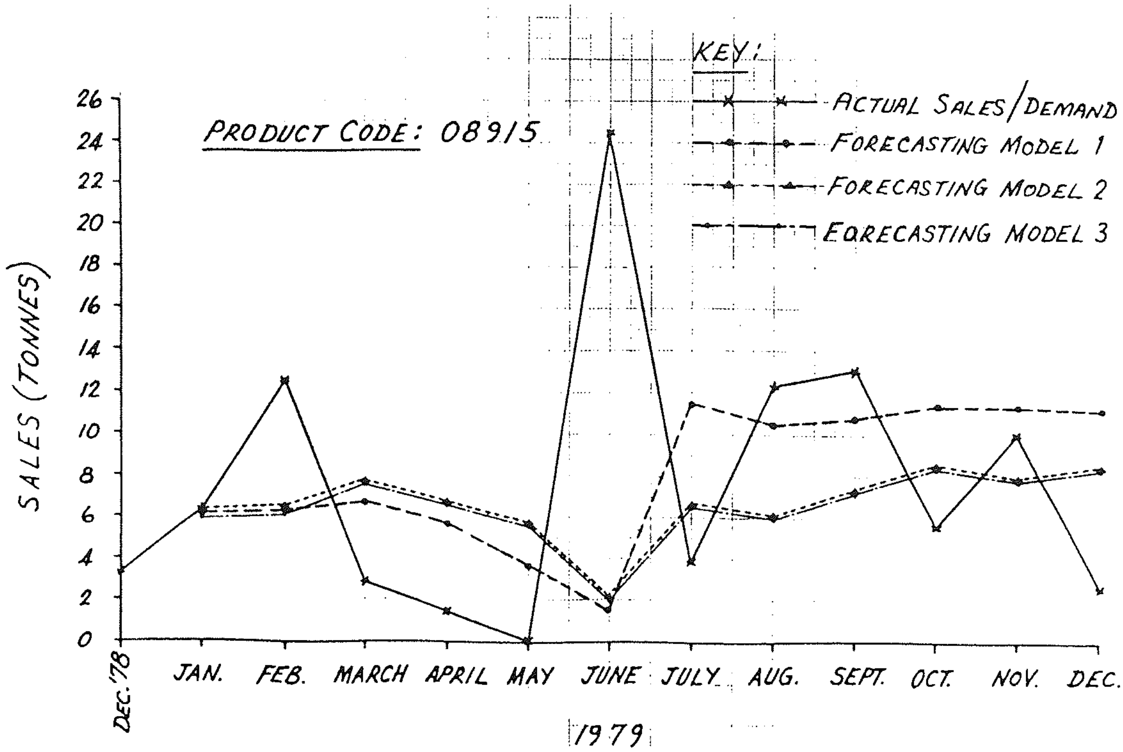


Fig. E25. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 08915

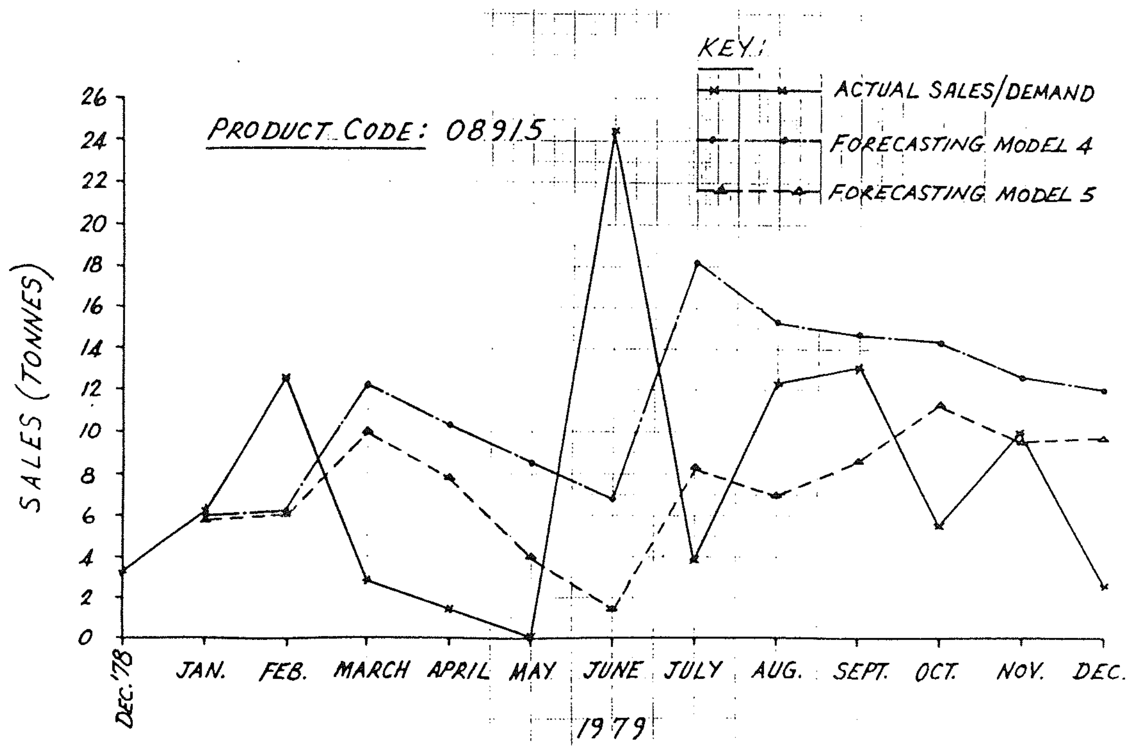


Fig. E26. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 08915

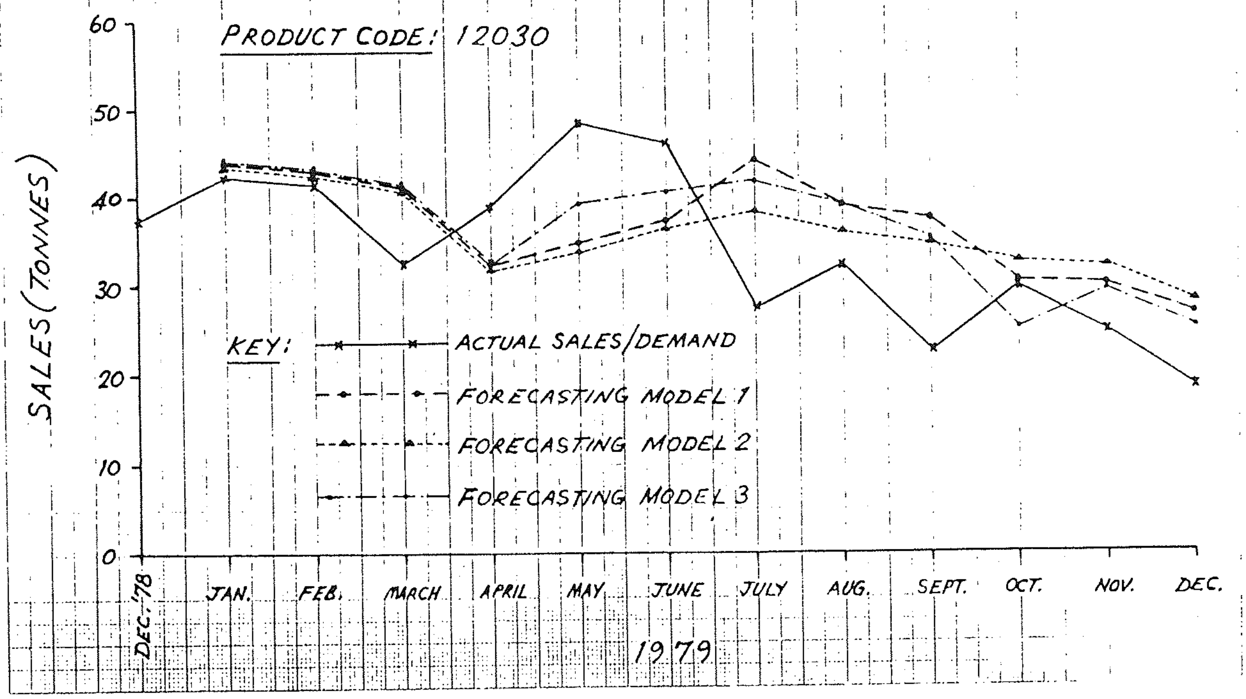


Fig. E27. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 12030

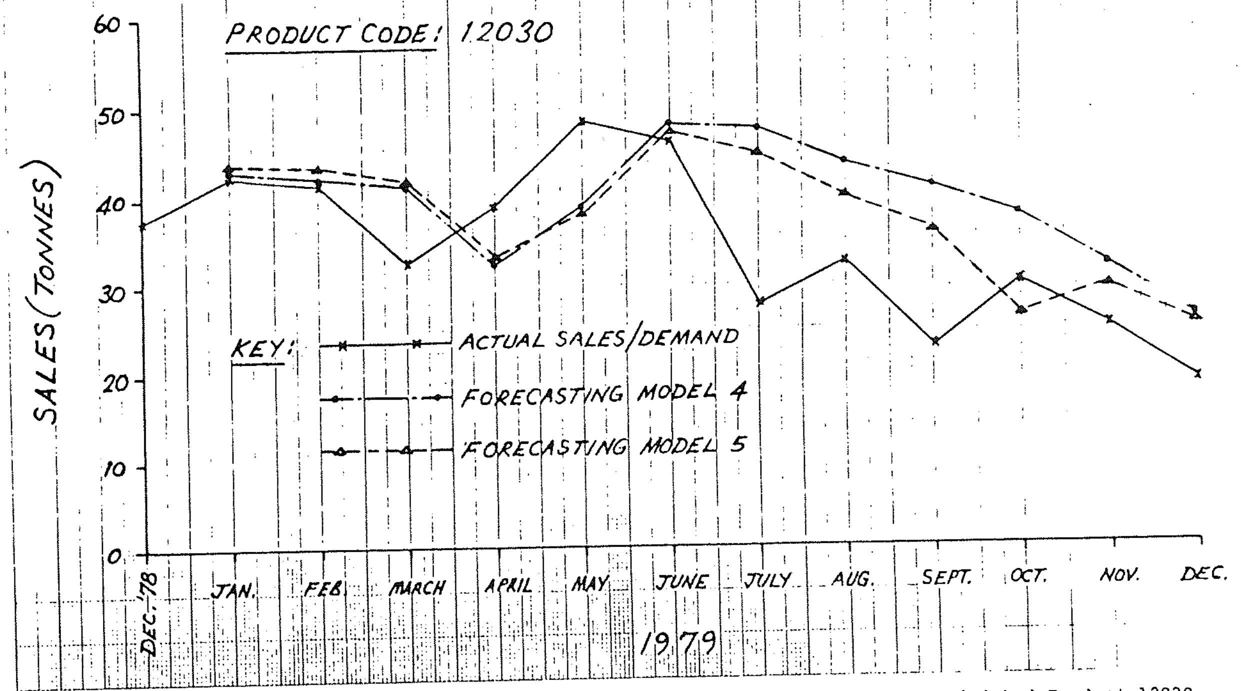


Fig. E28. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 12030

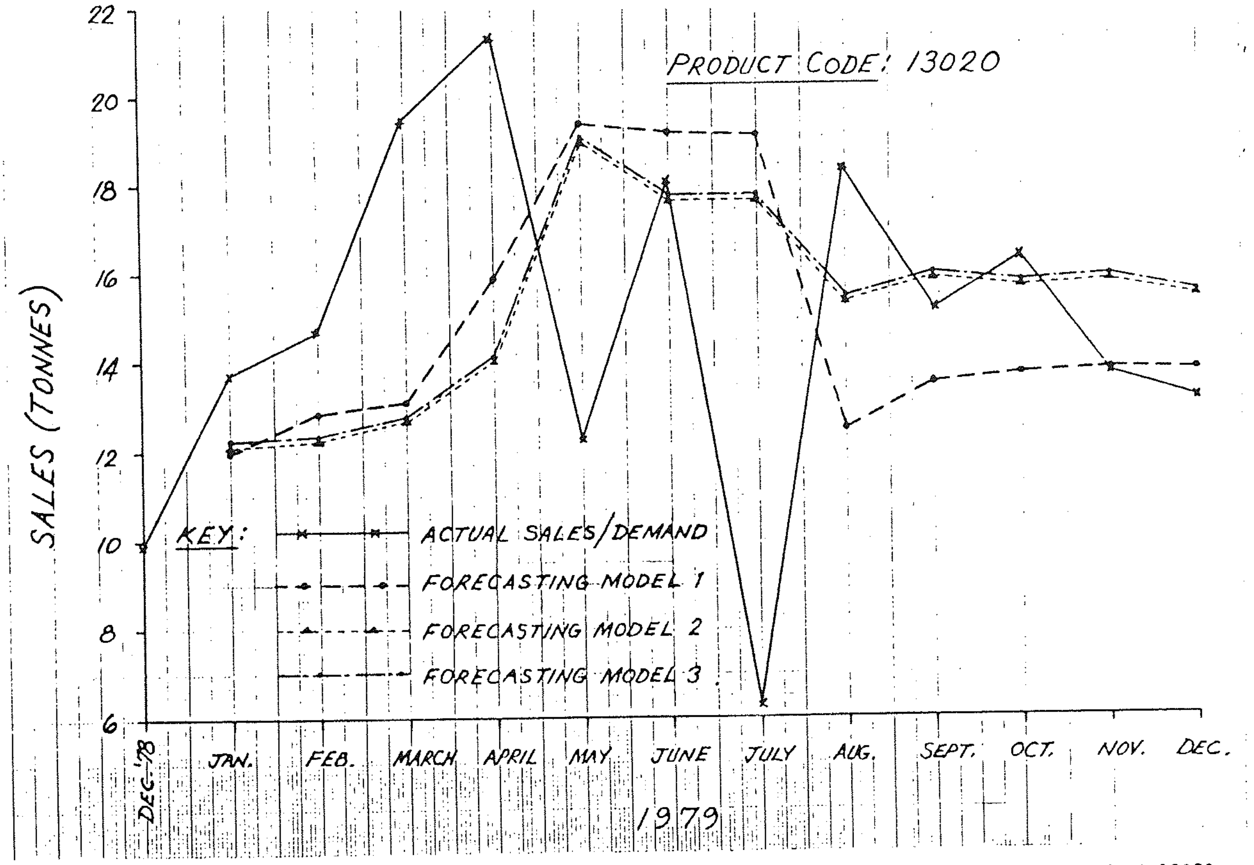


Fig. E29. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 13020

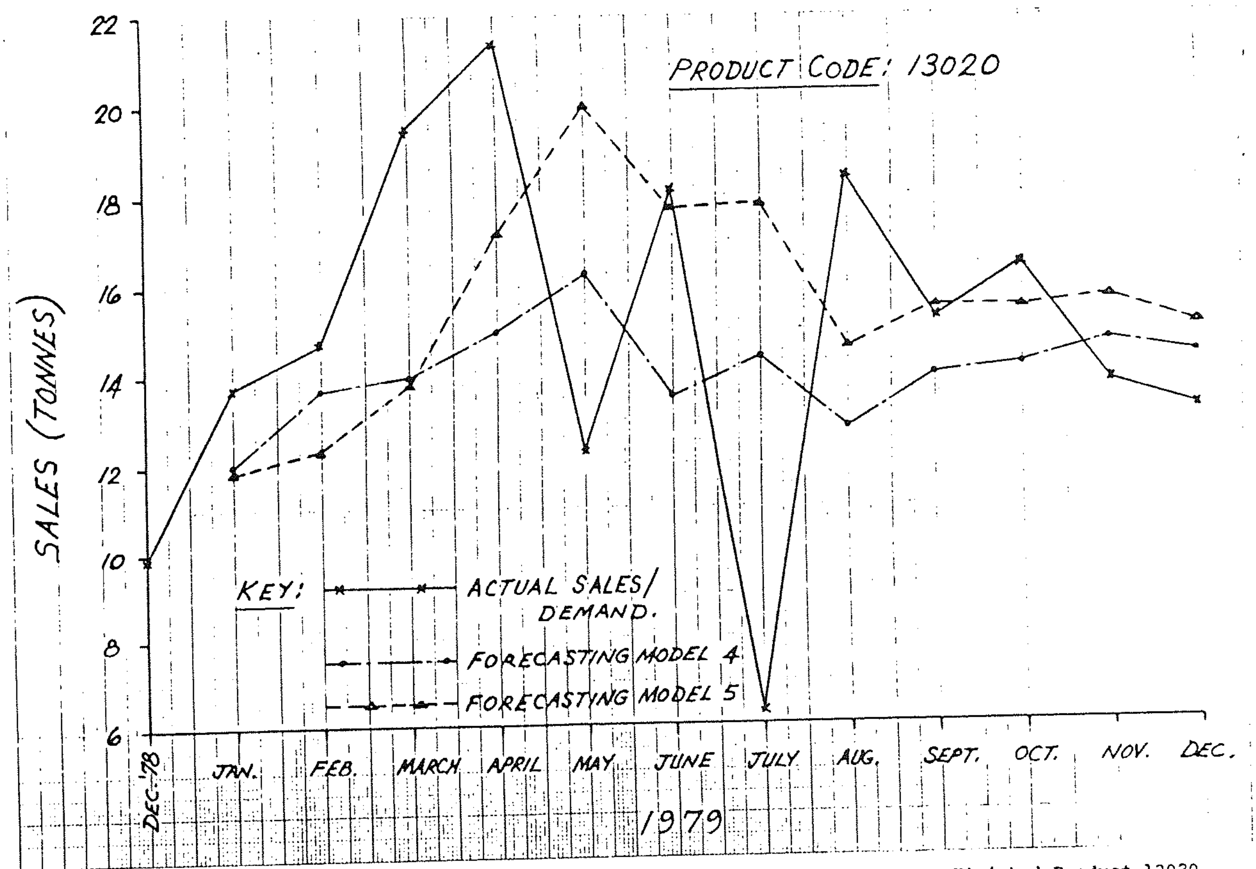


Fig. E30. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 13020

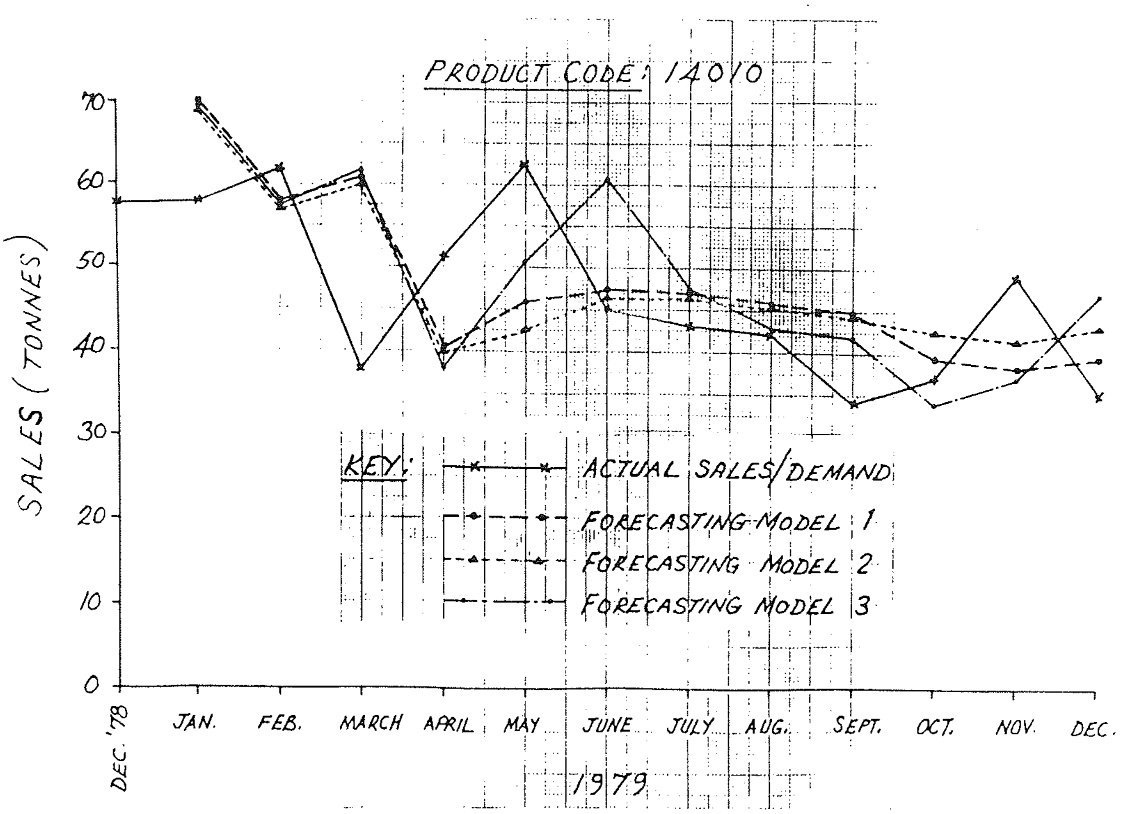


Fig. E31. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 14010

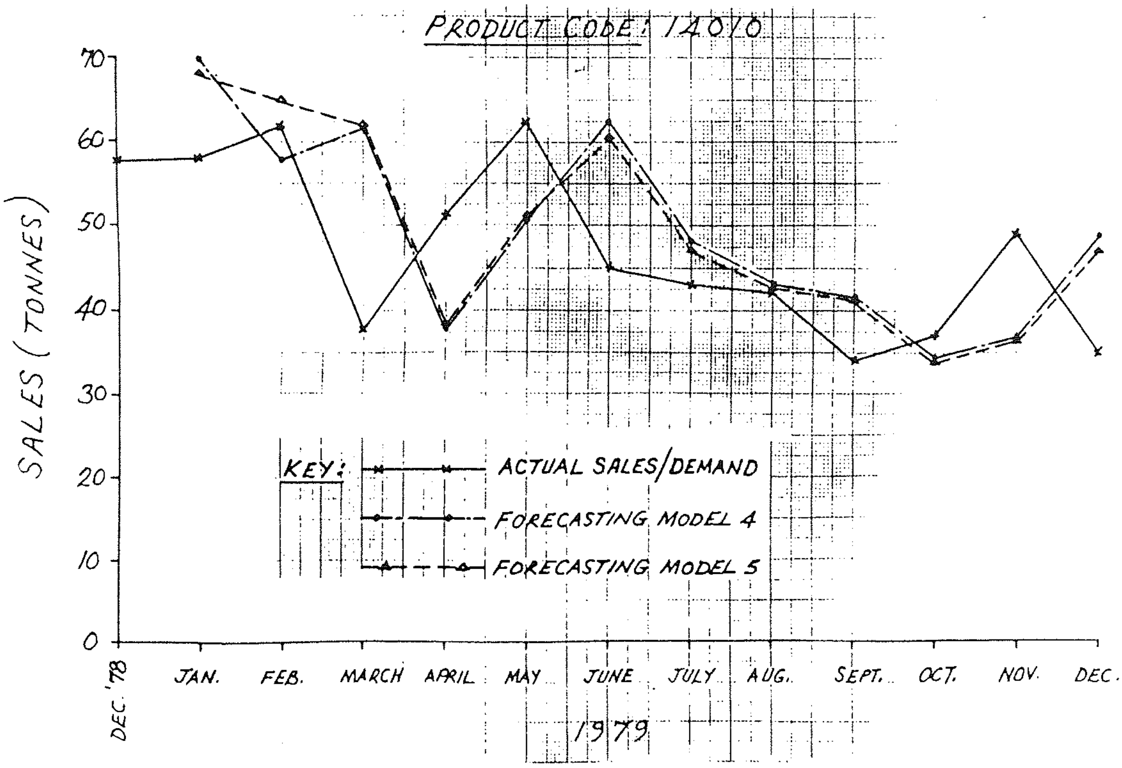


Fig. E32. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 14010

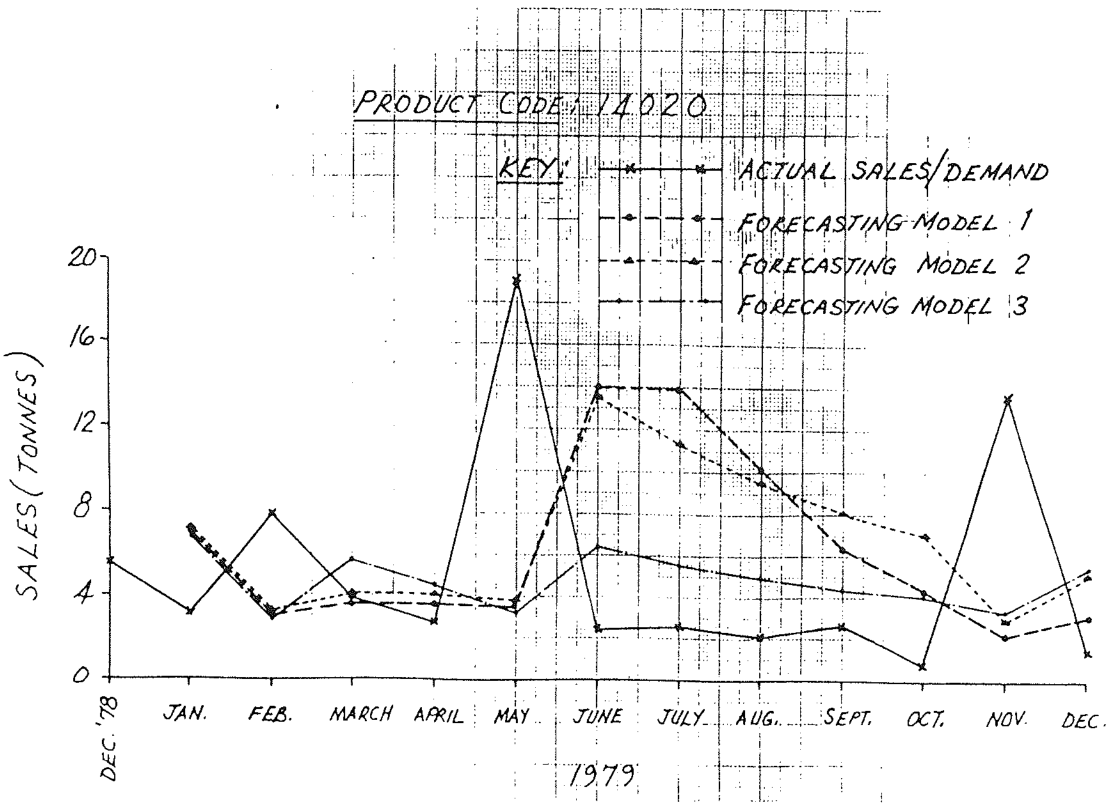


Fig. E33. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 14020

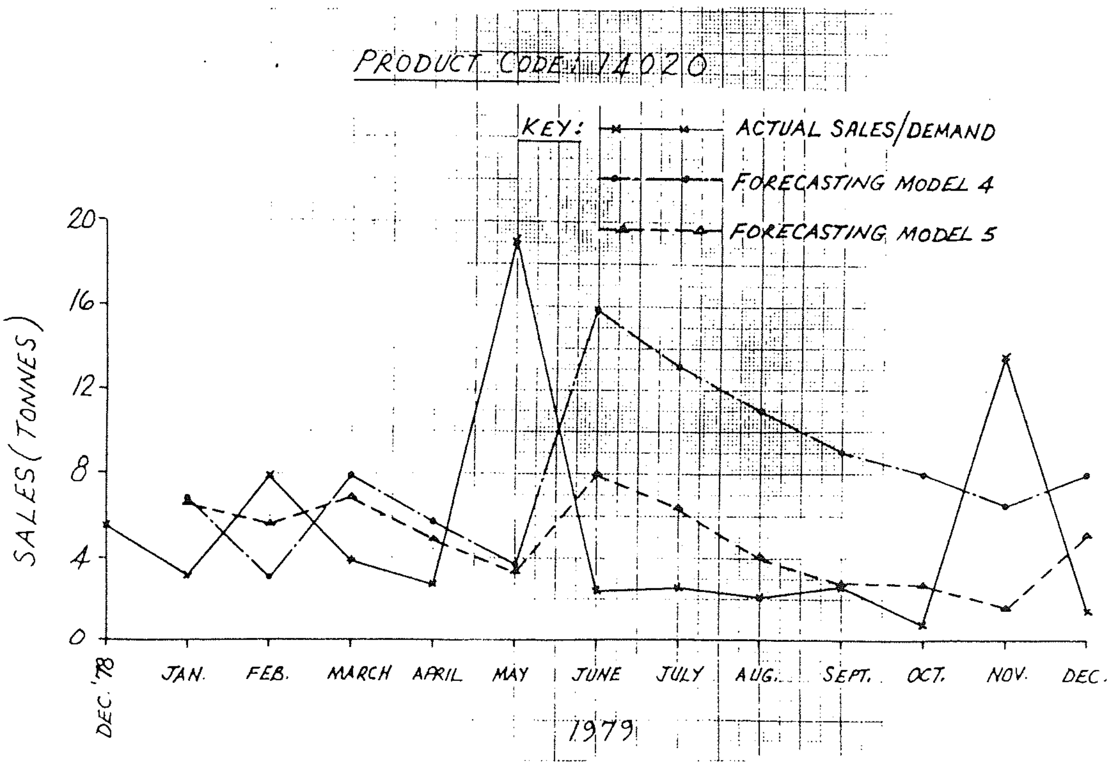


Fig. E34. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 14020

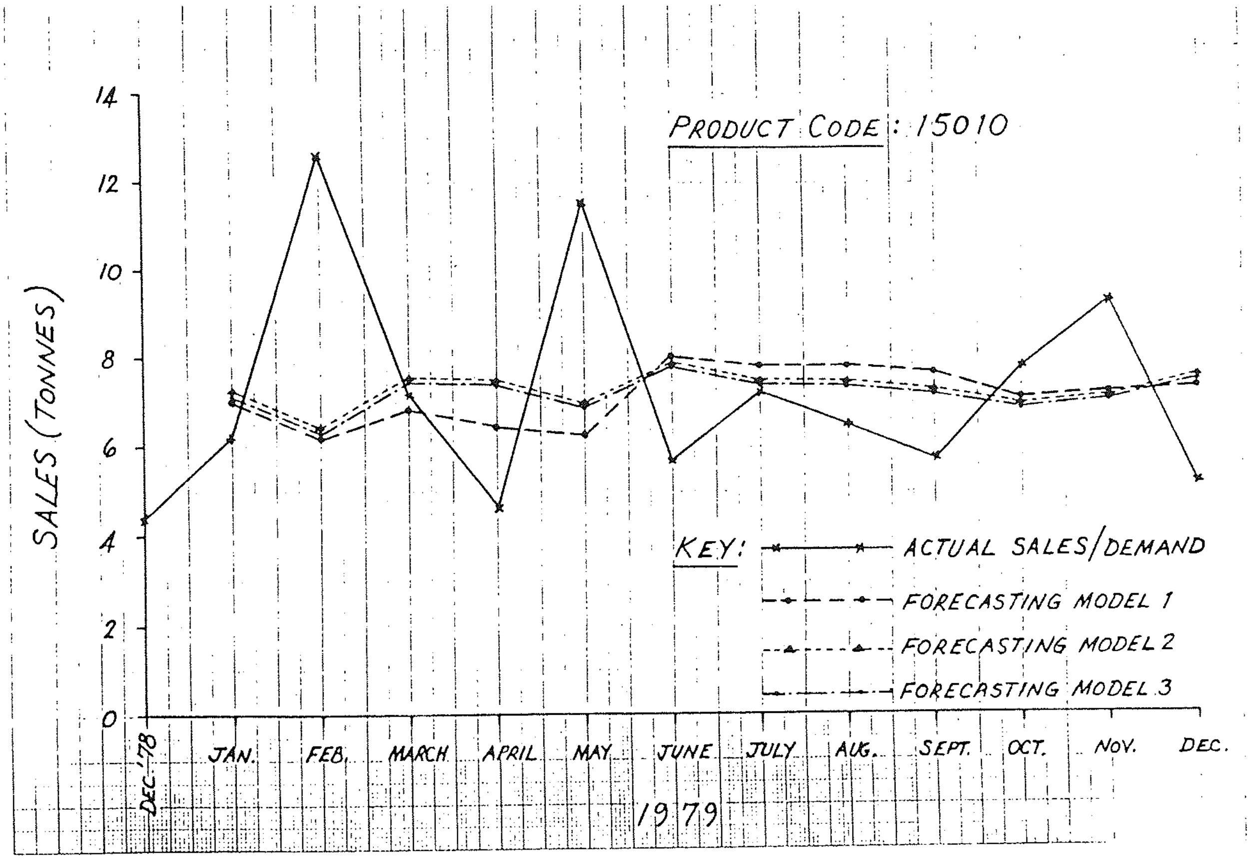


Fig. E35. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 15010

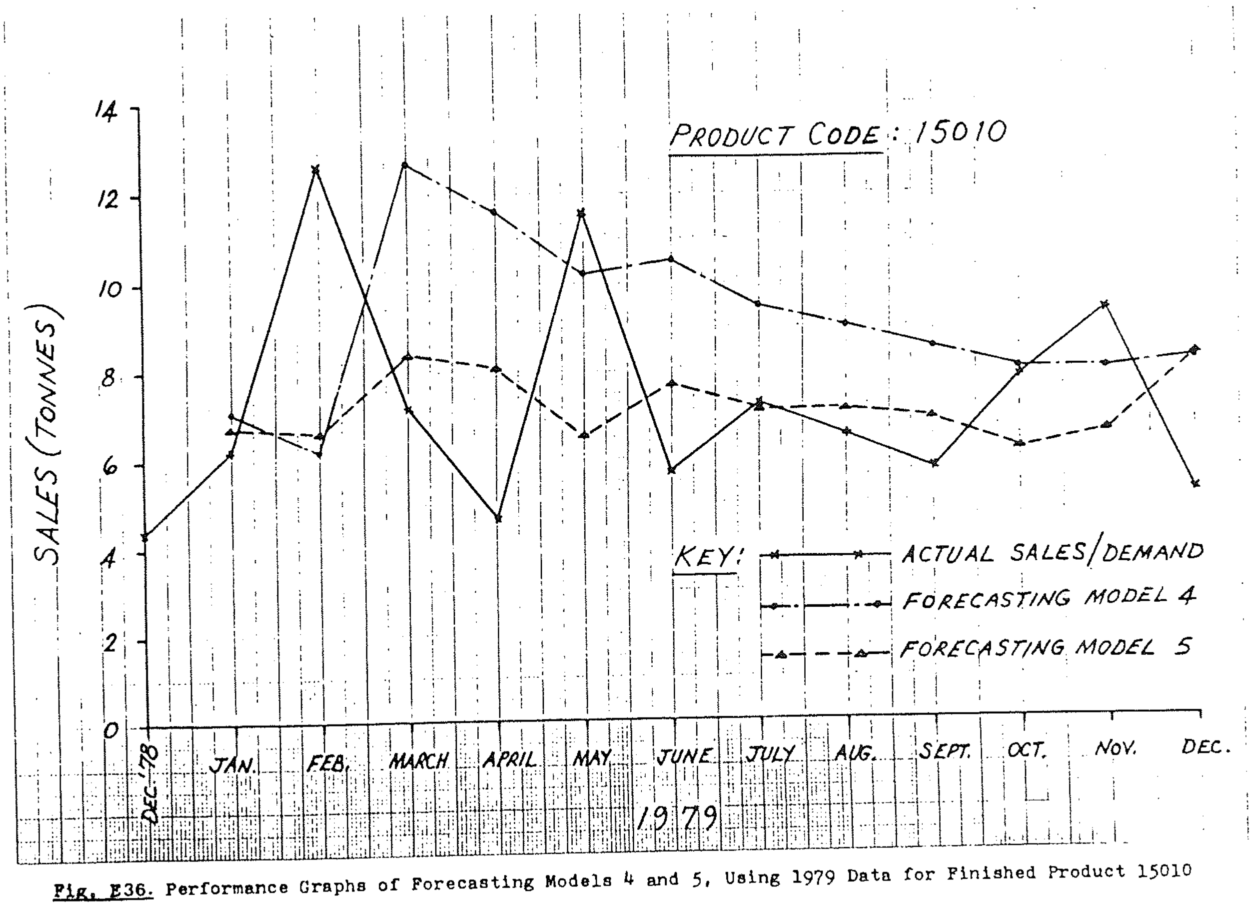


Fig. E36. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 15010

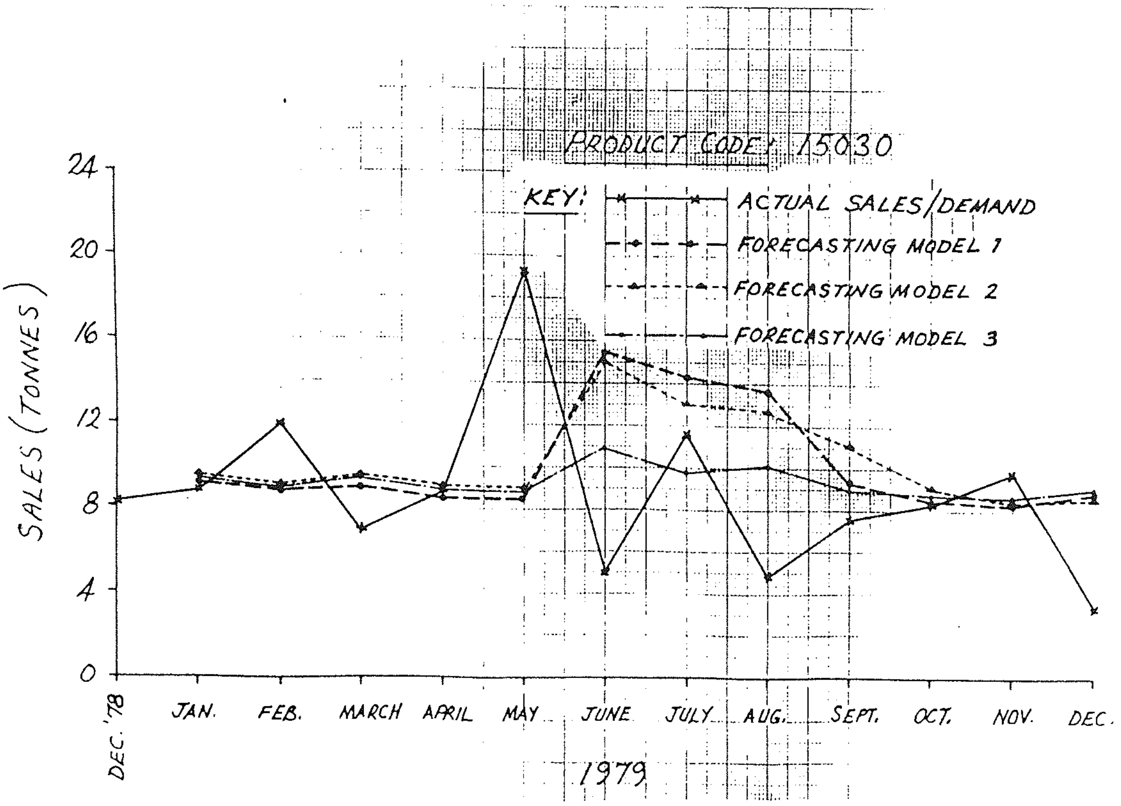


Fig. E37. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 15030

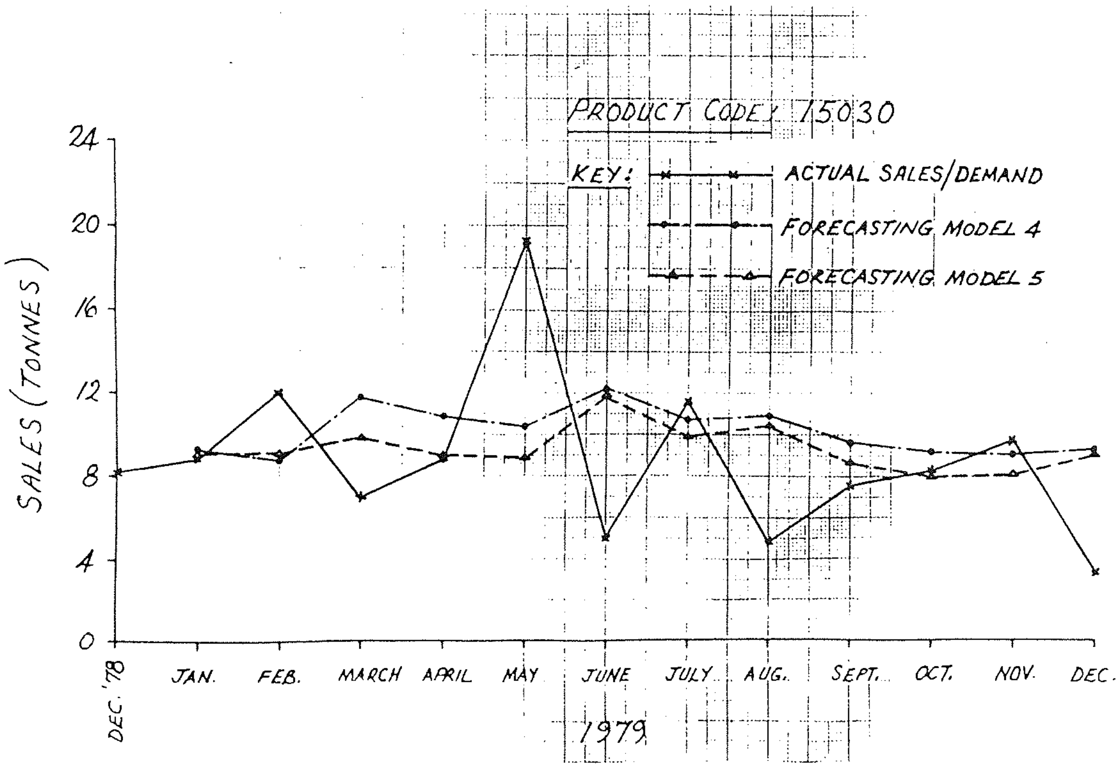


Fig. E38. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 15030

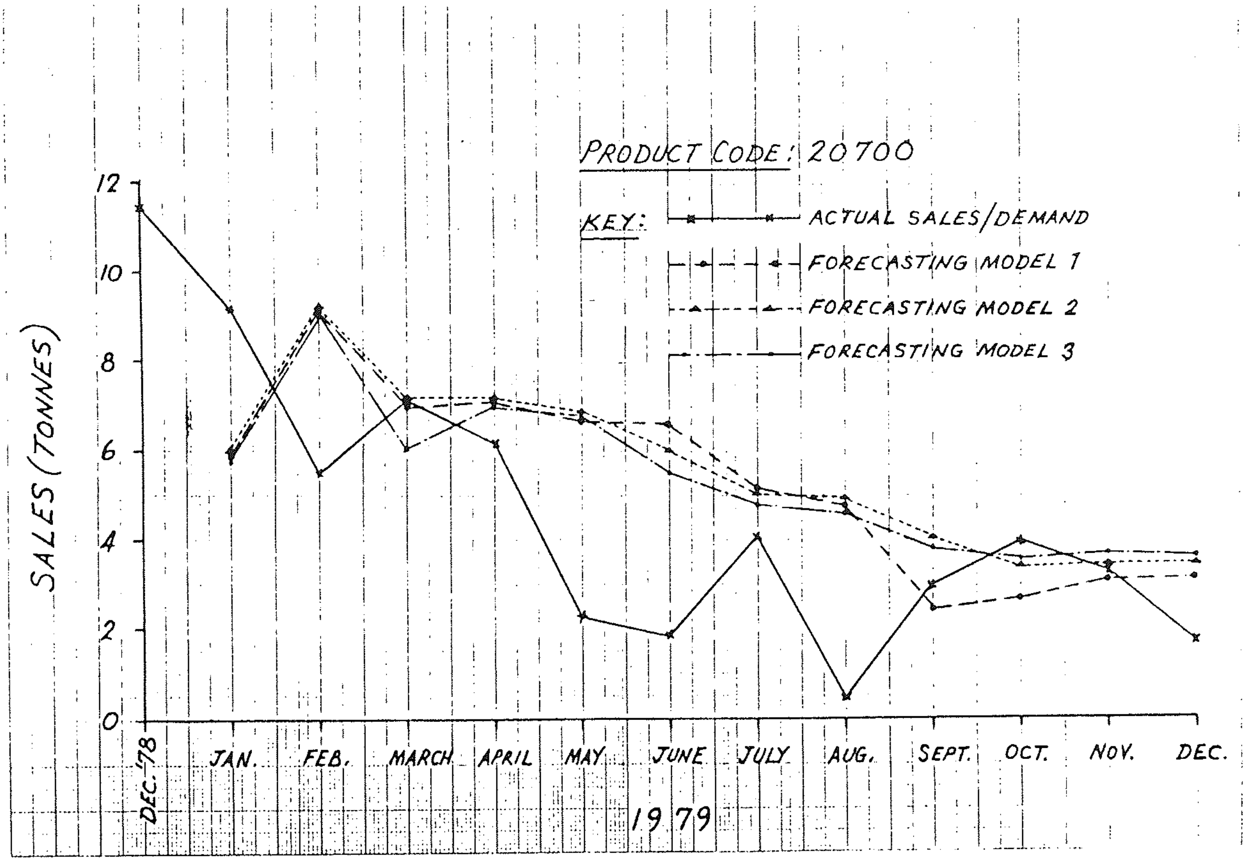


Fig. E39. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 20700

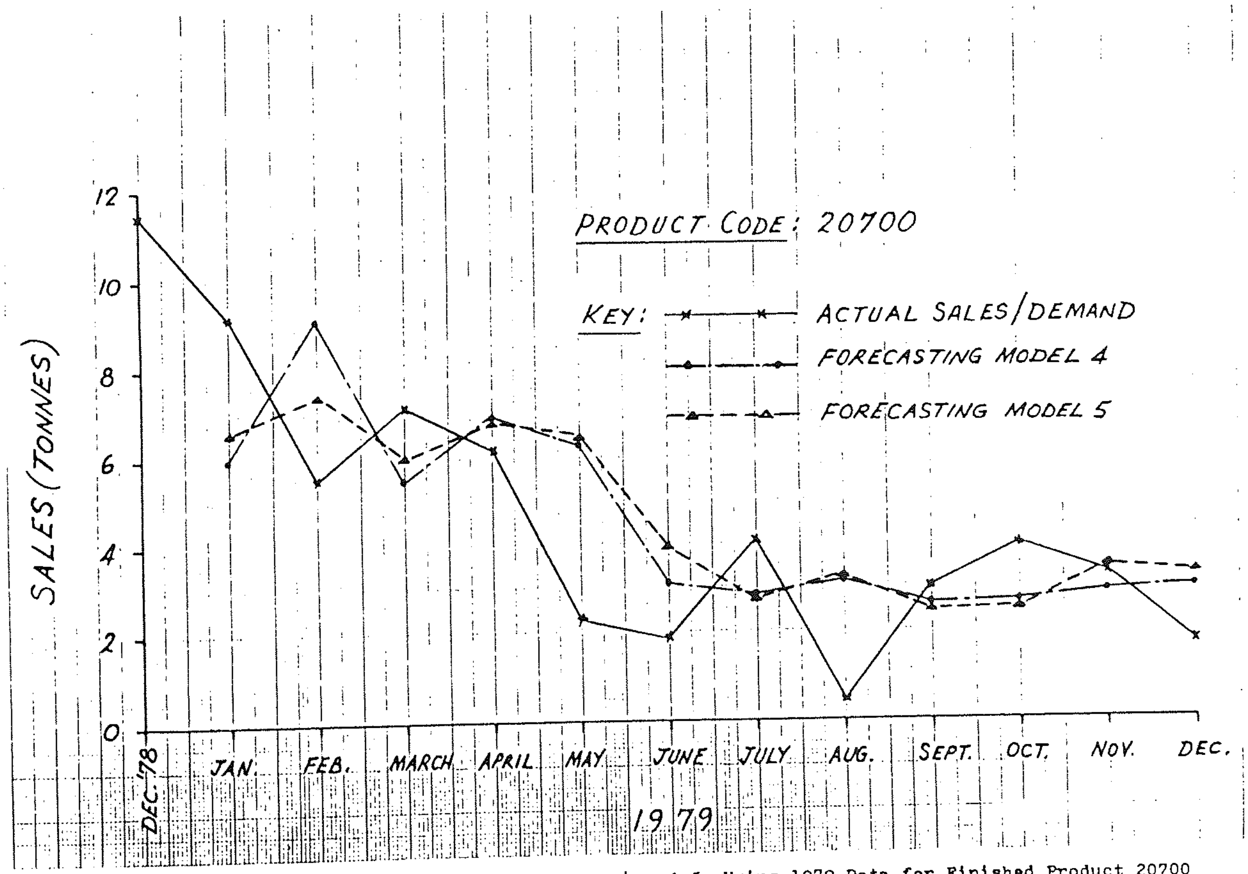


Fig. E40. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 20700

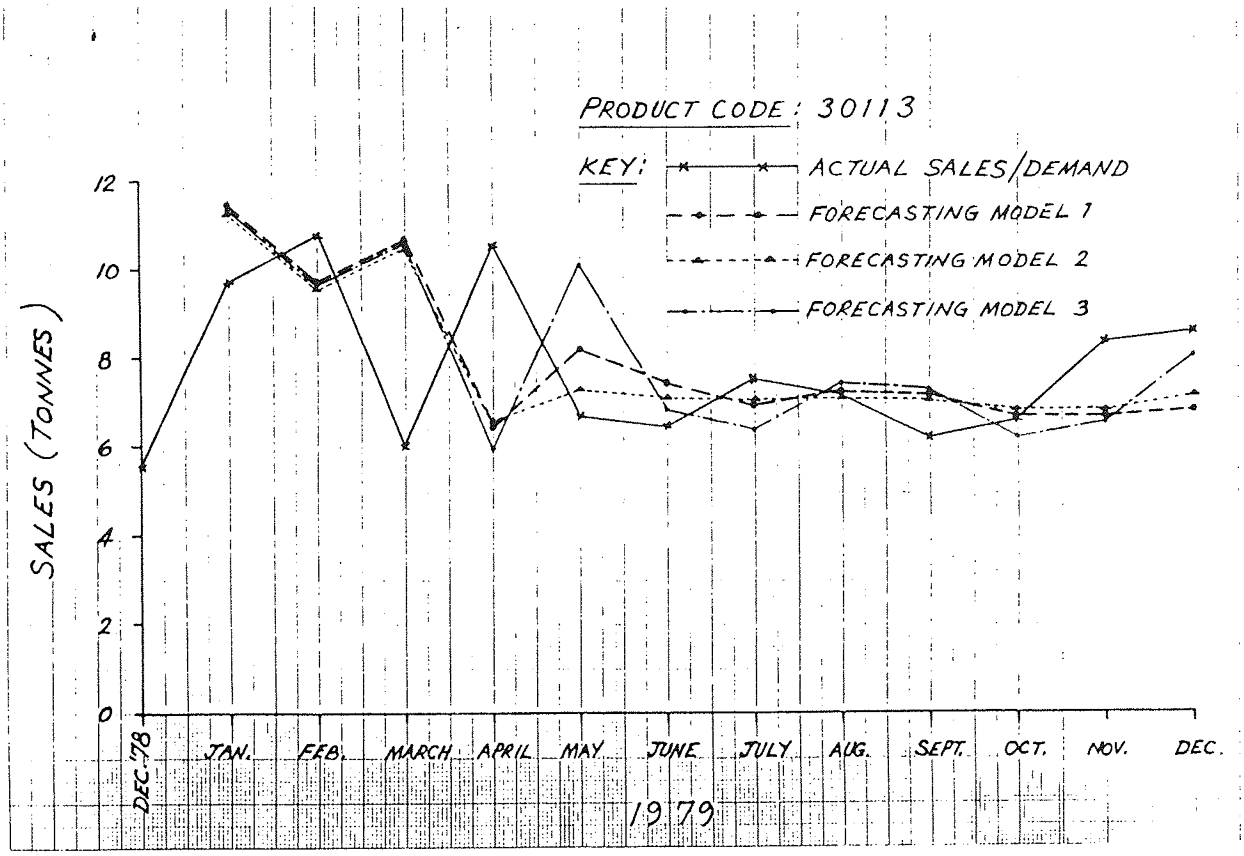


Fig. E41. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 30113

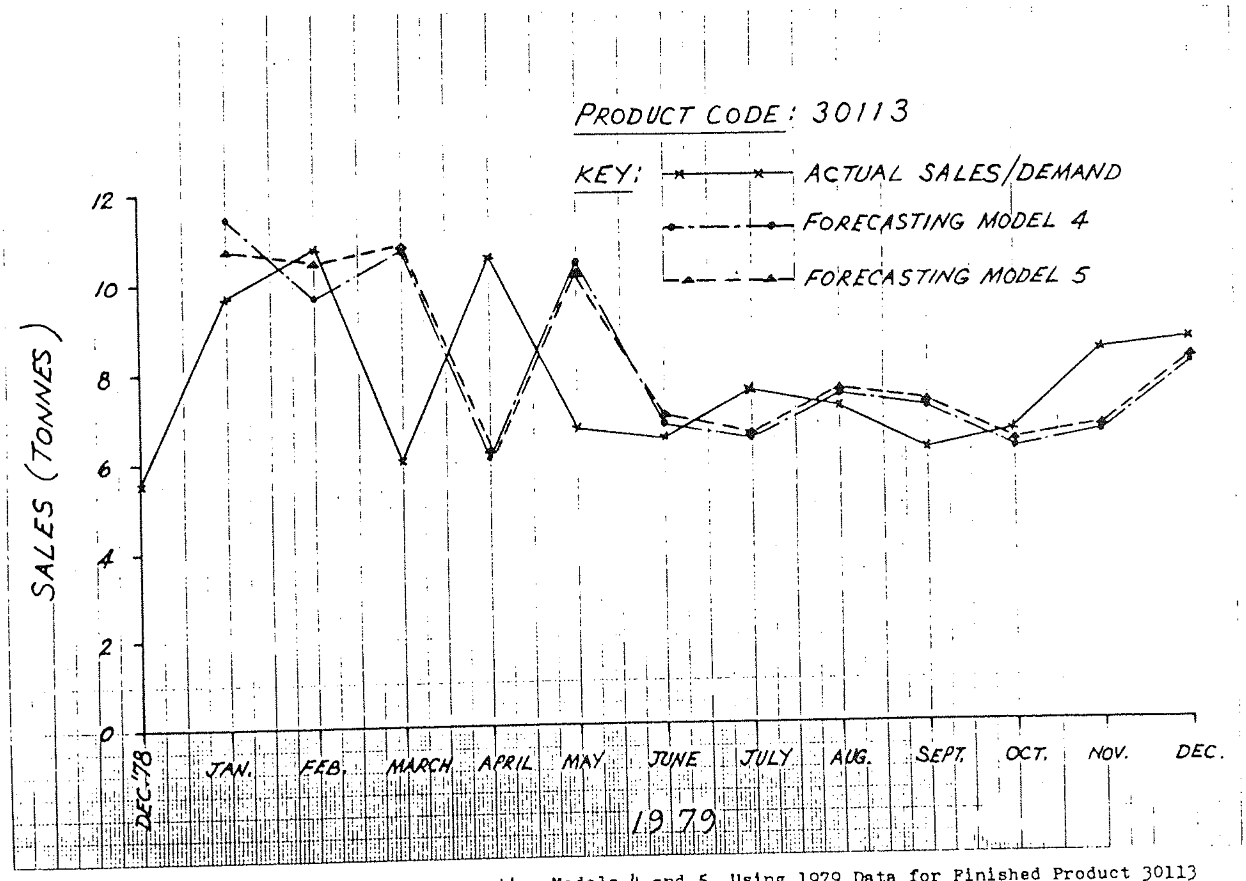


Fig. E42. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 30113

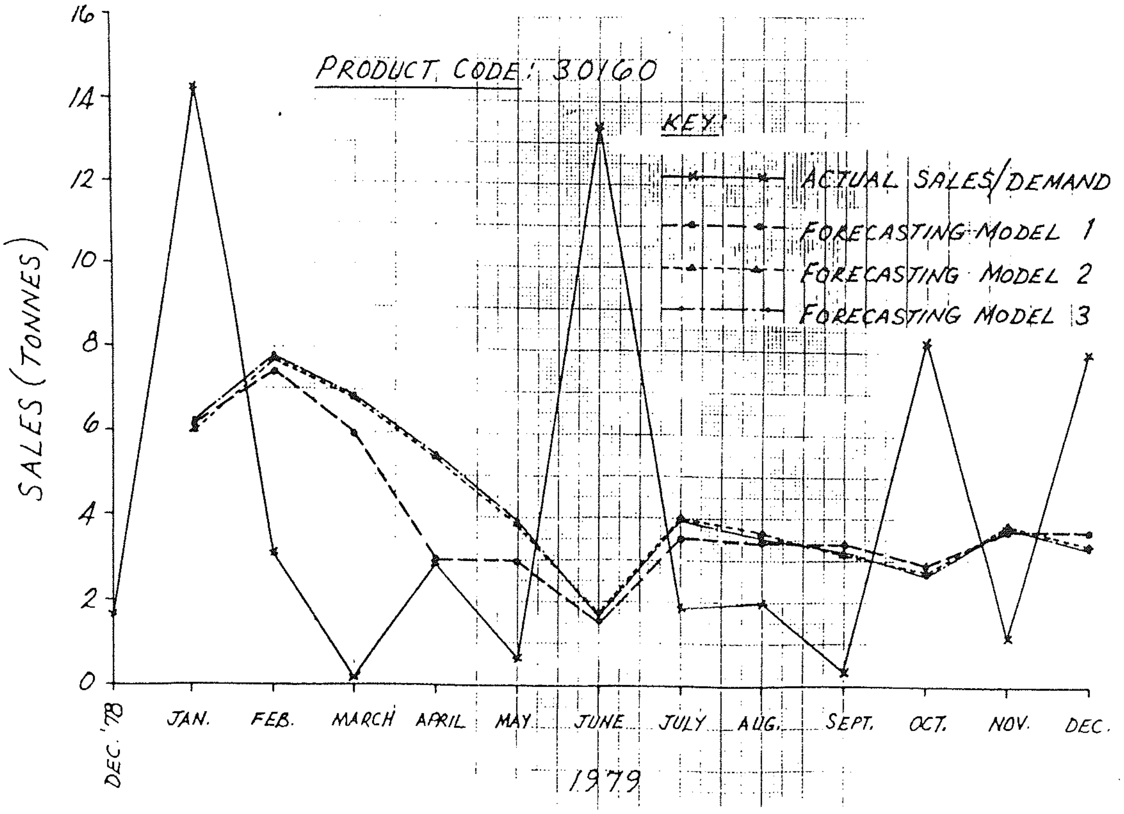


Fig. E43. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 30160

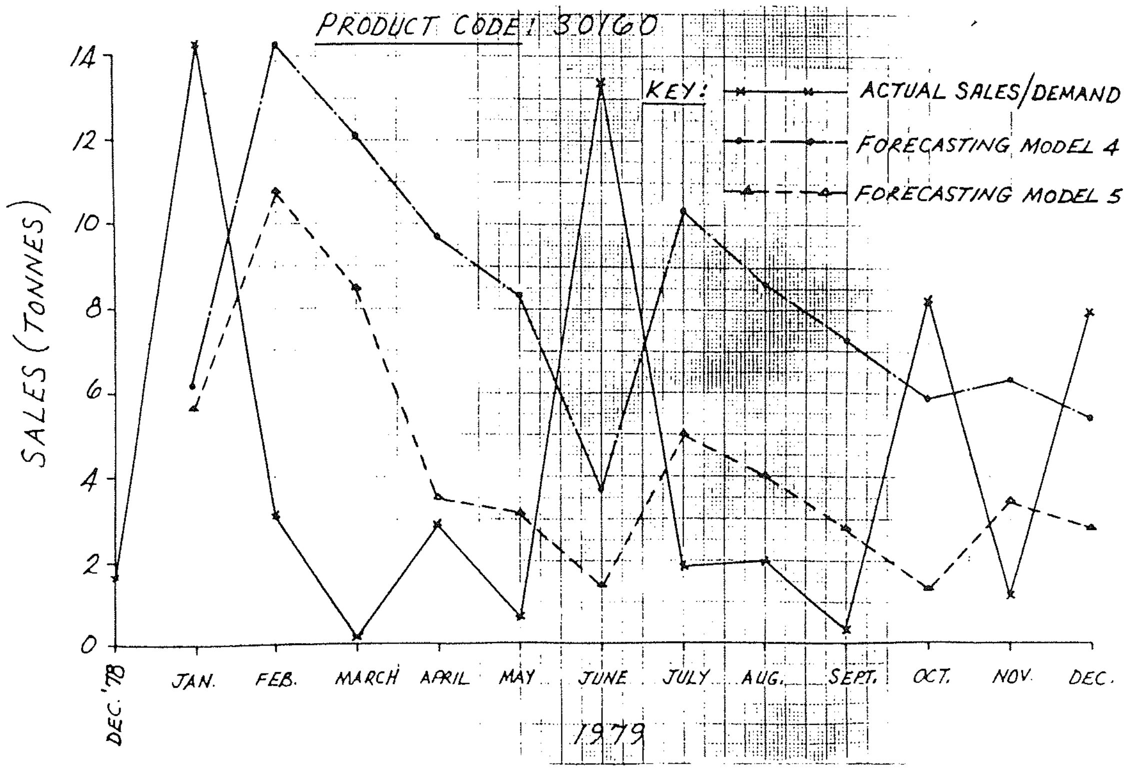


Fig. E44. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 30160

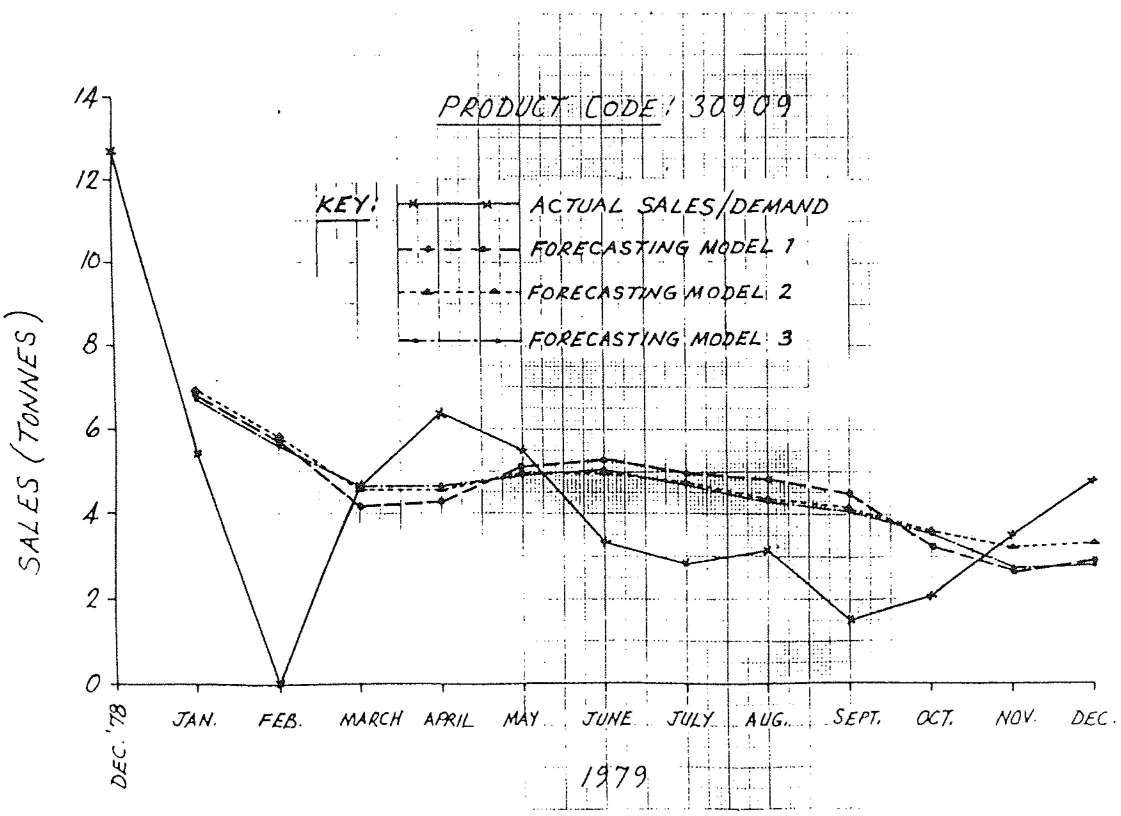


Fig. E45. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 30909

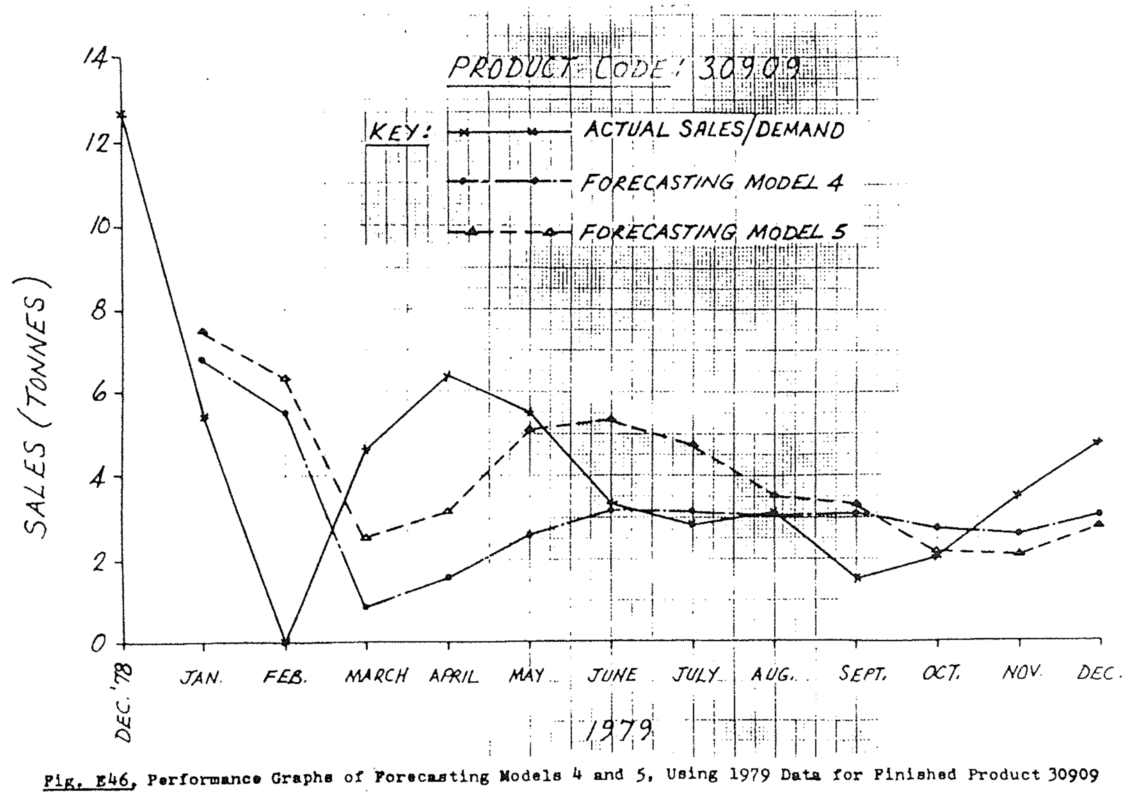


Fig. E46, Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 30909

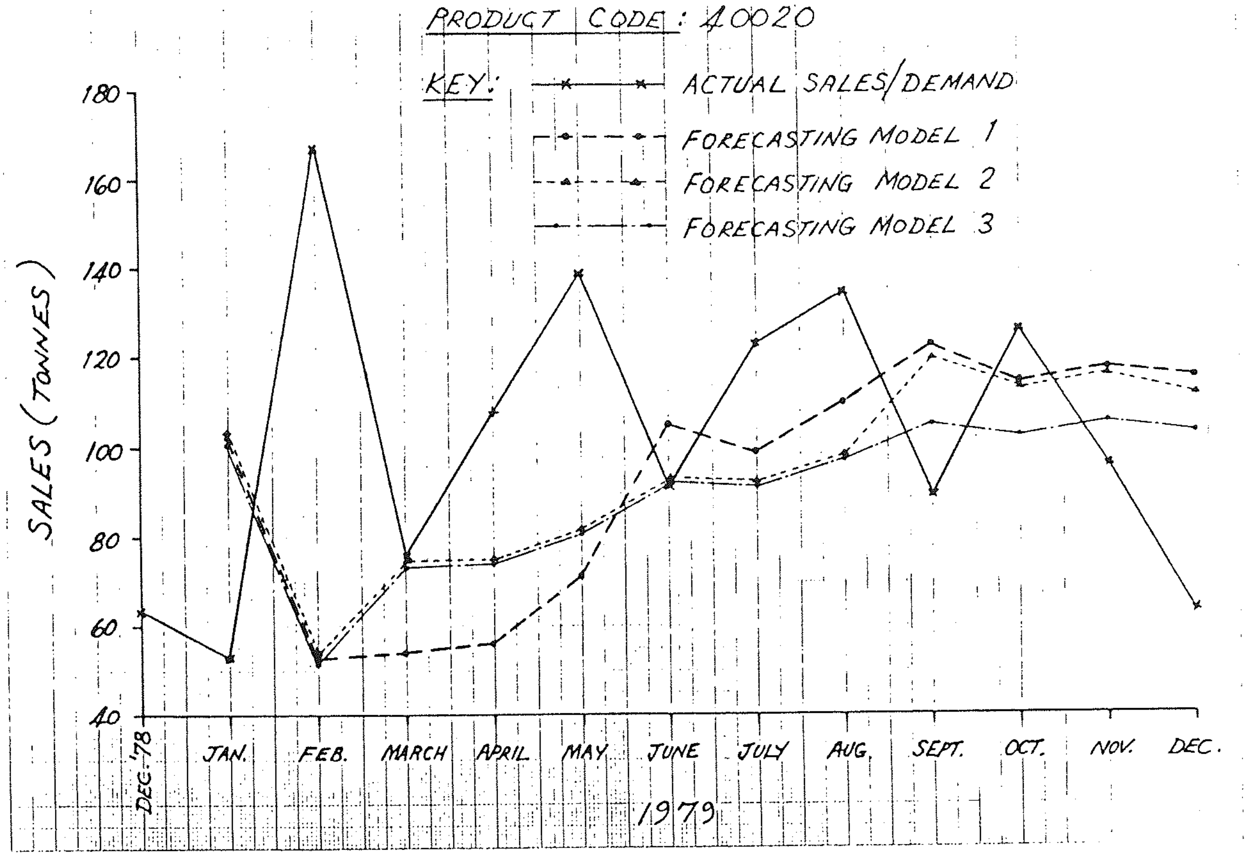


Fig. E47. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 40020

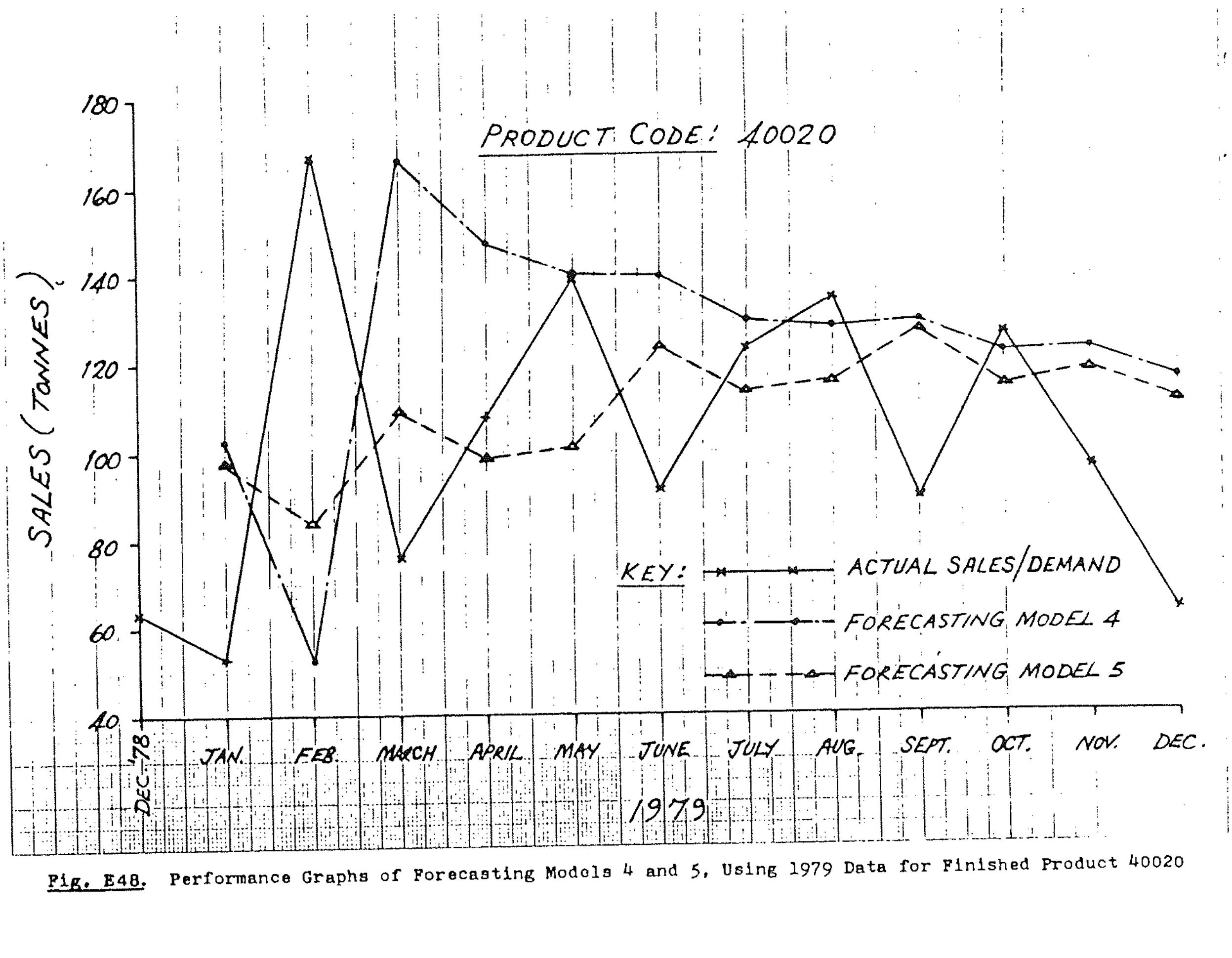


Fig. E48. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 40020

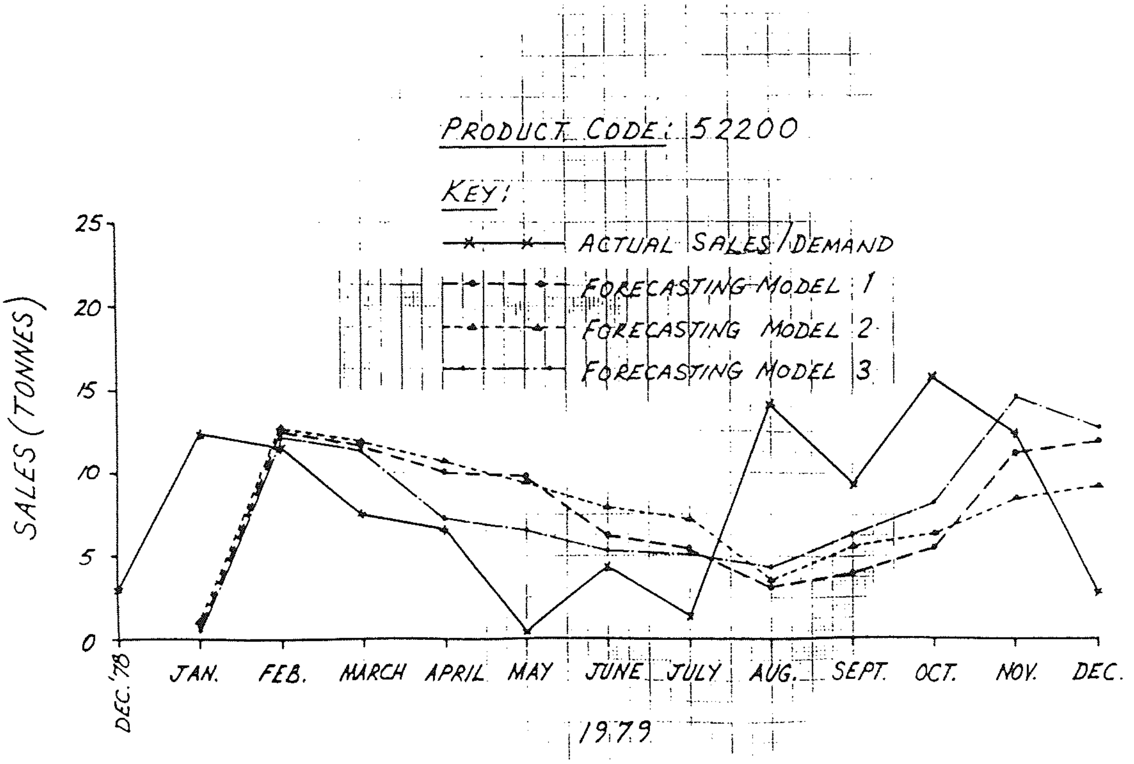


Fig. E49. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 52200

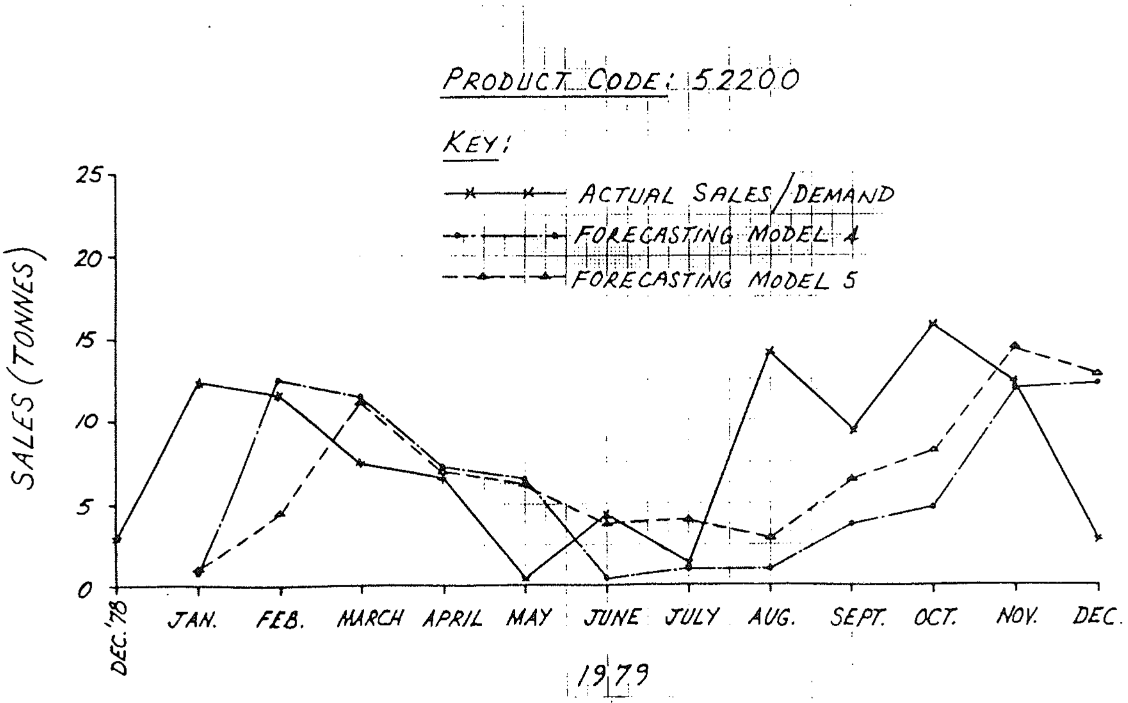


Fig. E50. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 52200

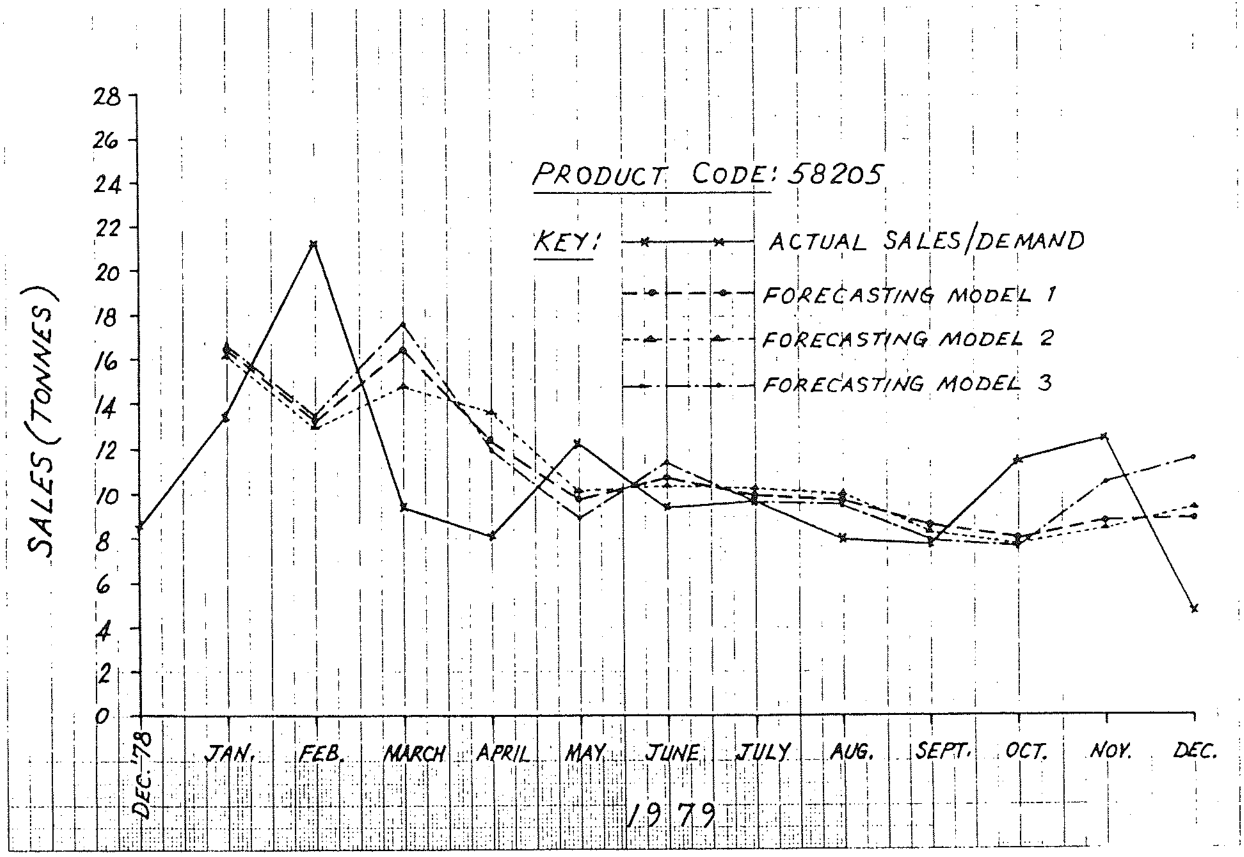


Fig. E51. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 58205

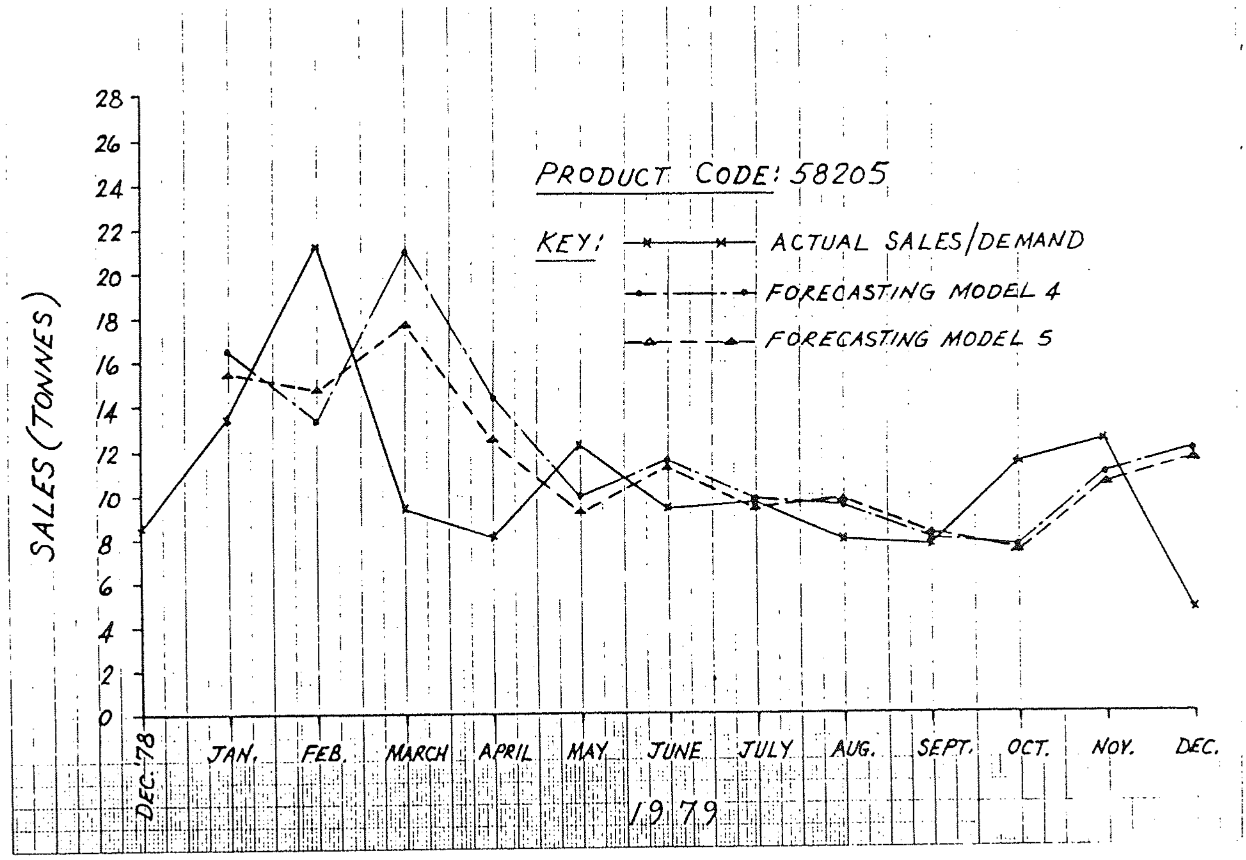


Fig. E52. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 58205

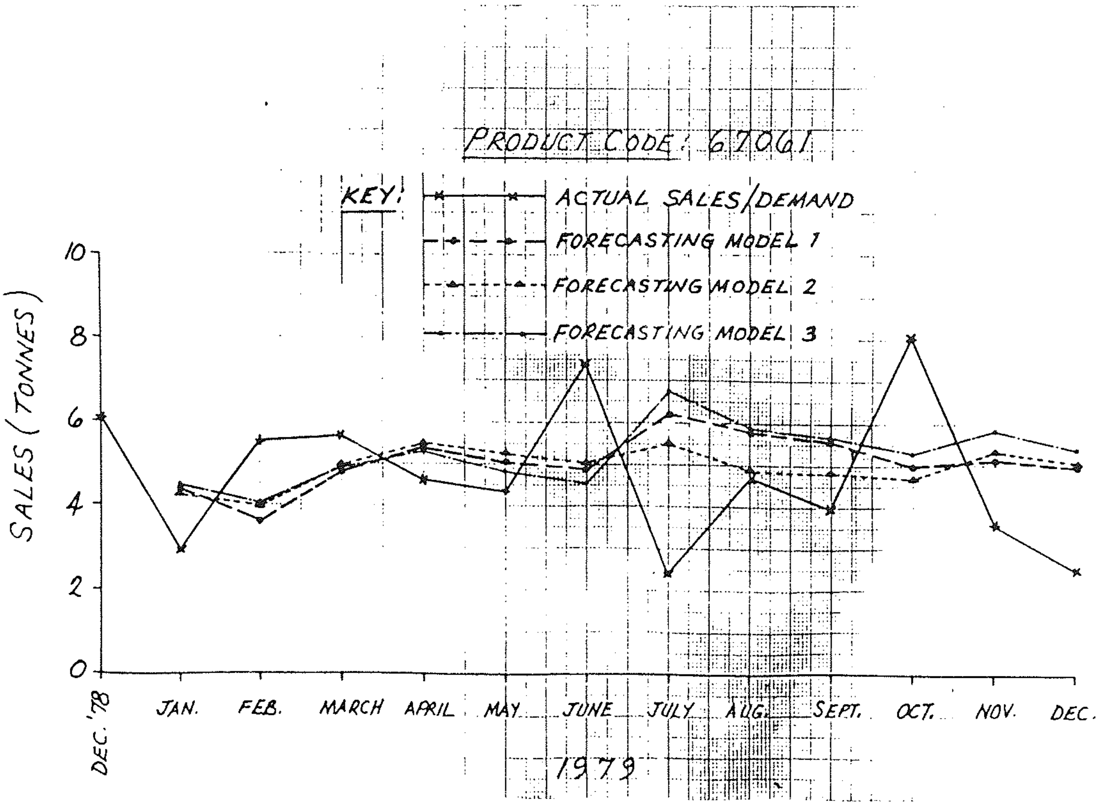


Fig. E53. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 67061

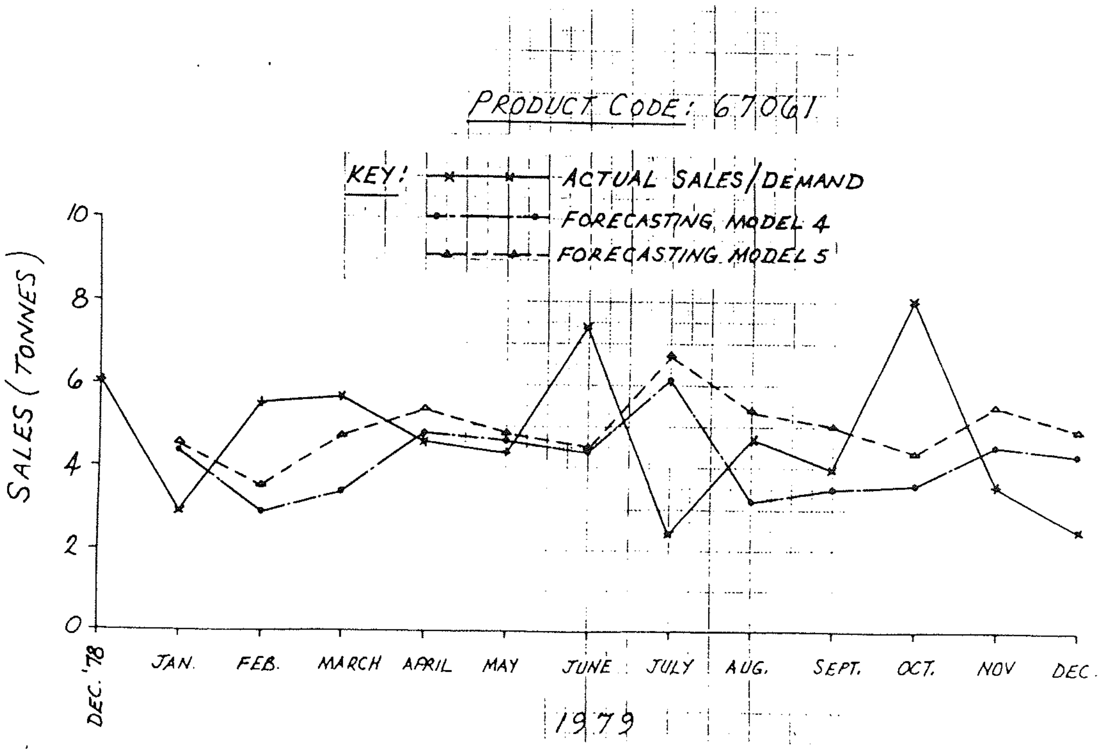


Fig. E54. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 67061

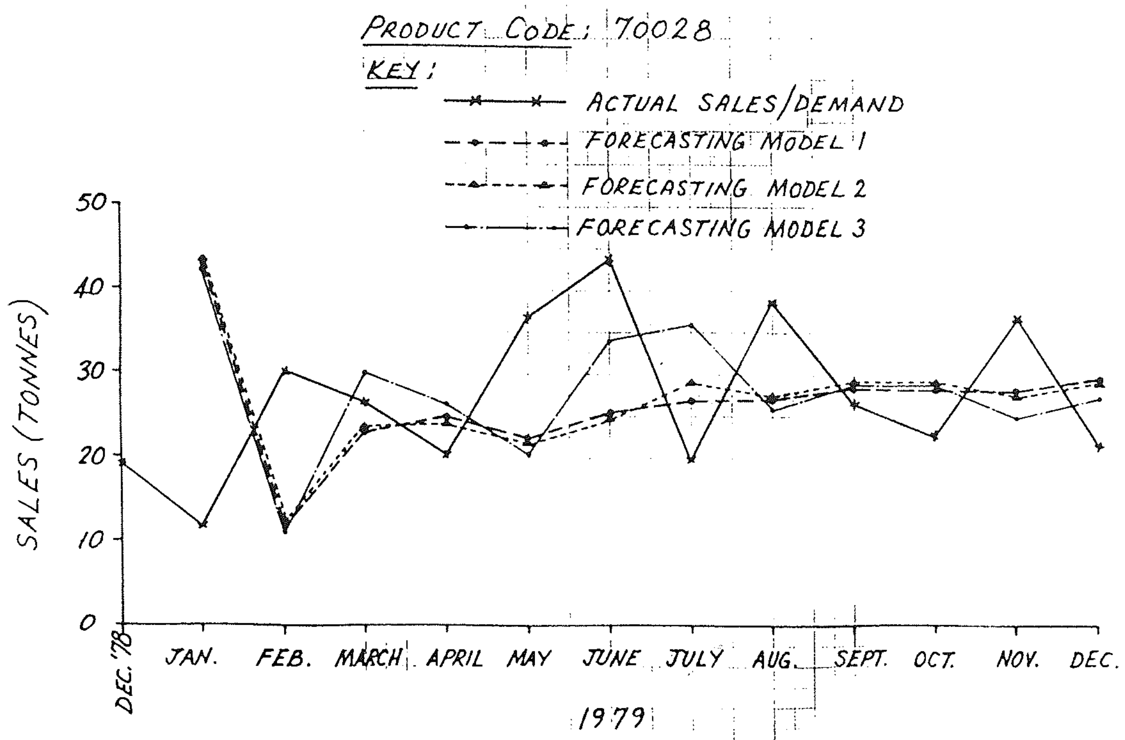


Fig. E55. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 70028

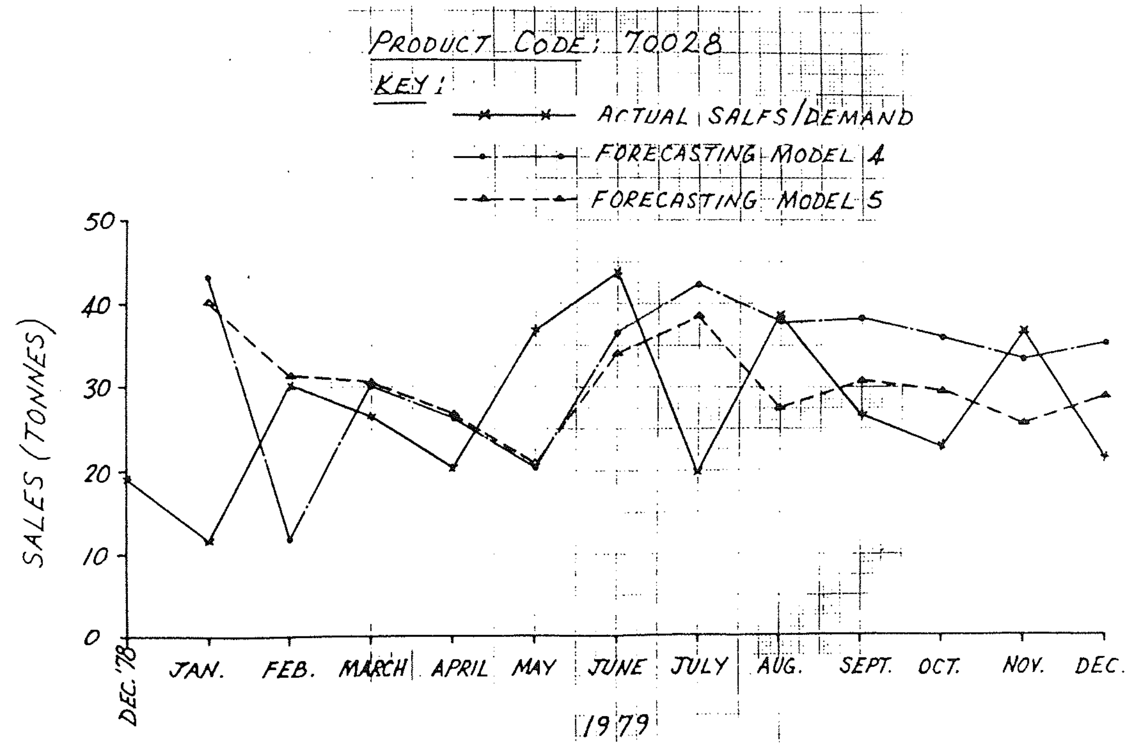


Fig. E56. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 70028

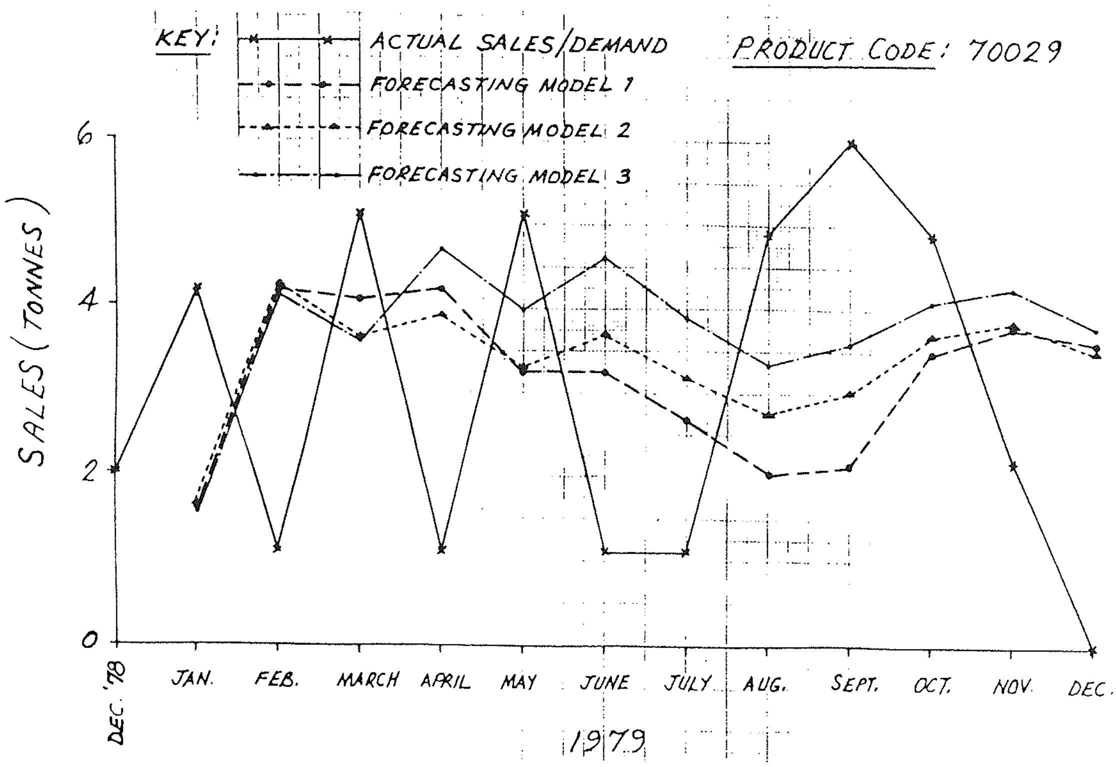


Fig. E57. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 70029

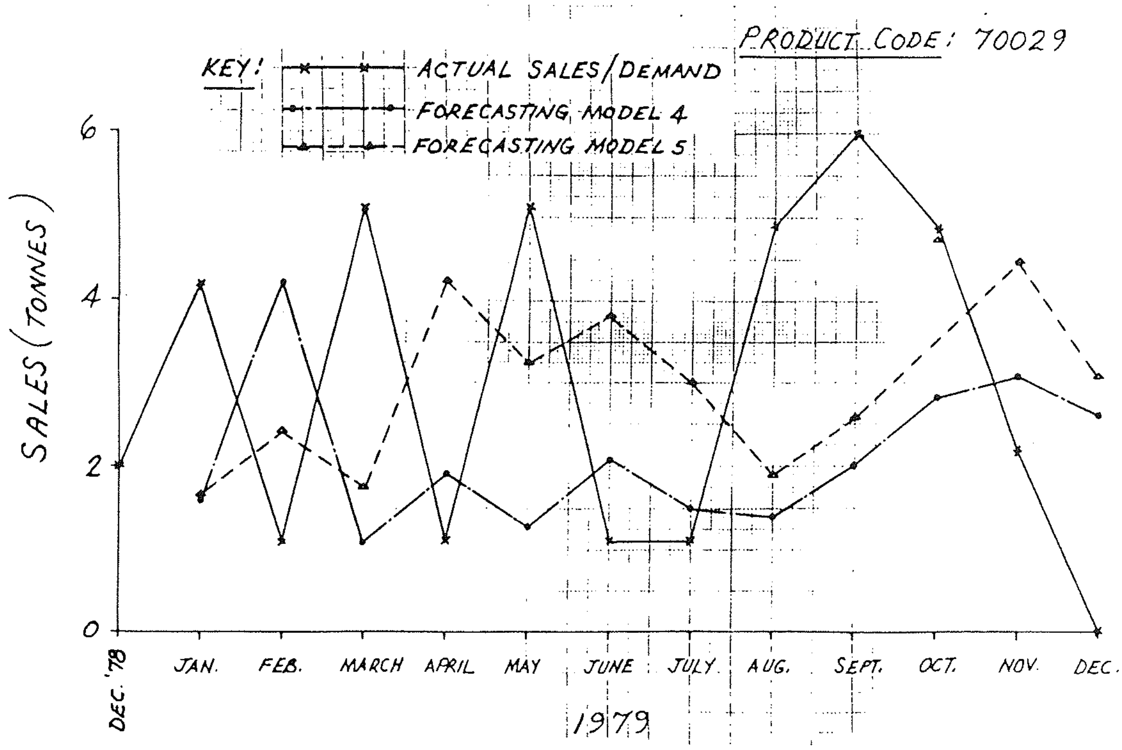


Fig. E58. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 70029

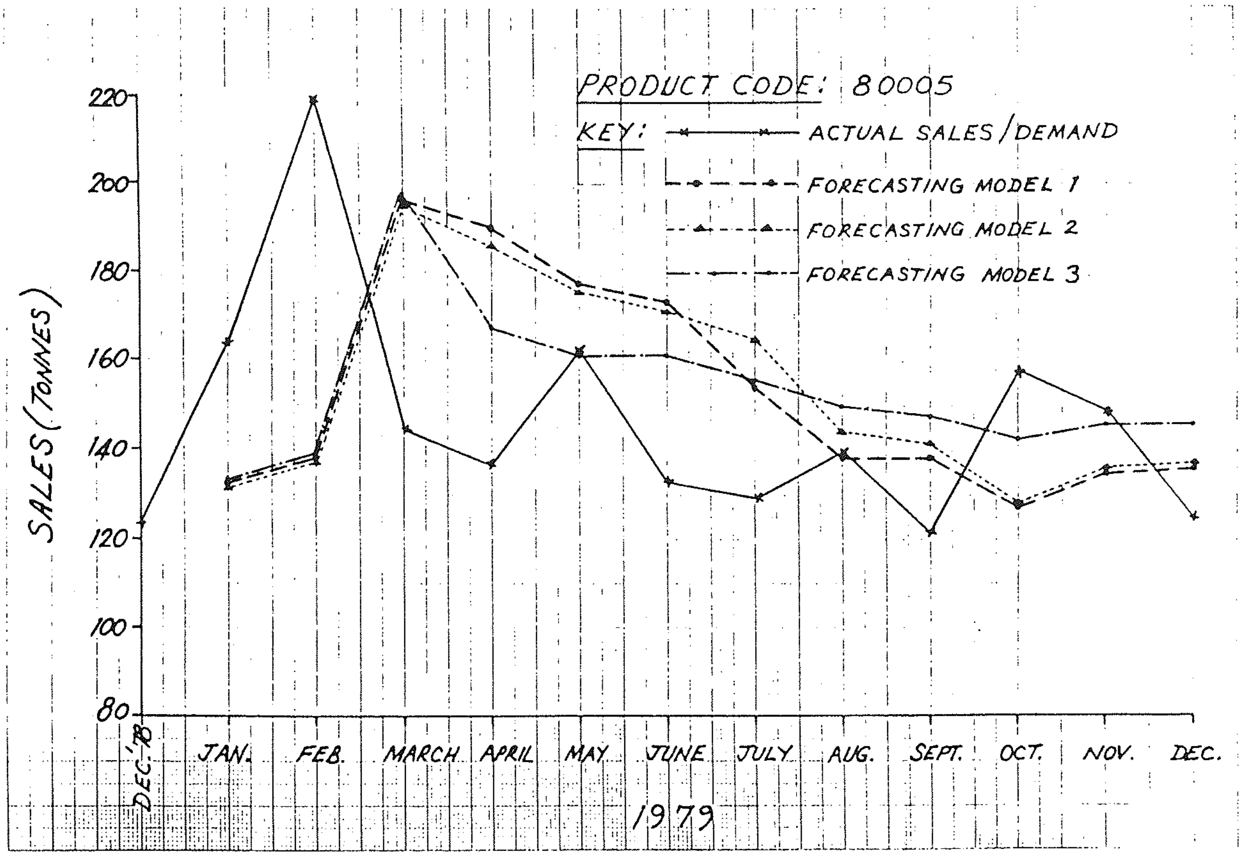


Fig. E59. Performance Graphs of Forecasting Models 1,2 and 3, Using 1979 Data for Finished Product 80005

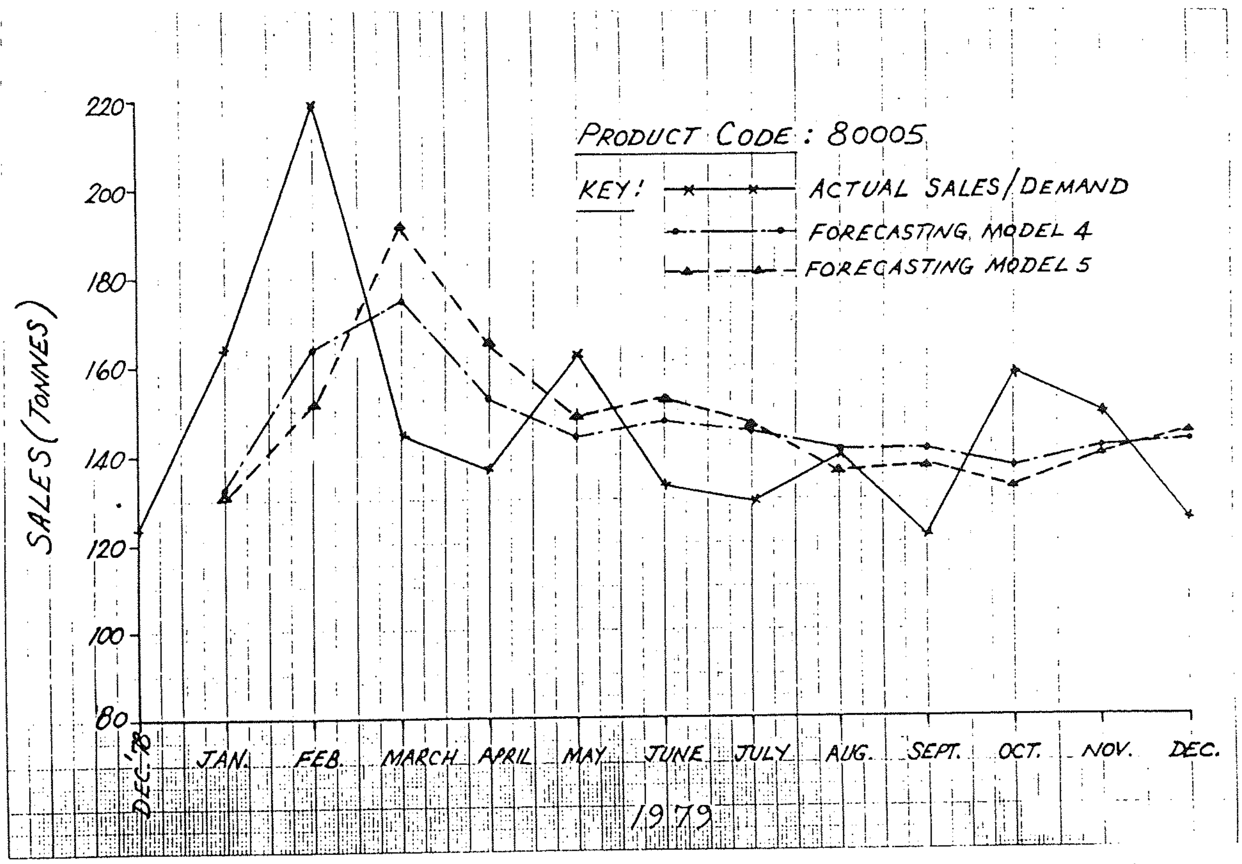


Fig. E60. Performance Graphs of Forecasting Models 4 and 5, Using 1979 Data for Finished Product 80005

Appendix F

Graphs Showing the Results of Testing Forecasting Model 5 with 1980 Sales/ Demand Data.

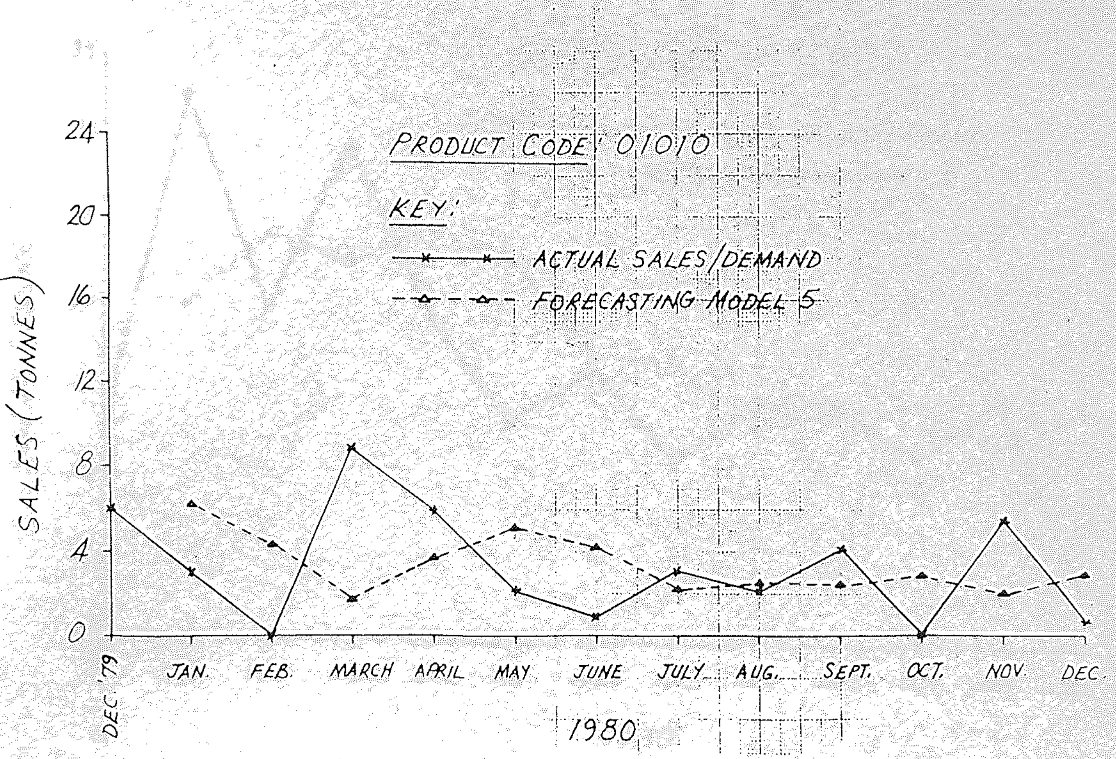


Fig. F1. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 01010

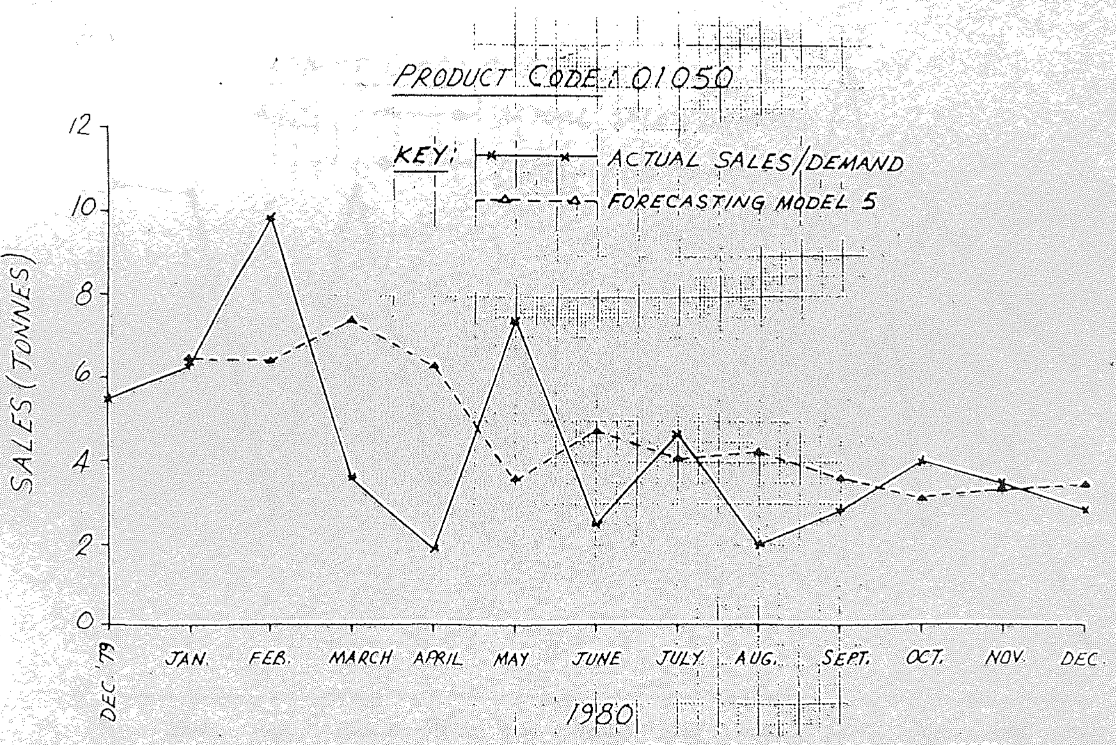


Fig. F2. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 01050

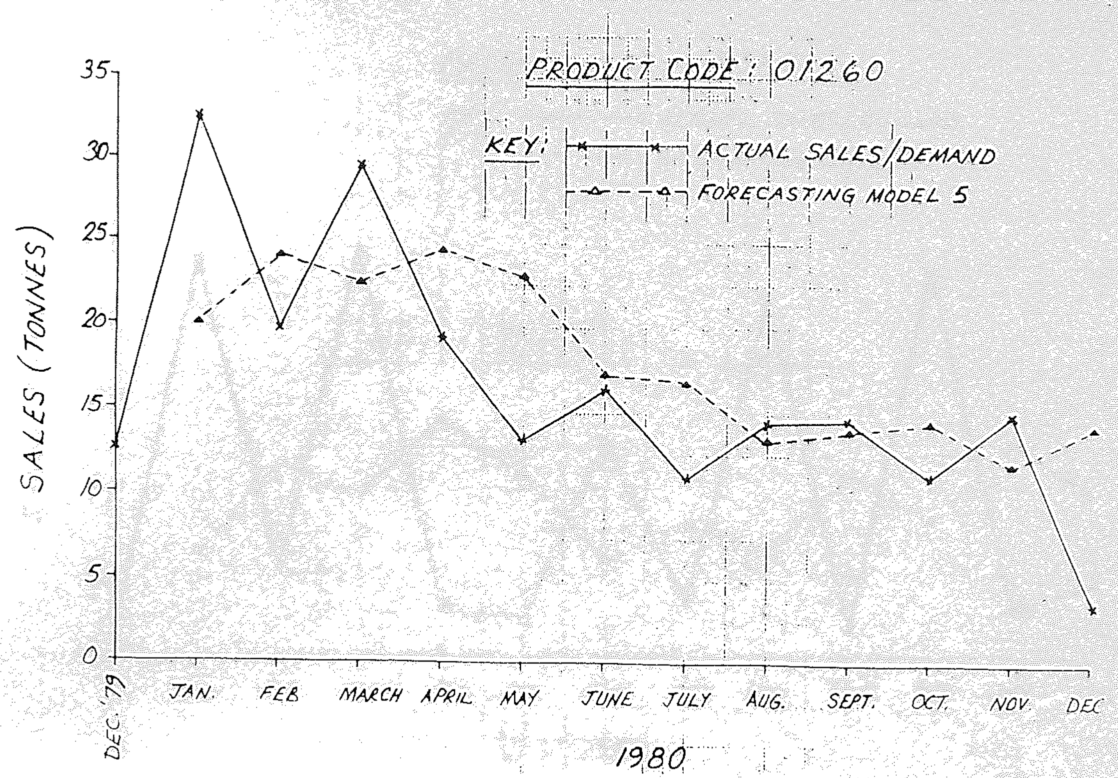


Fig. F3. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 01260

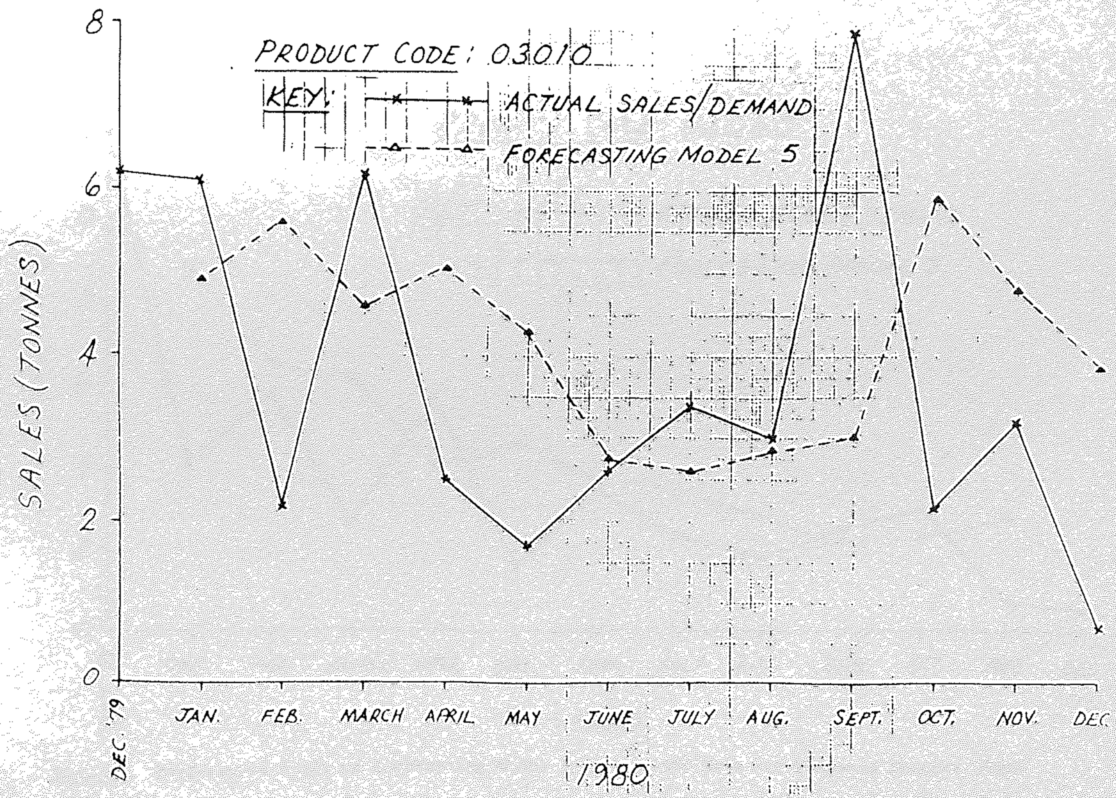


Fig. F4. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 03010

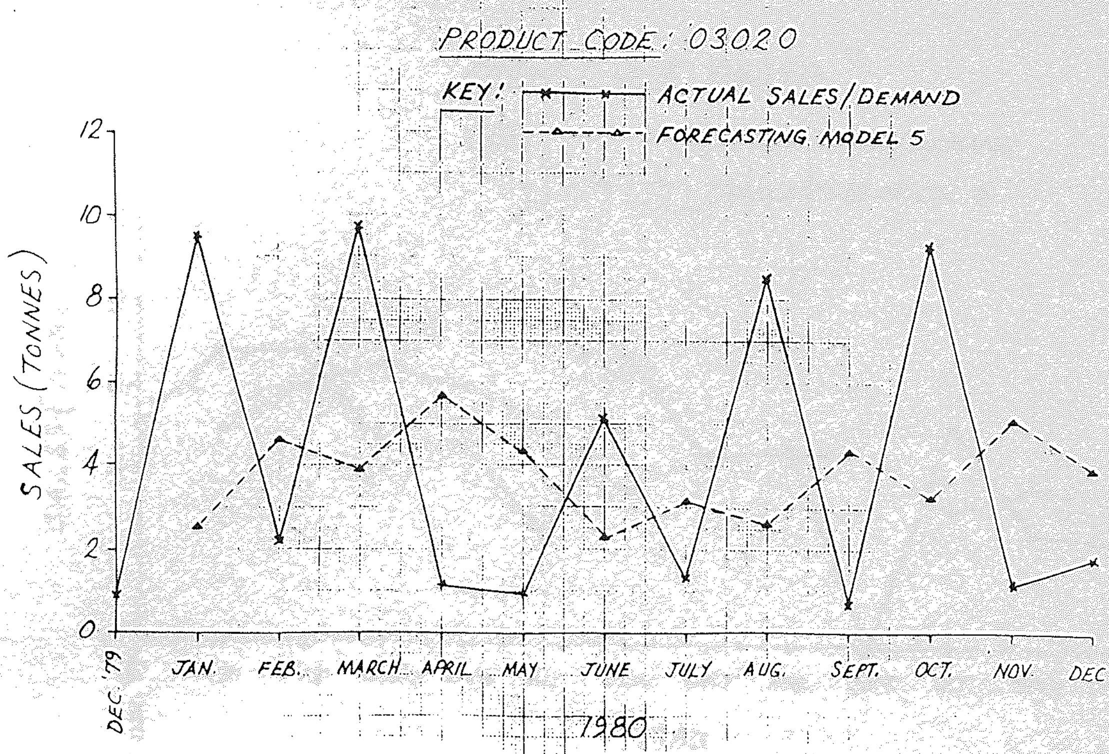


Fig. F5. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 03020

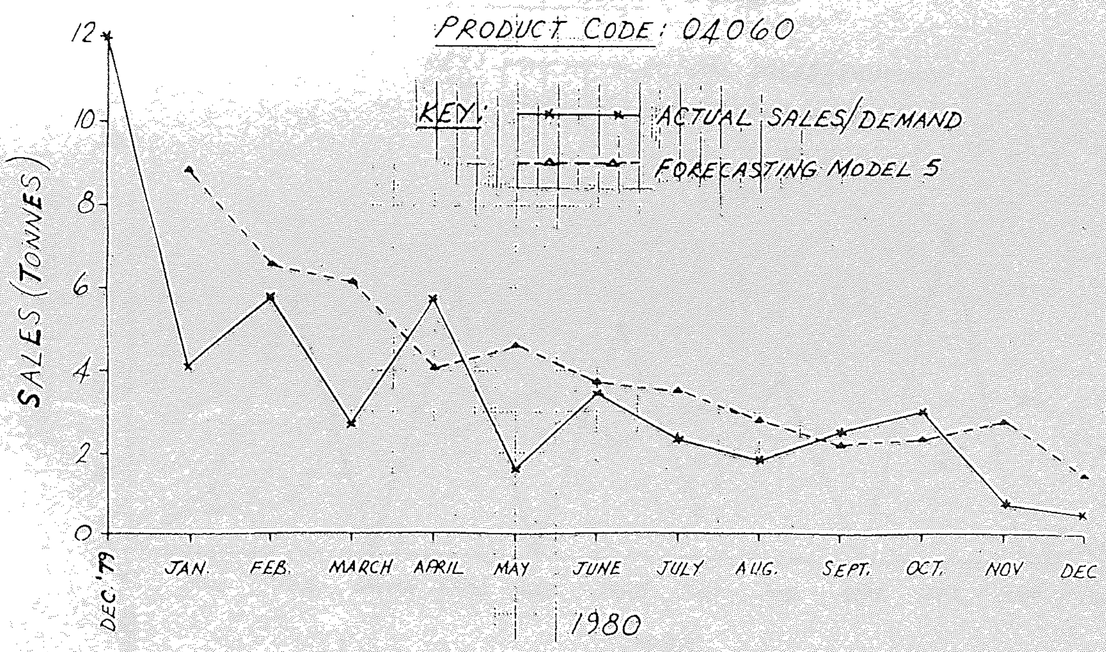


Fig. F6. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 04060

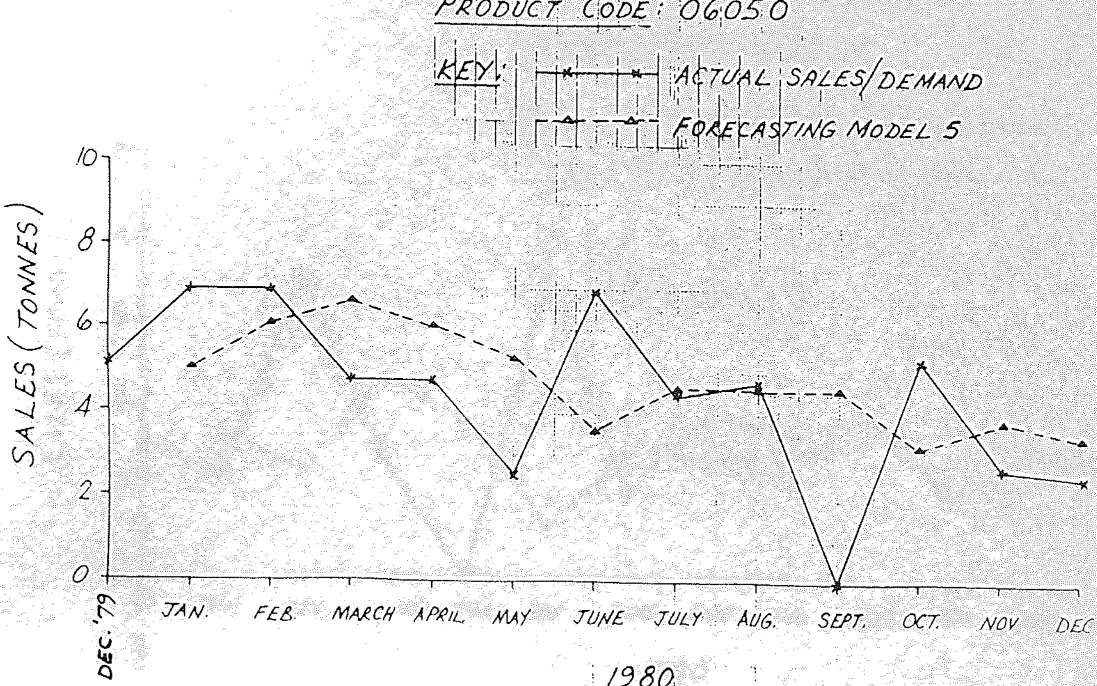


Fig. F7. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 06050

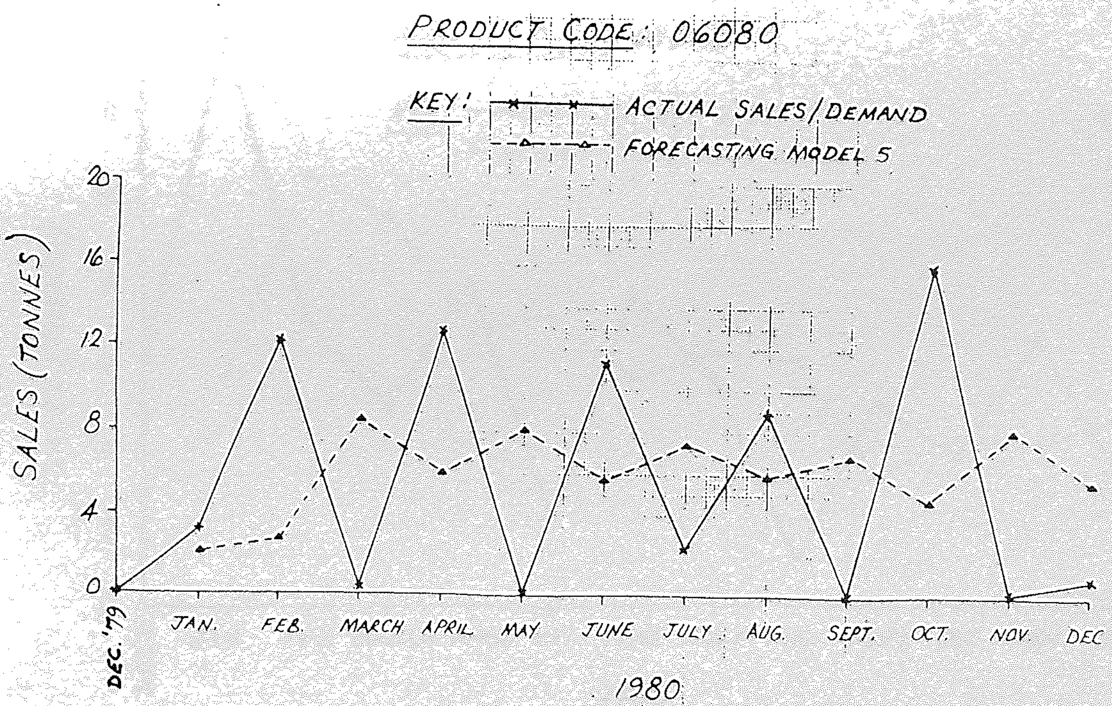


Fig. F8. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 06080

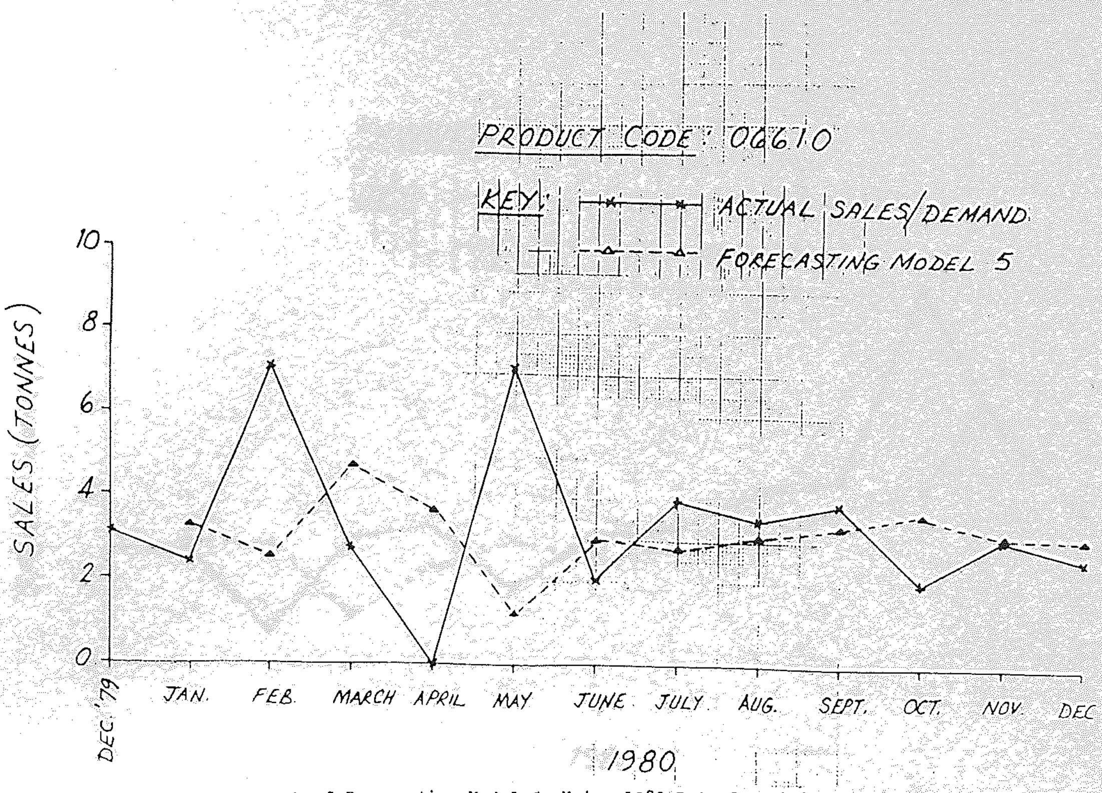


Fig. F9. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 06610

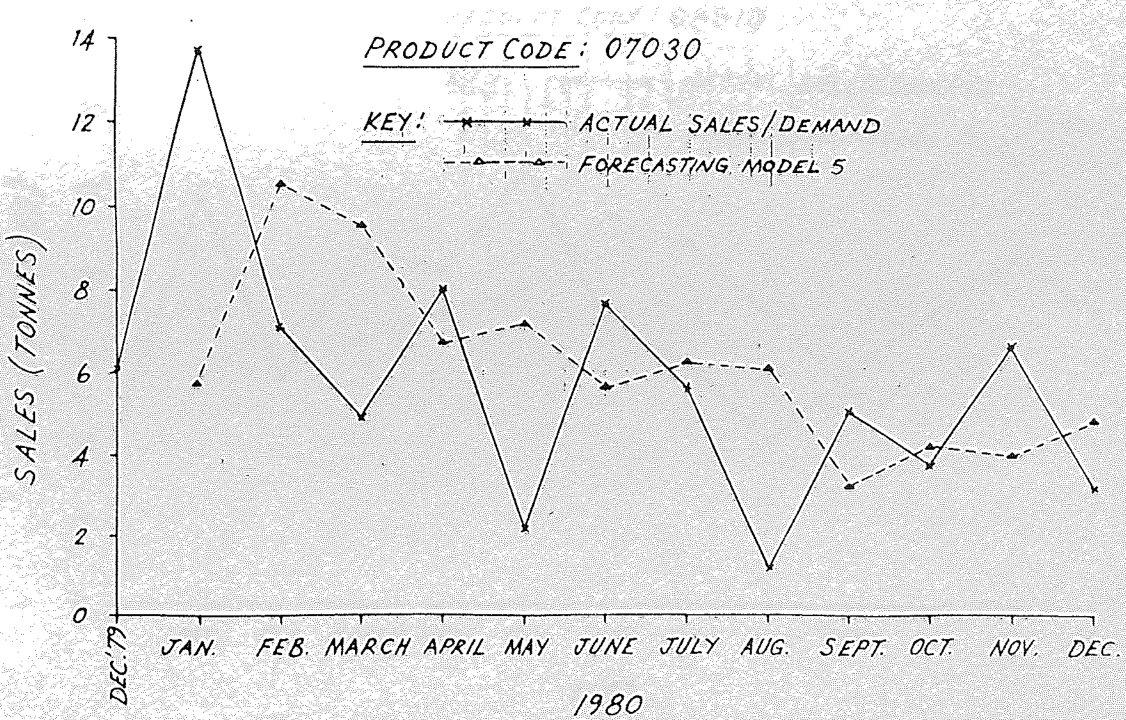


Fig. F10. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 07030

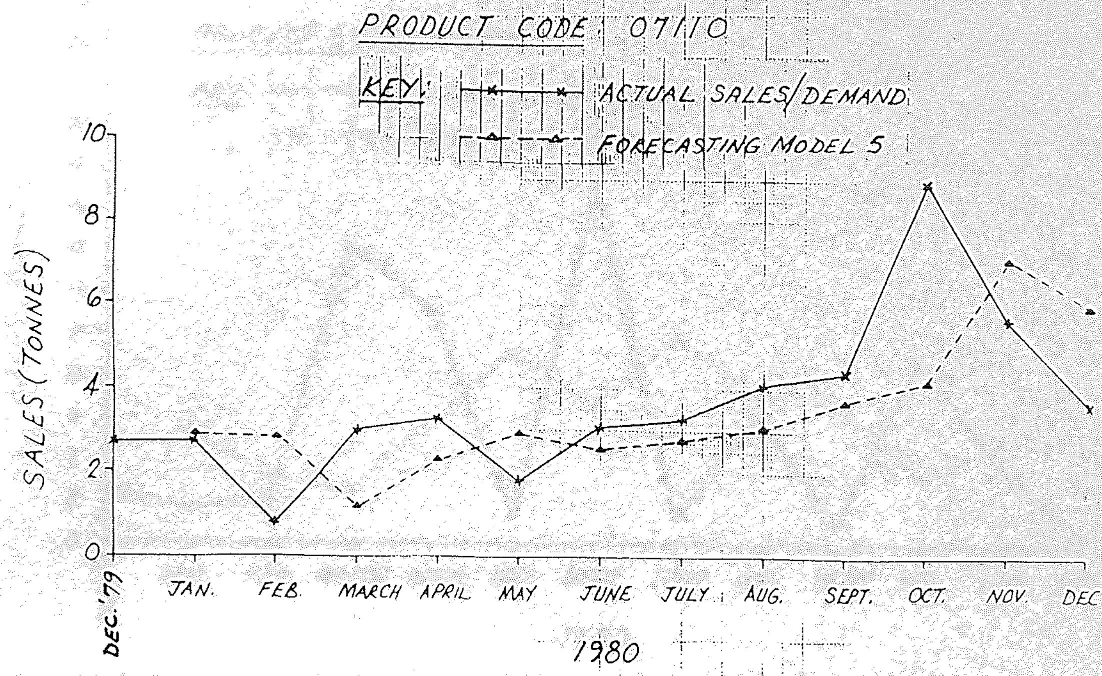


Fig. F11. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 07110

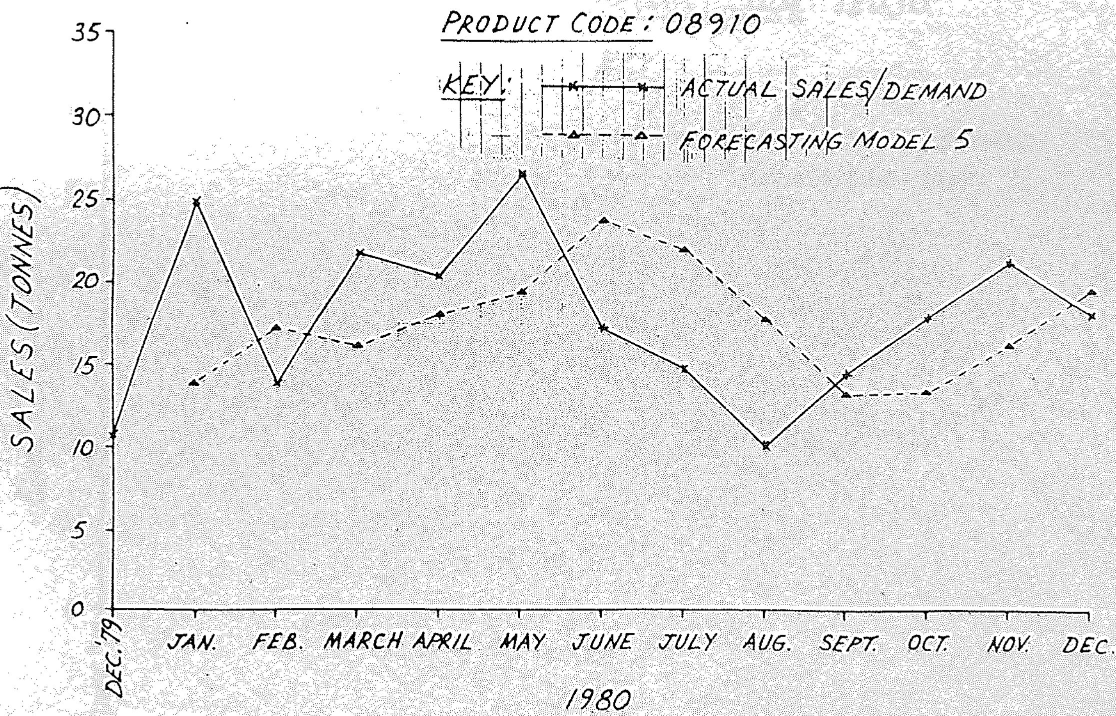


Fig. F12. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 08910

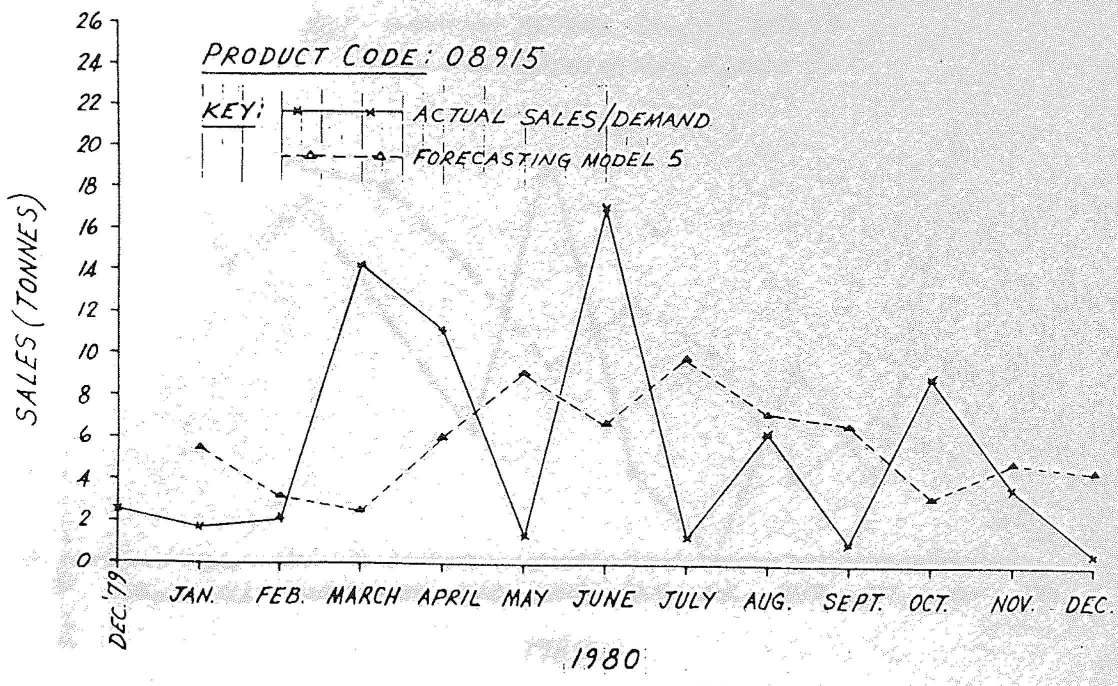


Fig. F13. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 08915

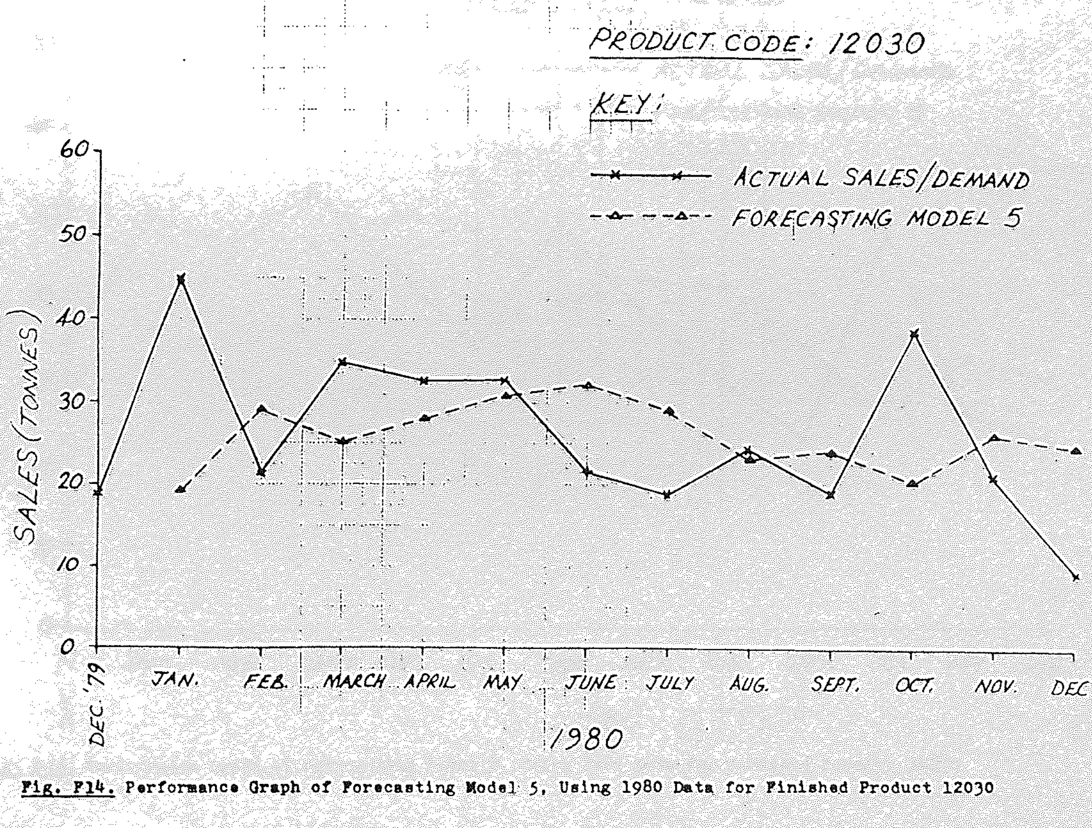


Fig. F14. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 12030

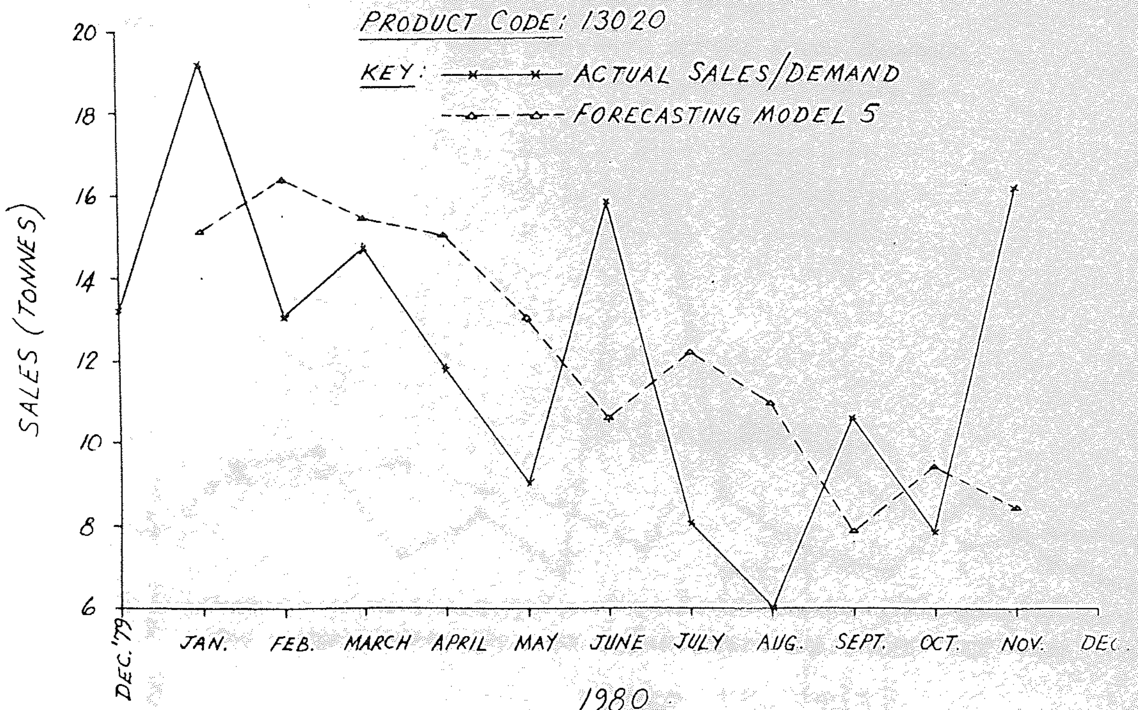


Fig. F15. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 13020

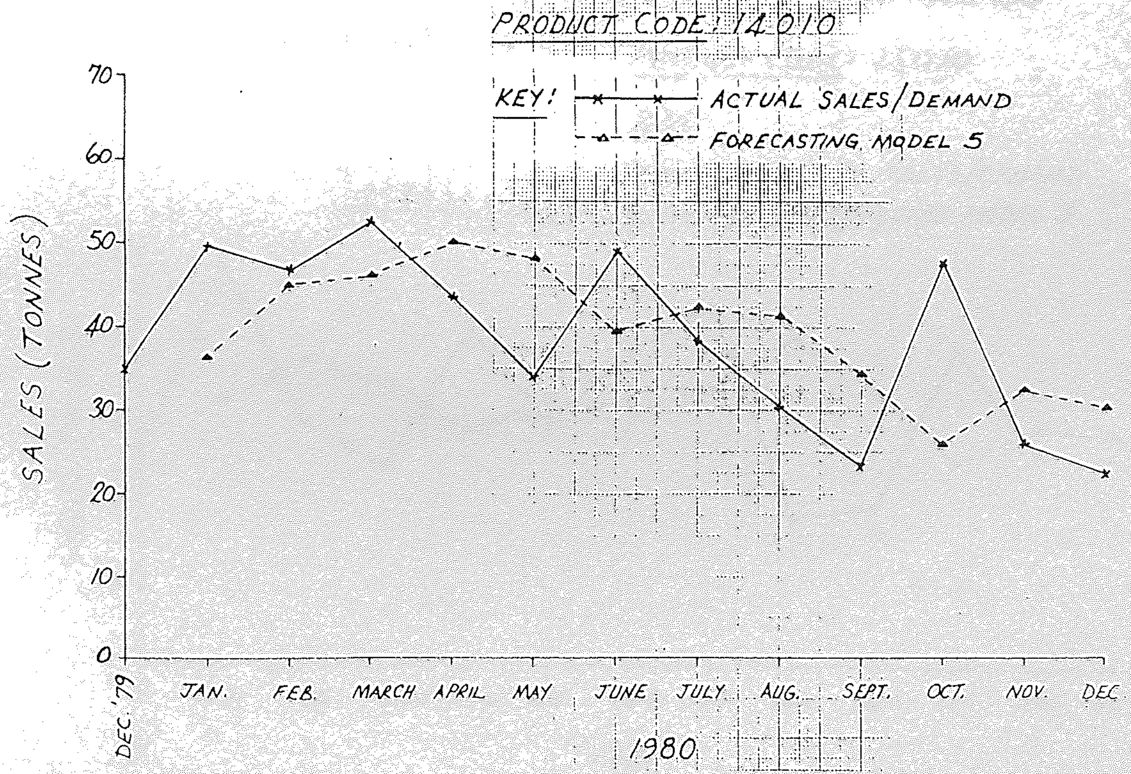


Fig. F16. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 14010

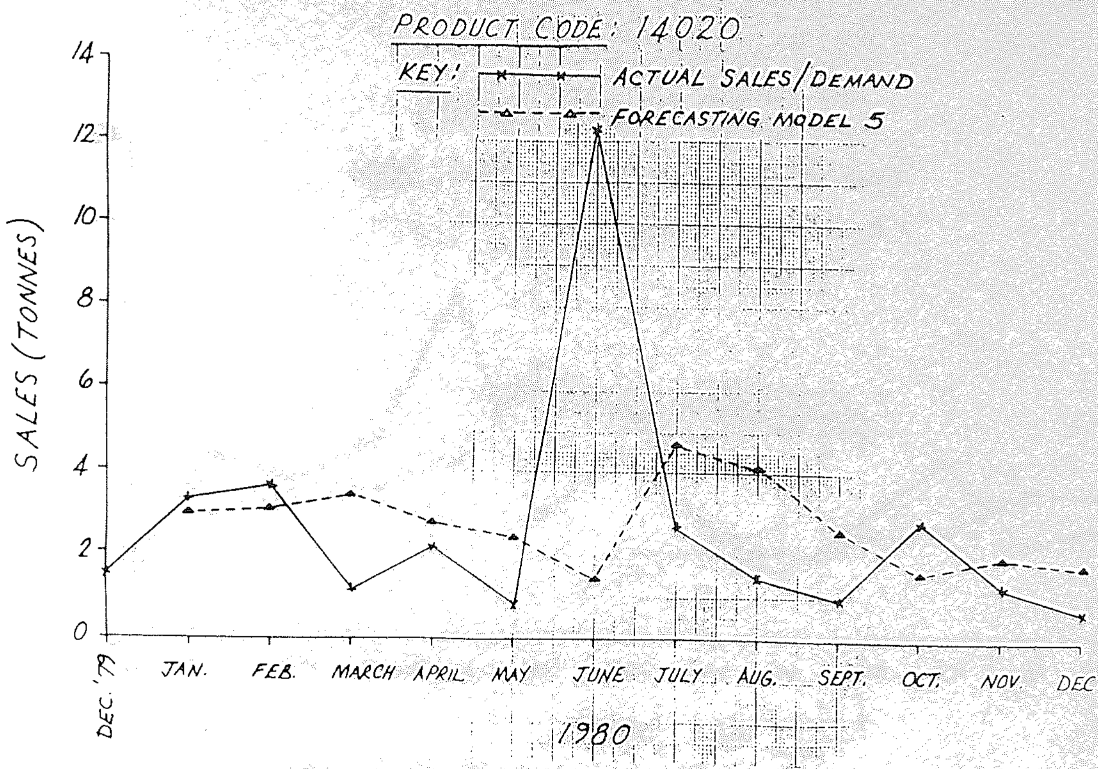


Fig. F17. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 14020

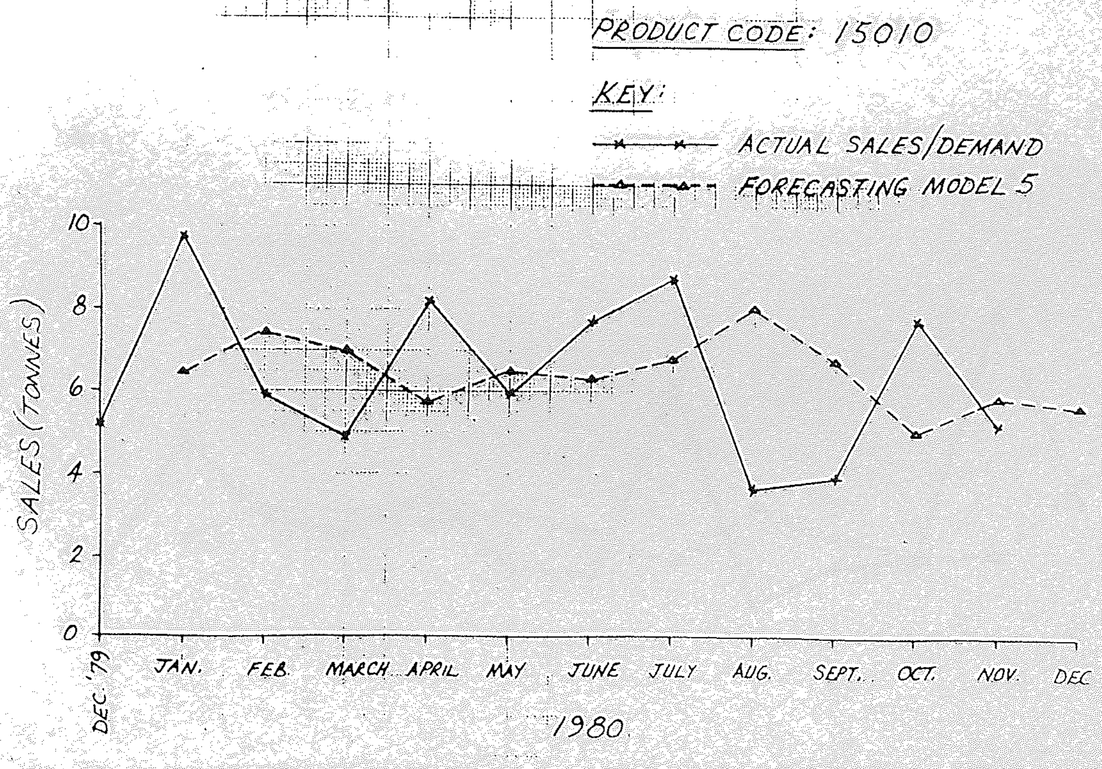


Fig. F18. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 15010

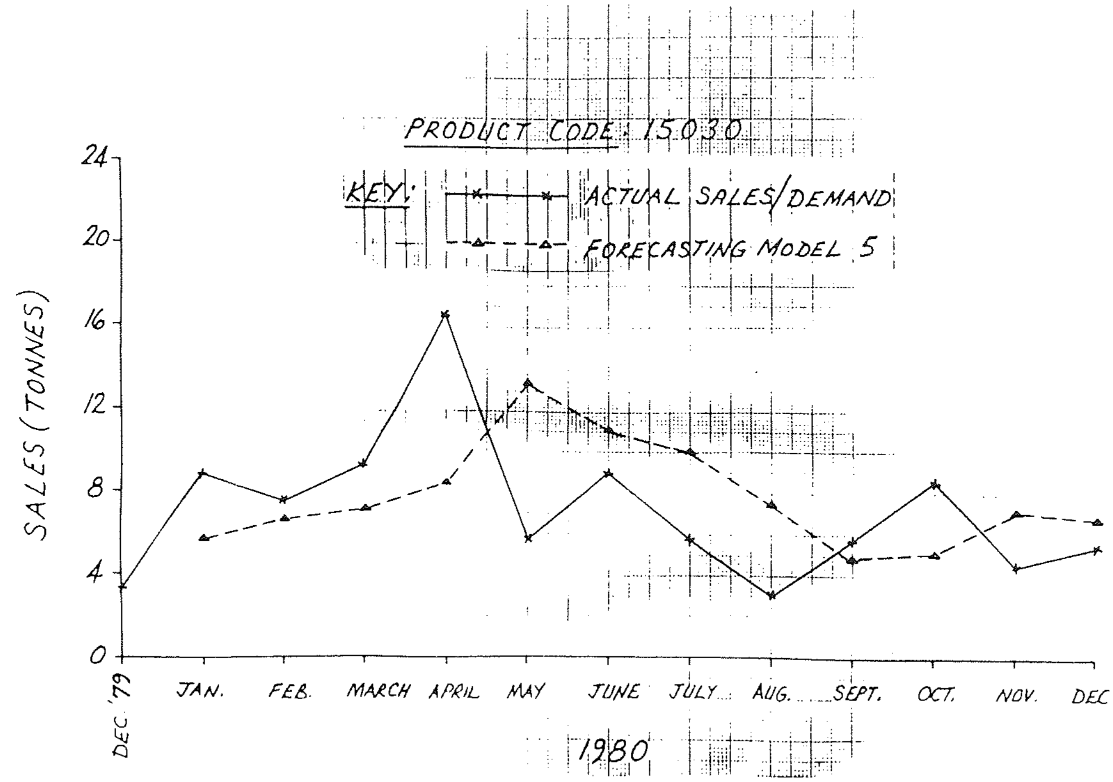


Fig. F19. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 15030

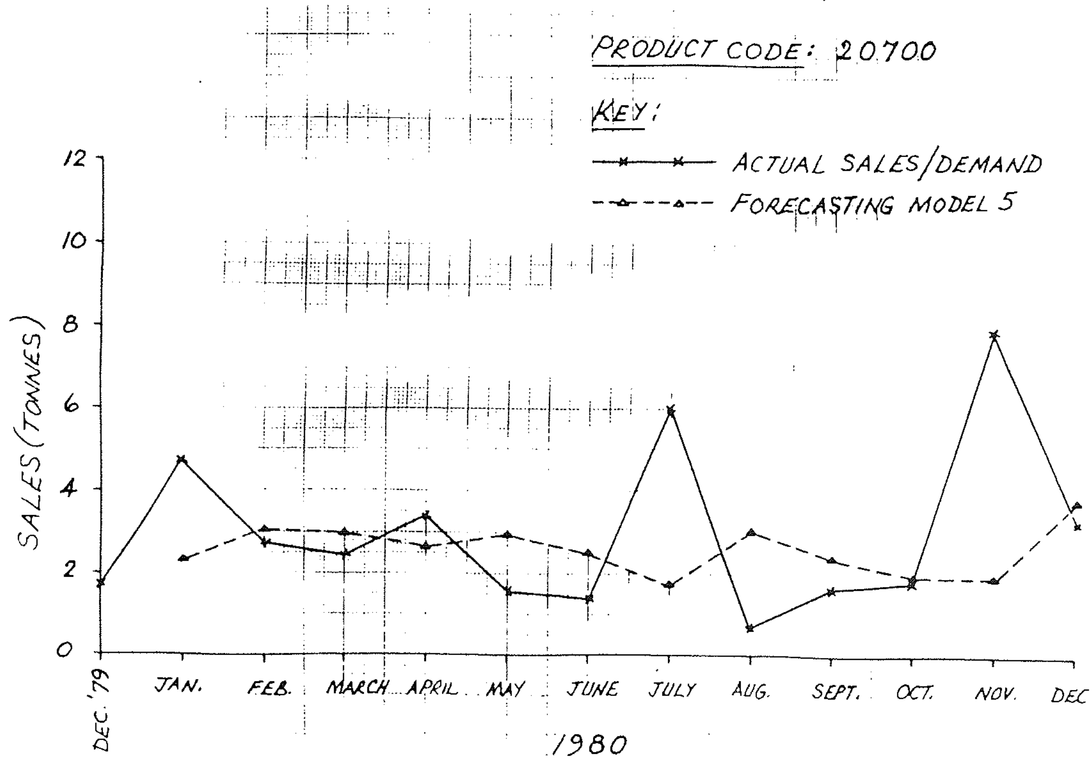


Fig. F20. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 20700

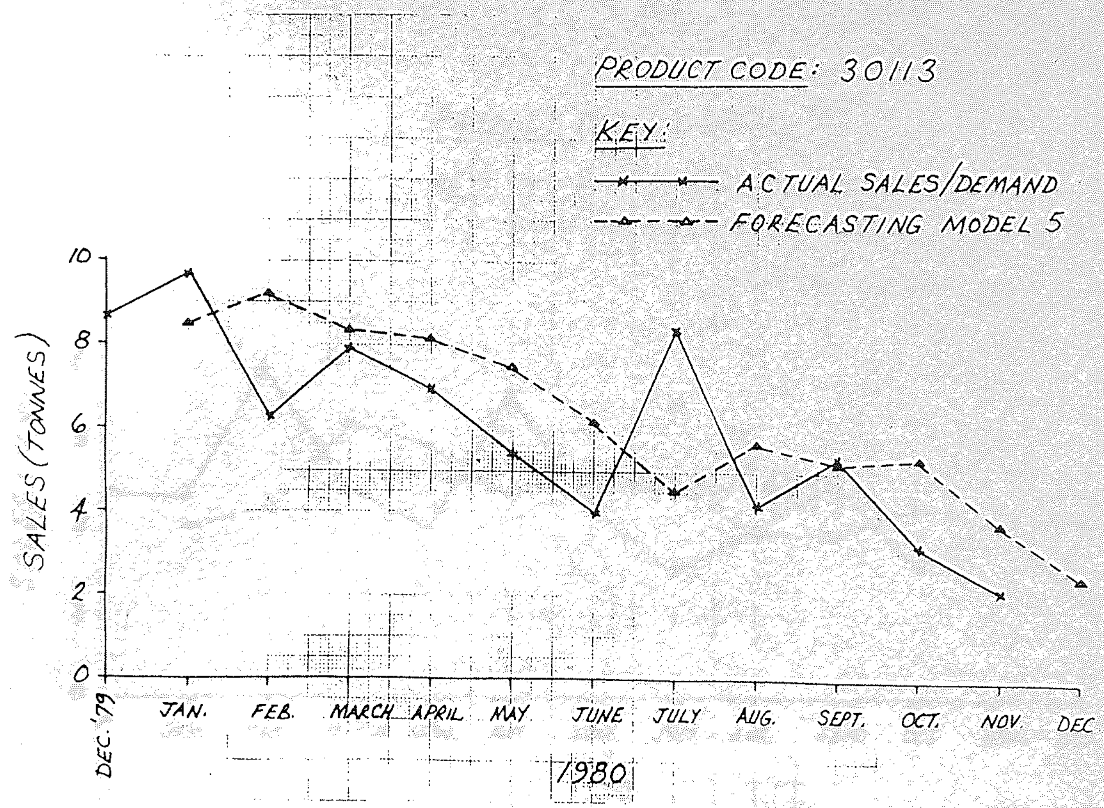


Fig. F21. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 30113

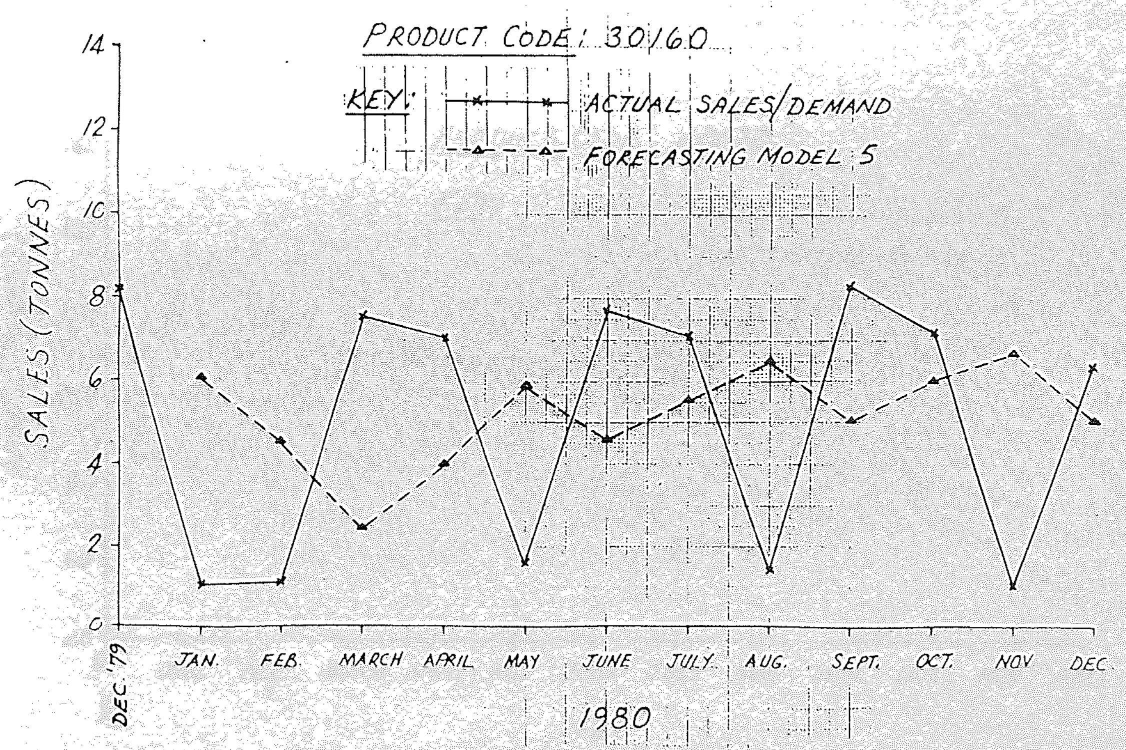


Fig. F22. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 30160

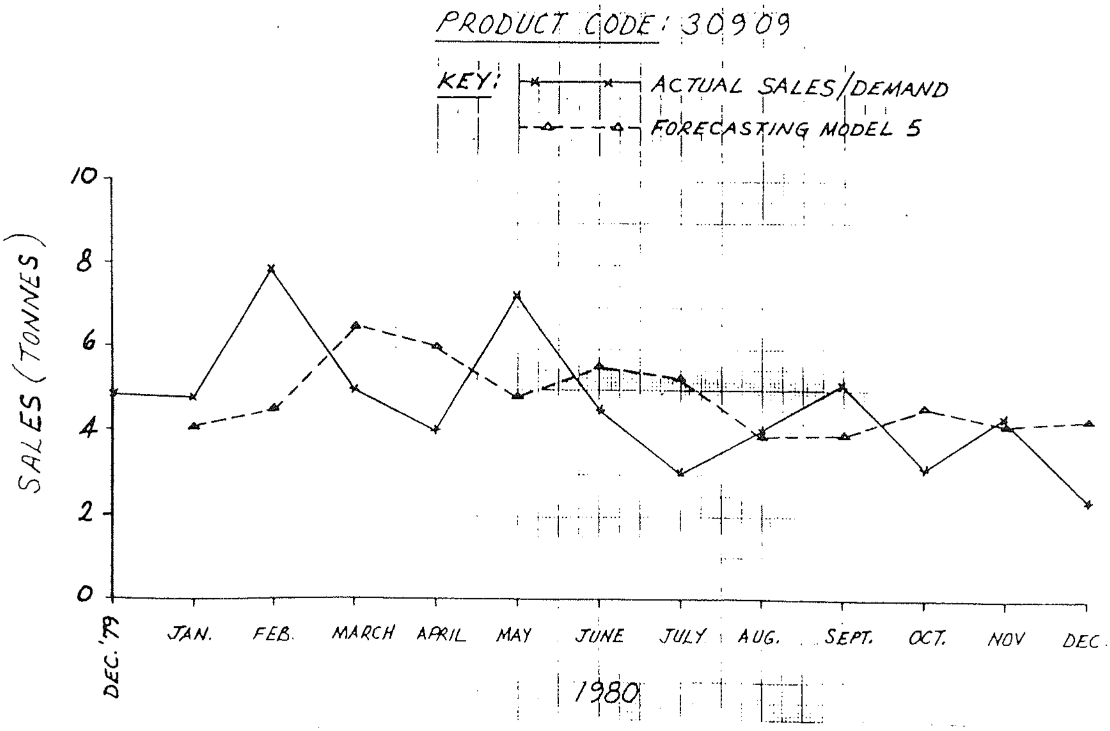


Fig. F23. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 30909

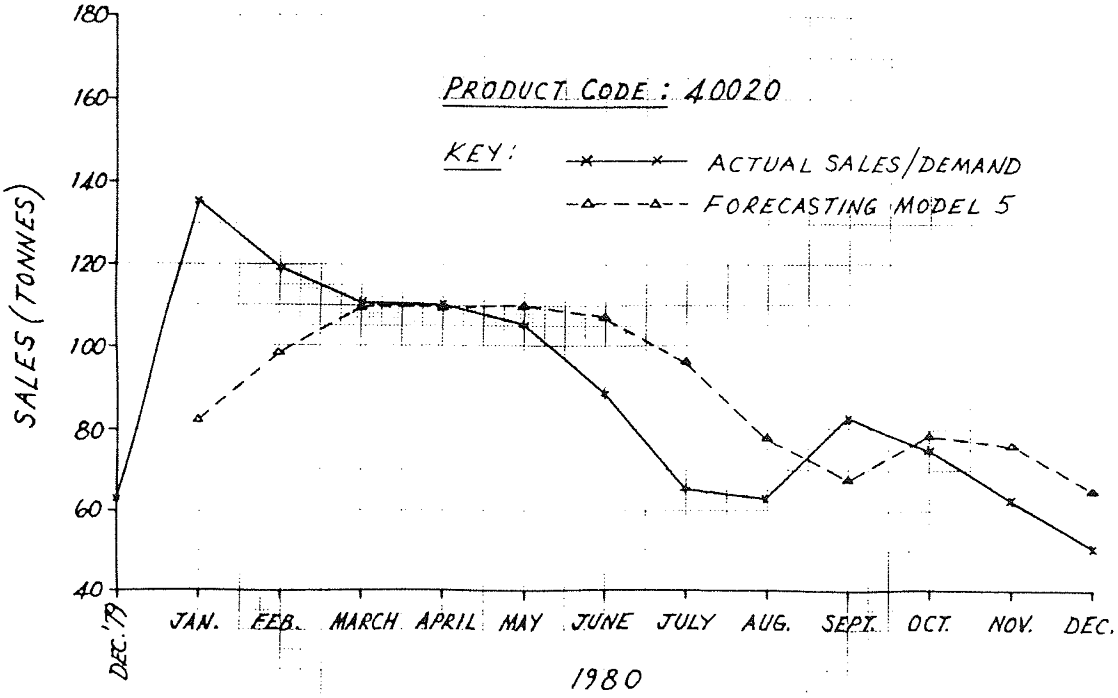


Fig. F24. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 40020

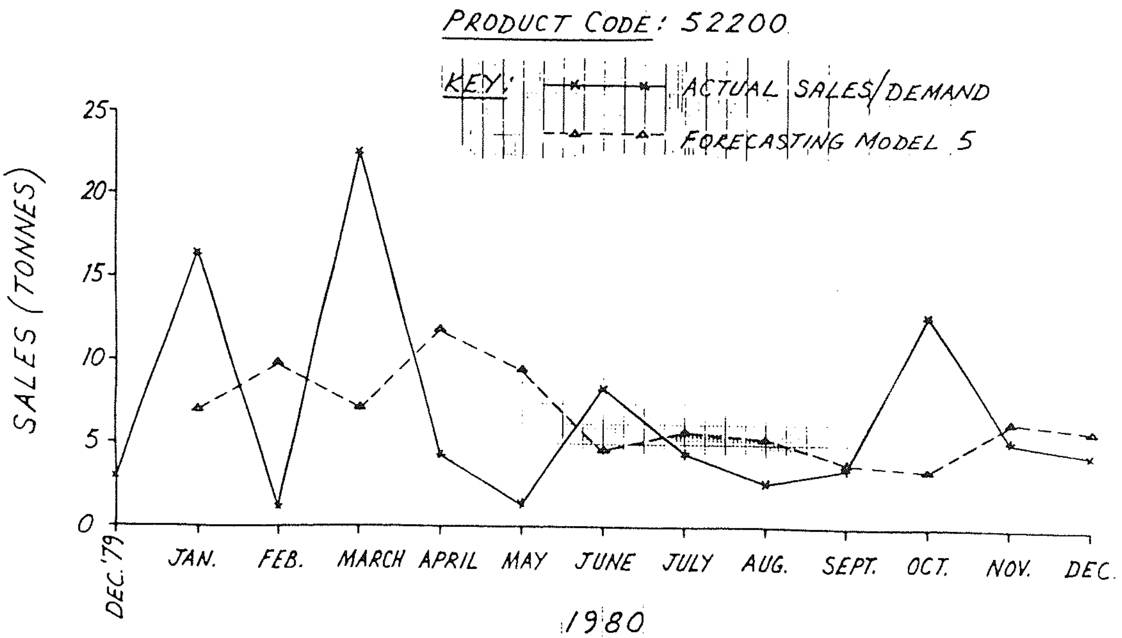


Fig. F25. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 52200

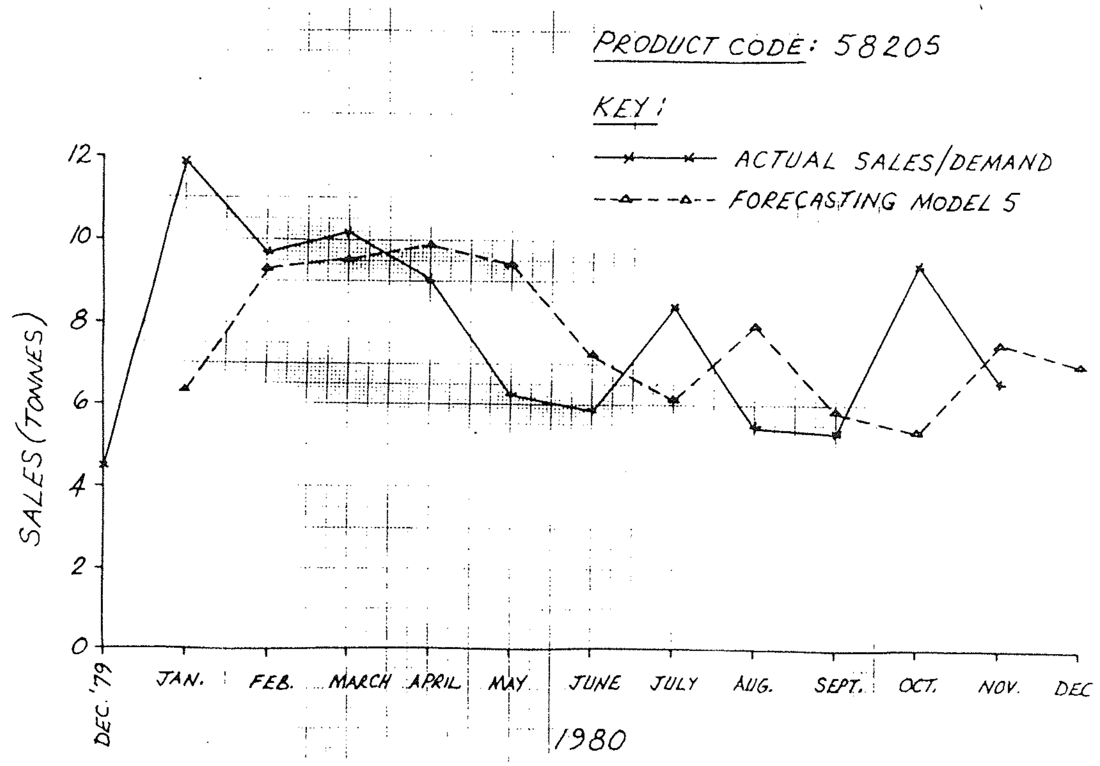


Fig. F26. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 58205

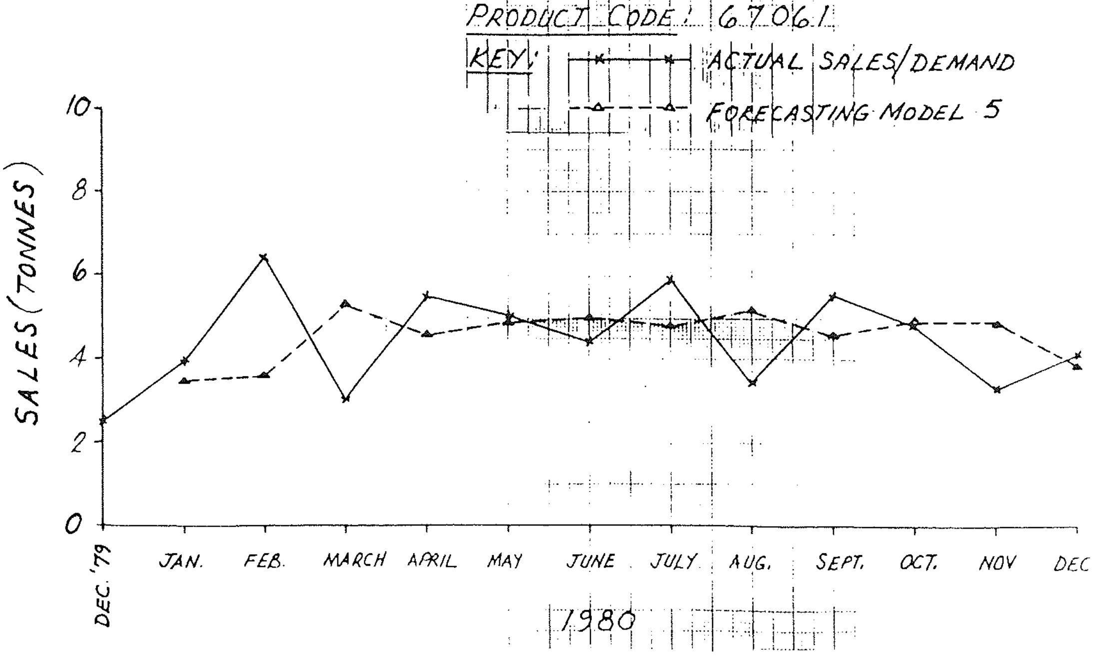


Fig. F27. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 67061

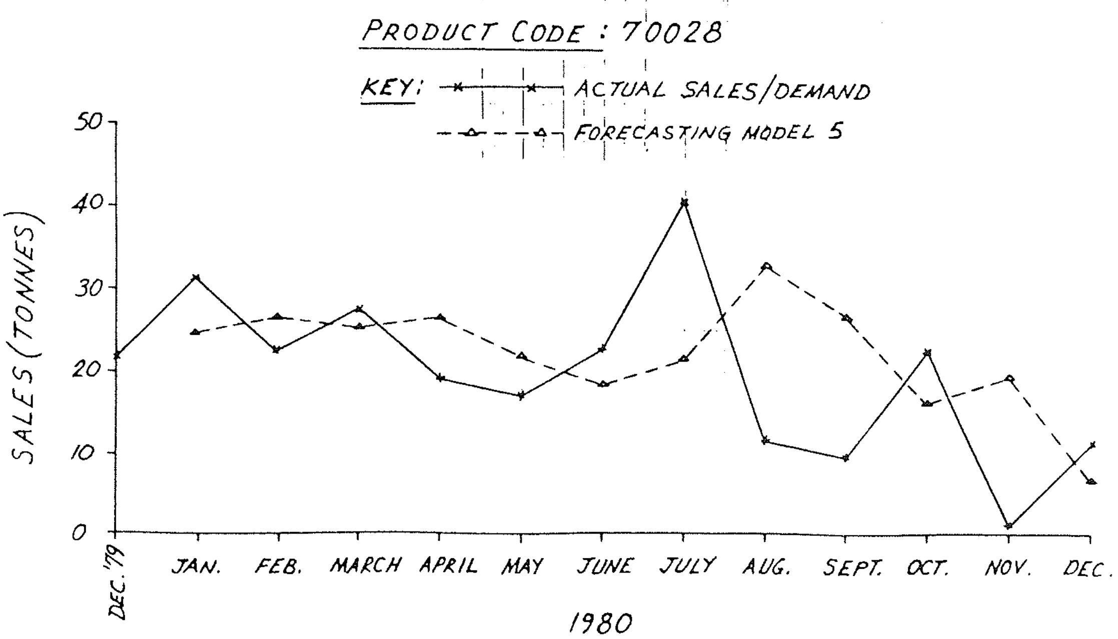


Fig. F28. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 70028

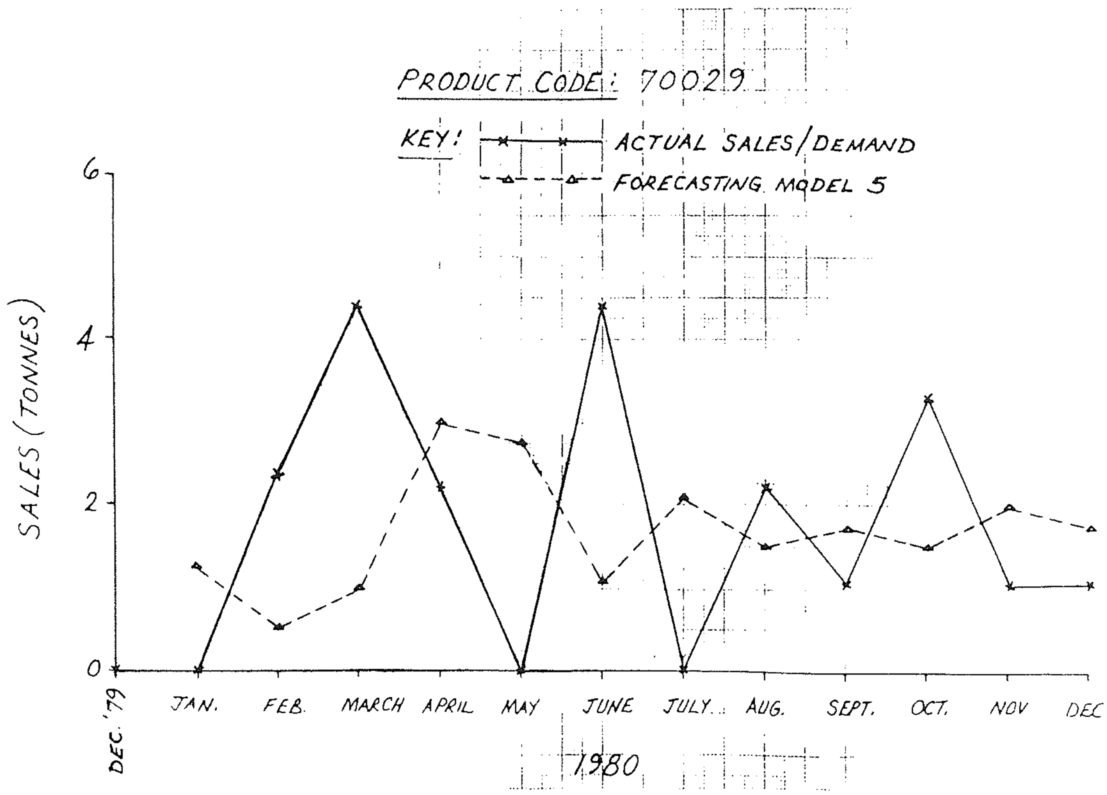


Fig. F29. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 70029

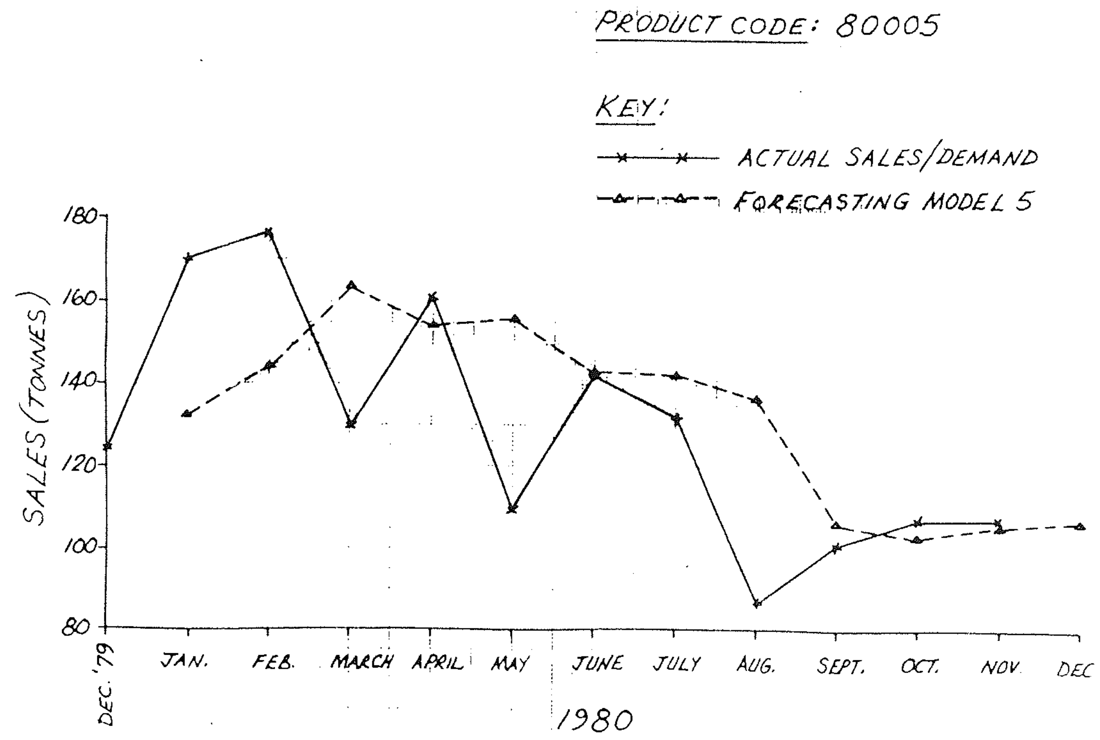


Fig. F30. Performance Graph of Forecasting Model 5, Using 1980 Data for Finished Product 80005

Appendix G

Partial Expectation (E(K))

For the purpose of clarity, the principle of partial expectation (symbolised as E(K)) is considered best explained in the context of its application within this thesis:

1) When applied to the Normal distribution of forecasting-errors of demand, it relates to the expected* amount ($E(K_D)\sigma_D$) by which demand will exceed $F_D + K_D\sigma_D$ during an ERP, given that demand greater than $F_D + K_D\sigma_D$ occurs (see Figure G.1).

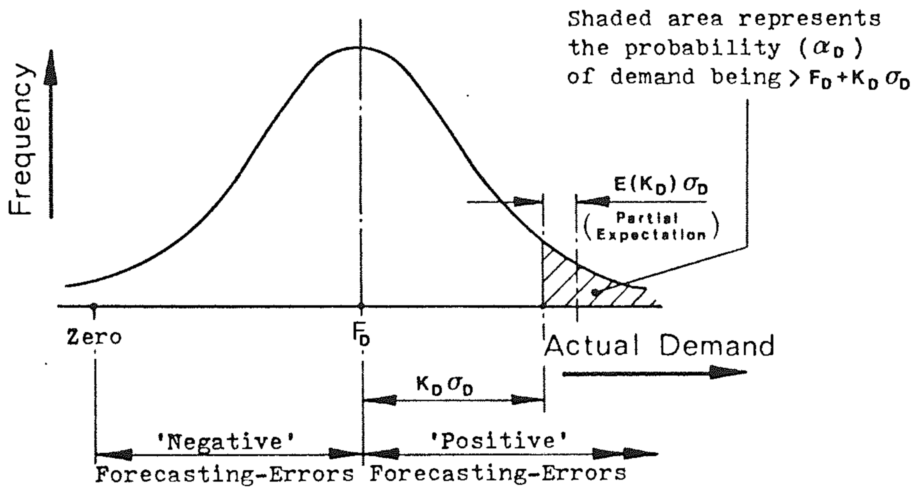


Fig. G.1 Diagrammatical Representation of Partial Expectation as Applied to the Normal Distribution of Demand Forecasting-Errors.

2) When applied to the Normal distribution of forecasting-errors of lead-time, it relates to the expected amount ($E(K_{LT})\sigma_{LT}$) by which lead-time will exceed $F_{LT} + K_{LT}\sigma_{LT}$ given that a lead-time greater than $F_{LT} + K_{LT}\sigma_{LT}$ occurs (see Figure G.2).

---

* Statistical average

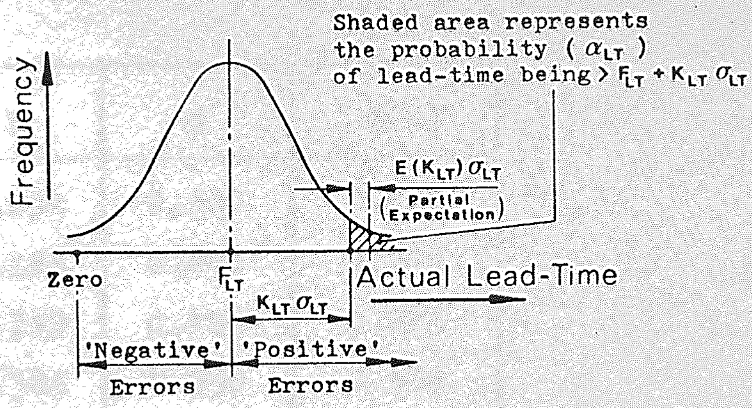


Fig. G.2 Diagrammatical Representation of Partial Expectation as Applied to the Normal Distribution of Lead-Time Forecasting-Errors.

In pure mathematical terms, it is the second integral over the range between some specified point on a Normal distribution and infinity (Ref 47). In layman's terms, it may be thought of as the average excess, given that there is some excess.

A comprehensive range of partial expectation values for associated values of K and α is presented for a 0,1 Normal distribution in Table G.1.

K	α	E(K)
0.000	0.500	0.400
0.126	0.450	0.340
0.253	0.400	0.285
0.385	0.350	0.236
0.524	0.300	0.190
0.674	0.250	0.149
0.842	0.200	0.111
1.036	0.150	0.078
1.282	0.100	0.047
1.645	0.050	0.021
1.960	0.025	0.009
2.326	0.010	0.004
2.576	0.005	0.002
3.090	0.001	0.000

Table G.1 Partial Expectation Values for Associated Values of K and α, Presented for a 0,1 Normal Distribution.

Appendix H

Computer Program-Listing of
Stock Control Methodology Simulation.

NAME OF SIMULATION: STOCK CONTROL METHODOLOGY

```
READY.

 2 PRINT"ENTER NAME OF SIMULATION"
 3 INPUT A$
 5 PRINT"ENTER PRODUCT CODE"
 10 INPUT C$
 15 PRINT"ENTER PRODUCT DESCRIPTION"
 20 INPUT D1$
 25 PRINT"ENTER AVERAGE TRANSACTION QTY"
 30 INPUT Q1
 31 PRINT"ENTER METHOD OF STORAGE:1=BARRELS; 2=BULK"
 32 INPUT M1
 33 IF M1=1 THEN 37
 34 PRINT"ENTER AVERAGE BARREL TRANSACTION QTY IN TONNES"
 35 INPUT Q3
 37 OPEN4,4:CMD4
 38 PRINT£4,"NAME OF SIMULATION: ";A$
 39 PRINT£4,"PRODUCT CODE: ";C$
 41 PRINT£4,"PRODUCT DESCRIPTION: ";D1$
 43 CLOSE 4
 55 PRINT"ENTER ESTIMATED NO OF REPLENISHMENTS"
 60 INPUT N
 65 N=N+10
 68 DIM L(12)
 70 DIM A(N)
 71 DIM A6(10)
 72 DIM B(10)
 73 DIM C(4,12)
 74 DIM D(12)
 75 DIM J(10)
 76 DIM K6(10)
 77 DIM N(4,12)
 78 DIM V(10)
 79 DIM E6(10)
 80 DIM M(10)
 81 FOR G=0 TO 8
 82 READ K6(G)
 83 DATA 0,0.5,1.04,1.282,1.645,2.00,2.25,2.75,3.00
 84 NEXT G
 85 FOR G=0 TO 8
 86 READ A6(G)
 87 DATA 0.5,0.31,0.15,0.10,0.05,0.023,0.012,0.003,0.001
 88 NEXT G
 89 FOR G=0 TO 8
 90 READ E6(G)
 91 DATA 0.401,0.2,0.077,0.048,0.021,0.008,0.004,0.001,0
 92 NEXT G
 125 IF M1=1 THEN 142
 130 DIM D2(12)
 135 DIM N3(4,12)
 140 DIM C3(4,12)
 142 READ H,R2,C6
 145 READ F1,F2,S4,M4,T4,R4,F3,E4,D
 146 READ F,M5,T
 148 W1=0
 150 Q4=0
 152 P2=0
```

Appendix H: Computer Program-Listing of Stock Control Methodology Simulation (page 1 of 7 pages).

```
154 J2=0
158 R=0
159 GOSUB 3000
160 GOSUB 3500
161 GOSUB 4000
162 L=0
164 OPEN 4,4: CMD4
166 PRINT"STOCK-LEVEL = ";L
168 PRINT£4
170 PRINT£4
172 CLOSE 4
205 K1=0
210 K=1
215 B(K)=0
217 M(K)=0
220 V(K)=0
225 X1=0
230 X2=0
240 R=1
245 A(R)=0
250 L1=0
255 S=0
260 J(K)=0
355 M=1
357 READ D(M)
360 IF D(M)>0 THEN 400
362 W=1
364 IF B(K)=0 THEN 368
366 V(K)=V(K)+1
368 W1=W1+1
369 IF S=1 THEN 710
370 P2=P2+1
372 GOTO 960
374 IF W<4 THEN 380
376 L1=L1+L
378 GOTO 1330
380 L1=L1+L
382 W=W+1
388 GOTO 364
400 W=1
402 X=D(M)/Q1
404 IF (X-(INT(X)+0.5)) >=0 THEN 410
406 X=INT(X)
408 GOTO 415
410 X=INT(X)+1
415 X1=X1+X
417 N(W,M)=X*RND(1)
419 IF W=1 THEN 440
420 IF W=2 THEN 455
430 GOTO 460
440 N(W,M)=N(W,M)*0.5
450 GOTO 460
455 N(W,M)=N(W,M)*0.666
460 IF (N(W,M)-(INT(N(W,M))+0.5))>=0 THEN 485
470 N(W,M)=INT(N(W,M))
480 GOTO 490
485 N(W,M)=INT(N(W,M))+1
490 IF B(K)=0 THEN 510
500 V(K)=V(K)+1
510 C(W,M)=N(W,M)*Q1
515 X=X-N(W,M)
520 IF X>0 THEN 560
522 X=0
560 A(R)=A(R)+C(W,M)
565 W1=W1+1
567 IF S=1 THEN 570
568 P2=P2+1
570 IF C(W,M)<=L THEN 650
575 Z=0
```

Appendix H: Computer Program-Listing of Stock Control Methodology Simulation (page 2 of 7 pages).

```
580 IF Q1>L THEN 600
585 L=L-Q1
590 Z=Z+1
595 GOTO 580
600 X2=X2+Z
605 N(W,M)=N(W,M)-Z
610 J(K)=J(K)+N(W,M)
615 B1=N(W,M)*Q1
620 B(K)=B(K)+B1
625 M(K)=M(K)+B1
630 GOTO 700
650 L=L-G(W,M)
655 X2=X2+N(W,M)
700 IF (L-B(K))>P THEN 960
705 IF S=0 THEN 810
710 C=C+1
715 IF C<>T THEN 960
716 IF (Q-B(K))>=0 THEN 720
717 B(K)=B(K)-Q
718 Q2=0
719 GOTO 760
720 Q2=Q-B(K)
722 IF B(K)=0 THEN 760
725 K1=K
730 K=K+1
735 J(K)=0
740 V(K)=0
745 B(K)=0
747 M(K)=0
760 L=L+Q2
762 OPEN4,4:CMD4
764 PRINT£4,"NEW STOCK-LEVEL = ";L
765 PRINT£4
766 PRINT£4,"BACKORDER QTY = ";INT(B(K)*1000)/1000
768 PRINT£4
770 CLOSE 4
775 S=0
780 GOTO 700
810 GOSUB 3000
815 GOSUB 3500
820 GOSUB 4000
822 IF S=0 THEN 830
824 S=0
826 GOTO 960
830 S=1
835 T=2*RND(1)+1
840 IF (T-(INT(T)+0.5))>=0 THEN 860
845 T=INT(T)
850 GOTO 865
860 T=INT(T)+1
865 C=0
870 R=R+1
875 A(R)=0
880 W1=0
882 P2=0
960 IF M1=2 THEN 975
965 IF D(M)=0 THEN 374
970 GOTO 1290
975 IF W>1 THEN 981
980 READ D2(M)
981 IF D2(M)=0 THEN 965
982 IF W>1 THEN 1020
990 X3=D2(M)/Q3
995 IF (X3-(INT(X3)+0.5))>=0 THEN 1010
1000 X3=INT(X3)
1005 GOTO 1015
1010 X3=INT(X3)+1
1015 X1=X1+X3
1020 IF W<4 THEN 1035
```

<u>Appendix H</u>: Computer Program-Listing of Stock Control Methodology Simulation (page 3 of 7 pages).

```
1025 N3(W,M)=X3
1030 GOTO 1105
1035 N3(W,M)=X3*RND(1)
1040 IF W=1 THEN 1055
1045 IF W=2 THEN 1065
1050 GOTO 1070
1055 N3(W,M)=N3(W,M)*0.5
1060 GOTO 1070
1065 N3(W,M)=N3(W,M)*0.666
1070 IF (N3(W,M)-(INT(N3(W,M))+0.5))>=0 THEN 1085
1075 N3(W,M)=INT(N3(W,M))
1080 GOTO 1090
1085 N3(W,M)=INT(N3(W,M))+1
1090 X3=X3-N3(W,M)
1095 IF X3>0 THEN 1105
1100 X3=0
1105 C3(W,M)=N3(W,M)*Q3
1110 A(R)=A(R)+C3(W,M)
1120 IF C3(W,M)<=L THEN 1205
1125 Z=0
1130 IF Q3>L THEN 1150
1135 L=L-Q3
1140 Z=Z+1
1145 GOTO 1130
1150 X2=X2+Z
1155 N3(W,M)=N3(W,M)-Z
1160 J(K)=J(K)+N3(W,M)
1165 B2=N3(W,M)*Q3
1170 B(K)=B(K)+B2
1175 M(K)=M(K)+B2
1200 GOTO 1215
1205 L=L-C3(W,M)
1210 X2=X2+N3(W,M)
1215 IF (L-B(K))>P THEN 1285
1220 IF S=1 THEN 1285
1225 GOSUB 3000
1230 GOSUB 3500
1232 GOSUB 4000
1234 IF S=0 THEN 1238
1235 S=0
1237 GOTO 1285
1238 S=1
1240 T=2*RND(1)+1
1245 IF (T-(INT(T)+0.5))>=0 THEN 1260
1250 T=INT(T)
1255 GOTO 1265
1260 T=INT(T)+1
1265 G=0
1270 R=R+1
1275 A(R)=0
1280 W1=0
1283 P2=0
1285 IF D(M)=0 THEN 374
1290 L1=L1+L
1295 IF W=3 THEN 1315
1300 IF W=4 THEN 1330
1305 W=W+1
1310 GOTO 417
1315 W=4
1320 N(W,M)=X
1325 GOTO 490
1330 L(M)=L
1332 IF M=12 THEN 1345
1335 M=M+1
1340 GOTO 357
1345 OPEN 4,4:CMD 4
1360 PRINT£4
1365 PRINT£4
1370 PRINT£4,"AVERAGE WEEKLY STOCK-LEVEL = ";INT((L1/48)*100)/100
1375 PRINT£4
```

Appendix H: Computer Program-Listing of Stock Control Methodology Simulation (page 4 of 7 pages).

```
1377 PRINT£4,"TOTAL NO OF STOCK REPLENISHMENTS = ";R
1378 PRINT£4
1379 PRINT£4,"AVERAGE PERIOD BETWEEN RAISING REPLENISHMENT-ORDERS = ";
1380 PRINT£4,INT((48/R)*10)/10;"WEEKS"
1381 PRINT£4
1382 PRINT£4
1384 PRINT£4,"TOTAL NO OF TRANSACTIONS = ";X1
1385 PRINT£4
1386 PRINT£4
1387 PRINT£4,"NO OF TRANSACTIONS SATISFIED EX-STOCK = ";X2
1389 PRINT£4
1390 PRINT£4,"SERVICE-LEVEL = ";INT((X2/X1)*1000)/10;" %"
1395 PRINT£4
1400 PRINT£4,"TOTAL NO OF STOCKOUTS = ";K1
1402 PRINT£4
1405 CLOSE 4
1410 IF K1=0 THEN 1517
1415 V=0
1416 J2=0
1417 B=0
1418 C2=0
1420 FOR K=1 TO K1
1425 V=V+V(K)
1426 J2=J2+J(K)
1427 B=B+M(K)
1428 IF V(K)<=2 THEN 1430
1429 C2=C2+M(K)
1430 NEXT K
1431 IF V>=K1 THEN 1435
1432 V=K1
1435 OPEN 4,4:CMD 4
1436 PRINT£4,"TOTAL NO OF STOCKOUT ORDERS IN YEAR = ";J2
1437 PRINT£4
1438 PRINT£4
1440 PRINT£4,"PROBABILITY OF STOCKOUT = ";INT((V/48)*100)/100
1445 PRINT£4
1450 FOR K=1 TO K1
1455 PRINT£4,"NUMBER OF ORDERS IN STOCKOUT ";K;" = ";J(K)
1465 PRINT£4
1470 PRINT£4,"TOTAL BACKORDER QTY IN STOCKOUT ";K;" = ";INT(M(K)*100)/100
1475 PRINT£4
1480 PRINT£4,"TOTAL DURATION OF STOCKOUT ";K;" = ";V(K);" WEEKS"
1485 PRINT£4
1490 PRINT£4
1495 NEXT K
1500 PRINT£4,"AVERAGE TOTAL BACKORDER-QTY PER STOCKOUT = ";INT((B/K1)*100)/100
1505 PRINT£4
1510 PRINT£4
1515 GOTO 1535
1517 OPEN4,4:CMD4
1520 PRINT£4,"PROBABILITY OF STOCKOUT APPROACHES ZERO"
1525 PRINT£4
1530 PRINT£4
1535 CLOSE 4
1540 H3=L1*H
1545 R3=R2*R
1550 S3=C2*C6
1555 T3=H3+R3+S3
1700 OPEN4,4:CMD4
1705 PRINT£4,"INVENTORY HOLDING COST FOR YEAR = £";INT(H3*100)/100
1710 PRINT£4
1715 PRINT£4,"TOTAL REPLENISHMENT COST FOR YEAR = £";INT(R3*100)/100
1720 PRINT£4
1725 PRINT£4,"TRUE TOTAL STOCKOUT COST FOR YEAR = £";INT(S3*100)/100
1730 PRINT£4
1735 PRINT£4
1737 PRINT£4,"TOTAL INVENTORY OPERATING COST FOR YEAR = $";INT(T3*100)/100
1738 PRINT£4
1740 PRINT£4
1741 PRINT£4
```

Appendix H: Computer Program-Listing of Stock Control Methodology Simulation (page 5 of 7 pages).

```
1742 PRINT£4
1743 FOR I=1 TO 12
1744 PRINT£4,"END OF MONTH ";I;" STOCK-LEVEL = ";INT(L(I)*100)/100
1746 PRINT£4
1747 NEXT I
1748 PRINT£4,"TOTAL QUANTITY ORDERED IN YEAR = ";Q4
1749 CLOSE 4
1750 DATA 0.67,147.5,77.77,6,23.91,-1.68,6.91,-0.25
1755 DATA 0,20.18,16.88,35,2,0.58,2
1760 DATA 13,15,5,8,2,53
1765 DATA 10,6,3,11,5,3
1770 GOTO 5000
3000 IF R=0 THEN 3005
3001 IF W1 > 0 THEN 3004
3002 W1=1
3003 A(R)=C(W,M)+C3(W,M)
3004 D=(A(R)/W1)*P1
3005 E1=D-F2
3010 E2=D-F3
3020 S4=(0.2*E1)+(0.8*S4)
3025 M4=(0.2*ABS(E1))+(0.8*M4)
3030 T1=INT((S4/M4)*100)/100
3040 F2=(0.3*D)+(0.7*F2)
3050 IF ABS(T1)<0.46 THEN 3105
3055 REM CHECK FOR PREVIOUS TREND READINGS
3060 IF R4=1 THEN 3080
3065 R4=1
3070 T4=T1
3075 GOTO 3110
3080 REM CHECK FLUCTUATION OF TREND
3085 IF T4*T1 > 0 THEN 3160
3090 R4=1
3095 T4=T1
3100 GOTO 3110
3105 R4=0
3110 REM CHECK FORECAST BIAS
3115 IF E4*E2 > 0 THEN 3140
3125 A4=0.3
3130 B4=0.7
3135 GOTO 3175
3140 A4=0.6
3145 B4=0.4
3155 GOTO 3175
3160 T4=T1
3165 A4=ABS(T1)
3170 B4=1-A4
3175 E4=E2
3180 F3=(A4*D)+(B4*F3)
3185 S1=1.092*M4
3190 RETURN
3500 E=T-F
3510 M5=(0.2*ABS(E))+(0.8*M5)
3515 F=(0.3*T)+(0.7*F)
3520 IF (F-(INT(F)+0.5))>=0 THEN 3535
3525 F=INT(F)
3530 GOTO 3540
3535 F=INT(F)+1
3540 S2=1.092*M5
3545 RETURN
4000 G=0
4005 B6=1-A6(G)
4010 IF G=0 THEN 4030
4015 D6=(F3+K6(G)*S1+E6(G)*S1)/P1
4020 H6=K6(G)*S1*H*(0.5*A6(G)*((2*F3+K6(G)*S1)/D6)+P1*B6)
4025 GOTO 4035
4030 H6=0
4035 S6=E6(G)*S1*C6*A6(G)
4040 T6=H6+S6
4045 IF G=0 THEN 4060
4050 IF T6>M6 THEN 4080
```

Appendix H: Computer Program-Listing of Stock Control Methodology Simulation (page 6 of 7 pages).

```
4055 IF G=9 THEN 4075
4060 M6=T6
4065 G=G+1
4070 GOTO 4005
4075 M6=T6
4080 J=0
4085 A7=A6(J)
4090 B7=1-A7
4095 K7=K6(J)
4100 IF J=0 THEN 4115
4105 H7=(1-(A7*A6(G)))*K7*S2*(F3+K6(G)*S1)*H
4110 GOTO 4120
4115 H7=0
4120 E7=E6(J)
4125 S7=A6(G)*A7*(E6(G)*S1+E7*S2*D6)*C6
4130 T7=H7+S7
4135 IF J=0 THEN 4150
4140 IF T7>M7 THEN 4170
4145 IF J=9 THEN 4165
4150 M7=T7
4155 J=J+1
4160 GOTO 4085
4165 M7=T7
4170 Q7=F3+K6(G)*S1
4172 IF R=0 THEN 4179
4175 Q=Q7-(L-(B(K)+(A(R)/W1)*F))
4176 GOTO 4180
4179 Q=Q7
4180 IF (Q-(INT(Q)+0.5))>=0 THEN 4200
4185 Q=INT(Q)
4190 GOTO 4205
4200 Q=INT(Q)+1
4205 P=(F+K7*S2)*((F3+K6(G)*S1)/P1)
4210 IF M1=1 THEN 4222
4215 P=INT(P*1000)/1000
4220 GOTO 4230
4222 IF (P-(INT(P)+0.5))>=0 THEN 4228
4224 P=INT(P)
4226 GOTO 4230
4228 P=INT(P)+1
4230 OPEN 4,4:CMD4
4254 PRINT£4,"PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = ";
4255 PRINT£4,P2;" WEEKS"
4256 Q4=Q4+Q
4257 PRINT£4
4258 IF M1=1 THEN 4500
4259 PRINT£4,"REPLENISHMENT ORDER QTY ";R;" = ";Q;" TONNES"
4260 PRINT£4
4265 PRINT£4,"REORDER LEVEL ";R;" = ";P;" TONNES"
4270 PRINT£4
4275 PRINT£4,"DEMAND SAFETY-STOCK = ";INT(K6(G)*S1*1000)/1000;" TONNES"
4280 PRINT£4
4285 PRINT£4,"LEAD-TIME SAFETY-STOCK = ";
4287 PRINT£4,INT(K7*S2*((F3+K6(G)*S1)/P1)*1000)/1000;" TONNES"
4290 GOTO 4535
4500 PRINT£4,"REPLENISHMENT QTY ";R;" = ";Q;" BARRELS"
4505 PRINT£4
4510 PRINT£4,"REORDER LEVEL ";R;" = ";P;" BARRELS"
4515 PRINT£4
4520 PRINT£4,"DEMAND SAFETY-STOCK = ";INT(K6(G)*S1*10)/10;" BARRELS"
4525 PRINT£4
4530 PRINT£4,"LEAD-TIME SAFETY-STOCK = ";
4532 PRINT£4,INT(K7*S2*((F3+K6(G)*S1)/P1)*1000)/1000;" BARRELS"
4535 CLOSE 4
4536 GOTO 4540
4538 S=2
4540 RETURN
5000 END
READY.
```

<u>Appendix H</u>: Computer Program-Listing of Stock Control Methodology Simulation (page 7 of 7 pages).

Appendix J

Details Relating to the Production of 'Actual' Stock Replenishment Lead-Times in All Simulation Testing.

Random Number Generated	'Actual' Lead-Time	Effective Probability of Occurrence
$\geqslant 0$ but $\leqslant 0.25$	1 Week	0.25
> 0.25 but $\leqslant 0.75$	2 Weeks	0.50
> 0.75 but $\leqslant 1$	3 Weeks	0.25

The lead-time was thus effectively chosen from a uniform distribution with a minimum of one week and a maximum of three weeks, rounded to a whole number of weeks. This distribution was chosen as it fitted closely the replenishment supply service provided by the Production Department, on the Barton site, at the time.

Appendix J: Details Relating to the Production of 'Actual' Stock Replenishment Lead-Times in All Simulation Testing.

Appendix K

Example of Test-Simulation Results Print-Out
for the Stock Control Methodology

```
PRODUCT CODE: 01050
PRODUCT DESCRIPTION: EVCUT BF

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  0  WEEKS
REPLENISHMENT QTY  0  =  23  BARRELS
REORDER LEVEL  0  =  20  BARRELS
DEMAND SAFETY-STOCK =  5.3  BARRELS
LEAD-TIME SAFETY-STOCK =  2.891  BARRELS
STOCK-LEVEL =  23
```

'Start-up' Values

```
PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  1  WEEKS
REPLENISHMENT QTY  1  =  17  BARRELS
REORDER LEVEL  1  =  21  BARRELS
DEMAND SAFETY-STOCK =  4.7  BARRELS
LEAD-TIME SAFETY-STOCK =  1.939  BARRELS
```

Printed Immediately Following Replenishment Calculations

```
NEW STOCK-LEVEL =  33
BACKORDER QTY =  0
```

Stock Situation Immediately <u>Following</u> a Simulated Delivery.

```
PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  2  WEEKS
REPLENISHMENT QTY  2  =  42  BARRELS
REORDER LEVEL  2  =  24  BARRELS
DEMAND SAFETY-STOCK =  5  BARRELS
LEAD-TIME SAFETY-STOCK =  1.805  BARRELS
NEW STOCK-LEVEL =  26
BACKORDER QTY =  0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  1  WEEKS
REPLENISHMENT QTY  3  =  51  BARRELS
REORDER LEVEL  3  =  40  BARRELS
DEMAND SAFETY-STOCK =  7.8  BARRELS
LEAD-TIME SAFETY-STOCK =  4.219  BARRELS
NEW STOCK-LEVEL =  56
BACKORDER QTY =  0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  5  WEEKS
REPLENISHMENT QTY  4  =  4  BARRELS
REORDER LEVEL  4  =  34  BARRELS
DEMAND SAFETY-STOCK =  9.2  BARRELS
```

<u>Appendix K</u>: Example of Test-Simulation Results Print-Out for the Stock Control Methodology (p.1 of 5 pages).

LEAD-TIME SAFETY-STOCK = 2.946 BARRELS

NEW STOCK-LEVEL = 32

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS

REPLENISHMENT QTY 5 = 2 BARRELS

REORDER LEVEL 5 = 24 BARRELS

DEMAND SAFETY-STOCK = 9.6 BARRELS

LEAD-TIME SAFETY-STOCK = 1.723 BARRELS

NEW STOCK-LEVEL = 4

BACKORDER QTY = 16

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS

REPLENISHMENT QTY 6 = 58 BARRELS

REORDER LEVEL 6 = 28 BARRELS

DEMAND SAFETY-STOCK = 10 BARRELS

LEAD-TIME SAFETY-STOCK = 2.933 BARRELS

NEW STOCK-LEVEL = 39

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 3 WEEKS

REPLENISHMENT QTY 7 = 7 BARRELS

REORDER LEVEL 7 = 25 BARRELS

DEMAND SAFETY-STOCK = 9.9 BARRELS

LEAD-TIME SAFETY-STOCK = 2.147 BARRELS

NEW STOCK-LEVEL = 25

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS

REPLENISHMENT QTY 8 = 11 BARRELS

REORDER LEVEL 8 = 24 BARRELS

DEMAND SAFETY-STOCK = 8.1 BARRELS

LEAD-TIME SAFETY-STOCK = 2.785 BARRELS

NEW STOCK-LEVEL = 29

BACKORDER QTY = 0

Appendix K: Example of Test-Simulation Results Print-Out for the Stock Control Methodology (p.2 of 5 pages).

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 1 WEEKS

REPLENISHMENT QTY 9 = 12 BARRELS

REORDER LEVEL 9 = 24 BARRELS

DEMAND SAFETY-STOCK = 6.7 BARRELS

LEAD-TIME SAFETY-STOCK = 3.228 BARRELS

NEW STOCK-LEVEL = 27

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 1 WEEKS

REPLENISHMENT QTY 10 = 6 BARRELS

REORDER LEVEL 10 = 22 BARRELS

DEMAND SAFETY-STOCK = 7.2 BARRELS

LEAD-TIME SAFETY-STOCK = 3.425 BARRELS

NEW STOCK-LEVEL = 19

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS

REPLENISHMENT QTY 11 = 4 BARRELS

REORDER LEVEL 11 = 18 BARRELS

DEMAND SAFETY-STOCK = 7 BARRELS

LEAD-TIME SAFETY-STOCK = 2.307 BARRELS

NEW STOCK-LEVEL = 16

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS

REPLENISHMENT QTY 12 = 5 BARRELS

REORDER LEVEL 12 = 17 BARRELS

DEMAND SAFETY-STOCK = 6.5 BARRELS

LEAD-TIME SAFETY-STOCK = 2.437 BARRELS

NEW STOCK-LEVEL = 7

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS

REPLENISHMENT QTY 13 = 23 BARRELS

REORDER LEVEL 13 = 18 BARRELS

DEMAND SAFETY-STOCK = 6.5 BARRELS

LEAD-TIME SAFETY-STOCK = 2.206 BARRELS

Appendix K: Example of Test-Simulation Results Print-Out for the Stock Control Methodology (p.3 of 5 pages).

```
NEW STOCK-LEVEL =  23

BACKORDER QTY =  0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  1  WEEKS
REPLENISHMENT QTY  14  =  9  BARRELS
REORDER LEVEL  14  =  17  BARRELS
DEMAND SAFETY-STOCK =  5.6  BARRELS
LEAD-TIME SAFETY-STOCK =  1.653  BARRELS
NEW STOCK-LEVEL =  11
BACKORDER QTY =  0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  0  WEEKS
REPLENISHMENT QTY  15  =  13  BARRELS
REORDER LEVEL  15  =  16  BARRELS
DEMAND SAFETY-STOCK =  4.7  BARRELS
LEAD-TIME SAFETY-STOCK =  2.011  BARRELS
NEW STOCK-LEVEL =  17
BACKORDER QTY =  0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT =  1  WEEKS
REPLENISHMENT QTY  16  =  10  BARRELS
REORDER LEVEL  16  =  15  BARRELS
DEMAND SAFETY-STOCK =  4.6  BARRELS
LEAD-TIME SAFETY-STOCK =  2.121  BARRELS
SIMULATION RUN COMPLETED; OVERALL PERFORMANCE RESULTS FOLLOW:
AVERAGE WEEKLY STOCK-LEVEL =  21
TOTAL NO OF STOCK REPLENISHMENTS =  17
AVERAGE PERIOD BETWEEN RAISING REPLENISHMENT-ORDERS =  2.8 WEEKS

TOTAL NO OF TRANSACTIONS =  39

NO OF TRANSACTIONS SATISFIED EX-STOCK =  33
SERVICE-LEVEL =  84.6  %
TOTAL NO OF STOCKOUTS =  2

TOTAL NO OF STOCKOUT ORDERS IN YEAR =  6

PROBABILITY OF STOCKOUT =  .06
```

Appendix K: Example of Test-Simulation Results Print-Out for the Stock Control Methodology (p.4 of 5 pages).

NUMBER OF ORDERS IN STOCKOUT 1 = 3

TOTAL BACKORDER QTY IN STOCKOUT 1 = 21

TOTAL DURATION OF STOCKOUT 1 = 1 WEEKS

NUMBER OF ORDERS IN STOCKOUT 2 = 3

TOTAL BACKORDER QTY IN STOCKOUT 2 = 21

TOTAL DURATION OF STOCKOUT 2 = 2 WEEKS

AVERAGE TOTAL BACKORDER-QTY PER STOCKOUT = 21

AVERAGE INVENTORY HOLDING COST FOR YEAR = £ 514.07

TOTAL REPLENISHMENT COST FOR YEAR = £ 450.5

TRUE STOCKOUT COST FOR YEAR = £ ZERO

TOTAL INVENTORY OPERATING COST FOR YEAR = £ 964.57

END OF MONTH 1 STOCK-LEVEL = 26

END OF MONTH 2 STOCK-LEVEL = 12

END OF MONTH 3 STOCK-LEVEL = 42

END OF MONTH 4 STOCK-LEVEL = 32

END OF MONTH 5 STOCK-LEVEL = 4

END OF MONTH 6 STOCK-LEVEL = 32

END OF MONTH 7 STOCK-LEVEL = 22

END OF MONTH 8 STOCK-LEVEL = 20

END OF MONTH 9 STOCK-LEVEL = 16

END OF MONTH 10 STOCK-LEVEL = 23

END OF MONTH 11 STOCK-LEVEL = 11

END OF MONTH 12 STOCK-LEVEL = 10

TOTAL QUANTITY ORDERED IN YEAR = 293

Appendix K: Example of Test-Simulation Results Print-Out for the Stock Control Methodology (p.5 of 5 pages).

Appendix L

Computer Program-Listing of
Simulation of Edgar Vaughan's '10% Policy'.

NAME OF SIMULATION: E.VAUGHAN 10% POLICY

READY.

```
2 PRINT "ENTER NAME OF SIMULATION"
3 INPUT A$
5 PRINT"ENTER PRODUCT CODE"
10 INPUT C$
15 PRINT"ENTER PRODUCT DESCRIPTION"
20 INPUT D1$
25 PRINT"ENTER AVERAGE TRANSACTION QTY"
30 INPUT Q1
31 PRINT"ENTER METHOD OF STORAGE:1=BARRELS; 2=BULK"
32 INPUT M1
33 IF M1=1 THEN 37
34 PRINT"ENTER AVERAGE BARREL TRANSACTION QTY IN TONNES"
35 INPUT Q3
37 OPEN4,4:CMD4
38 PRINT£4,"NAME OF SIMULATION: ";A$
39 PRINT£4,"PRODUCT CODE: ";C$
41 PRINT£4,"PRODUCT DESCRIPTION: ";D1$
43 CLOSE 4
65 N=30
68 DIM L(12)
70 DIM A(N)
72 DIM B(15)
73 DIM C(4,12)
74 DIM D(12)
75 DIM J(15)
77 DIM N(4,12)
78 DIM V(15)
80 DIM M(15)
125 IF M1=1 THEN 142
130 DIM D2(12)
135 DIM N3(4,12)
140 DIM C3(4,12)
142 READ H,R2,C6
145 PRINT"ENTER MAXIMUM STOCK-LEVEL"
147 INPUT S8
150 PRINT"ENTER REORDER-LEVEL"
155 INPUT P
162 L=S8
164 OPEN 4,4:CMD4
166 PRINT£4,"STOCK-POLICY:"
168 PRINT£4
170 PRINT£4,"MAXIMUM STOCK-LEVEL = ";S8
172 PRINT£4
174 PRINT£4,"REORDER-LEVEL = ";P
176 PRINT£4
177 PRINT£4
179 PRINT£4,"START-UP STOCK-LEVEL = ";S8
180 PRINT£4
182 PRINT£4
184 CLOSE 4
200 W1=0
205 K1=0
210 K=1
215 B(K)=0
217 M(K)=0
220 V(K)=0
225 X1=0
230 X2=0
240 R=1
245 A(R)=0
250 L1=0
```

Appendix L: Computer Program-Listing of Simulation of Edgar Vaughan's '10% Policy' (page 1 of 5 pages).

```
255 S=0
260 J(K)=0
355 M=1
357 READ D(M)
360 IF D(M)>0 THEN 400
362 W=1
364 IF B(K)=0 THEN 368
366 V(K)=V(K)+1
368 IF S=1 THEN 710
370 W1=W1+1
372 GOTO 960
374 IF W<4 THEN 380
376 L1=L1+L
378 GOTO 1330
380 L1=L1+L
382 W=W+1
388 GOTO 364
400 W=1
402 X=D(M)/Q1
404 IF (X-(INT(X)+0.5)) >=0 THEN 410
406 X=INT(X)
408 GOTO 415
410 X=INT(X)+1
415 X1=X1+X
417 N(W,M)=X*RND(1)
419 IF W=1 THEN 440
420 IF W=2 THEN 455
430 GOTO 460
440 N(W,M)=N(W,M)*0.5
450 GOTO 460
455 N(W,M)=N(W,M)*0.666
460 IF (N(W,M)-(INT(N(W,M))+0.5))>=0 THEN 485
470 N(W,M)=INT(N(W,M))
480 GOTO 490
485 N(W,M)=INT(N(W,M))+1
490 IF B(K)=0 THEN 510
500 V(K)=V(K)+1
510 C(W,M)=N(W,M)*Q1
515 X=X-N(W,M)
520 IF X>0 THEN 555
522 X=0
555 IF S=1 THEN 570
560 A(R)=A(R)+C(W,M)
565 W1=W1+1
570 IF C(W,M)<=L THEN 650
575 Z=0
580 IF Q1>L THEN 600
585 L=L-Q1
590 Z=Z+1
595 GOTO 580
600 X2=X2+Z
605 N(W,M)=N(W,M)-Z
610 J(K)=J(K)+N(W,M)
615 B1=N(W,M)*Q1
620 B(K)=B(K)+B1
625 M(K)=M(K)+B1
630 GOTO 700
650 L=L-C(W,M)
655 X2=X2+N(W,M)
700 IF (L-B(K))>P THEN 960
705 IF S=0 THEN 910
710 C=C+1
715 IF C<>T THEN 960
716 IF (Q-B(K))>=0 THEN 720
717 B(K)=B(K)-Q
718 Q2=0
719 GOTO 760
720 Q2=Q-B(K)
722 IF B(K)=0 THEN 760
725 K1=K
```

<u>Appendix L</u>: Computer Program-Listing of Simulation of Edgar Vaughan's '10% Policy' (page 2 of 5 pages).

```
730 K=K+1
735 J(K)=0
740 V(K)=0
745 B(K)=0
747 M(K)=0
760 L=L+Q2
762 OPEN4,4:CMD4
764 PRINT£4,"NEW STOCK-LEVEL = ";L
765 PRINT£4
766 PRINT£4,"BACKORDER QTY = ";B(K)
768 PRINT£4
770 CLOSE 4
775 S=0
780 GOTO 700
810 GOSUB 3000
830 S=1
835 T=2*RND(1)+1
840 IF (T-(INT(T)+0.5))>=0 THEN 860
845 T=INT(T)
850 GOTO 865
860 T=INT(T)+1
865 C=0
870 R=R+1
875 A(R)=0
880 W1=0
960 IF M1=2 THEN 975
965 IF D(M)=0 THEN 374
970 GOTO 1290
975 IF W>1 THEN 981
980 READ D2(M)
981 IF D2(M)=0 THEN 965
982 IF W>1 THEN 1020
990 X3=D2(M)/Q3
995 IF (X3-(INT(X3)+0.5))>=0 THEN 1010
1000 X3=INT(X3)
1005 GOTO 1015
1010 X3=INT(X3)+1
1015 X1=X1+X3
1020 IF W<4 THEN 1035
1025 N3(W,M)=X3
1030 GOTO 1105
1035 N3(W,M)=X3*RND(1)
1040 IF W=1 THEN 1055
1045 IF W=2 THEN 1065
1050 GOTO 1070
1055 N3(W,M)=N3(W,M)*0.5
1060 GOTO 1070
1065 N3(W,M)=N3(W,M)*0.666
1070 IF (N3(W,M)-(INT(N3(W,M))+0.5))>=0 THEN 1085
1075 N3(W,M)=INT(N3(W,M))
1080 GOTO 1090
1085 N3(W,M)=INT(N3(W,M))+1
1090 X3=X3-N3(W,M)
1095 IF X3>0 THEN 1105
1100 X3=0
1105 C3(W,M)=N3(W,M)*Q3
1110 IF S=1 THEN 1120
1115 A(R)=A(R)+C3(W,M)
1120 IF C3(W,M)<=L THEN 1205
1125 Z=0
1130 IF Q3>L THEN 1150
1135 L=L-Q3
1140 Z=Z+1
1145 GOTO 1130
1150 X2=X2+Z
1155 N3(W,M)=N3(W,M)-Z
1160 J(K)=J(K)+N3(W,M)
1165 B2=N3(W,M)*Q3
1170 B(K)=B(K)+B2
```

Appendix L: Computer Program-Listing of Simulation of Edgar Vaughan's '10% Policy' (page 3 of 5 pages).

```
1175 M(K)=M(K)+B2
1200 GOTO 1215
1205 L=L-G3(W,M)
1210 X2=X2+N3(W,M)
1215 IF (L-B(K))>P THEN 1285
1220 IF S=1 THEN 1285
1225 GOSUB 3000
1235 S=1
1240 T=2*RND(1)+1
1245 IF (T-(INT(T)+0.5))>=0 THEN 1260
1250 T=INT(T)
1255 GOTO 1265
1260 T=INT(T)+1
1265 C=0
1270 R=R+1
1275 A(R)=0
1280 W1=0
1285 IF D(M)=0 THEN 374
1290 L1=L1+L
1295 IF W=3 THEN 1315
1300 IF W=4 THEN 1330
1305 W=W+1
1310 GOTO 417
1315 W=4
1320 N(W,M)=X
1325 GOTO 490
1330 L(M)=L
1332 IF M=12 THEN 1345
1335 M=M+1
1340 GOTO 357
1345 OPEN 4,4:CMD 4
1360 PRINT£4
1365 PRINT£4
1370 PRINT£4,"AVERAGE WEEKLY STOCK-LEVEL = ";INT((L1/48)*100)/100
1375 PRINT£4
1377 PRINT£4,"TOTAL NO OF STOCK REPLENISHMENTS = ";R
1378 PRINT£4
1379 PRINT£4,"AVERAGE PERIOD BETWEEN RAISING REPLENISHMENT-ORDERS = ";
1380 PRINT£4,INT((48/R)*10)/10;" WEEKS"
1381 PRINT£4
1382 PRINT£4
1384 PRINT£4,"TOTAL NO OF TRANSACTIONS = ";X1
1386 PRINT£4
1387 PRINT£4,"NO OF TRANSACTIONS SATISFIED EX-STOCK = ";X2
1389 PRINT£4
1390 PRINT£4,"SERVICE-LEVEL = ";INT((X2/X1)*1000)/10;" %"
1395 PRINT£4
1400 PRINT£4,"TOTAL NO OF STOCKOUTS = ";K1
1402 PRINT£4
1405 CLOSE 4
1410 IF K1=0 THEN 1517
1415 V=0
1417 B=0
1420 FOR K=1 TO K1
1425 V=V+V(K)
1427 B=B+M(K)
1430 NEXT K
1431 IF V>=K1 THEN 1435
1432 V=K1
1435 OPEN 4,4:CMD 4
1440 PRINT£4,"PROBABILITY OF STOCKOUT = ";INT((V/48)*100)/100
1445 PRINT£4
1450 FOR K=1 TO K1
1455 PRINT£4,"NUMBER OF ORDERS IN STOCKOUT ";K;" = ";J(K)
1465 PRINT£4
1470 PRINT£4,"TOTAL BACKORDER QTY IN STOCKOUT ";K;" = ";INT(M(K)*100)/100
1475 PRINT£4
1480 PRINT£4,"TOTAL DURATION OF STOCKOUT ";K;" = ";V(K);" WEEKS"
1485 PRINT£4
1490 PRINT£4
1495 NEXT K
```

Appendix L: Computer Program-Listing of Simulation of Edgar Vaughan's '10% Policy' (page 4 of 5 pages).

```
1500 PRINT£4,"AVERAGE TOTAL BACKORDER-QTY PER STOCKOUT = ";INT((B/K1)*100)/100
1505 PRINT£4
1510 PRINT£4
1515 GOTO 1535
1517 OPEN4,4:CMD4
1520 PRINT£4,"PROBABILITY OF STOCKOUT APPROACHES ZERO"
1525 PRINT£4
1530 PRINT£4
1535 CLOSE 4
1540 H3=L1*H
1545 R3=R2*R
1550 S3=B*C6
1555 T3=H3+R3+S3
1700 OPEN4,4:CMD4
1705 PRINT£4,"AVERAGE INVENTORY HOLDING COST FOR YEAR = £";INT(H3*100)/100
1710 PRINT£4
1715 PRINT£4,"TOTAL REPLENISHMENT COST FOR YEAR = £";INT(R3*100)/100
1720 PRINT£4
1725 PRINT£4,"TOTAL STOCKOUT COST FOR YEAR = £";INT(S3*100)/100
1730 PRINT£4
1735 PRINT£4
1740 PRINT£4,"TOTAL INVENTORY OPERATING COST FOR YEAR = $";INT(T3*100)/100
1741 PRINT£4
1742 PRINT£4
1743 FOR I=1 TO 12
1744 PRINT£4,"END OF MONTH ";I;" STOCK-LEVEL = ";L(I)
1746 PRINT£4
1748 NEXT I
1749 CLOSE 4
1750 DATA 0.531,26.5,35.43
1760 DATA 8,12,46,44,8,50
1765 DATA 8,35,4,13,8,2
1770 GOTO 5000
3000 Q=(S8-L)+B(K)
3005 IF (Q-(INT(Q)+0.5))>=0 THEN 3020
3010 Q=INT(Q)
3015 GOTO 3050
3020 Q=INT(Q)+1
3050 OPEN4,4:CMD4
3052 PRINT£4
3055 PRINT£4,"PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = ";
3056 PRINT£4,W1;" WEEKS"
3057 PRINT£4
3058 PRINT£4,"CURRENT STOCK-LEVEL = ";L
3059 PRINT£4
3060 PRINT£4,"BACKORDER QTY = ";B(K)
3061 PRINT£4
3062 IF M1=1 THEN 3085
3070 PRINT£4,"REPLENISHMENT ORDER QTY ";R;" = ";Q;" TONNES"
3080 GOTO 3200
3082 PRINT£4
3085 PRINT£4,"REPLENISHMENT ORDER QTY ";R;" = ";Q;" BARRELS"
3200 CLOSE 4
3205 RETURN
5000 END
READY.
```

Appendix L: Computer Program-Listing of Simulation of Edgar Vaughan's '10% Policy' (page 5 of 5 pages).

Appendix M

Example of Test-Simulation Results Print-Out
for Edgar Vaughan's '10% Policy'

PRODUCT CODE: 01050
PRODUCT DESCRIPTION: EVCUT BF

STOCK-POLICY:

MAXIMUM STOCK-LEVEL = 30

REORDER-LEVEL = 15

START-UP STOCK-LEVEL = 30

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 5 WEEKS

CURRENT STOCK-LEVEL = 2

BACKORDER QTY = 7

Values at Time of Raising Replenishment Order

REPLENISHMENT ORDER QTY 1 = 35 BARRELS

Actual Replenishment Quantity and Takes into Account Backorders (See Footnote at End of Print-Out)

NEW STOCK-LEVEL = 2

BACKORDER QTY = 7

Stock Situation Immediately Following a Simulated Delivery.

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS

CURRENT STOCK-LEVEL = 2

BACKORDER QTY = 7

REPLENISHMENT ORDER QTY 2 = 35 BARRELS

NEW STOCK-LEVEL = 23

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 2 WEEKS

CURRENT STOCK-LEVEL = 9

BACKORDER QTY = 0

REPLENISHMENT ORDER QTY 3 = 21 BARRELS

NEW STOCK-LEVEL = 23

BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 2 WEEKS

CURRENT STOCK-LEVEL = 2

BACKORDER QTY = 0

REPLENISHMENT ORDER QTY 4 = 28 BARRELS

NEW STOCK-LEVEL = 23

BACKORDER QTY = 0

Appendix M: Example of Test-Simulation Results Print-Out for Edgar Vaughan's '10% Policy' (page 1 of 4 pages).

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 1 WEEKS
CURRENT STOCK-LEVEL = 2
BACKORDER QTY = 0
REPLENISHMENT ORDER QTY 5 = 28 BARRELS
NEW STOCK-LEVEL = 23
BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 4 WEEKS
CURRENT STOCK-LEVEL = 9
BACKORDER QTY = 0
REPLENISHMENT ORDER QTY 6 = 21 BARRELS
NEW STOCK-LEVEL = 9
BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 0 WEEKS
CURRENT STOCK-LEVEL = 9
BACKORDER QTY = 0
REPLENISHMENT ORDER QTY 7 = 21 BARRELS
NEW STOCK-LEVEL = 16
BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 3 WEEKS
CURRENT STOCK-LEVEL = 9
BACKORDER QTY = 0
REPLENISHMENT ORDER QTY 8 = 21 BARRELS
NEW STOCK-LEVEL = 23
BACKORDER QTY = 0

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 4 WEEKS
CURRENT STOCK-LEVEL = 2
BACKORDER QTY = 0
REPLENISHMENT ORDER QTY 9 = 28 BARRELS
NEW STOCK-LEVEL = 16
BACKORDER QTY = 0

Appendix M: Example of Test-Simulation Results Print-Out for Edgar Vaughan's '10% Policy' (page 2 of 4 pages).

PERIOD ELAPSED SINCE DELIVERY OF LAST REPLENISHMENT = 2 WEEKS

CURRENT STOCK-LEVEL = 9

BACKORDER QTY = 0

REPLENISHMENT ORDER QTY 10 = 21 BARRELS

NEW STOCK-LEVEL = 23

BACKORDER QTY = 0

<u>SIMULATION RUN COMPLETED</u>; <u>OVERALL PERFORMANCE RESULTS FOLLOW</u>:

AVERAGE WEEKLY STOCK-LEVEL = 12.2

TOTAL NO OF STOCK REPLENISHMENTS = 11

AVERAGE PERIOD BETWEEN RAISING REPLENISHMENT-ORDERS = 4.3 WEEKS

TOTAL NO OF TRANSACTIONS = 39

NO OF TRANSACTIONS SATISFIED EX-STOCK = 25

SERVICE-LEVEL = 64.1 %

TOTAL NO OF STOCKOUTS = 6

PROBABILITY OF STOCKOUT = .14

NUMBER OF ORDERS IN STOCKOUT 1 = 7

TOTAL BACKORDER QTY IN STOCKOUT 1 = 49

TOTAL DURATION OF STOCKOUT 1 = 5 WEEKS

NUMBER OF ORDERS IN STOCKOUT 2 = 1

TOTAL BACKORDER QTY IN STOCKOUT 2 = 7

TOTAL DURATION OF STOCKOUT 2 = 0 WEEKS

NUMBER OF ORDERS IN STOCKOUT 3 = 1

TOTAL BACKORDER QTY IN STOCKOUT 3 = 7

TOTAL DURATION OF STOCKOUT 3 = 0 WEEKS

NUMBER OF ORDERS IN STOCKOUT 4 = 2

TOTAL BACKORDER QTY IN STOCKOUT 4 = 14

TOTAL DURATION OF STOCKOUT 4 = 1 WEEKS

NUMBER OF ORDERS IN STOCKOUT 5 = 1

TOTAL BACKORDER QTY IN STOCKOUT 5 = 7

TOTAL DURATION OF STOCKOUT 5 = 0 WEEKS

<u>Appendix M</u>: Example of Test-Simulation Results Print-Out for Edgar Vaughan's '10% Policy' (page 3 of 4 pages).

NUMBER OF ORDERS IN STOCKOUT 6 = 2

TOTAL BACKORDER QTY IN STOCKOUT 6 = 14

TOTAL DURATION OF STOCKOUT 6 = 1 WEEKS

AVERAGE TOTAL BACKORDER-QTY PER STOCKOUT = 16.33

AVERAGE INVENTORY HOLDING COST FOR YEAR = £ 298.86

TOTAL REPLENISHMENT COST FOR YEAR = £ 291.5

TRUE STOCKOUT COST FOR YEAR = £ 1220.1

TOTAL INVENTORY OPERATING COST FOR YEAR = £ 1810.46

END OF MONTH 1 STOCK-LEVEL = 16

END OF MONTH 2 STOCK-LEVEL = 2

END OF MONTH 3 STOCK-LEVEL = 9

END OF MONTH 4 STOCK-LEVEL = 16

END OF MONTH 5 STOCK-LEVEL = 2

END OF MONTH 6 STOCK-LEVEL = 16

END OF MONTH 7 STOCK-LEVEL = 9

END OF MONTH 8 STOCK-LEVEL = 16

END OF MONTH 9 STOCK-LEVEL = 23

END OF MONTH 10 STOCK-LEVEL = 2

END OF MONTH 11 STOCK-LEVEL = 9

END OF MONTH 12 STOCK-LEVEL = 16

Note: Throughout the above simulation, Replenishment Order Quantity equals Maximum Stock Level minus Current Stock Level, plus Backorder Quantity.

Appendix M: Example of Test-Simulation Results Print-Out for Edgar Vaughan's '10% Policy' (page 4 of 4 pages).

Appendix N

Photo-Reduced Copy of the Report:

'The Procedure for the Processing of Orders at Trafford Park'

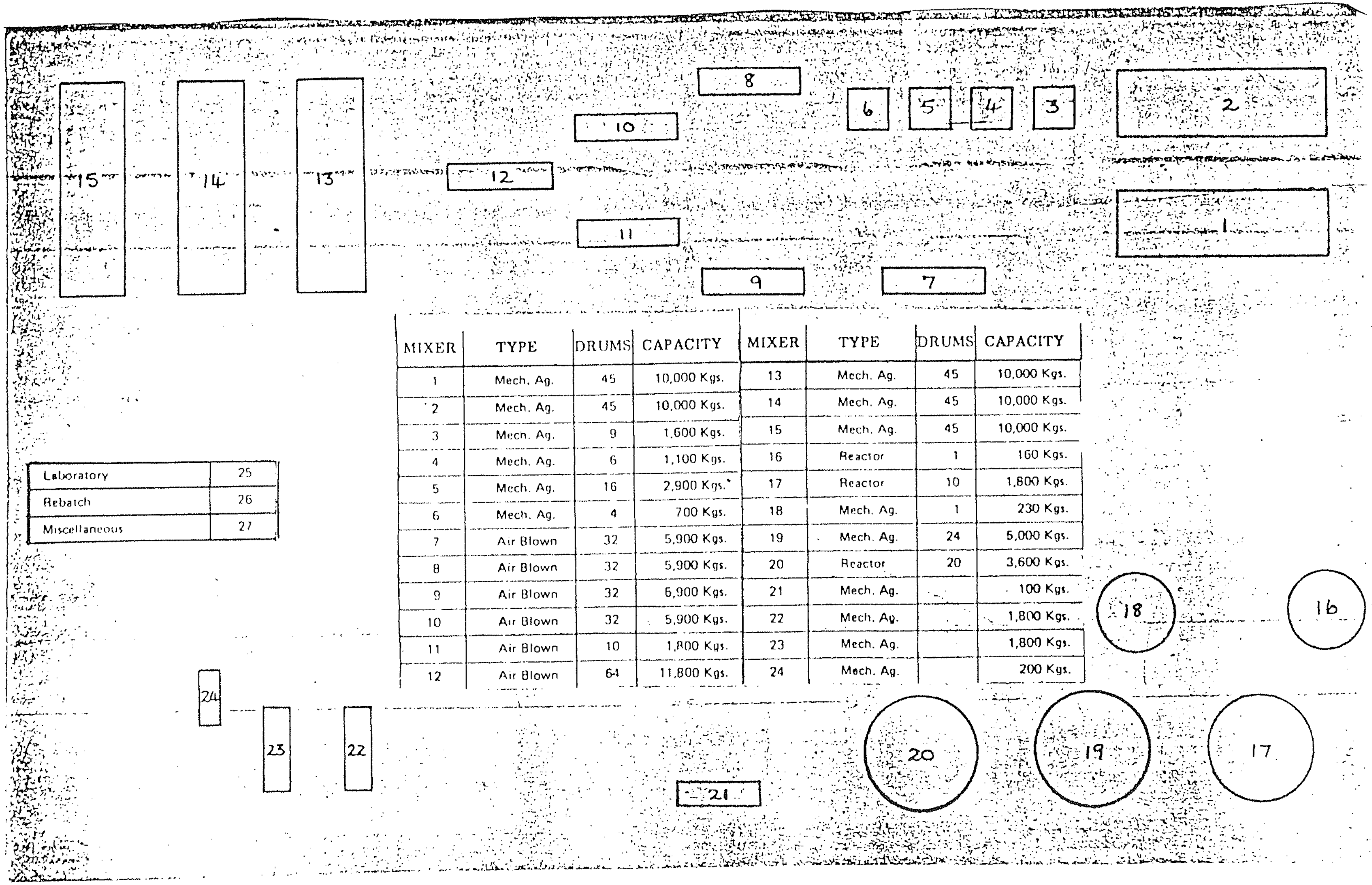
(December 1978)

The Procedure for the Processing of Orders at Trafford Park

(December 1978)

Aston University

Illustration has been removed for copyright restrictions



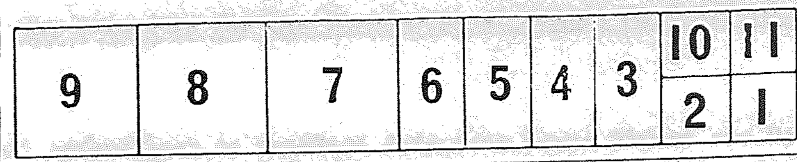
MIXER	TYPE	DRUMS	CAPACITY
1	Mech. Ag.	45	10,000 Kgs.
2	Mech. Ag.	45	10,000 Kgs.
3	Mech. Ag.	9	1,600 Kgs.
4	Mech. Ag.	6	1,100 Kgs.
5	Mech. Ag.	16	2,900 Kgs.
6	Mech. Ag.	4	700 Kgs.
7	Air Blown	32	5,900 Kgs.
8	Air Blown	32	5,900 Kgs.
9	Air Blown	32	6,900 Kgs.
10	Air Blown	32	5,900 Kgs.
11	Air Blown	10	1,800 Kgs.
12	Air Blown	64	11,800 Kgs.

MIXER	TYPE	DRUMS	CAPACITY
13	Mech. Ag.	45	10,000 Kgs.
14	Mech. Ag.	45	10,000 Kgs.
15	Mech. Ag.	45	10,000 Kgs.
16	Reactor	1	160 Kgs.
17	Reactor	10	1,800 Kgs.
18	Mech. Ag.	1	230 Kgs.
19	Mech. Ag.	24	5,000 Kgs.
20	Reactor	20	3,600 Kgs.
21	Mech. Ag.		100 Kgs.
22	Mech. Ag.		1,800 Kgs.
23	Mech. Ag.		1,800 Kgs.
24	Mech. Ag.		200 Kgs.

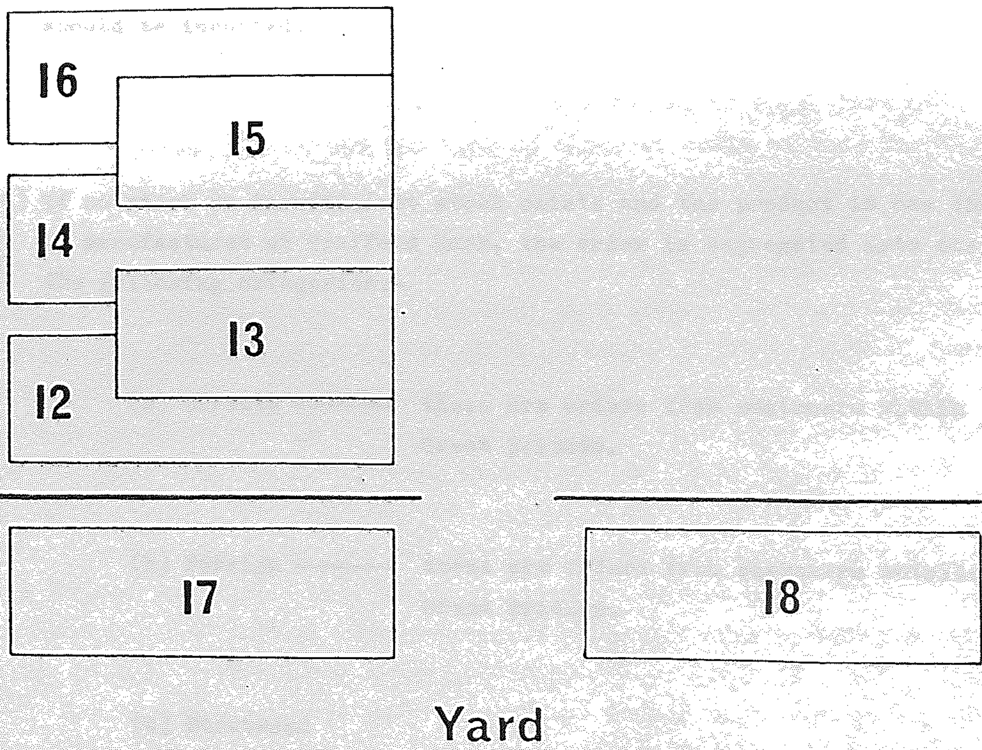
Laboratory	25
Rebatch	26
Miscellaneous	27

Capacity available at Trafford Park - ref. Plan of Works shown on the previous page.

27th. October 1975



TANK NO.	MATERIAL	CODE.	CAPACITY (LITRES)	
1	De-Airex 6080-CWX	-	14,000	
2	Reolube Hyd.110	15801	14,000	
3	Polyethylene Glycol 400	14620	27,200	
4	Triethanolamine	683	27,200	
5	Mono Propylene Glycol	2793	27,200	
6	Monoethylene Glycol	300	27,200	
7	Alliance 85	10870	54,500	
8			54,500	
9	SPO 37	10570	54,500	
10	Reolube Hyd.110	15801	14,000	
11	De-Airex 6080-CWX	-	14,000	
12	Tufflo	10675	36,000	
13	150 Bright Stock E	10420	14,000	
14	500 Solvent Neutral 95-VI	10410	36,000	
15	160 VT Bright Stock LP.1701	1196	18,000	
16	Pale Spindle Oil LP.305	930	36,000	
17	100 Solv.Neutral 100 VI	10140	36,000	
18	300 Burning Oil	10020	36,000	



Raw Material Storage Capacity at Trafford Park - ref. Plan of Works

The Procedure for the Processing of Orders at Trafford Park

All orders*sent to Trafford Park from Legge Street are delivered to the Transport Department and arrive at approximately 8.30 a.m., via. Burntwood. These are initially dealt with by the Transport Manager, who first examines the possibility of satisfying such orders from stock. This he does by refering to the 'Finished Stock Book' (Ref. Appendix 1). In doing so, one of the following actions is taken:-

(i) If sufficient stock exists, the order is placed onto the 'Shipping - List' (Ref. Appendix 2) for that day. This is a list of customers and their respective requirements, compiled by the Transport Manager and issued to the Warehouse Foreman on a daily basis.

(ii) If no stock or insufficient stock exists and the product is one that is manufactured at Burntwood then a 'Requisition' (Ref. Appendix 3) is raised and sent to Burntwood. This is accompanied by the comment "Order Waiting" and implies that a lead-time of no more than 5 days should be incurred.

(iii) If no stock or insufficient stock exists and the product is one that is manufactured at Trafford Park, the order is segregated into one of the following categories:-

(a) Directs ——— these are orders from customers within Great Britain.

(b) Foreign ——— these are orders from customers outside Great Britain.

(c) Burntwood

(d) High Wycombe

* Ref. Appendix 1A

(e) Paisley

A 'Manufacturing List'* is then typed by the Transport Manager for each category and given to the Production Supervisor for the purpose of manufacture.

Upon receiving the Manufacturing Lists, the Production Supervisor studies each and marries-up any orders for the same product. For each product, he then makes reference to one of the 'Master Cards' (Ref. Appendix 5).

Master Cards specify the quantity of each raw material that must be used when producing a particular product-blend. Also included on the cards are the relevant manufacturing details and any hazard/special instructions. In most instances, formulas quoted on Master Cards are for standard batch sizes, i.e. the Master Card states the exact weight that must be used of each raw material to make a particular batch size. Consequently, for popular products more than one Master Card can exist, each Master Card representing a different batch - quantity. However, in some cases, the formula on the Master Card is merely given in percentage form. Where this is the case, it is necessary for the Production Supervisor to calculate the weight that must be added of each raw-material to give the size of batch desired.

Having determined from the Master Card the degree of complexity of producing the product-blend and the type of mixer it could be made in, the Production Supervisor then refers to the 'Production Schedule Card'(Ref.Appendix 6) for that week. When scheduling orders, priority is always given to orders termed 'Directs'. Further, orders requiring delivery in a Road Tanker Wagon (R.T.W.), i.e. 'bulk-orders', are only scheduled after consulting both the Production Schedule Card <u>and</u> the Transport Manager. If the Production Supervisor decides that the order can be manufactured during the period considered, the Production Schedule Card is suitably completed. He then takes three copies off the Master Card which is for a batch quantity equal to or just larger than the manufacture-quantity decided upon. For orders where the Master Card states the formula in percentage form, the raw material weights calculated are entered onto a copy of the Master Card and two additional copies taken. In all cases, the original Master Card is returned to the file. The manufacturing details directly related to the order being considered (e.g. Mixer No., Date Required, etc.) are then entered onto each copy of the Master Card along with a batch-number taken from the 'Log Book' (Ref. Appendix 7). Having done this, the Production Supervisor records the batch number and product-name in the 'Finished-

* This is basically a list of orders for products requiring manufacture (Ref. Appendix 4)

Products Book' (Ref. Appendix 8) together with a note, under the date column, as to the number of barrels required to be stenciled. This information is ulti - mately given to the 'Stenciler' who reports to the Production Supervisor on average twice a day. At this stage, a tick is placed on the Manufacturing List(s) concerned against the date when the order was issued from Legge Street. This reminds the Production Supervisor that the order(s) in question has been scheduled. Two copies of the Master Card are then passed to the Blending Foreman. The third copy (henceforth termed the 'Office Copy') is given to the Goods Receiving/ Raw - Materials Clerk to enable him to carry out a stock check on the raw materials needed to produce the blend. This he does by refering to the 'Raw Material Stock Book' (Ref. Appendix 9). The anticipated requirements of each raw material are then entered by him onto the appropriate page. These figures are written in pencil since experience shows that the actual quantities used in a blend frequently vary slightly from those specified on the Master Card. Should it be found that there is a shortage of stock for any of the raw materials required, the Production Supervisor is immediately informed. He in-turn advises the Blending Foreman. The order is, under these circumstances, withdrawn fom the production-schedule until the raw materials are supplied. Where stock-levels are found to be adequate, the Office Copy is then passed to the 'Production Records Clerk'.

When receiving his two copies of the Master Card, the Blending Foreman enters onto a 'Production Card' (Ref. Appendix I0) the product name, the batch number and the mixer to be used. Both copies are then given to a 'Blender'.

Before commencing manufacture, the Blender first establishes whether there are any raw materials needed to be requisitioned from stock. In instances where there are he then does so using one of the copies of the Master Card. Usually there are adequate raw materials in the blending area. The second copy of the Master Card is used by him as a reference to the manufacturing instructions.Whilst preparing the blend, the Blender also enters onto this copy the <u>actual</u> quantity of each raw material used. As soon as the blend is completed, a sample is taken by the Blender and given to the 'Materials Control Laboratory' for tests. The copy of the Master Card used in producing the blend also accompanies the sample. In the meantime, the mixer containing the finished blend is not emptied until the results pertaining to the sample are received from the laboratory. Should the sample show the batch to be not quite correct, the laboratory writes on the copy of the Master Card what further quantities of raw materials need to be added. This procedure may be required to be carried out more than once. When laboratory tests show the batch to be acceptable, the copy of the Master Card is stamped as being "passed" and is signed by one of the laboratory personnel. This copy of the Master Card is then retained by the laboratory for collection by the Prod - uction Records Clerk. Finally, one of the laboratory personnel goes to the Blending Foreman's office and enters onto the Production Card the weight per package, the specific gravity of the batch and their signiture.

Upon being told of the laboratory's acceptance of the blend (this is usually done by the Blender), the Blending Foreman in the case of bulk-orders immedi - ately informs the Production Supervisor. The latter then crosses the order(s) off the appropriate Manufacturing List(s) and advises the Transport Manager that the order(s) is ready for delivery.

With regard to completed orders requiring delivery in barrels, the Blending-Foreman first instructs a 'Filler' to empty the mixer containing the finished blend into the barrels previously stenciled. As soon as this is done, the Filler goes to the Blending Foreman's office and writes on the Production Card the number of packages (barrels) filled, the 'Piece' * weight, the date and his sig-niture. The Blending Foreman then tells the Production Supervisor that the order(s) is available for delivery. The procedure then onwards is as that described for bulk-orders.

Meanwhile, each day, the Production Records Clerk periodically goes into the Blending Foreman's office and consults the Production Card. In this way he assertains what orders have been passed since his previous visit. For each newly completed order, he records in the Log Book the specific gravity of the blend, the weight per package and the quantity produced (this is generally recorded in terms of barrels and size of Piece). He then goes to the laboratory and collects the 'Works Copies' of the Master Cards for the orders completed. From each of these, he copies the actual raw material quantities used onto the Office Copy of the Master Card. Doing this provides a further check on the make-up of the blend

* Name given to the last barrel used in emptying a mixer. The term 'Piece' is used since this barrel is, in most cases, only partly filled.

and the figures recorded by the Blender. The latter are then used by him, in conjunction with the information contained in the Log Book, to calculate the total input and output (in terms of kilograms) and thus any 'loss' or 'gain'*. These too are then written on the Office Copy of the Master Card. The Total Net (T.N.) output is further recorded in the Finished Products Book in both terms of kilograms and, where applicable, barrels.

At this point, the Production Records Clerk raises a 'Blue Stock Sheet' (Ref. Appendix 11) onto which he enters the basic details of the batch manufactured. The columns under the general heading 'Office Use Only' are, with the exception of the 'Gross' and 'Tare' columns (used in reference to the Piece produced) no longer used. The original is then passed to the Transport & Finished Products Clerk. A second copy is also sent to the Chief Chemist who is based at Head Office, Legge Street. Finally, the Office Copy of the Master Card is given to the Goods Receiving/Raw Materials Clerk, the Works Copy being filed.

The Goods Receiving/Raw Materials Clerk uses the Office Copy of the Master Card to check / correct the figures written earlier in the Raw Material Stock Book in pencil. When this is done, the Office Copy of the Master Card is then filed.

Subsequent to receiving all Blue Stock Sheets the Transport & Finished Products Clerk up-dates the Finished Stock Book. Each Blue Stock Sheet is then filed.

In order to know what new additions to stock have been made, the Transport Manager examines the Finished Stock Book every morning. This is done specifically

* Measurement of output against input

for orders for which there was originally insufficient / no stock and as a result are outstanding. As the stock figure for a particular product is seen to increase so the order(s) requisting that product is placed onto the Shipping List for the following day. The Shipping List is, as described earlier, ultimately given to the Warehouse Foreman who organizes the removal of stock.

As each order is dealt with by one of the warehouse personnel so a 'Stock Advice Card' is raised, the information contained being the product name, the batch number, the amount removed from stock and the customer to whom it was allocated. The quantity of stock remaining is not advised since this is difficult to establish owing to the storage methods employed. When completed, the Stock Advice Card is passed to the Transport Manager.

Upon obtaining the above, the Transport Manager enters the batch number(s) of the stock removed onto the appropriate Works Order. He then records the transaction in the Finished Stock Book and adjusts the stock figure accordingly. In instances where the Stock Advice Card is associated with a requisition from Burntwood, High Wycombe or Paisley an 'Internal Works Order' (Ref. Appendix 12) is first raised. The procedure thenceforth is identical to that described for outside customers. Stock Advice Cards are normally received by the Transport Manager the same day as that of issueing the respective Shipping Lists.

Finally, the Customer Receipt and Invoice Copies of the Works Order are removed and accompany the order upon delivery. The Works Copy is at this point filed. When the signed Customer Receipt Copy is returned, the Transport Manager attaches it to the Office Copy and both are then sent to Head Office at Legge Street.

<u>APPENDICES</u>

Appendices removed
pgs 328-371 for copyright reasons

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