CONTROL OF FINISHED GOODS STOCKS IN DUNLOP TYRE DIVISION

A THESIS SUBMITTED BY

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TO THE UNIVERSITY OF ASTON IN BIRMINGHAM

FOR AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

AWARDED THE DEGREE OF M.Phil.

MAY 1979

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SUMMARY

The objective of the research was originally defined to be the study of the feasibility of developing a more efficient stock control and replenishment system, covering the requirements of the sponsor's European marketing operations. Firstly, the general theories of inventory control and of organizations are reviewed separately, and then the theory is applied to the analysis of the organization of inventory control in the region of interest. As a result, general recommendations are made for the application of inventory control methods, and, realising the practical limitations to change which exist in such an organization, a design strategy is proposed for development towards the eventual objective of implementing a "push" system.

The rest of the research is devoted to specific methods of improving the quality of information used in the current decision making mechanisms, with the aim of providing something of more immediate and practical value to the sponsor. An automatic forecasting procedure is developed to cope with the characteristics of European demand. The procedure is based on Bayesian methods, so that it can be adapted for interactive use, and it also includes a facility for detecting and coping with discontinuities in the data. An analysis of actual demand from Europe is made, showing the model to be suitable for its characteristics, and the response of the procedure is demonstrated on several product histories. Computer data files are used to compare the lead times of the principal planning activities between customers and between product groups, and the analysis is used as the basis of proposals for improvements in both operational and management reporting of lead times.

KEY WORDS:-

INVENTORY CONTROL
MULTI-ECHELON DISTRIBUTION
PUSH SYSTEM
ORGANIZATION DESIGN
BAYESIAN FORECASTING

ACKNOWLEDGEMENTS

I wish to record my thanks and appreciation to the sponsors, Dunlop Tyre Division, and especially Mr. McNair and Mr. F.J. Charlton for their personal support and interest throughout its duration. Mr. McNair not only allowed me the opportunity and the freedom to develop my ideas, but also provided the necessary encouragement.

Many others, both in Tyre Division and Europe Sales Division, have given me invaluable assistance on the project. In particular, I would like to mention the staff of the Export Department, Mr. R. Withey, Mr. W.G.'Leeson and Mr. I. Morley.

I am also most grateful to Mrs. C. Bowker for the skill and care with which she typed the final version of the text.

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CHAPTER 1

INTRODUCTION TO THE RESEARCH PROJECT

1. Introduction

This chapter gives a general description of the sponsoring organization as an international company. It aims to make the original statement of the research objectives intelligible, and it provides a background to the work on the project.

1-1 The Growth of the Dunlop Company

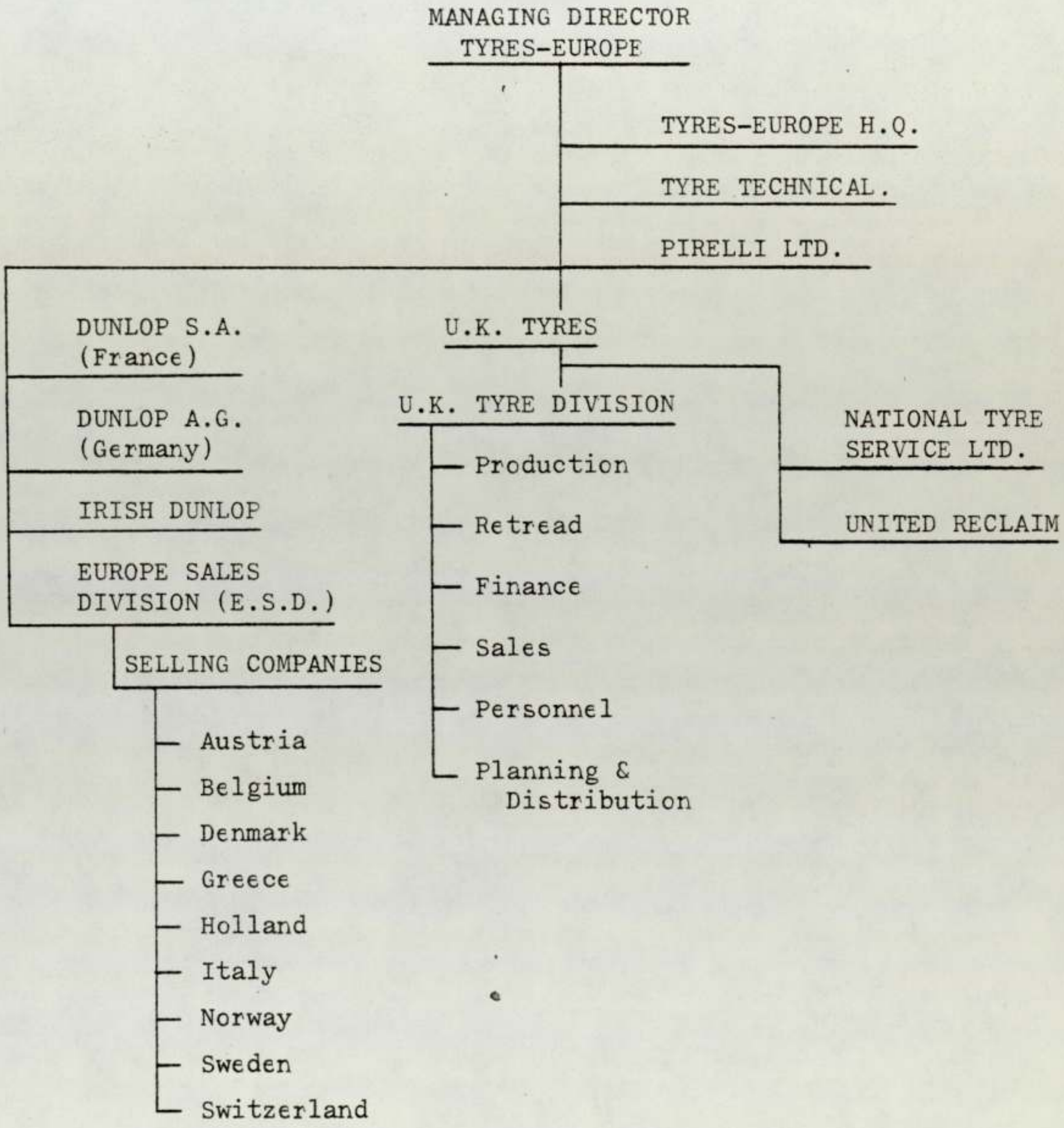
The tyre industry began at the turn of the century after the invention of the first practicable pneumatic tyre by John Boyd Dunlop. The Dunlop Company grew rapidly to meet the requirements of the cycle and automobile industries in the Midlands. It opened factories in Coventry and Birmingham and later bought rubber estates (in Malaya) and cotton mills (in Rochdale, Lancashire) to provide raw material for tyre production.

The Company also expanded by producing other rubber based goods (sports equipment, flooring, hose pipes etc.) and by acquiring a system of tyre wholesale warehouses. It now has more than one hundred factories in many countries throughout the world, and marketing companies in many more. Its areas of interest are basically - (a) rubber-like materials; (b) precision engineering; and (c) semi-durable products. The tyre remains a major part of the business of the group.

The U.K. Tyre Division now has four factories, in Birmingham (Fort Dunlop), Liverpool, Glasgow and Washington, County Durham. In the rest of Europe there are factories in France, West Germany and the Republic of Ireland (see fig. 1). Fort Dunlop is one of the largest tyre factories in Europe, making 100,000 tyres and 50,000 tubes every week, and employing 6,500 people. Apart from factory warehouses, there is a network of

FIGURE 1

THE TYRES-EUROPE ORGANISATION



28 tyre depots and a majority-owned distributor.

Europe Sales Division (E.S.D.) is responsible for marketing Dunlop tyres in Eastern and Western Europe, and it supports nine European Selling Companies for this purpose. These companies are the preferred channel of distribution in their own countries and approximately 30% of their sales are sourced from U.K. factories. For many of them, the U.K. has been the "normal" source of supply, but sourcing is now mainly influenced by the proportion of British vehicle sales and relative prices.

1-2 The Product Range

U.K. Tyre Division supplies a wide range of tyres under the Dunlop, India and other brand names. The Dunlop name is associated with higher quality and price, and a more comprehensive range, while other brands tend to be aimed at specific areas of the economy market. The various types, uses and constructions of tyres are summarized in table 1. A number of factors account for variations within these categories and as a result there are about 900 car tyres alone in the range.

1. Size - The width and internal diameter of a tyre corresponds to the size of the wheel. Car tyres are 10 to 15 inches in diameter and truck tyres are between 16 and 24 inches.

2. Quality - New tyres are tested for shape and uniformity and given a "bar" rating on a three bar scale. In general, only three bar tyres are suitable for export and original equipment. Two bar tyres are suitable for the replacement market.

3. Ply Rating - Cross ply tyres are produced with different numbers of fabric plies. Extra plies add to the strength of the tyre, so a van tyre may be a reinforced car tyre. Car tyres have between 2 and 6 plies, while heavy trucks have between 12 and 18.

TABLE 1

PRINCIPAL TYRE GROUPS

- MOTORCYCLE
- CAR
  - CROSSPLY
    - Tubed
    - Tubeless
  - RADIAL
    - Steel
    - Textile
- TRUCK
  - CROSSPLY
    - Small
    - Large
  - RADIAL
    - Small
      - Tubed
    - Large
      - Tubed
      - Tubeless
- TRACTOR
  - FRONT
  - REAR
- EARTHMOVER
  - SMALL
  - LARGE
  - EXTRA LARGE

MINOR TYRE GROUPS

BARROW & TROLLEY

DENOVO (Dunlop's Fail-safe tyre)

INDUSTRIAL TRUCK

LAND ROAD & IMPLEMENT

RACING TYRES & SLICKS

VAN

VINTAGE CAR

4. Pattern - This is the form of the tread rubber after moulding. It affects performance in terms of traction and wet grip and is also used to differentiate between brands for marketing purposes.

5. Speed Rating - Some car tyres are built to be used at high speeds and carry SR, HR and VR ratings, according to the maximum safe speed.

6. Miscellaneous - The U.S.A. require all automotive products to have "Federal markings", for which tyre moulds have to be engraved, but not all are. There are other superficial distinctions such as kerbing ribs and white side walls.

A seven figure "MPG ITEM" code is used to distinguish each variation. New tyres are coded and recorded on a computer stock file as they enter the stores, after inspection. The first three digits of the code identify the brand, construction and use, as in table 1. (Major Product Group). The other digits are used to distinguish the other characteristics listed above.

In addition to tyres, a wide variety of accessories are supplied. Tyres are often fitted to wheels from Dunlop's Rim and Wheel Division for vehicle manufacturers. Every tubed tyre requires a new tube when replaced, and all the corresponding tubes are available. Truck tyres often require a "flap" to prevent abrasion with the rim, and to act as a seal. Some other rubber based products, such as radiator hoses, patches and rubber solution are sold. A wide range of garage equipment such as hydraulic jacks, wheel alignment gauges, pressure gauges and a whole range of Schrader valves and equipment is also available.

1-3 Planning and Distribution

The function of the Planning and Distribution Division of U.K.T.D. is to co-ordinate the marketing and production activities and to organize the distribution of finished goods. The division consists of the five departments shown in figure 2.

The principal planning tool is the Management Plan. It is drawn up annually in September to give combined estimates of the requirements of each marketing division and major customer for the following year. (The markets are summarized in figure 3). When the first estimates are available, they are assessed by computer routines to determine whether there is any conflict with production capacity. If so, the estimates are revised and re-assessed until agreement is reached. The plan is used by Planning Department to make the appropriate plant and equipment available, and to set production targets. It is also used as a basis for financial and inventory control, and it is reviewed in March and September mainly for financial purposes.

The Supplies Department decides weekly production schedules which are then translated into component requirements and programmed on the factory. The schedules are devised from a consideration of stock levels, firm (or "outstanding") orders and "policy". The department is also responsible for allocating finished goods to the various markets as they become available.

Exports from U.K.T.D. go to approximately 200 countries in Europe and overseas, and Dunlop maintains a sales organization to promote its interests in these areas. The Export Department at Fort Dunlop handles the commercial processes related to the movement of these goods. Export markets generally, and Europe in particular, require tyres of high quality. The time goods spend in transit is substantially longer for overseas than for any home market, and it is important to use freight efficiently. Stiff penalties can result from not fulfilling the requirements of a

FIGURE 2

THE ORGANISATION OF U.K. TYRE DIVISION

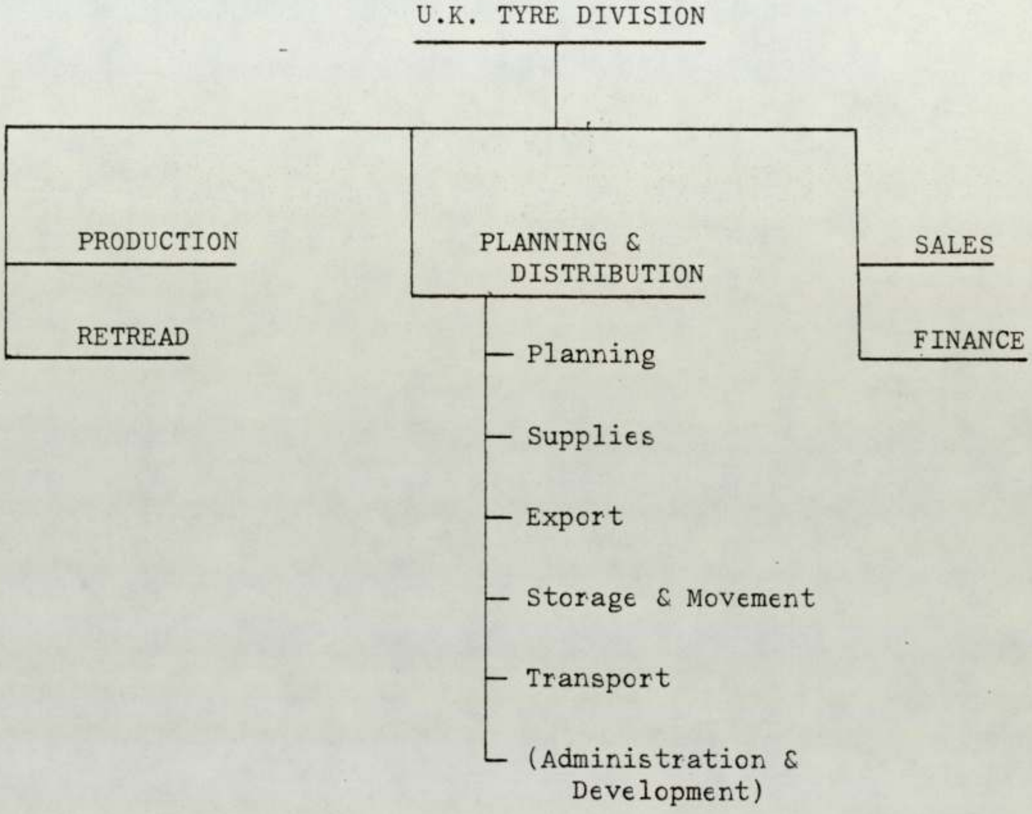
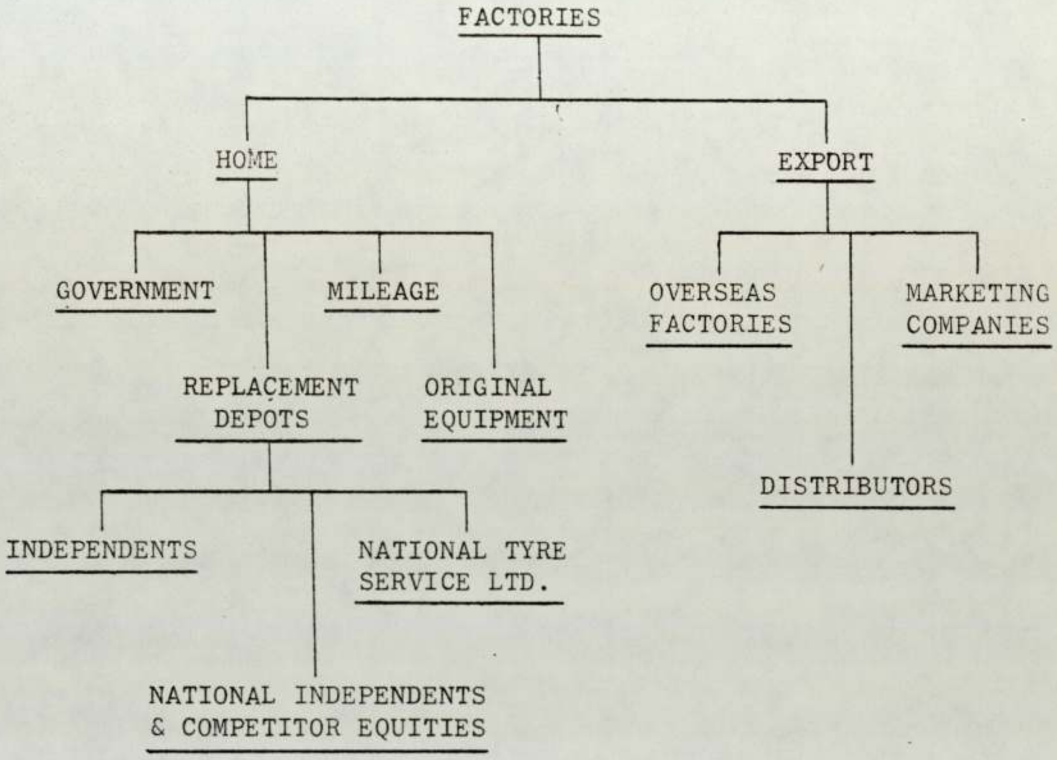


FIGURE 3

DISTRIBUTION FROM U.K. FACTORIES



contract or a foreign government. All these conditions and restrictions must be observed in addition to offering the customer a service.

1-4 Description of the Project

Motivation

The performance of Planning and Distribution Division had improved substantially since it was set up in 1970/1. This was due largely to the co-ordination of its activities and the development of computer systems in the areas of Supplies, Storage and Movement, and Transport. Computer systems have been developing to assist the operation of the Export Department more recently. There had also been a history of complaints about poor service from customers in foreign territories, especially E.S.D. The Export Manager (Mr. T. McNair) considered it appropriate for a study to be made of the long-term development of control systems for the major export markets.

Another reason for being concerned about inventory control was the high interest rate of around 15%. The capital investment in inventory has an opportunity cost equivalent to at least this rate, so there is a strong incentive to use inventory more efficiently. Even if the size of inventory remains constant, inflation increased the cost of finished goods and hence the corresponding investment.

If the size of inventories can be reduced, it may be possible to reduce warehouse expenses, and providing better service may allow a reduction in the terms of credit offered. During the period of the project trends in currency exchange rates made British goods much less attractive, and amplified the importance of these factors.

Objectives of the Research

The initial definition of the project was to study the feasibility of developing a stock control and replenishment system covering the requirements of E.S.D. from U.K.T.D. The objectives of the system were defined as -

(a) to reduce the overall capital tied up in finished goods by improved systems and liaison between the two companies; and

(b) to reduce lead times for provisioning and delivery of export orders, especially for Europe.

Before starting the investigation into the main area of interest, I was set a minor project by Mr. McNair. It was to develop policy guidelines for the acceptance and handling of small orders and small accounts by the Export Department, with the objective of establishing criteria to determine a minimum economic size for an order. This project arose from the concern of Export Department staff for the amount of time consumed by small amounts of business, with apparently little reward. It lasted five months and also served as a period of familiarization with the staff and operations of the Department. The work on this project, and the conclusions drawn from the study, are recorded in Appendix 1.

1-5 Current Inventory Control Practices

The principal method of controlling finished goods stocks in the factory warehouses is the weekly size by size production scheduling carried out by the Supplies Department. Production of sizes which have the largest demand is continuous and fairly constant. Since these take up most of the available capacity, the weekly re-scheduling is mainly concerned with the less popular items.

The general objective is to maintain a balanced inventory, i.e. to maintain supplies of the majority of sizes without overstocking any one size. In particular, the policy towards high volume, or "key" items is to maintain supplies at all times, while less cover is allowed "normal" items. Low volume items are made in batches to last up to ten weeks, and stocks tend to be reserved at national warehouses rather than in regional depots. Items with abnormal or irregular demand are made only to fulfil firm orders. Typically, a moulding machine is used for a group of these items in rotation.

The regional depots which supply the home replacement market are replenished with the aid of a computerized system which regularly calculates current requirements. The necessary information is derived from daily records of sales at each depot. If goods in the national warehouses are in free supply, these requirements are automatically allocated to the depots. If they are in short supply because output from the factory cannot maintain stocks, they are allocated manually. The requirements of other markets are only allocated manually. (The procedure of allocation involves establishing the priorities of the various markets based on their special requirements and general policy.)

Stocks are only deliberately reserved for the export market in high volume sizes, and the weekly allocations are made only against outstanding orders. Little control is exerted by the Export Department over national stocks. All its allocated stock is waiting either to be packed and despatched, or for other items to become available to make up a consignment.

The Export Department needs to maintain contacts with other departments because of the demanding nature of its market. Monthly meetings are held with the Supplies Department to plan allocations for short supply sizes, and direct contacts are kept to deal with special problems as they arise. Interdepartmental meetings are held to ensure that tyres of the appropriate standard are available.

The Dunlop Selling Company in Denmark keeps computer records of its sales, and stocks are reported at least once a month as a basis for generating orders. A re-order quantity is suggested by the computer for generating orders. A re-order quantity is suggested by the computer for each item, which is reviewed by the General Manager to ensure that it is reasonable and possibly to take account of other factors. A lead time of twelve weeks is assumed in the calculations, although this is admittedly pessimistic. More detail of the Company's operations are contained in a report written about the author's visit there. (See Appendix 2)

CHAPTER 2

REVIEW OF INVENTORY CONTROL THEORY

2-1 Independent Warehouse Operation

- 2-1-1 The Function of Inventory
- 2-1-2 The Demand Process
- 2-1-3 Stocking Policies
- 2-1-4 Inventory Control
  - Inventory Costs
  - Re-ordering
  - Stratification
  - The Strategic Choice of Policies
  - Choice of Service Level

2-2 Production-Inventory Systems

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- 2-2-2 Classification of Production-Inventory Systems

2-3 Multi-Echelon Systems

- 2-3-1 Ordering Procedures
- 2-3-2 Stability
- 2-3-3 The Push System

2-4 Summary

CHAPTER 2

REVIEW OF INVENTORY CONTROL THEORY

2. Introduction

This chapter reviews the concepts and language of the control of finished goods inventories. The meanings of some terms differ, depending on the structure of the distribution network to which they refer. The aim is to make these distinctions clear, and to state how they will be used in the rest of the text. To begin with, many of the basic terms are defined in the context of an independent warehouse, which is the basic distribution structure. Then there is a brief description of the relation between inventory control and factory programming, and finally, more complex distribution networks are examined.

2-1 Independent Warehouse Operation

First, consider a warehouse physically separated from its sources of supply and its customers, and with its own management responsible for maintaining stock levels. Normally, the warehouse will keep a stock of a variety of different products, to serve a localized market. Here the term "stock" will be applied to an available quantity of a specific item, and the term "inventory" will be applied to the aggregation of all the stocks of different items.

2-1-1 The Function of Inventory

In the context of this warehouse, there are four main functional reasons for holding a stock of any particular item.

1. Safety Stock - A product is normally re-ordered from the supplier before its stock level has fallen to zero. This allows for the delay between the order being

generated and the receipt of the goods into stock, and for the uncertainty about customer orders during that time. The safety stock is the difference between the re-order level and the demand expected. It therefore represents the protection against abnormally high demand.

2. Working Stock - When a shipment is received into stock, the re-order trigger is exceeded. This excess is termed the working stock, and represents the quantity to be sold prior to the next re-order.

3. Pipeline Stock - Usually this is defined as the quantity in transit from the supplier to the warehouse. It can also be applied to a quantity on order.

4. Seasonal Stock - When stocks are ordered in excess of current requirements, to provide for an anticipated higher demand, the excess is termed seasonal stock.

The inventory of the warehouse as a whole has a broader purpose than these four individually, which is to act as a buffer between, or decouple, the demands of the customers and the operation of the supplier. It makes them less dependent on each other, and reduces the need for highly organized control. The customer has a local, reliable supply, and the supplier can plan on the basis of larger orders to make production and distribution more economical.

2-1-2 The Demand Process

In any time period, the orders received from customers for a specific product will not normally be known in advance. However, it may be possible to detect regularities in the orders, either intuitively, or by a formal statistical technique. By doing so, it is assumed that there is an underlying process generating the orders which cannot be observed directly. Typically, this process is assumed to be composed of level, trend and seasonal factors, which may be estimated from the history of orders, and used to forecast future demand. An estimate is also made of the variation of the observation about the process. This represents how much uncertainty is associated with forecasts of future events, assuming that the same process is at work. It also has a major influence on the size of safety stocks.

However, it is unlikely that the process will continue to be representative of customer demand indefinitely. Any number of economic or competitive trends, political decisions, strikes, or even periods of untypical weather, could be responsible for a significant change in the underlying process. If the process ceases to be representative of demand, the history of demand ceases to be relevant in estimating the process. Forecasts can then only be made from other sources of information, experience or guesswork.

2-1-3 Stock Policies

A stocking policy is a set of rules which is designed to control the stock of a particular product. It defines the period between reviews of the stock level, the level at which orders are triggered, the size of the order, and the action taken during a stockout. There are four distinct types of policy which may be applied to different classes of product, or in different situations.

1. Re-order Level Policy (R.O.L.) - The stock level is reviewed continuously, against a specified re-order level. When the stock falls to, or below, that level, a replenishment order is generated. In its simplest

operation it is implemented as a "two bin" system for cheap items, i.e. the level is reviewed whenever a withdrawal is made and a fixed replenishment quantity is obtained.

2. R.O.L. Policy Subject to Periodic Reviews - A fixed replenishment order is placed at each review if the stock falls to, or below, the re-order level.

3. Re-Order Cycle Policy (R.O.C.) - Orders are generated at each periodic review, calculated as the difference between the current level and a maximum (specified) level.

4. The (s,S) Policy - Stock is reviewed periodically, and an order is generated if the stock is below a re-order level (s). The order quantity is determined as the difference between the current and a maximum level (S).

To use one of these policies, it is necessary to set the review period, re-order level, maximum stock level, and re-order quantity appropriately. They are termed "policy variables" and they depend on -

(a) the leadtime;

(b) the level and variability of demand;

(c) the required protection against stockouts; and

(d) the capacity of the warehouse.

The leadtime may be defined in this situation to be the delay between a re-order level being triggered and the receipt of goods into stock. It may be known, or it may be relatively stable. However, in general, many of the comments made about the demand process apply to the leadtime. It may vary significantly in itself, between products or between suppliers.

The protection against stockouts may be measured in one of two ways. The first, which is usually termed "vendor service level", is defined as the probability of not running out of stock during each review period. If a level of protection is chosen, the corresponding safety stock can be calculated from the distribution of demand during a leadtime. It is a suitable measure of efficiency of the warehouse, especially when backordering is allowed during a stockout. The second measure, called "customer service level", is defined as the proportion of customer demand filled from available stock per annum. This is useful in judging the level of stockouts from the viewpoint of the customer, and especially in the retail situation. Two other measures of service are derived from these. One is the expected time a shortage will last. The other is the proportion of orders filled from stock.

There is a great deal of literature concerned with determining the policy variables to achieve optimal, stable behaviour when used. A typical approach is to express "ordering costs" and "holding costs" as functions of the review period, the re-order level and quantity, and minimise the total cost subject to constraints of service and capacity. Sometimes, a cost is attributed to stockouts and included in the total cost function, when it is considered appropriate.

2-1-4 Inventory Control

The methods of controlling individual items have been described, and it is now appropriate to examine the choices available for applying them to the operation of the warehouse as a whole.

Inventory Costs

The costs of operating an inventory can be divided into three types:-

1. Ordering costs - which are usually independent of the size of orders, include order administration, receiving and inspection costs for incoming goods.

2. Storage or Holding costs - include the opportunity cost of capital invested in inventory, direct storage costs, deterioration costs, and insurance.

3. Stock out or Runout Costs - are judged to be attributable to stockouts, i.e. cost of lost sales or loss of customer goodwill.

J.F. Magee (54 Pt.1) considering the costs that influence inventory policy, notes that they are "......characteristically not those recorded, at least not in a directly available form, in the usual industrial accounting system." His concern is that the relevant costs may not be clear to all those who make policy, creating confusion and inconsistency. He lays down two criteria which apply to the costs that should be used for inventory control policy:-

1. The costs shall represent "out of pocket" expenditures, i.e. cash actually paid out or opportunities for profit foregone.

2. They shall represent those costs whose magnitude is affected by the schedule, plan or policy.

Re-ordering

The stocking policies described above trigger an order either at a fixed time interval, or at a given re-order level. An alternative is to assign a "can-order level" to each product, so that when one member of the family crosses its own re-order level, an order is made for all the products below their can-order levels. Another way is to calculate the value of forecast shortages one leadtime into the future and reorder all the items when the value falls below a threshold. The policies also give a choice between a fixed order quantity, and an order quantity that will bring the stock up to a maximum level. An alternative to this is to make a joint order from one supplier to take advantage of truck loads, discount rates and palletized quantities, etc.

A technique of inventory control called "Coverage Analysis" by J. Murdoch (in 52 Ch.9) was developed with the objective of minimizing capital invested in inventory throughout the whole range of stocked items, subject to keeping the total number of replenishment orders per annum the same as it was before the introduction of the scheme. Coverage is defined as the ratio of an item's average stock level to its annual usage. The technique is based on the proposal that the number of orders placed per annum should be proportional to the square root of annual sales, because the number of orders is claimed to be more important than the order size in reducing the capital investment.

Stratification

In describing loosely the treatment of families of items, the idea of product stratification, or classification, has been introduced. Products are grouped or considered as families because of their physical or functional characteristics. But for the purpose of inventory control it is useful to use other classifications, which may be the basis for choosing a stocking policy, a forecasting system, or an economic order quantity.

The most important classification is by value of annual sales and 'ABC Analysis' is a simple practical example. Class C items are cheap and make up the largest portion of the stocked range, class B items are more valuable and less numerous, and class A items are few in number and valuable. The range can be divided into any number of useful classes e.g. in Coverage Analysis there may be ten or more.

The Strategic Choice of Policies

A range of possibilities have been outlined for the control of inventory, and a guide is now given for applying them suitably. It can only be a guide since alternative policies may be equally effective, or the relative costs may change. The choice has been called strategic because it is made on the basis of factors which do not change frequently.

1. A fixed order policy is suitable for class C items, when infrequent large orders essentially eliminate the risk of a stockout. These items are usually only important when there are none available.

2. The re-order cycle policy is very common. It is a simple systematic policy suitable for class B items. Reviews of stock levels can be made in a regular sequence, and orders placed jointly with one supplier. A shorter review period gives tighter control over stocks.

3. For valuable class A items, the sophistication of control need only depend on what can be afforded in the way of information gathering and analysis. Usually, a form of re-order level policy is used with a continuous stock review, regular forecasts of demand, and regular reviews of availability.

4. A policy with a specified maximum stock level can be used to incorporate a constraint of limited warehouse capacity.

5. An (s,S) policy is recommended by R.G. Brown (14, p.246) for items with particular uneven demand.

6. Coverage analysis is suitably applied to an independent warehouse when it does not recommend substantial changes in replenishment

orders. Its main attraction is the simplicity of application to a whole inventory.

Choice of Service Level

Having decided on a policy for different classes of items, the policy variables must be set for each item. The mathematical models of the policies require either that stockout costs are identified, or that a level of service is chosen. W. Lampkin (49) favours the evaluation of stockout costs for classes of items which are similar in that respect, as opposed to finding classes of items which require the same level of service. By contrast, R.G. Brown (14, Ch.10) does not consider evaluating stockout costs. He views the choice of service level as a tactical one, balanced against the total investment required to meet it, and he suggests factors which may affect the relative propensity to invest in inventory. The distribution of the investment throughout the range is seen as a strategic choice, and six alternative rules are given for it:-

1. The same level of service is applied to each item;
2. The safety stock for each item is set at a level which minimises the number of back-orders (or lost sales) for a given investment.
3. The same safety factor (= safety stock/standard deviation of demand during the leadtime) is applied to each item.
4. The number of weeks supply is set to determine the safety stock.
5. The safety stock is set to minimise the total number of replenishment orders that require expediting.
6. The safety stock is set to minimise the expected number of customer orders that will not be filled from stock.

For an independent warehouse, rule (2) is recommended as being most appropriate, because it protects the customer service level with a minimum inventory.

The contrast between the approaches of Brown and Lampkin is not as strong in principle as described here. The theory underlying Brown's approach does incorporate shortage costs, but simplifying assumptions are made which make the results independent of them. This is discussed further in Section 2-3-3. Even so it is easier to evaluate service levels relative to those of a competitor than to compare shortage costs.

The term service level has been defined in terms of the standard analyses of the policies. There are other aspects of the warehouse operation which contribute to the overall "service" that is offered to customers, e.g. emergency action during stockouts, credit allowance, delivery, extent of product range, and acceptance of small orders.

2-2 Production-Inventory Systems

The beginning of the chain of distribution of finished goods is the output of a factory, which usually undergoes some quality control inspection, and is put in the factory warehouse. The function of this inventory is precisely the same, except that it is more directly related to the need for stable production. The major difference between the factory warehouse and the independent warehouse is in the economics of placing orders. In determining a suitable re-order quantity the cost of holding stock is balanced against the cost of setting up a batch of production, as opposed to the order costs. The set up costs are generally the most important in the model.

2-2-1 Terminology

As implied above, the terminology and the control policies defined for an independent warehouse can be applied in fairly obvious ways to the factory warehouse, e.g. "stabilization stock" is a term used instead of seasonal stock.

J.F. Magee (54, Pt.I) gives a rule for the valuation of inventory in this situation:-

> "For production planning and inventory management purposes the investment value of goods in inventory should be taken as the cash outlay at the time of production that would have been delayed if the goods were not made then but at a later time, closer to the time of sale."

When estimates of future activity are made to decide inventory, production and employment levels, the "planning horizon time" is the term used for the periods over which the estimates are made. They depend on the leadtimes of internal operations as well as the uncertainties of the market.

2-2-2 Classification of Production-Inventory Systems

Planning of production and inventory levels is usually well co-ordinated, and could even be described as inseparable. E.S.Buffa (17) makes the distinction between "continuous" and "intermittent" systems. He defines a continuous system as one in which demand is in relatively large volumes of standardized items, and production lines are carefully designed for them. An intermittent system is one where the production capacity is very large in relation to demand for any particular item, or where there is a wide variety of alternative styles, sizes or designs of a standard product. In a continuous system, the operation is geared to producing for stock to meet varying demand. In the intermittent system, the emphasis is on scheduling production facilities for demand as it arises. In practice, a system may be classed as predominantly one or the other, though it may be combination of both.

J. Woodward (in 60, Ch.4) uses a classification of production processes of three overlapping groups, covering ten distinct classes. Group I is small batch and unit production, group II is a large batch and mass production, and group III is process production.

J.F. Magee (54, Pt.3) lists some characteristics of sales and production which affect production-inventory systems, and the following are relevant here:-

1. The same total quantity sold in a large number of small orders can characteristically be supported by substantially less inventory than if sold in a few large orders, unless the orders are planned.

2. Handling large unpredictable fluctuations in sales requires flexibility and additional capacity in production as well as carefully designed rules for controlling inventory balances.

3. The inventory problems of a business are directly related to its inability to forecast sales with precision. The responsibility of forecast errors for inventory needs should be clearly recognised and the control system should be adapted to the type of forecasts possible.

4. The delay between deciding to adjust a production rate and the action becoming effective directly influences the size of inventory needed.

5. A realistic inventory control system must recognize the limitations in flexibility which exist in production, inventory

and customer service needs.

This final point is particularly relevant in this review. Most of the methods examined already treat items individually, but the interactions between items produced by common resources cannot be ignored.

2-3 Multi-Echelon Systems

Finished goods usually pass through a chain of warehouses before reaching their ultimate consumer. The sequential order is usually related to decreasing geographical spread of customers, and decreasing size. The term "echelon" is applied to those warehouses on the same level in the chain, and the term "multi-echelon system" is used for two or more levels considered together. So far, the distinction has been made between independent and factory warehouses, and it is now necessary to consider the behaviour of multi-echelon systems composed of these elements, and how they can operate effectively.

The company which produces goods may own (or own companies which own) the distribution network. Ownership has two significant results for inventory control:-

1. The company can integrate the operations of individual warehouses to use its inventory investment more efficiently than if they operate independently. (This equally well applies to other aspects of physical distribution, like optimal location of warehouses, efficient goods handling etc.).

2. The economics of ordering within the company are different from ordering from an external supplier. In the former case, the investment in inventory was determined when the factory decided the production quantity and is not altered by moving it to another warehouse.

2-3-1 Ordering Procedures

There are a number of routine procedures for getting the right amount of stock to each warehouse in the distribution network. For simplicity, the situation considered here is a two-echelon system with a factory warehouse supplying a number of regional warehouses, but the ideas can be extended to more complicated systems straightforwardly.

1. The simplest mode of operation is for each warehouse to behave as if it were totally independent, and the comments made about re-ordering in section 2-1-4 apply.

2. If the regional warehouses can establish time-phased requirements for each item, the factory can accumulate them to use as a basis for planning production. "Requirements Planning" reduces the flexibility necessary in the factory for responding to haphazard demand.

3. In a "base stock system", each warehouse reports all its sales to the central supply point, which are then interpreted as "replenishment orders". Convenient shipments are made up to replace all that has been sold. If demand increases, the warehouse places a "stock order" to increase its level of safety stock. The advantage of this system is that the factory is always aware of the current level of sales.

4. It is quite possible that the regional stocks will become unbalanced, i.e. excesses in one region and shortages in another. This situation can be reviewed periodically by a group with access to a record of all current stock levels, and least-cost transhipments can be arranged to correct the imbalance.

5. In his paper "Multiple Triggers and Lot Sizes", P.R. Winters (68) considers the problem of when to start a production run, on the

basis of stock status at a number of locations. He derives an expression for the expected cost of inventory during a leadtime, dependent on the various stock levels. The condition that this expression is a minimum can be used to test periodically whether a production run is justified.

6. A.J. Gradwohl (37) shows how a dynamic programming model of a multi-echelon system can be used to give a set of least-cost inventory decisions. The analysis applies to a single item, and is so complex that it can only sensibly be used on a very high value item with an economic order quantity of one.

2-3-2 Stability

G. Hadley and T.M. Whitin (39) review alternative approaches to inventory control, giving particular attention to the analytical models available. After this they say -

> "In studying complex inventory supply systems, one is often much more interested in the dynamic stability and frequency response of the system, than in an optimal operating doctrine derived under the assumption that the stochastic processes associated with the system are not changing with time."

They then discuss simulation techniques which can be used to analyse these dynamic characteristics in a specific context.

A description of what is meant by dynamic stability and frequency response is given by E.S. Buffa (17, Ch.8). The example is a simulation model of a three-echelon production-inventory system, in which each echelon operates independently under a conventional periodic review policy. The response of this system is tested by introducing a ten percent step decrease in consumer demand. There is an inherent delay in transmitting the change to the factory, which is essentially the sum of all the intermediate review periods. The effect is that excess stock builds up throughout the delay, and production has to be cut back substantially more than ten percent. This action introduces a "lightly damped" oscillation in all the inventories. This shows how delays in the system amplify the effect on the factory of any change in demand.

The effect can be reduced substantially by reporting consumer demand directly to the factory, over and above the re-order procedure. The effect was also shown to be reduced by eliminating the entire distributor echelon from the system. Lastly, the clerical delays in the original model were reduced to test the effect of simply speeding the flow of information. The effect was minor, and the general conclusion was drawn that only structural changes will yield major improvements. This means that it is better to use a control system designed specifically for a multi-echelon system, rather than to search for optimal policies for individual warehouses.

2-3-3 The Push System

It has been shown that there is a need for a method of inventory control tailored to the multi-echelon system, and while the ordering procedures of section 2-3-1 partially satisfy the need, the "push system" was developed by R.G. Brown (14) to meet this requirement. It is based on two theoretical results published by K.F. Simpson.

The first paper, "In-Process Inventories" (66), looked at the general question of how big inventories should be to achieve optimum operating efficiency in a base stock system of replenishment. (In fact it applies to any process-inventory chain). The result is that the inventory should always be the maximum reasonable demand during a leadtime i.e. that the service for each inventory should be zero. Translated into practical terms, it means that to achieve a target customer service level with a minimum inventory, any warehouse must be replenished within a short and predictable leadtime. (All risk of stock shortages should be taken at the last warehouses in the network). Nothing has been said about how to achieve this, but it has emphasized the importance of dependable supplies.

In the second paper, "A Theory of Allocation of Stocks to Warehouses" (65), Simpson deals with the problem of how best to allocate a given quantity of stock to a number of warehouses. He shows that it should be allocated in such a way that the probabilities of each warehouse selling a quantity greater or equal to the amount allocated, during the horizon period, are equalized. After making more assumptions about the homogeneous nature of demand among warehouses, a general formula is derived for calculating the best allocation quantity (or "fair share") for each warehouse, dependent on the mean and variance of expected demand. (The analysis can be applied to a more general problem of allocation of resources between facilities, to derive analogous results.)

This theory of allocation leads to the fundamental concept of the push system, which is that given information about the demand and stock status at a number of warehouses, to be supplied from common limited resources, a fair share allocation can be calculated for each. It is natural that the information should be gathered and used at the supplying warehouse. Thus, the resources are "pushed" out to the field, and the responsibility of maintaining supply does not rest with the receiving warehouse. It is in this respect that the push system is different from the other methods of control described above, which are called "pull" systems.

Consider a two-echelon system consisting of a national warehouse and a number of regional warehouses, where the stocks are termed "master" and "satellites" respectively. The leadtime in this system is re-defined to include only administrative times, transit time and the interval between shipments. The re-order level at the factory includes a "national safety stock" calculated from a forecast of national demand and production leadtime, to give "perfect" service to the satellites. At the regional warehouse, the re-order level is calculated to give a predetermined level of service to customers. Nationally, when the stocks of a particular item need review, the regional sales are projected into the future and compared with the stock on hand, so that fair share allocations can be made. Shipments can then be built up from a list of these allocations, giving priority to those items which are most urgently needed.

The advantages of the push system, which relies on transmission and processing sales data, can be summarized as follows:-

1. It allows the investment in inventory to be a minimum for a given level of customer service, in a multi-echelon system.

2. It allows production to be programmed with a view of the current state of the market, and the real priorities.

3. Stock can be used tactically to obtain the best possible service from the amount available.

4. It provides a data base which can be used to search for available stock, when it is generally low.

2-4 Summary

The chapter makes a comprehensive review of the various approaches and techniques available to control inventories. The methods are described in the context of the type of distribution system in which they apply, and it is apparent that there is a natural tendency to use information processing technology in more complicated networks. Stability was introduced as a highly desirable characteristic of a multi-echelon system, and the push system was shown to embody the advantages of all the other methods of control.

CHAPTER 3

A REVIEW OF THE THEORY OF ORGANIZATIONS

CHAPTER 3

A REVIEW OF THE THEORY OF ORGANIZATIONS

3. Introduction

The more recently developed methods of inventory control for multi-echelon systems (described in Chapter 2) involve particular forms of organization. The implication is that these forms of organization are best suited to the task of control. In this chapter, the theory of organizations is reviewed to show the relation between systems of control and organizational form. A second purpose is to provide a framework for studying the present structure of Dunlop's Tyre Division.

To begin with, relevant ideas from the general theory of systems are outlined, and then organizations are seen as particular types of systems. The rest of the chapter uses the concept of "organization design" as a framework for the remaining topics.

3-1 System Concepts and Characteristics

The term "system" has been used, up to here, in an every day sense to mean a method or a set of operations directed to some task. It will now be introduced as a technical term, fundamental to an area of study called General Systems Theory. This in turn is the basis of some important ideas used in organization theory.

3-1-1 General Terminology

A "system" has been defined by R.L. Ackoff (1) as a set of inter-related elements, i.e. something composed of two or more elements, with each element related to another in some way. S. Beer (10) gives four characteristics by which "viable" systems can be recognised:-

1. They cohere within some frame of reference;
2. They survive through time within some appropriate definition of continued identity;
3. To achieve this they prescribe to themselves certain rules of equilibrial activity which are tolerable to continued existence;
4. They assimilate their experiences into self-regulating processes of learning, adaptation and evolution.

The state of the system is the set of its relevant properties. The environment of the system is the set of elements and related properties which affect the system, but are not part of it. A closed system effectively has no environment, whereas an open system does. The boundary of the system is essentially the distinction between elements of the system and those of the environment. The effect of the environment on the system is termed the input, and its response is termed the output.

The generality of these definitions (e.g. no restriction has been placed on the terms element and relation) indicates a high level of abstraction and, correspondingly, a wide range of applicability. But it is also claimed that the range of systems concepts provide a "way of thinking" or an "approach" for scientific investigation. The essence of the "systems approach" is that of wholeness or holism. Usually contrasted with the reductionist or mechanistic type of analysis typical of the principal sciences, it lays emphasis on considering the function and behaviour of the system as a whole, and taking account of the influence of the environment. It is not a rival approach, but a complementary one. L.von Bertalanffy (11) says that the approach has been particularly successful in interdisciplinary research, and in studying the behaviour of organisms.

Many special terms are used in the literature of General Systems Theory, and some more relevant ones are introduced here. A feedback mechanism uses the output of a system, or information about the output, to affect the input in a specified way. A negative feedback mechanism tests the output against a standard, and affects the input so that the output tends towards the standard. This principle, which is closely allied to that of control and dynamic equilibrium, is often described as "error-compensating" or "self-correcting". Applied to living organisms, the principle is called homeostasis, where the mechanism is not usually explicit.

Variety is defined as the number of possible states of affairs of interest of a system. A priori, there is a corresponding amount of uncertainty about the actual state of affairs. If constraints or relationships are imposed on the system, the variety reduces, and so does the uncertainty. According to the laws of Thermodynamics, there is a tendency in a closed physical system for entropy (i.e. chaos or disorder) to increase. An open system characteristically takes in energy from its environment to maintain itself, to grow, and to become more complex. It is said to import "negative entropy".

Differentiation is a form of adaptation in which part of the system becomes more specialized in order to perform particular functions more effectively. (An obvious example is the division of labour) As a result the system becomes more complex, and less homogeneous, so it must solve the problem of co-ordinating the specialized parts. This necessary counterpart to differentiation is called integration.

3-1-2 The Feedback Loop Model

One major area of interest of General Systems Theory is the dynamic behaviour of complicated systems. J.W. Forrester (26) developed a general approach to investigating these characteristics using the feedback loop as the basis element of a general model. He distinguishes two types of variables called rates and levels. A level variable is a stock or accumulation of some conserved commodity. A rate variable represents the level of activity resulting from some explicit or implicit policy. The feedback loop consists of a commodity flow into a "level" controlled by a "rate".

The rate variable is determined by four components:-

1. The standard or goal of the loop;

2. The observed condition, which is information about the current values of level variables;

3. An expression of the discrepancy between the standard and the observed condition;

4. An algebraic statement, representing the dependence of the rate on the discrepancy.

To apply the feedback loop model, it is necessary to define a boundary to the study which includes all the components which are interacting to generate the behaviour of interest. Forrester gives a test of independence to distinguish between level variables of the system and of the environment. It ensures that the effect of the environment is not structural, and so the boundary is called closed.

To summarize the model, four hierarchical levels can be identified:-

1. The closed boundary;
2. The feedback loop structure;
3. Rate and level variables;
4. The local standard, the observed condition, the discrepancy and the action.

The order of a system is defined as the number of level variables required to model it. The links between the feedback loops in the model are represented by coupling equations, which are in general non-linear. A complex system is defined as a high order, multiple-loop, non-linear feedback structure, which represents a very wide class of systems. Forrester (30) identifies a number of behavioural characteristics which seem to be common to complex systems, and they are summarized here:-

1. Counter-Intuitive Behaviour - Most of the solutions to problems which appear to be sensible intuitively will not give the expected results.
2. Insensitivity to Parameter Changes - The dynamic characteristics of the system will not be affected significantly by changes in most of the parameters. This is also true of most changes in policy.
3. Control through Influence Points - The system will be sensitive to changes in a few parameters and to some structural changes. These are not usually self-evident.

4. Long Term versus Short Term Response - Changes in a system commonly cause short term responses in an opposite direction to the long term effects.

3-1-3 The Five System Hierarchy

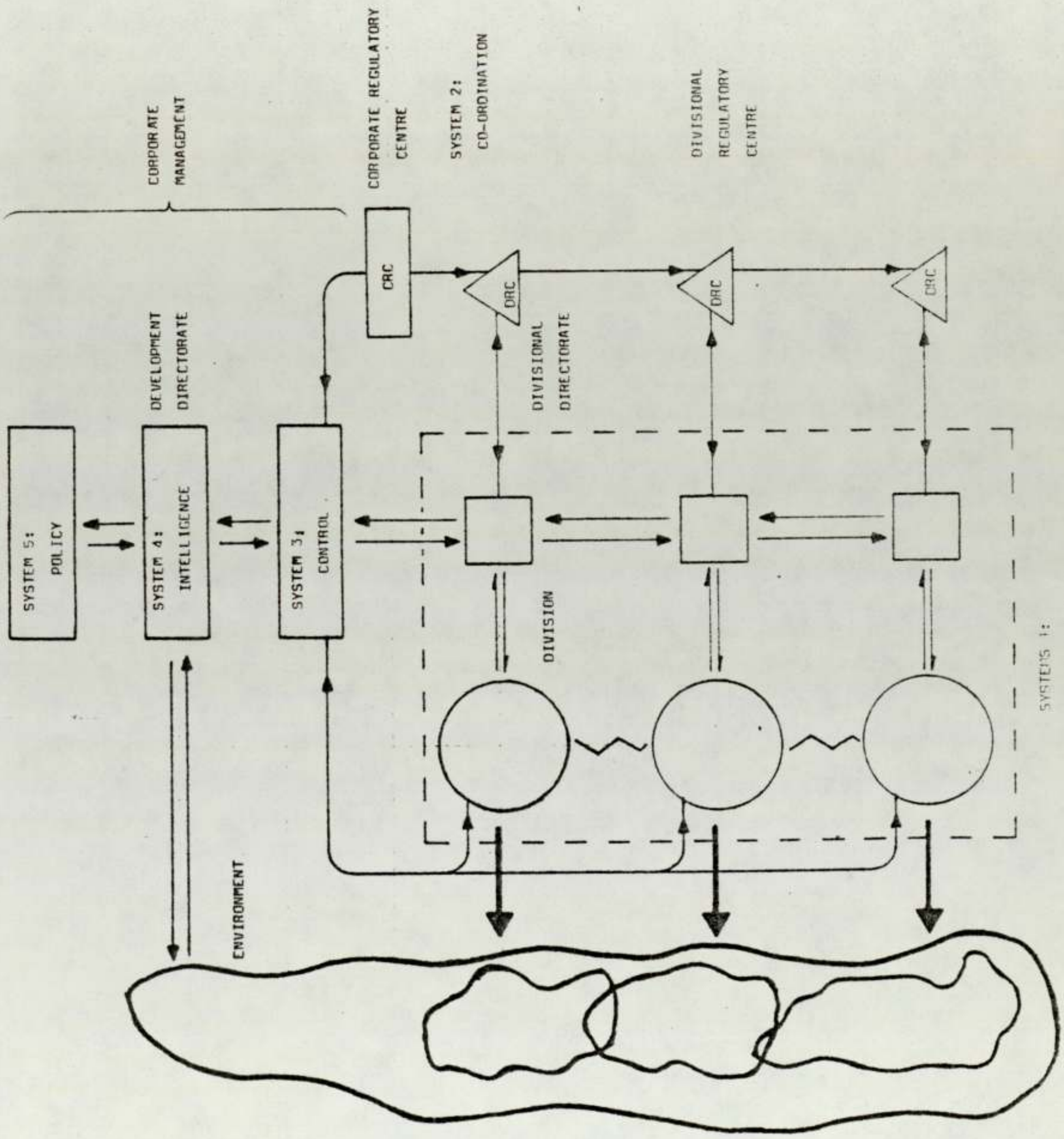
In contrast to the feedback loop model which can theoretically be used to represent any complex system, S. Beer (7) has developed a single model of a whole class of systems through his study of Cybernetics. More specifically, it is a model of the elements of control and communication of any viable system (as defined in section 3-1-1). A viable system is capable of withstanding unanticipated shocks or perturbations, and primary examples are animal life forms. He claims that the model is an abstraction from the animal nervous system and that its elements are a necessary and sufficient representation of the information and control mechanisms of any viable organization. These elements may not be distinguishable entities in any system, but their functions must be present.

A viable system contains a number of activity centres which deal with the environment in some way. For the moment these can be thought of as "black boxes". A "system one", the first in the hierarchy, has the function of planning and programming one of the activity centres. See figure 4. The job of "system two" is to monitor and co-ordinate the behaviour of the separate activities, so that their interaction is balanced. It must also be aware of how the plans are used by the systems one, and how they can be modified to meet the objectives of the system as a whole, while maintaining the balance between them.

System three has the overall responsibility of maintaining systems one and two by strategic and tactical planning. As well as receiving regular information about the activities, it can inquire about specific

FIGURE 4

THE FIVE SYSTEM HIERARCHY



aspects of the activities in detail. System three also reports the routine summaries of operations upwards to system four. The general function of systems two and three is to integrate the specialized (differentiated) activities controlled by systems one.

The general function of systems four and five is normative planning (i.e. choosing operational objectives) for the whole system. System five has the responsibility for making policy using a model of the environment, while system four provides system five with the required intelligence about internal and external events, and transmits policy decisions to system three.

The activity centres may themselves be viable systems, and if so, they can each be modelled by the five system hierarchy. The organization may be an activity centre within a larger viable organization. This leads to the concept of the recursive nature of the model, i.e. that a viable system is itself composed of viable systems. A result of this is that to a large extent viable systems are self-regulating and self-organizing.

3-2 System Simulation

A model is a representation of some characteristics of an object, system or idea in some form other than that of the entity itself. It is usually a simplification, concentrating on the aspects of interest. A simulation model is essentially a theory describing the structure and inter-relations of a system, which demonstrates its dynamic characteristics. The feedback loop model of section 3-1-2 is the basis of a simulation technique developed by J.W. Forrester (26) called "Industrial Dynamics". It is capable of modelling complex systems which cannot be dealt with by mathematical analysis, and it is particularly suitable for analysing industrial control systems. The DYNAMO compiler was developed to simplify the programming of such models.

However, its application is a major project which, according to K.J. Schlager (63), requires an operationally practical information system, practitioners experienced in using the technique, and continuing support from all levels of management. Some of the original studies took several years to complete.

3-3 Organizations as Systems

Implicit in the preceding descriptions of general systems was the idea that an organization is a type of system. R.L. Ackoff (1) gives a quite complicated definition of an organization. It consists of elements that have and can exercise their own wills (i.e. people), has a functional division of labour, has communicating parts, and has at least one part which controls the rest of the system. He considers Cybernetics to be concerned only with "organisms" which do not have elements with wills of their own, but S. Beer (7, Ch.11) sees it merely as a weakness of the model that its elements are self-conscious. Instead, Beer distinguishes between viable organizations and institutions, an institution being dependent on external sources for direction and survival. Katz and Kahn (48) list a number of consequences of viewing organizations as systems. They emphasize the dependence of an organization on its environment for materials and human resources, and that it is vital to study the environment. They also say that organizations try to maintain their stability by using protective devices and by moving towards tighter integration and co-ordination.

Emery and Trist (5, Ch.10) develop the theme of the effect of organizational environment, by classifying the market in the following way:-

1. Placid-Randomized - This represents the classical economic market of perfect competition, which is predictable and well behaved.

2. Placid-Clustered - Imperfect competition results in a less stable environment, where the right strategies are important.

3. Disturbed-Reactive - There is a significant competitive challenge and the market is dominated by a small number of large firms.

4. Turbulent fields - Dynamic processes cause large changes in the environment, requiring strategic and tactical planning. There is a great deal of uncertainty about the reaction to plans, and a reliance on new technology to meet the challenge.

They introduce the concept of "causal texture", in addition to open and closed systems, to describe the strong interaction between the organization and its environment.

3-4 Analysis of Organizations

It is appropriate to begin this section with a definition of organization, to fix ideas. J.R. Galbraith (32, p.3) gives a suitable one, which is similar to Ackoff's. An organization is -

1. composed of people and groups of people;
2. in order to achieve some shared purpose;
3. through a division of labour;
4. integrated by information based decision processes;
5. continuously through time.

A considerable amount of literature has been devoted to the question of whether there is a best way to organize, or whether organization is determined by its objectives, processes and environment. Lawrence and Lorsch (50, Ch.8) review the work of six authors on this subject and come to the conclusion that -

> "These studies offer a formidable body of evidence that organizational forms must depend on the task and environmental conditions."

J. Child (20) reviews the schools of thought on the effectiveness of management structure, which relate it to -

(a) technological implications;
(b) environmental requirements;
(c) the effect of size; and
(d) motivational effects.

His conclusion is that any of these approaches oversimplifies the situation by identifying only a few factors for investigation. He also considers a methodological limitation of the research to be simply that there is an inadequate conceptualization of management structure, which empirical research cannot overcome. T.L. Whisler (56) discusses the impact of information technology on organizational control, and summarizes it as centralizing control structures and scrambling the power structure among functional departments.

Contingency theory was formulated in an attempt to resolve the limitations of these approaches. It says -

1. there is no one best way to organize; and
2. not all ways to organize are equally effective.

J.R. Galbraith (32) introduces the idea of organizational design as the search for a fit between organizing modes (see section 3-4-2) and integrating individuals into the organization, to further its objectives in the broadest sense. He assumes that the organizing modes are common to all organizations, and that these must be combined with their unique aspects when formulating a design. His position is that there are significant areas of choice in the structure or organizations, and that the choice should be identified and made consciously.

Galbraith refines the idea of organization design by taking it to include the strategic choice of policy variables in five distinct, but inter-related, areas. This is summarized in Table 2, and it provides the framework for the rest of this section. The first sub-section reports the views of an economist on the objectives of an organization and its relation to its environment. The second deals with the relation between task uncertainty and organizing modes. Finally, Cybernetics is reviewed as an analysis of information and decision processes. "People" and "reward systems" are not considered relevant to the development of this argument.

3-4-1 The Technostructure

J.K. Galbraith (34) considers that the major influence over the changing nature of industrial organizations in the twentieth century has been the increased technological sophistication of their products. This increased sophistication produces three main effects:-

1. The time needed to research and design new products is increasing and the resulting commitment of capital to development is large. This long term commitment requires long term stability and planning, so the organization must find ways of minimizing the risk inherent in the process. It can do this by influencing consumer markets, assuring markets by contract, or by vertical integration of supply and demand chains.

TABLE 2

THE CONCEPT OF ORGANIZATION DESIGN

Area of Strategic Choice	Organization Design Policy Variables
(1) Task (Resulting from choice of domain and objectives)	Diversity Difficulty Variability
(2) Structure (Organizing Mode)	Division of labour Departmentalization Configuration Distribution of power
(3) Information and Decision Processes	Decision mechanism Frequency Formalization Data base
(4) Reward System	Compensation system Promotion basis Leadership style Job design
(5) People	Promotion Training & Development Transfer Selection

2. Technologists and applied scientists are necessary to the functioning of the organization. A large number of decisions, and all the important ones, draw on expert knowledge possessed by more than one man. So the organization is guided essentially by a hierarchy of committees of experts. Galbraith defines the technostructure to be all those who participate in this group decision making, or the organization which they form.

3. Organizations grow and become more complex. Size is necessary to withstand the residual risk which cannot be eliminated by other methods.

In discussing industrial organizations, Galbraith asserts that the pre-eminent goal is survival. This implies that an organization is primarily concerned with preserving its autonomy by securing a minimum of earnings. He says that the overwhelming choice of the second goal is for the greatest possible rate of corporate growth, because it is the best defence against contraction.

3-4-2 Task Uncertainty and Organizing Modes

In his book "Organization Design" J.R. Galbraith (32) sets out the relation between task uncertainty and organization design. Task uncertainty is defined as the difference between the amount of information required to perform a task and the amount possessed by the organization. The information required to perform the task is referred to as the complexity of the task. Galbraith postulates that -

> "the greater the task uncertainty, the greater the amount of information that must be processed among decision makers, during task execution, in order or achieve a given level of performance."

This in turn leads to the hypothesis that the observed variations in organizational forms are variations in "organizing modes" which -

(a) increase the ability to pre-plan or make decisions about activities in advance of execution;

(b) increase their flexibility to adapt to the inability to pre-plan; or

(c) decrease the level of performance required for continued viability.

The relationship of structure to uncertainty (and information) is described by using a mechanistic model of the organization as an information processing network. The rest of this section looks at the organizing modes which can be used to cope with co-ordinating interdependent sub-tasks.

Hierarchy of authority, as represented by an organization chart, is the most obvious mode of co-ordination. It is an efficient information processing mechanism because of the small number of communication channels between any two units. Its disadvantage is the restricted capacity for communication, so when these channels are overloaded other mechanisms must be used.

Rules and procedures are decisions which can be made in advance of task execution, and can therefore be formalized. They eliminate the need for communication between interdependent units and allow repetitive decisions to be made at lower levels of the organization, so reducing the need for them to be referred up the hierarchy. If the task uncertainty increases so that there are too many exceptions for the hierarchy to cope with, it must allow discretion at lower levels. To be fairly certain that appropriate decisions are made, two strategies can be used -

1. Instead of planning procedures centrally, craft or professional training of the employees is undertaken. This strategy often results in a reduction of the span of control.

2. The task can be divided into parts, each with its own specific objectives or goals.

The success of the organization in co-ordinating its tasks by these methods depends on the frequency of exceptions and the capacity of the hierarchy to handle them. If uncertainty increases still further, there are two general ways of dealing with it:-

(a) reduce the need for information processing;

(b) increase the capacity to process information.

There are five strategic choices available, of which the first three belong to category (a), and the other two belong to category (b). It is this set of strategies which Galbraith calls organizing modes.

1. Environmental Management - Instead of changing the internal structure, the organization can attempt to influence its environment by managing demand, vertical integration and co-operative schemes. It is even possible for it to manoeuvre to a new, more manageable, environment.

2. Creation of Slack Resources - The number of exceptions depends on the level of performance, so task uncertainty can be reduced simply by reducing the level of performance. The result is that the organization uses more resources, and the excess is termed "slack".

3. Creation of Self-contained Tasks - In this strategy, the emphasis is changed from functional task design to one in which a group has all the necessary resources to perform an alloted task. It is typified by a team of professionals working on a single project with a definite aim. The strategy simplifies the co-ordination of resources and tends to reduce the division of labour.

4. Investment in Vertical Information Systems - Operational plans degenerate and need to be revised because reality is never quite as predicted. If plans have to be revised frequently because of this uncertainty, too much time is absorbed by the replanning activity. By investing in machines which collect, process and communicate information, the replanning can become virtually automatic.

5. Creation of Lateral Relations - The final organizing mode is to allow decisions to be taken (selectively) which cut across formal lines of authority. Decisions are brought nearer to the points where problems occur. The four basic mechanisms for doing this are direct contact, evolution of liaison roles, formation of inter-departmental groups, and creation of integrating roles.

The choice or combination of these organizing modes depends on which will cost the least to use in the situation of interest. But they are also hypothesized to be an exhaustive set of alternatives. This means that the organization does adopt one of these strategies when faced with increased uncertainty, and if it does not choose one consciously, the result will be reduced performance in the form of slack resources.

3-4-3 Cybernetics

The basic cybernetic model has been outlined very briefly in section 3-1-3. It provides a blueprint for the necessary control and communication mechanisms in any viable organization, and a framework for the use of other management science techniques. The relevance of the model to the study of an organization is in identifying -

(a) the recursive levels of the organization; and

(b) the correspondence between the model and existing mechanisms.

The complete model shows where information channels are necessary, and the positions of filters and monitoring devices which control the volume of communications. The regulatory functions of an organization can typically be analysed by operational research techniques. System three governs the balance of operations between the individual activity centres, a problem which could be studied by Industrial Dynamics. In common with Industrial Dynamics, however, expertise in applying the techniques surrounding Cybernetics is not yet widely available.

3-5 Summary

The theory of organizations has been reviewed to provide an insight into the relationship between structure and control in them. Some models were described, deriving from General Systems Theory, which are the basis of scientific techniques of organizational analysis. Various alternative organizing modes were described, which are available to deal with increasing task uncertainty. The concept of organization design was introduced, which identifies inter-related areas of strategic choice of policy variables. It provided a framework for the other forms of analysis, showing the area of applicability of each.

CHAPTER 4

THE ORGANIZATION OF INVENTORY CONTROL WITHIN TYRES-EUROPE

CHAPTER 4

THE ORGANIZATION OF INVENTORY CONTROL WITHIN TYRES-EUROPE

4. Introduction

In this chapter inventory control is viewed as an organizational task in the sense of the information processing model, and its techniques are described in terms of the organizing modes they require. Methods of inventory control used within Tyres-Europe are described in these terms and they are then related to the cybernetic model.

4-1 Task Analysis of Inventory Control

This section discusses inventory control in terms of organizing modes and shows which strategies are used in the Tyres-Europe organization. First of all, the terminology of the information processing model is explained more fully than in chapter 3, to make clear the use of some important terms.

4-1-1 Complexity

The problem of analysing the behaviour of a number of entities which interact (i.e. a system) is in general complex, unless the relationships are of a particularly simple form. If these entities are feedback loops, only four or five are required to form a "complex system" (using J.W. Forrester's definition), which can only be investigated by simulation. Even a system of variables constrained by linear relations (which can be handled by straightforward mathematical techniques) would only be solved by programming a computer if there were more than six or eight variables. So the more complex analyses of inventory control deal with the interaction effects between products (e.g. in production scheduling, capacity constraints and joint re-order levels) or between warehouses (e.g. Gradwohl (37)), see section 3-2-1. If all the items in a system are dealt with independently, the problem reduces to one of devising a work schedule to cope with them efficiently.

The aim in applying mathematical and computational techniques to complex systems is to increase the level of performance while simplifying decision making. The costs of the strategy are in the preliminary analysis and in a system which will provide appropriate information. The broad framework of chapter 2 was to describe the alternative methods of inventory control in order of increasing complexity.

4-1-2 Uncertainty

Uncertainty also creates difficult decisions. It arises either because -

(a) the outcome of future events is not known or predetermined; or because

(b) the relevant information is not available.

The former cause of uncertainty can be tackled by constructing a stochastic model of the events, i.e. by formalizing the relation between what is known and what is not. If uncertainty is caused by an inadequate communication system, the cybernetic model is available to help redesign it. Alternatively successful techniques can be copied from other organizations.

The basic element of uncertainty in inventory control is that of the demand process during the next replenishment lead time. It can be estimated from sales data, perhaps in the form of "variance of demand during the lead time". A stocking policy can be thought of as converting this uncertainty into safety stock.

4-1-3 The Task of Inventory Control

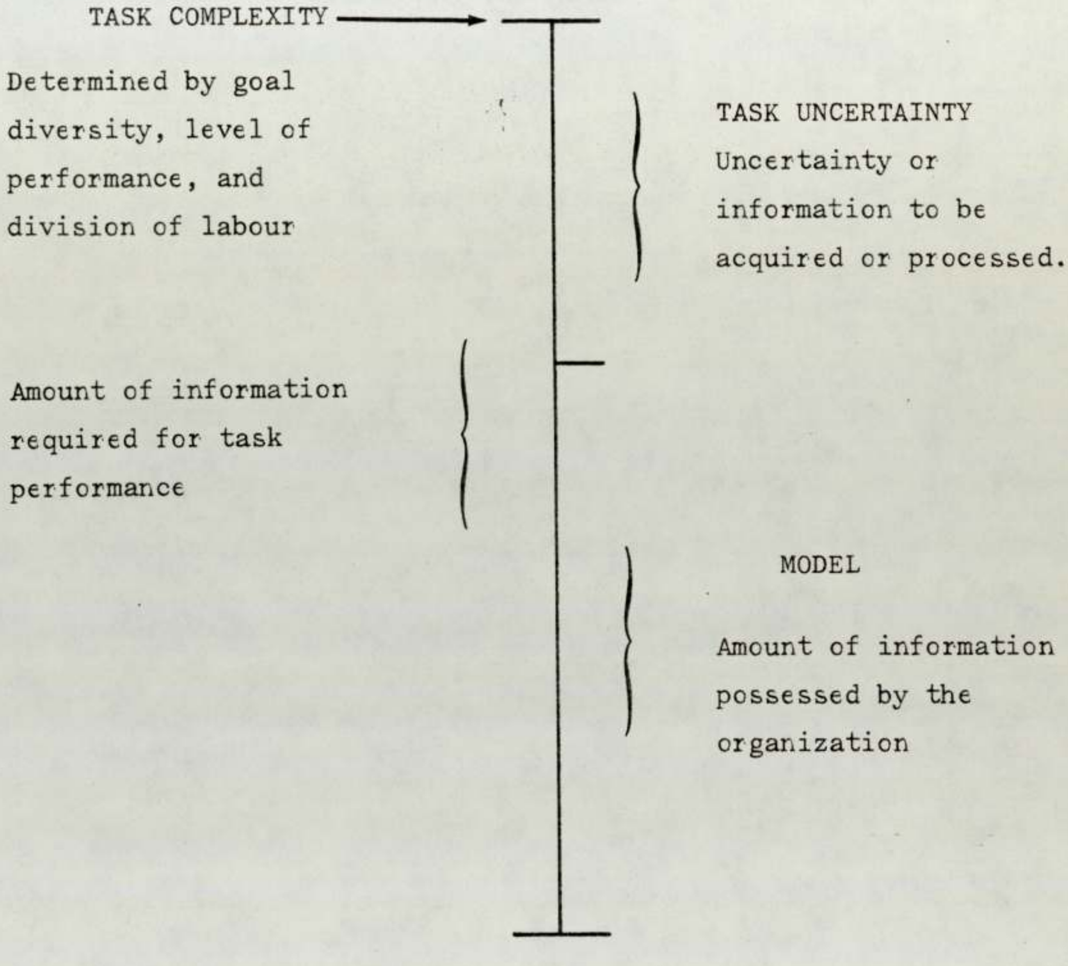
J.R. Galbraith (p.39, 32) equates the complexity of the task with the amount of information required for its performance, and describes it as being a function of the number of relevant variables and the required level of performance. This notion of task complexity takes in only part of what was meant by complexity in section 4-1-1, emphasizing that as tasks become more complex they require more information.

Suppose there is a recurring decision which can be analysed and formulated in a model, so that whenever the decision needs to be taken it can be calculated using current information in the model. The current information is what Galbraith refers to as "task uncertainty". (This is not obvious either from the preceding discussion of uncertainty, although it is the uncertainty surrounding the task that makes current information necessary for its execution.) This in turn means that the decision cannot be made in advance. So the basic effect of uncertainty is to limit the ability of the organization to predetermine its activities. The structure of the model is the amount of information already possessed by the organization. By using a new model, it may be possible to increase performance, but there will always be some residual task uncertainty. The use of these terms is summarized in figure 5. They are not defined in a way that makes them easily quantifiable, and Galbraith mentions several attempts to measure them which were only partially successful.

From this analysis, it can be seen that it is possible to increase task uncertainty either by gathering information more frequently, or by broadening the scope of the data base. Both have the potential for increasing the level of performance, but the extra information has to be used effectively in the model. It may also be possible to increase the

FIGURE 5

DETERMINANTS OF INFORMATION AND TASK UNCERTAINTY



level of performance by reducing the uncertainty surrounding the task, i.e. by environmental management, see section 4-2.

A model which deals most effectively with a multi-echelon system, say, must take account of the objectives of all the warehouses in the network, and use information from them all simultaneously. Such a model will necessarily be complex, and must depend on a centralized information system. The theoretical work of Simpson (65 & 66) (see section 2-3-3) certainly fits this description even though simplifying assumptions are made. The principal assumption is that the objectives of each warehouse are dictated by the efficiency of the system as a whole.

It has been assumed here that the model was a formal one which could be used automatically, and this was for the sake of simplicity. In most real situations this model is implicit in the mind of a manager in a planning process, or in the workings of a committee. This does not change the argument at all, but implicit models have very different characteristics:-

(a) they can only deal with a limited amount of complexity;

(b) they can be used with insufficient information and without formal information systems;

(c) they are not necessarily consistent;

(d) they cannot be tested for their operational stability.

4-2 Organizing Modes of Inventory Control

Having explained what is meant by the task uncertainty of inventory control, it is possible to review the set of alternative organizing modes in relation to this task and show how they are used in Dunlop's European organization. Since these modes are hypothesized to be a complete set, it is reasonable to expect that all the techniques mentioned in chapter 2 can be interpreted as one, or combinations of, these modes. Conversely, it is to be expected that the alternative approaches suggested by the organizing modes are a complete set.

Environmental Management

The existence of marketing and distribution organizations like E.S.D. is the result of an environmental strategy which may have been stimulated by the wish to grow and diversify. But if it was the result of a desire to be less susceptible to the instabilities inherent in a distribution network, or if it was for the more general purpose of forward planning, then it can be viewed as a strategy to reduce the environmental uncertainty of inventory control. Supplying tyres to vehicle manufacturers in the anticipation of future sales can also be seen in this way.

Self-Contained Tasks

This strategy requires that groups are formed with the necessary resources to provide a specified output. The interpretation of this in terms of inventory control is to provide a factory at each distribution point. It is not appropriate to consider this any further.

Slack Resources

If the environmental uncertainty of an inventory control system increases, then the organization will convert it into higher stocks and/or worse service unless another strategy is consciously adopted. It is only possible to reduce stock levels and improve service (i.e. to increase the level of performance) by using more complex controls. Conversly, slack resources reduce the need to deal with complexity. This confirms the logic of the original formulation of the project.

Procedures and Professionalism

If the requirements of the market are stable (i.e. there is little uncertainty about demand) production and inventories can be effectively preplanned, allowing for such factors as shortfalls in production and seasonalities. The planning procedure can be formalized and exceptional circumstances are referred up the hierarchy for decision.

If there is extra complexity or uncertainty, the routine procedures can be augmented by allowing discretion to people responsible for a market area or a product line. The judgement of these people is derived from knowledge and experience of products, customers, availability and modulated by the policy guidelines laid down by senior management. This mode is used significantly in Dunlop. Examples are the role of the product leader in the Supplies Department, and the stock review procedure carried out by the manager of the selling company in Denmark (see section 1-5). Both depend on the success of the person as a forecaster for their performance.

Vertical Information Systems

The use of information systems can be characterized by four main variables (p.25, 32):-

(a) the decision mechanism - Formal inventory control models were the main subject of chapter 2, but other methods of control were mentioned for multi-echelon systems which used implicit models (section 2-3-1, (1),(2) & (4)). Tyre Division's depot stock system is distinctive because, to some extent it makes requisitions automatically on the basis of a formal model. When an automatic scheduling system was considered by Dunlop's Group Management

Services in 1972, it was thought unlikely that they could construct a comprehensive decision model (see appendix 3). So at present, the complex task of scheduling is performed by the product leader in a professional role, using an implicit decision model.

(b) Formalization (i.e. the systematic or routine collection of information) - is determined by the requirements of the decision mechanism. A typical formalized system in inventory control would collect sales, stocks and lead time for a warehouse. An independent warehouse uses a decision mechanism to convert it into orders, whereas a push system processes it centrally to decide on fair share allocations. A systems analyst can advise on the most efficient way to process this information, but it is not necessary for it to be done by a machine.

(c) The scope of the data base - In general, as the information system draws on a wider area of interdependent sub-units, the plans produced will better reflect the objectives of the system as a whole. The Fort Dunlop systems are limited to information about immediate customers, but are complete in that sense.

(d) The frequency of making decisions or replanning - As the period between reviews is decreased, plans will become less susceptible to decay. Most of the operational files at Fort Dunlop are updated daily, while scheduling and allocation procedures have a weekly cycle. The depot stock system can make requisitions daily, but Dunlop A/S Denmark has a monthly cycle.

Lateral Relations

In the absence of a programme for co-ordinating differentiated activities, or if the required information is not easily quantifiable, lateral relations will tend to arise. They will start informally and develop into formal roles. This mode is used extensively in Dunlop. Between Export and Supplies Departments, the Export Supplies Co-ordination Section fills this role by direct contact and weekly meetings. One of its main functions is to negotiate allocations for Export and then divide them amongst its customers.

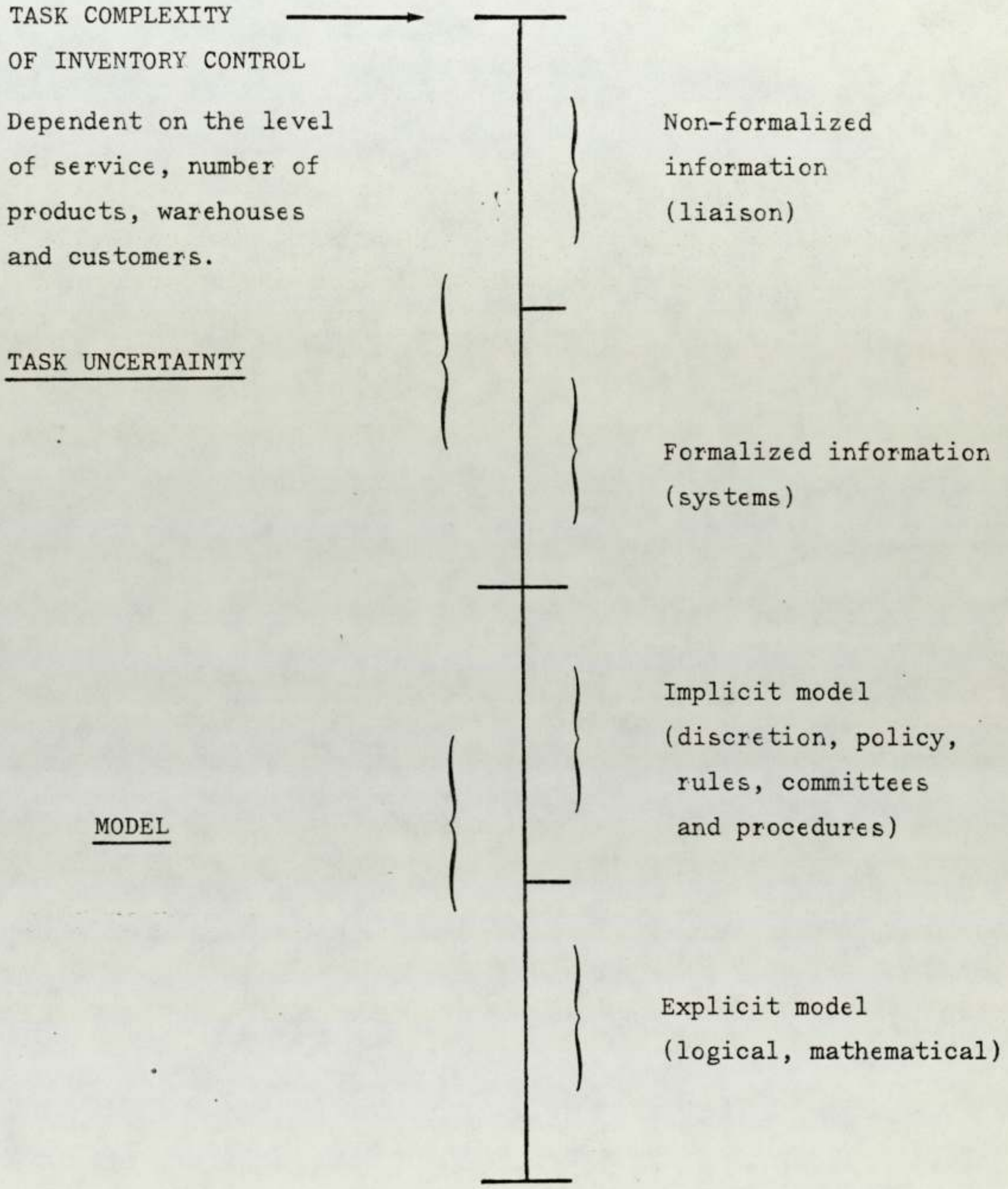
The Tyres-Europe H.Q. organization evolved out of the need to co-ordinate European manufacturing and marketing operations after it became the responsibility of a single director. Its main function is to translate projected sales into requirements for plant and machinery, and to decide where goods can best be produced. In this small organization the Supplies Liaison Manager is responsible for looking after the interests of E.S.D. when normal supplies are inadequate, and he assists in the disposal of excess stocks.

Summary

The fundamental distinctions and areas of choice in organizing inventory control are summarized in figure 6. The theoretical approach is to improve performance and stability by using information from the whole of the distribution network (under consideration) in an appropriate decision model. Some systems make routine decisions automatically and require minimal intervention, while others are dependent on discretion and supervision. A push system uses a method of replenishment which is

FIGURE 6

THE BASIC CHOICES FOR ORGANIZING INVENTORY CONTROL



theoretically superior to any pull system.

The other alternatives open to an organization are to:-

(a) try to influence external events which cause uncertainty and instability;

(b) develop control systems using localized information systems; or

(c) develop liaison between warehouses and echelons.

The first alternative is outside the scope of the project, being much more closely allied to the marketing and production functions. Therefore, this approach will not be considered further.

In Tyre Division the formalized information systems have a very limited decision making capability because of the difficulty in modelling the processes involved. At present, no data base extends beyond its own division, and consequently liaison roles have been established in an attempt to stabilise interdivisional activities.

4-3 A Cybernetic View of Inventory Control in Tyres-Europe

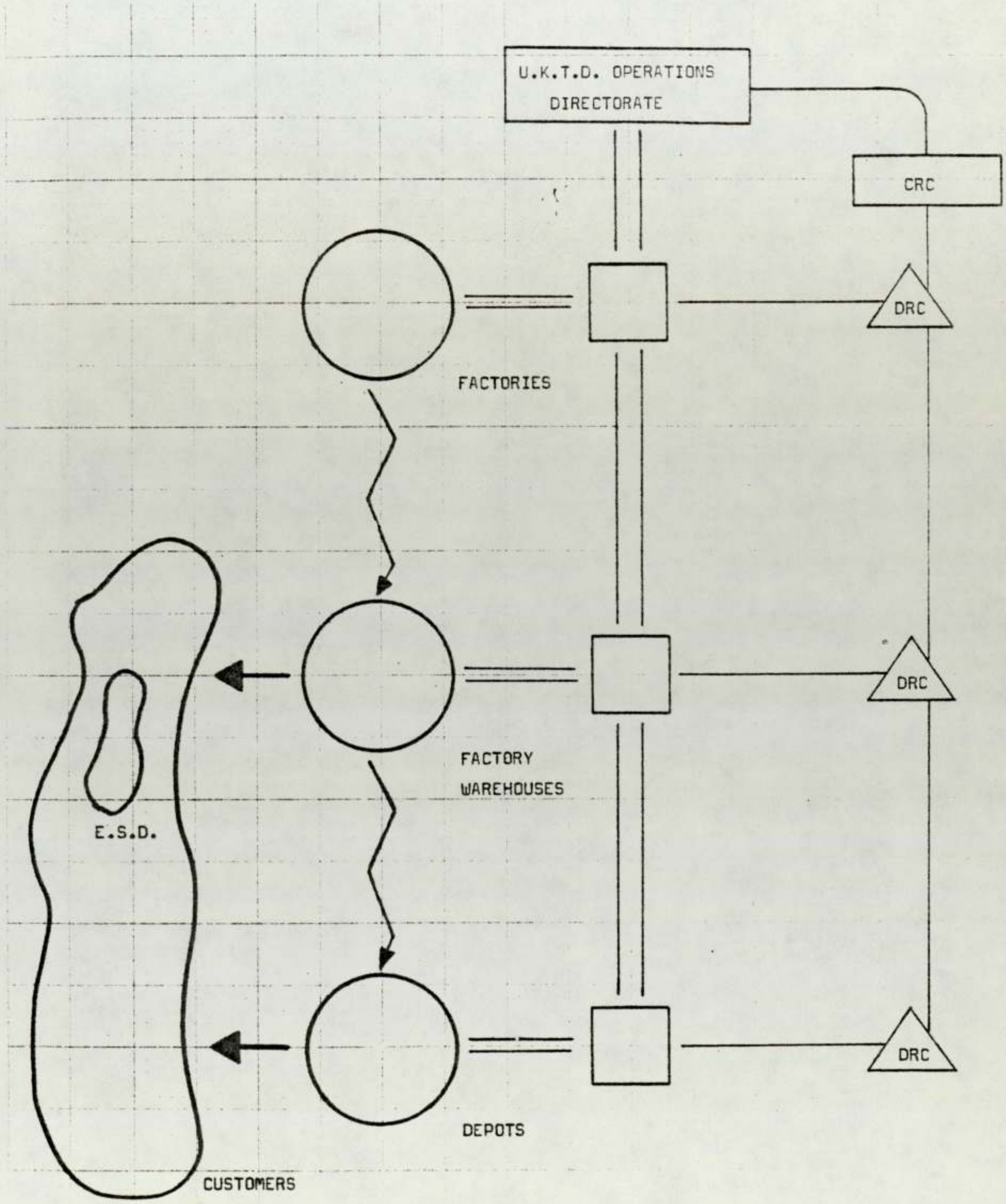
The discussion so far has pointed to some similarities between the organization of Planning & Distribution and that of Tyres-Europe. In this section, the cybernetic model of the firm is applied to examine this similarity further, and to draw conclusions about them.

4-3-1 Tyres Division

The model shown in figure 7 views Tyre Division as a "corporation" and its manufacturing, warehouse and depot operations as "divisions". E.S.D. is a part of the environment of this corporation. System two monitors and co-ordinates the behaviour of these divisions in order that their interactions are balanced, and reports them to system three. Therefore its principal function in this model is inventory control. The

FIGURE 7

A CYBERNETIC VIEW OF INVENTORY CONTROL IN TYRE DIVISION



existing formal information systems covering order administration, base stores and depot stock correspond well to the channels of communication predicted by the model.

The function of the corporate regulatory centre is to maintain a balance of supplies which is best for the corporation as a whole, and therefore corresponds to the model (explicit or implicit) used for inventory control. In Tyre Division it is implicit in the scheduling and allocation procedures. Information comes up to the corporate regulatory centre through formal computer systems (supplemented by informal systems in the form of liaison) and current policy towards markets down from system three.

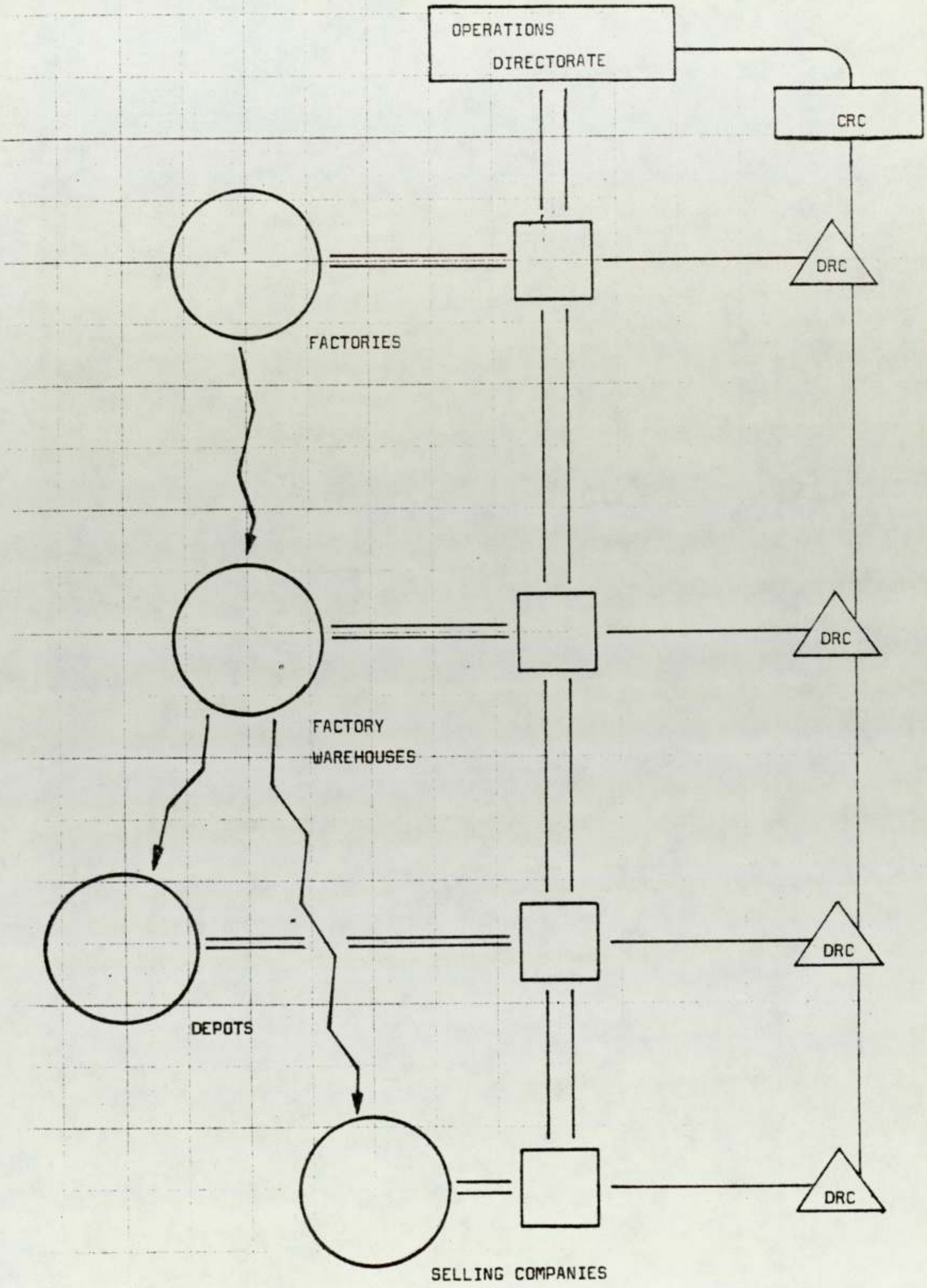
Assuming that this is a good model, cybernetics predicts that this corporation will be strongly autonomous and concerned above all with its own success as an organization. It is my impression of Tyre Division that this is so.

4-3-2 Tyres-Europe

The model shown in figure 8 includes the project area as a part of a Tyres-Europe "corporation". It incorporates the previous model of Tyre Division, the analogous organizations in France, Germany and Eire, and E.S.D. To a large extent these organizations operate autonomously, with their own reporting procedures and directors/general managers. The interactions which do take place are co-ordinated by the Tyres-Europe H.Q. organization. In general, these amount to planning future activities and giving advice on problems when they occur. As an example, the role of the Supplies Liaison Manager is to monitor the performance of the selling companies, to help deal with exceptional stocks and shortages, and to give regular information about stock availability. This corresponds in the model to some of the functions of the divisional regulatory centre.

FIGURE 8

CYBERNETIC CONTROL IN A TYRES-EUROPE "CORPORATION"



So the importance of this model is that it includes the project area as an intrinsic part.

The corporate regulatory centre in this model incorporates the centres of the manufacturing divisions. But the model also predicts a mechanism which will take a "superior" (or metasystemic) view of the priority of each division when, for example, supplies fail. In this situation, the divisional regulatory centre has the authority to dictate, rather than to advise, corrective action, in the knowledge that it will be effective. There is no machinery in the Tyres-Europe organization to perform this function, and while the manufacturing divisions are organized in such a way that they can take care of their own interests, E.S.D. does not have a comparable tactical influence. In an organization without an effective corporate regulatory centre it is typical for a highly competitive situation to develop when normal conditions break down, with each autonomous unit trying to get as much out of the situation as it can, in any legitimate way it can devise.

4-3-3 Allocation Policy

The allocation procedure used by Tyre Division is the decision mechanism which balances supplies between markets in times of shortage, and therefore influences the stability of the distribution network. The policy towards allocations is one of the regulators of this mechanism, and so it is appropriate to explain its rationale more fully.

The home replacement market makes the largest single contribution per item and is the largest single market. The original equipment market provides a smaller contribution, but is considered important because of its influence on replacement sales. It is also necessary to prevent supply failures to expensive production lines.

In addition to the requirements of exporting mentioned already, the periods for which credit is allowed are much longer. Consequently, in times of poor cash flow, exporting goods in short supply becomes even less attractive. So the Export Department must compete with substantial opposition for allocations, without being able to offer any inducements. The main argument that can be used is the length of time an order has been outstanding. Periodically, the plight of export orders comes to the attention of senior management at the system three level, and they are given priority. This is usually short lived, and the "natural" priority becomes re-established.

4-3-4 Summary

This view of the Tyres-Europe organization has shown that it is composed of a number of autonomous units, but that it is incomplete when considered as a single viable organization. The result of this is that the interests of E.S.D. are not sufficiently well represented in the tactical planning procedures of Tyre Division. Senior management can intervene in the routine procedures to attempt to redress this imbalance.

CHAPTER 5

PRINCIPAL RECOMMENDATIONS

CHAPTER 5

PRINCIPAL RECOMMENDATIONS

1. INTRODUCTION

So far, it has been explained how techniques of inventory control relate to the forms of organization which they require, and the way these forms are used in the relevant areas of Tyres-Europe. The analysis also indicates how performance can be improved, so in this chapter suggestions are made, on the basis of the analysis, as to how systems of control could be improved. General conclusions are reached about the effective use of data processing machinery, and the problems of altering organizational forms are mentioned. As a result, a design framework is proposed for any future development of control systems.

First of all, the most significant of the theoretical aspects of the problem are briefly restated.

5-1 Review of the Project

The project originated from a wish to improve the performance of the inventory control systems linking E.S.D. to U.K.T.D. Task analysis suggests that this can be achieved by improving the model (explicit or implicit) used in the decision mechanism, or, to put it another way, by using more complex controls. Theoretically, the model can be improved by making it more representative of environmental uncertainty and the complex behaviour of the system to be controlled. A Cybernetic view of the project area shows that there is a deficiency in the mechanism of co-ordination required for adequate control, indicating a specific area for improvement.

Increasing the scope of the data base may be necessary for the use of an explicit model, and may improve the performance of an implicit one. Collecting data more frequently may also help. At present, information systems are used most significantly in the support of professionalized decision making roles, and have a limited decision making capability. Simulation of production-inventory systems shows that information about consumer demand can be used to stabilize inventories while simply speeding up the flow of information has only a minor effect on performance. In the Tyres-Europe organization, liaison roles have been used in an attempt to stabilize inter-divisional activities. The final alternative is to reduce the uncertainty and complexity of the environment (in the marketing and production control areas) but this is considered to be outside the scope of the project.

The service experienced by Dunlop A/S Denmark is the subject of many explanations. Less emotive among these are the poor quality of goods produced, and the complexity and low priority of the export market. The approach taken here is to use this theoretical background to make suggestions for the improvement of relevant aspects of the Tyres-Europe organization.

5-2 The Push System

The push system is the only method considered which has all the theoretically desirable characteristics mentioned for a multi-echelon system. It is a refinement of the base stock system, in that it is capable of allocating limited amounts of stock in an optimal way (i.e. by equalizing the expected lost sales at each warehouse). It also enables available stock to be distributed throughout the network in an optimal way.

5-2-1 The Multiple Warehouse System

All previous discussion of the push system has been in reference to its theoretical basis. But it is also the basis of a library of time-sharing programs called the Multiple Warehouse System, developed by R.G. Brown, and described in reference 14. The library covers a complete set of inventory management functions, from shop floor control to testing alternative distribution strategies. The individual programs are highly modular, featuring a range of options and parameters which can be tailored to the individual needs of a company, and additions to the library are designed to be compatible with all the previous programs. So it is possible to use a small number of applications initially and gradually develop their use as required. The system can be used on a time-sharing basis permanently, or temporarily while the company installs the programs on its own machinery.

The fact that such programs already exist does not preclude a company designing its own push system, but it would mean repeating very extensive development work which has been done already. The recent trend in Tyre Division has been to concentrate on the development of computerized administrative systems, and operations research has ceased completely. So the option of developing a push system from scratch would not be worth considering.

5-2-2 The Implications of a Push System

One of the difficulties of implementing a push system is political. Because it uses a specific model for making "fair share" allocations, it has a well defined position in the corporate regulatory centre of the divisions being co-ordinated. This position must be supported by an operations directorate (system three) to give it the legitimate authority. If the distribution echelons are not effectively under a single management, it may not be possible to ensure the level of co-operation required to make such a system work. To put it another way, the initiative for developing a push system must come from the operations directorate of the divisions which will use it, and these divisions may react against it.

Dunlop's European Selling Companies have operated almost as independent companies from the viewpoint of Tyre Division, so a push system developed by Tyre Division may be seen as threatening the autonomy of these companies. A similar argument applies to the inclusion of National Tyre Services within such a system.

Regardless of where a push system is introduced in the network, its main features remain the same. Each warehouse sends information about its sales, receipts and backorders for every product to a central processing unit. Sales data is used to make short-term forecasts of requirements for each item in each location. (As for any other system of inventory control, it works best with statistically stable demand, see chapter 6.) This data is also used to make forecasts about demand in the whole network for production scheduling and planning. The supply leadtime in this system is defined as the time between deciding to replenish (i.e. making an allocation) and the receipt of goods into stock. This leadtime is monitored for each warehouse.

An allocation procedure is triggered either when the factory warehouse receives fresh stock or when a re-order level is broken in one of the satellite warehouses. The requirements of each satellite over the planning horizon are displayed against available stock. Normally, this stock is allocated in "fair share" quantities according to need. If it does not meet immediate needs, a national reserve safety stock, called a "master warehouse", is used (see Appendix 4, Section 3-4-3).

5-3 Production Scheduling and Allocation

It has not yet proved possible to explicitly model the complexity of the factory (see Appendix 3), so the scheduling procedure is likely to continue to be based on human discretion supported by a mixture of formalized and informal information systems. For the same reason, it is difficult to give a consistent measure of the performance of the procedure. But task analysis gives the qualitative insight that any improvement must embody a design which makes more effective use of information (which can be made available), and is therefore more complex.

At present, all the available information is used in determining the schedule for the week ahead. The procedure would be more complex, and able to use more information, if a provisional schedule was made for up to four weeks ahead covering all outstanding orders. The scheduling within this four week period would be structured according to the relative priority of outstanding orders. It would be necessary to systematize and refine the meaning of priority for use in a formal procedure. This could be achieved by categorizing markets or groups of customers according to their profitability or percentage contribution, etc. and setting the "maximum time outstanding" for each category as a management objective. Then as each order was received and set up on the computer, it would be given a label showing its "latest allocation date", possibly taking account of the special requirements of the particular customer.

The scheduler could then build up schedules for successive weeks, covering the orders with the earliest allocation dates first, and then fitting the rest in to suit. The requirements of markets with regular and stable demand would be estimated by the scheduler and fitted onto the schedule in the same way. When a new order was set up with a high priority, it would be fitted in possibly by displacing another with a later allocation date. If the new order could only be included by violating its priority, the customer would be informed of the situation, and it would appear on a management exception report indicating a limitation in production capacity. In the event of a failure in production which violated latest allocation dates, they would all be reset with "today's" date until cleared.

Although outstanding orders strongly influence the projected schedules for the next few weeks, production is not committed against specific orders. The allocation procedure is similarly influenced by the list of requirements in the order of their latest allocation dates, but the essential flexibility of the procedure remains. The intention of the system is to reduce the need for flexibility. Initially, there may be a temptation for urgent orders to preempt others, and while this is occasionally acceptable, the balance of priority should be regulated by making adjustments to the "maximum time outstanding" settings.

To show more clearly what is meant by this, an example of the way orders from E.S.D. might be treated is described. The procedure is shown schematically in figure 9. For simplicity, it is assumed that orders take one week to reach Fort Dunlop, and that goods take two weeks to be packed, despatched and shipped. Also assume that the maximum time outstanding is set at four weeks.

An order is despatched from the selling company at the beginning of week 1. The order has been calculated using an appropriate formula (see section 5-4) to cover predicted sales up to the end of week 6. When the order is received, at the beginning of week 2, the order is set up and any free supply items are allocated. The rest of the order is fitted onto the schedule for weeks 3, 4 and 5 as convenient. If any items cannot be fitted into this planning horizon, they are not accepted as current orders. In this case, the Supplies Liaison Manager and the

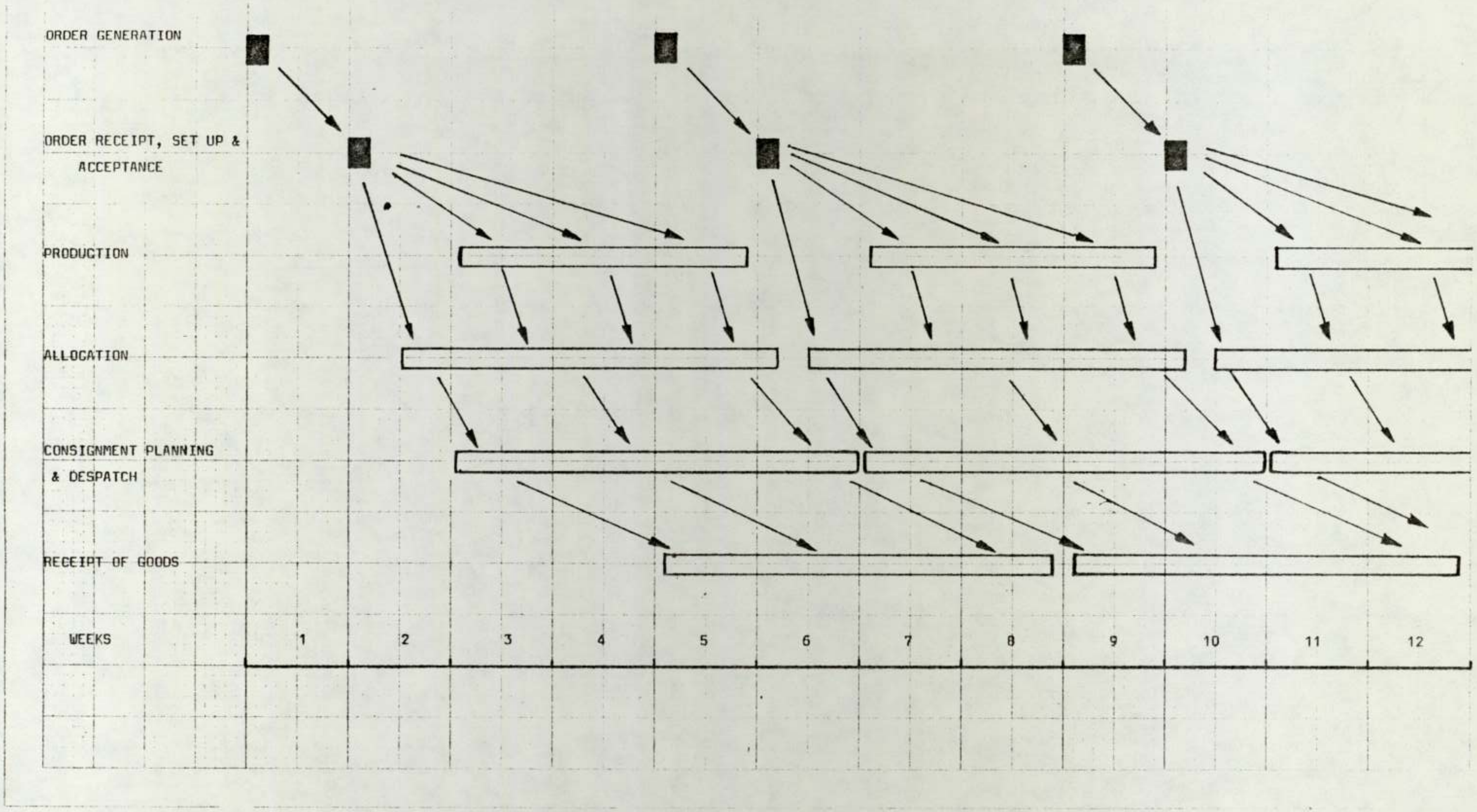


FIGURE 9

ORDER PROGRESS UNDER A REVISED SCHEDULING PROCEDURE customer are informed, and either an alternative source is arranged, or the items are set up in the forward order report. The scheduler can then bring the order onto his four week plan when it is convenient.

In week 3, the scheduler revises the schedules for weeks 4 and 5, but he is not allowed to defer the order to week 6 because of its latest allocation date. Allocations made in week 2 appear on the consignment planning report, as usual, for loads to be built up and despatched. The remainder of the order is produced by the end of week 5, and is received by the customer by the end of week 8.

The main advantage of this procedure is that the production scheduler has the information necessary to effectively control the time for which an order is outstanding. This is the basis for a consistent and predictable supply. Notice also that if orders were only placed at the beginning of each four week period, consignment planning would still be a continuous process.

5-4 Selling Company Operations

The leadtimes experienced by the selling company in Denmark may give rise to a sense of hopelessness when contemplating the task of reducing the size of inventories (see Figure 10). However, task analysis suggests the approach of using information more effectively, and possibly in a more complex model. The method of control actually used is a re-order cycle policy, with monthly reviews, and using the assumption of a twelve week leadtime. The results of this method are shown in Table 3, in terms of -

(a) the number of weeks stock held in November 1976
(for steel radial car)

(b) the ratio of turnover to finished stock value, for
all tyre products over a period of six months in 1976.

Also shown is a record of the average leadtimes experienced for "SP4" steel radials in 1976. (This value corresponds to the mean of 52 days shown in figure 10). See Table 4.

5-4-1 The Re-order Cycle Policy

If some simplifying assumptions are made, it is possible to estimate the average number of weeks cover under such a policy from theoretical considerations; i.e. with a leadtime, L, of 12 weeks, a review period, R, of 4 weeks, and assuming that the demand, D, is stable and derived from a Normal $(\overline{D}, \sigma_D^2)$ distribution with $V = \sigma_D / \overline{D} = 0.75$.

The average stock level under such a policy is given by the formula:-

$$\tfrac{1}{2} \overline{D} (L+R) + k \sigma_D \sqrt{(L+R)} .$$

Dividing this expression by the expected weekly demand, D, gives the average number of weeks cover, or AWC:-

$$\tfrac{1}{2} (L+R) + k (\sigma_D / \overline{D}) \sqrt{(L+R)} .$$

Substituting appropriate values for k to give protection against stockouts of 90% and 95% (k = 1.3 & 1.65 respectively) gives the following results:-

AWC @ 90% level -- 11.9 wks. (1a)

AWC @ 95% level -- 12.95 wks. (1b)

The correspondence with the actual figures shown in table 3 is fairly close, so the assumptions appear to be reasonable.

Suppose now that the assumption of a twelve week leadtime is

TABLE 3

STOCK ANALYSIS FOR CAR MPG, DUNLOP A/S DENMARK, 25/10/76

	UNITS ON HAND	WEEKS STOCK	UNIT SALES FOR LAST 12 MONTHS
CROSSPLY	116	8.9	680
CROSSPLY T/L	6080	13.4	23661
RADIAL TEXTILE T/L (70s)	371	10.7	1809
RADIAL STEEL (70s)	500	18.2	1428
RADIAL STEEL T/L	13223	20.3	33929
RADIAL TEXTILE T/L	3876	9.5	21139
JOHN BULL CROSSPLY	3881	11.5	17607
JOHN BULL RADIAL	3059	9.4	16878
TOTAL	31848	13.7	120939

TURNOVER/FINISHED STOCK RATIO, FOR SIX MONTHS OF 1976

	RATIO	ROLLING 12 MONTHS	
		TOTAL TURNOVER	AVERAGE STOCK
MAY	4.91	25826	5265
JUNE	4.82	25646	5320
JULY	4.88	25584	5244
AUGUST	4.85	25239	5202
SEPTEMBER	4.72	24771	5251
OCTOBER	4.67	24873	5330

TABLE 4

AVERAGE LEADTIMES FOR DUNLOP A/S DENMARK FROM U.K. FACTORIES

(Based on receipts of SP4 car radial steel in 1976)

	AVERAGE LEADTIME IN DAYS	
	MONTH	TO DATE
MAY	43.8	43.8
JUNE	55.6	52.1
JULY	36.8	47.6
AUGUST	49.4	48.4
SEPTEMBER	49.3	48.6
OCTOBER	56.3	49.8

rejected on the basis of Figure 10, and that instead the leadtime is assumed distributed as Normal ($\bar{L}$, σ_L^2), with $\bar{L}$ = 7 and $\sigma_L^2 = 8$. (The assumption of normality may not appear to correspond well with the shape of the distribution in Figure 10, but agreement at the 90th and 95th percentiles is good, see Figure 11.) To calculate the average number of weeks cover under this new assumption, a slightly revised formula is needed:-

$$\tfrac{1}{2}\,(\bar{L}+R) + k\sqrt{(\sigma_p/\bar{D})^2\cdot(\bar{L}+R) + \sigma_L^2} \quad .$$

Substituting in appropriate values gives:-

AWC @ 90% level -- 10.4 wks. (2a) (12.6% less than 1a)

AWC @ 95% level -- 11.7 wks. (2b) (9.7% less than 1b)

This shows that if information of actual leadtimes were used in calculating re-order quantities, using the same policy, a reduction in stockholding of about 10% would be expected. Another way of saying this is that the effect of the leadtime being different from twelve weeks is to increase stockholding by about 10%. This result can be stated in yet another way which shows up the critical nature of assuming a leadtime of twelve weeks, and may even be a little surprising. If the actual leadtime from the U.K. is reduced on average (thus improving the level of service) while the company retains its assumption, the average stockholding in the company will increase. So improving service may actually be counter-productive.

Suppose now that leadtime estimates are used in the re-order policy, and supplies from the U.K. are improved so the leadtimes are distribued as Normal (6,2) (perhaps using the methods of section 5-3). With the

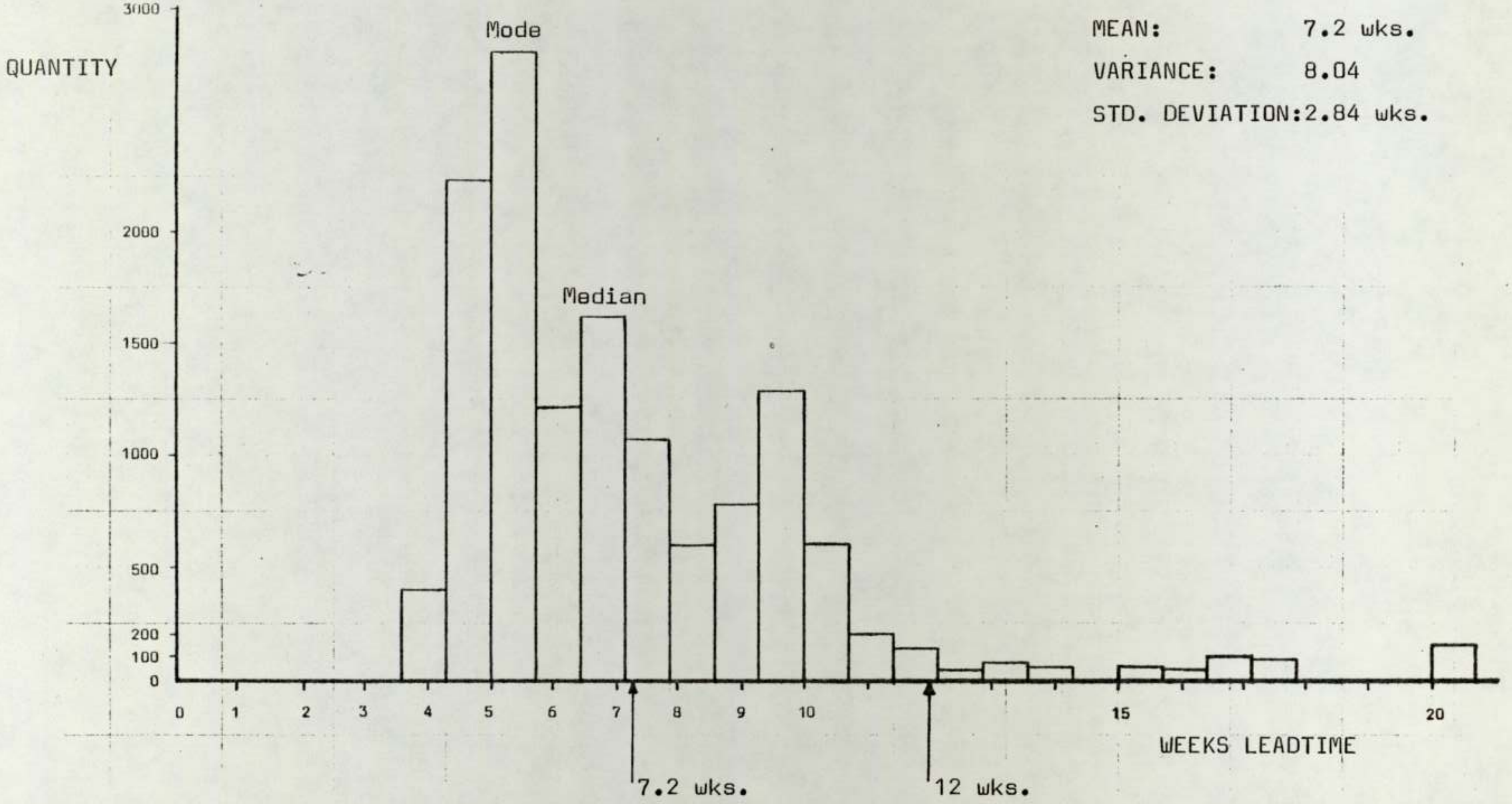
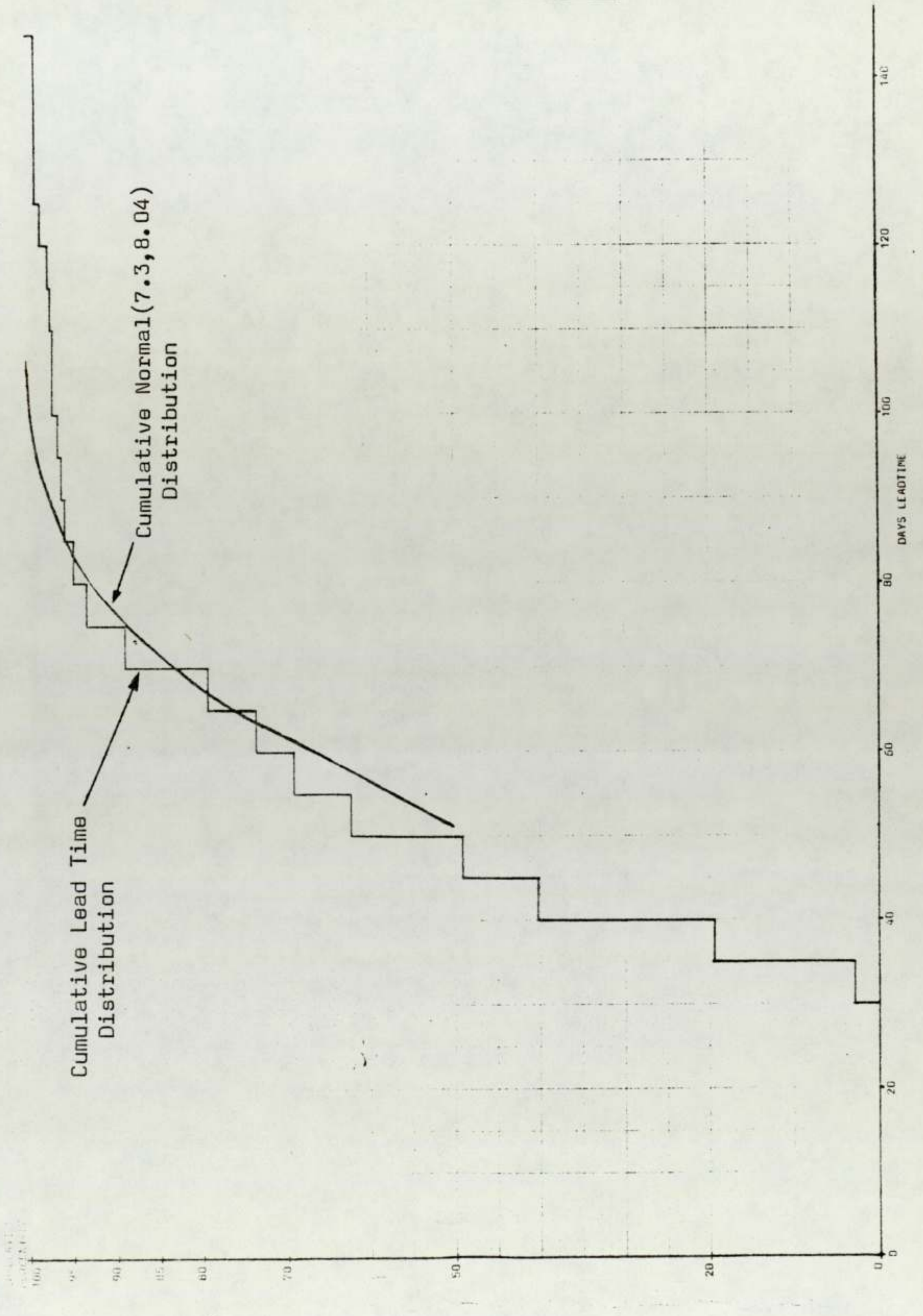


FIGURE 10

DISTRIBUTION OF LEADTIMES EXPERIENCED BY DUNLOP A/S DENMARK ex U.K.T.G. FOR STEEL RADIAL CAR TYRES, IN 1976

FIGURE 11

COMPARISON OF THE LEAD TIME DISTRIBUTION WITH THE CORRESPONDING NORMAL DISTRIBUTION



other assumptions as before:-

AWC @ 90% level -- 8.6 wks. (3a) (27.8% less than 1a)

AWC @ 95% level -- 9.6 wks. (3b) (26.2% less than 1b)

The principle of using leadtime information to reduce stocks can be applied to any item or group of items (or "stratum") which can be identified as having a fairly stable leadtime.

5-4-2 The Re-order Level Policy

If the period between stock reviews is reduced, the information processing model predicts that the performance will increase. Suppose then, that the company now uses a re-order level policy with weekly reviews. The average stock level under such a policy can be calculated from this formula:-

$$\tfrac{1}{2}\ \bar{D}\ (\bar{L} + R/2)\ +\ k\sqrt{\sigma_p^2\,(R/2 + \bar{L}\,)\ +\ \sigma_L^2\,\bar{D}^2}\quad ,$$

using the standard notation. The average number of weeks cover is given by:-

$$\tfrac{1}{2}\ (\bar{L} + R/2)\ +\ k\sqrt{(\,\sigma_p^2\,/\,\bar{D}\,)^2\,.\,(\bar{L} + R/2)\ +\ \sigma_L^2}\quad .$$

If this policy was introduced under the current assumption that $\bar{L} \div 12$, and $\sigma_L^2 = 0$:-

AWC @ 90% level -- 9.7 wks. (4a) (18.5% less than 1a)

AWC @ 95% level -- 10.6 wks (4b) (18.0% less than 1b)

Assuming the leadtime to be distributed as Normal (7 , 8) gives:-

AWC @ 90% level -- 8.3 wks. (5a) (30.3% less than 1a)

AWC @ 95% level -- 9.5 wks. (5b) (26.5% less than 1b)

Finally, with a leadtime distribution of Normal (6 , 2) :-

AWC @ 90% level -- 6.3 wks. (6a) (46.7% less than 1a)

AWC @ 95% level -- 7.2 wks. (6b) (44.6% less than 1b)

5-4-3 Summary

The analysis has shown that improvements in levels of inventory of between 25 and 30 percent could be made in this selling company, by systematically monitoring leadtimes and using this information in a re-order level policy with weekly reviews. Further improvements are possible if leadtimes are either reduced or made more predictable, but under the current procedure, it would actually have the effect of increasing inventories.

5-5 Information Systems

It has already been seen that the decision mechanism is, or should be, a principal determinant of the scope of a data base. The information required by the mechanism is a natural candidate for inclusion in a formalized data collection procedure, because it is usually well defined and reported regularly. The frequency of making decisions or re-planning is influenced by the amount of environmental uncertainty, and is limited primarily by whether the decision can be formulated in an explicit model. An improved formal information system is therefore a necessary aspect of developing an inventory control system, and it is appropriate to look at the use of information systems for distribution in other companies.

A conference on the subject of "Distribution in Europe" (see Appendix 4, section 4) included presentations of three case studies by Consultants from Arthur D. Little Inc. Although the subjects of the case studies were very different in nature, a number of general conclusions were drawn from them. Most interesting and relevant of these were the following:-

(a) European distribution must be managed as a single entity,
(b) central information is vital, and
(c) centralized stock planning is vital.

These conclusions support the approach of the push system and the cybernetic view of inventory control described in section 4-3.

A description of I.C.I.'s European Distribution System (E.D.S.) was presented to a seminar organized for the chemical and rubber industries (see Appendix 5). In 1973, the Europa Division of I.C.I. investigated the administrative efficiency of their organization, and established the need for an improved distribution system. The alternative recommended was a centrally supported real-time system to process orders, record stocks and produce invoices. The E.D.S. was designed to satisfy several needs:-

(a) the ability to grow as business expanded,
(b) improvement in customer service through better communication,
(c) better planning data for control, particularly of working capital,
(d) to view the business in a single European context, i.e. as "one business", and
(e) to reduce the clerical costs of administration.

The situation which existed prior to E.D.S. was a dependence on "stand alone" systems, characterized by multiple transfers of data, complex communication and incompatibility between systems. The alternative to the E.D.S. was the development of localized systems, which would intensify the interface problems and actually be more costly.

While I.C.I. had their own telecommunications network to serve the remote European locations, such a system could equally well be designed for use on a commercial data processing network (e.g. Honeywell Mark 3). Perhaps the most interesting aspect of the E.D.S. in the context of this thesis is the minimal emphasis placed on improving the decision mechanism ("better planning data") through the effective use of information. This is probably because explicit models are not used for planning, so the benefits are not estimable. It almost seems to justify the unified management of a European distribution system through a central information system regardless of the better planning it allows.

To sum up, there is a trend towards centralized European distribution systems, supported almost independently by the benefits of improved administrative efficiency and better inventory control.

5-6 A Design Strategy

A number of suggestions have been made for improving the organization and the aim of this section is to bring them together into an overall strategy for the future development of control systems. It is possibly even more difficult to organize a transformation from one form of organization to another, than it is to decide what the changes ought to be. However, all the organizing modes that can be used for this purpose have been mentioned. Here, four factors are identified which may limit the development and/or the effectiveness of an organization.

(a) A theoretical bottleneck is a limitation caused by the lack of knowledge of some phenomenon. Even if methods and expertise exist to solve a problem, the organization may be ignorant of them. Certainly one of the aims of this thesis is to make inventory control theory more widely appreciated.

(b) A development project may fail simply because the resources needed are not available, i.e. there is a resource bottleneck. The basic strategy of inventory control is to invest in more complex systems and then recover the outlay by reduced interest payments on working capital.

(c) A mature organization tends to create an abundance of rules and procedures which stifle change, while its complexity is a natural barrier to even understanding its behaviour. This may be thought of as an organizational bottleneck.

(d) A political bottleneck has already been mentioned as an aspect of introducing a push system. In general, any change in a method of working or in a role must be accepted by the people most directly affected by it, before it has any chance of success.

Consider an organization to be composed of three parts. The first part is common to all organizations. The cybernetic model, the information process processing model and Industrial Dynamics are examples of the general theory which are presumed to represent this common area. The second part includes those aspects which are common to a number of organizations, like the characteristics of the rubber industry or a type of distribution system. The third part is the set of characteristics which are unique to it, i.e. its history, location and personalities etc.

In chapter 4 the general theories were used to discriminate between methods of inventory control, and to explain their use in Tyres-Europe.

In this chapter, suggestions have been made for improving the application on this basis. Implicit in this was the assumption that the long-term choice of method is dictated by the universal and common parts of the organization, and that the unique features are less important in determining its eventual structure. Therefore, taking account of the limiting factors mentioned above, the basic strategy for development suggested here is to gradually increase the complexity of the decision making processes and the use of information, towards the eventual objective of implementing a push system throughout Europe. (Even so, it may be possible to implement a push system immediately.) As a result, each phase should be designed with enough flexibility so that it would fit into the final design with a minimum of alteration. The design strategy is summarised as follows:-

Phase 1	Systematise the collection of demand, stocks and lead times data for each product in each selling company warehouse. Monitor the distributions of lead times and demand, and make forecasts for up to four weeks ahead of the combined demand.
Phase 2	Improve the stocking policy operated by each selling company, using the information generated in phase 1.
Phase 3	Extend the planning horizon of U.K. production scheduling to four weeks, as suggested in section 5-3.
Phase 4	Introduce programs from the "Multiple Warehouse Systems" to cover replenishment of home replacement depots and selling companies.
Phase 5	Extend the use of the push system to all European distribution networks.

Phase 6 Centralise management and co-ordination of European distribution, using an integrated push system to cover all Dunlop owned distribution points.

5-7 Summary

It has been shown that, for theoretical reasons, the push system is the natural choice for inventory control in the context of the project area. But, accepting that there are many problems to be overcome, before such a system can be implemented, a programme of phased development has been proposed. Suggestions have also been made for improvements in the organization where inventory control decisions are made, i.e. in Selling Companies' ordering policies and in production scheduling. The trend towards centralised information has been seen to be supported both by improved administrative efficiency and better planning and inventory control.

CHAPTER 6

A SYSTEM FOR ESTIMATING EXPORT DEMAND

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A SYSTEM FOR ESTIMATING EXPORT DEMAND

6. Introduction

The following three chapters consider specific methods for improving the quality of information used in the current decision mechanisms. The aim is to provide something of practical value to the sponsoring company.

Demand estimates are a key part of any inventory control system, so this chapter describes a method suitable for detecting regularities in the demand on U.K.T.D. from the European Selling Companies. The method produces short-term forecasts for use by the production schedulers, and has the capability of incorporating probabilistic information derived from sources other than historical data.

6-1 Basic Requirements and Assumptions

There are a number of characteristics which are thought to be generally desirable in the context of forecasting for inventory control:-

(a) The model of the process should be parsimonious; i.e. it should be as simple as possible while giving an adequate representation of the data.

(b) The method should be robust; i.e. it should work even when the assumptions of the model are inappropriate.

(c) A "good" estimate is as valuable as an excellent one; i.e. there is no point using a method which is more sophisticated than the data it uses or the decision mechanism where it is used.

(d) The method should use as little storage capacity in the computer as possible, to keep the operating cost low.

Further to these general characteristics, it was assumed that an interactive capability would be desirable, but also that the system should work automatically when left alone. Initially, it was envisaged that the estimates would be revised on the basis of daily or weekly data, so it was expected to be sparse and show discontinuities. For this reason, seasonal models were considered inappropriate. The Bayesian method of forecasting described by Harrison and Stevens (43) were chosen for development because they appeared to accommodate these assumptions. The parametric form of the equations is ideal for interactive use by an operator who does not know the theory underlying the method.

6-2 Bayesian Estimation and Forecasting

The general results which apply to Bayesian forecasting are stated here briefly and without proof. Readers who wish to understand more of how it can be applied in many different contexts and forms are strongly recommended to references 43 and 44. The description is much more complete, and gives references to original sources. The general formulation is deceptively simple, considering the variety of interpretations that can be put on it.

6-2-1 The Dynamic Linear Model

A general form of the dynamic linear model is:-

$$\underline{y}_t = \underline{F}_t \underline{S}_t + \underline{v}_t \quad ; \quad \text{with } \underline{v}_t \sim N(\underline{0}, \underline{V}_t) \qquad (1)$$

$$\underline{S}_t = \underline{G}\, \underline{S}_{t-1} + \underline{w}_t \quad ; \quad \text{with } \underline{w}_t \sim N(\underline{0}, \underline{W}_t) \qquad (2)$$

where t is the time index,

$\underline{y}_t$ is the vector of observations $(y_{1t}, \dots, y_{mt})'$

$\underline{S}_t$ is the vector of process parameters $(S_{1t}, \dots, S_{nt})'$

$\underline{F}_t$ is the (mxn) matrix of indept. variables (known at time t),

$\underline{G}$ is the (nxn) system matrix (known or assumed),

and $\underline{V}_t = E(\underline{v}_t \underline{v}_t')$ & $\underline{W}_t = E(\underline{w}_t \underline{w}_t')$.

Equation (1) is the observation equation which specifies the stochastic dependence of the observations $\underline{y}_t$ on the process parameters $\underline{S}_t$. (2) is the system equation which specifies the dynamic characteristics of the process.

6-2-2 The Kalman Filter

It is required to estimate the process, $\underline{S}_t$, from the observations, $\underline{y}_t$. If the distribution of $\underline{S}_0$ prior to the first observation is Normal $(\underline{m}_0, \underline{C}_0)$, and $\underline{D}_t$ represents all the information derived from $\underline{y}_1, \dots \underline{y}_t$ and $\underline{F}_1, \dots \underline{F}_t$, then the posterior distribution of $\underline{S}_t$ given $\underline{D}_t$ is Normal $(\underline{m}_t, \underline{C}_t)$. Values of $\underline{m}_t$ and $\underline{C}_t$ are obtained recursively from the following equations:-

(3) $\hat{\underline{y}}_t = \underline{F}_t \underline{G} \underline{m}_{t-1}$ (mx1) estimate of $\underline{y}_t$

(4) $\underline{\epsilon}_t = \underline{y}_t - \hat{\underline{y}}_t$ (mx1) error vector

(5) $\underline{R}_t = \underline{G} \underline{C}_{t-1} \underline{G}' + \underline{W}_t$ (nxn) Var $(\underline{S}_t \mid \underline{D}_t)$

(6) $\hat{\underline{Y}}_t = \underline{F}_t \underline{R}_t \underline{F}_t + \underline{V}_t$ (mxm) Var $(\hat{\underline{y}}_t \mid \underline{V}_t, \underline{D}_t)$

(7) $\underline{A}_t = \underline{R}_t \underline{F}_t (\hat{\underline{Y}}_t)^{-1}$ (nxm)

(8) $\underline{m}_t = \underline{G} \underline{m}_{t-1} + \underline{A}_t \underline{\epsilon}_t$ (nx1)

(9) $\underline{C}_t = \underline{R}_t - \underline{A}_t \hat{\underline{Y}}_t \underline{A}_t'$ (nxn)

This set of equations, written in a form suitable for forecasting, is called the Kalman Filter, after R.E. Kalman (1963). Since the equations are recursive, the current posterior distribution, $(\underline{S}_t \mid \underline{D}_t)$, may be calculated directly from the most recent observation, $(\underline{y}_t, \underline{F}_t)$, and the previous posterior, $(\underline{S}_{t-1} \mid \underline{D}_{t-1})$. In this way, the distribution $N(\underline{m}_t, \underline{C}_t)$ contains all the information of the observations since $t = 0$.

6-2-3 The Forecast for k Steps Ahead

At time $t + k$ equations (1) and (2) become;

$$\underline{y}_{t+k} = \underline{F}_{t+k}\,\underline{S}_{t+k} + \underline{v}_{t+k} \qquad (10)$$

$$\& \qquad \underline{S}_{t+k} = \underline{G}\,\underline{S}_{t+k-1} + \underline{w}_{t+k} \,. \qquad (11)$$

The estimate of $\underline{S}_{t+k}$ at time t is:-

$$E(\underline{S}_{t+k} \mid \underline{D}_t) = \hat{\underline{m}}_{k,t} = \underline{G}\,\hat{\underline{m}}_{k-1,t} \qquad (12)$$

$$\& \qquad \mathrm{Var}(\underline{S}_{t+k} \mid \underline{D}_t) = \hat{\underline{C}}_{k,t} = \underline{G}\,\hat{\underline{C}}_{k-1,t}\,\underline{G}' + \underline{W}_{t+k} \,. \qquad (13)$$

In the case where $\underline{F}_t$ is known for all future time, estimates of the observations are obtained from (12) and (13) recursively as follows:-

$$\hat{\underline{y}}_{k,t} = \underline{F}_{t+k} \cdot \hat{\underline{m}}_{t+k} \quad \text{(k step ahead estimate)} \qquad (14)$$

$$\hat{\underline{Y}}_{k,t} = \underline{F}_{t+k} \cdot \hat{\underline{C}}_{t+k} \cdot \underline{F}'_{t+k} + \underline{W}_{t+k} \quad (= \mathrm{Var}(\hat{\underline{y}}_{k,t})) \qquad (15)$$

6-3 Component Models

This section describes individually the three models of which the final model is composed. The first two are derived directly from the dynamic linear model, and are used to demonstrate the workings of a Bayesian system. The third model is introduced specifically to deal with sparse data.

6-3-1 The Steady Model

The steady model for a time series is obtained from (1) & (2) by setting:-

$\underline{y}_t = y_t$, a single observation ;

$\underline{F}_t = 1$;

$\underline{S}_t = S_t$, a single process variable ;

$\underline{G} = 1$.

The resulting model is simply:-

$$y_t = S_t + v_t \quad ; \quad v_t \sim N(0,V_t) \; ; \qquad (16)$$

$$S_t = S_{t-1} + w_t \quad ; \quad w_t \sim N(0,W_t) \; . \qquad (17)$$

The equations which update $(S_t \mid D_t)$ from m_{t-1}, C_{t-1}, and y_t reduce to:-

$$\left.\begin{aligned} \hat{y}_t &= m_{t-1} \\ e_t &= y_t - \hat{y}_t \\ R &= C_{t-1} + W_t \\ \hat{Y} &= R + V_t \\ A_t &= R / \hat{Y} = (C_{t-1} + W_t) / (C_{t-1} + W_t + V_t) \end{aligned}\right\} \quad (18)$$

$$m_t = m_{t-1} + A_t e_t \qquad (19)$$

$$C_t = R - R^2 / \hat{Y} = A \; V_t \; . \qquad (20)$$

Eventual Behaviour

P.J. Harrison has shown that A_t tends to a limit, A, as the recursive procedure continues. (See reference 42.) The value of A is dependent only on the ratio $r = V/W$:-

$$A = \left((4r + 1)^{\frac{1}{2}} - 1 \right) \Big/ 2r \simeq 1 \Big/ r^{\frac{1}{2}}, \text{ for large } r \qquad (21).$$

This relationship is shown graphically in figure 12. Notice that under these conditions, equation (19) is now that of the simple Exponentially Weighted Moving Average, (with $\alpha = A$,) which is therefore a limiting form of the steady model. The main difference is the transient response when values of m_t and C_t' are altered manually. But also, whereas the choice of α is arbitrary (either as a compromise between stability and response or as the modulus of the tracking signal), A may be defined in terms of an estimate of r.

If it is reasonable to assume W_t equal to unity, then the equations become even more simple. A is solely dependent on V_t, which may be estimated from the one step ahead forecast errors.

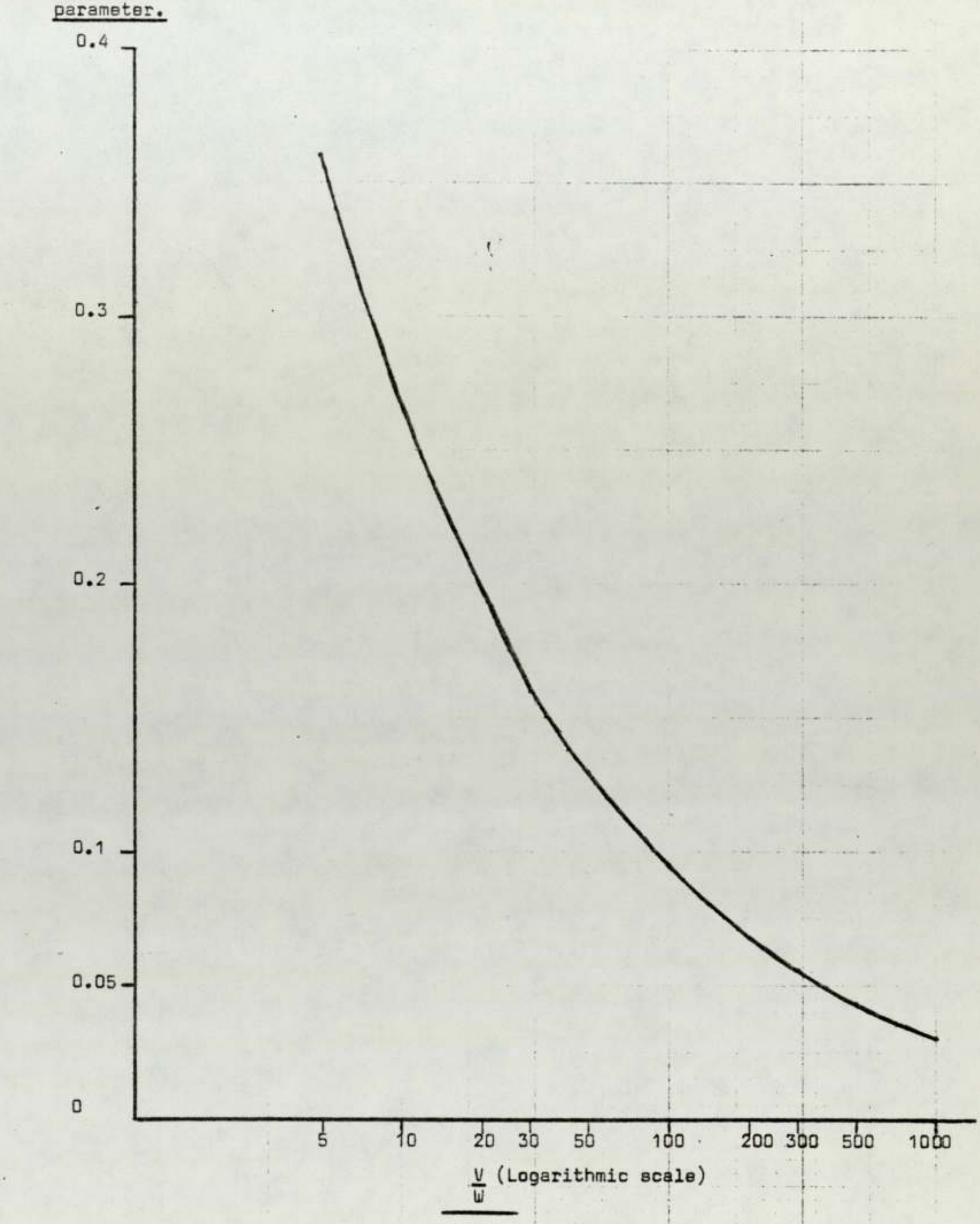
Transient Response

The dynamic behaviour of the steady model is best explained by an example. Suppose the initial prediction of the level of demand (i.e. the process parameter S which generates demand) for a new product is 100 units per week. Market research indicates that it will not be less than 50, and not greater than 150, with 95% confidence. Let $S_0 \sim N(100,625)$.

By comparing the new product with others in the range, an assumption is made about the variances of observation and process noise, i.e. $V = 400$, and $W = 25$. (N.B. This has the effect of increasing the uncertainty about the actual observation expected. $\mathrm{Var}(\hat{y}_1) = \hat{Y}_{1,0} = \hat{C}_1 + V = C_0 + W + V = 1050$; using equations (13) & (15). So the first week's demand is actually expected to be in the range 100 ± 65 units, with 95% confidence.) When the first week's demand is recorded as 125 units, m_1 and C_1 are

FIGURE 12

LONG TERM DEPENDENCE OF THE SMOOTHING PARAMETER ON THE RATIO V/W



calculated as follows:-

$$\hat{y}_1 = m_0 = 100$$

$$\epsilon_1 = y_1 - \hat{y}_1 = 25$$

$$R_1 = C_0 + W = 650$$

$$\hat{Y}_1 = R_1 + V = 1050$$

$$A_1 = R_1 / \hat{Y}_1 = 650/1050 = 0.62$$

$$m_1 = m_0 + A_1\epsilon_1 = 100 + 15.5 = 115.5$$

$$C_1 = A_1 V = 248 .$$

Results for the next four observaitons are shown in table 5. Initially C is large, and the forecast is very sensitive to new information. C delines rapidly towards its eventual value, and the forecast becomes much more stable. Since the updating procedure is mechanical, it can be carried out automatically, until information from external sources is incorporated by altering m and C.

6-3-2 The Linear Growth Model

The linear growth model is a simple extension of the steady model with an extra process parameter to represent a trend in the data.

Let $\underline{F}_t = (1 \ 0)$;

$$\underline{S}_t = (\mu_t \quad \beta_t)' \quad ;$$

$$\underline{G} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} .$$

TABLE 5

TRANSIENT RESPONSE OF THE STEADY MODEL

(V = 400, W = 25)

t	0	1	2	3	4	5	Eventual values
y	-	125	90	110	140	70	-
ϵ	-	25	-25.5	4.8	33.3	-45.9	-
R	-	650	273	187	152	135	113
Y	-	1050	673	587	552	535	513
A	-	0.62	0.41	0.32	0.28	0.25	0.22
m	100	115.5	105.5	106.7	115.9	104.3	-
C	625	248	162	127	110	101	88

The model can be written in the form of linear equations as follows:-

$$y_t = \mu_t + v_t , \qquad v_t \sim N(0,V_t) \qquad (22)$$

$$\left.\begin{aligned}\mu_t &= \mu_{t-1} + \beta_{t-1} + \delta\mu_t \\ \beta_t &= \beta_{t-1} + \delta\beta_t\end{aligned}\right\} , \quad \begin{bmatrix}\delta\mu_t \\ \delta\beta_t\end{bmatrix} \sim N(\underline{0},\underline{W}_t) . \qquad (23)$$

The procedure for updating $\underline{m}_t = (m_t \; b_t)'$ and $\underline{C}_t$ is simplified by assuming that (a) initially $C_{21} = C_{12}$, and (b) $\underline{W}_t = \begin{bmatrix}1 & 0 \\ 0 & W\end{bmatrix}$.

It is also convenient to use the notational convention that for a matrix $\underline{X}_{(nxm)} = (x_{ij})$, $x_{i.} = \sum_{j=1}^{m} x_{ij}$. The update equations become:-

$$\hat{y}_t = m_{t-1} + b_{t-1}$$

$$\epsilon = y_t - \hat{y}_t$$

$$\underline{R} = \begin{bmatrix}1 & 1 \\ 0 & 1\end{bmatrix} \underline{C}_{t-1} \begin{bmatrix}1 & 0 \\ 1 & 1\end{bmatrix} + \begin{bmatrix}1 & 0 \\ 0 & W\end{bmatrix} = \begin{bmatrix}(C_{..} +1) & C_{.2} \\ C_{2.} & (C_{22}+W)\end{bmatrix}$$

$$\hat{Y} = (1 \;\; 0) \; \underline{R} \begin{bmatrix}1 \\ 0\end{bmatrix} + V_t = C_{..} + 1 + V_t$$

$$\underline{A}_t = \begin{bmatrix}A_{1t} \\ A_{2t}\end{bmatrix} = \begin{bmatrix}R_{11}/\hat{Y} \\ R_{21}/\hat{Y}\end{bmatrix} \qquad (24)$$

$$\underline{m}_t = \begin{bmatrix}m_{t-1} + b_{t-1} + A_{1t}\epsilon \\ b_{t-1} + A_{2t}\epsilon\end{bmatrix} \qquad (25)$$

$$\underline{C}_t = \begin{bmatrix}R_{11}(1-A_{1t}) & R_{21}(1-A_{1t}) \\ R_{21}(1-A_{1t}) & R_{22}-R_{21}A_{2t}\end{bmatrix} = \begin{bmatrix}A_{1t}V_t & A_{2t}V_t \\ A_{2t}V_t & R_{22}-R_{21}A_{2t}\end{bmatrix} . \qquad (26)$$

The behaviour of $\underline{A}_t$ and $\underline{C}_t$ is very similar to that of the corresponding quantities in the steady model. Initially large values will decay rapidly towards the eventual values, and the forecast will become relatively stable. $\underline{A}_t$ tends to the limiting matrix $\underline{A} = (A_1 \ A_2)'$, and the values of A_1 and A_2 are solely dependent on V and W. Equation (25) has the same form as Holt's Linear Growth Predictor (the predictor for an I.M.A. process of order (0,2,2)). Table 6 shows values of A_1 and A_2 corresponding to a range of values for V and W.

6-3-3 The Intermittency Model

J.D. Croston (22) has shown that exponential smoothing gives an inappropriate forecast when applied to a process which is sampled more frequently than the events take place, i.e. an intermittent process. In this situation with sparse data, he suggests that a more useful and flexible forecast is obtained from the model:-

$$y_t = x_t \cdot z_t \quad , \quad z_t \sim N(\mu , \sigma^2)$$

where

$$x_t = \begin{cases} 1 \text{ with probability } (1/p) \text{ when } y_t \neq 0 ; \\ 0 \text{ with probability } (1-1/p) \text{ when } y_t = 0 ; \end{cases}$$

and

$$E\left((x_t - 1/p)(z_t - \mu) \right) = 0 .$$

The parameter p represents the average interval between non-zero observations. If q_t is the time since the last non-zero observation, then an unbiased estimate of p is:-

$$\hat{p}_t = \hat{p}_{t-1} \quad , \quad \text{when } x_t = 0 ;$$

$$\hat{p}_t = (1-\alpha)\hat{p}_{t-1} + \alpha q_t \quad , \quad \text{when } x_t = 1$$

where $E(\hat{p}_t) = p$, and $\text{Var}(\hat{p}_t) = \alpha (p-1)^2 / (2-\alpha)$. (27)

If the process z_t is estimated by a simple exponentially weighted moving average of the non-zero observations $(\hat{z}_t)$ then:-

$$E(\hat{z}_t) = \mu \text{, and } \text{Var}(\hat{z}_t) = \alpha \sigma^2/(2-\alpha). \quad (28)$$

TABLE 6

VALUES OF SMOOTHING CONSTANTS A_1 AND A_2 FOR A RANGE OF VALUES OF V AND W

W				V		
		80	160	240	320	400
0.8	A_1	.37	.32	.31	.28	.26
	A_2	.08	.06	.05	.04	.04
0.6	A_1	.35	.30	.29	.26	.25
	A_2	.07	.05	.05	.04	.03
0.4	A_1	.33	.28	.27	.24	.23
	A_2	.06	.04	.04	.03	.03
0.2	A_1	.29	.24	.23	.21	.20
	A2	.04	.03	.03	.02	.02

The natural estimate of demand per review period is $\hat{z}_t \,/\, \hat{p}_t$; which is unbiased, with

$$\mathrm{Var}\,(\hat{z}_t \,/\, \hat{p}_t) = \frac{\alpha}{(2-\alpha)} \cdot \left\{ \frac{(p-1)^2 \mu^2}{p^4} + \frac{\sigma^2}{p^2} \right\} . \tag{29}$$

6-4 An Automatic Procedure for Export Demand

It has been shown how the Bayesian structure allows information from sources other than the data to be freely incorporated in the forecasting process. The facility can be used entirely at the discretion of the person using or supervising it. While it is envisaged that the forecaster will use the system interactively on a visual display unit (of the type already in regular use), the development of a program for this purpose is beyond the scope of this project. The procedure described in this section is designed to cope well in the situation where there is no supervision.

6-4-1 The Model

The demand process is assumed to be intermittent, so the revision procedure only takes place when a non-zero demand occurs. The observation consists of this demand, y_t , and the time since the previous demand, q_t. A linear growth model, described by equations (22) and (23), is used for y_t , along with the corresponding assumptions. A steady model is used for both q_t and $|e_t|$, the absolute value of the one-step-ahead forecast error. These models use the following notation:-

$$\left.\begin{array}{lll} q_t = \pi_t + \delta q_t & , \; \delta_{qt} \sim N(0,V_p) & , \quad \pi \sim N(p,C_p) \; ; \\ \pi_t = \pi_{t-1} + \delta\pi_t & , \; \delta\pi_t \sim N(0,1) & ; \end{array}\right\} \tag{30}$$

$$\left.\begin{array}{llll} \epsilon_t = \eta_t + \delta\epsilon_t & , & \delta\epsilon_t \sim N(0,V_\epsilon) \ , & \eta \sim N(x,C_\epsilon) : \\ \eta_t = \eta_{t-1} + \delta\eta_t & , & \delta\eta_t \sim N(0,1) \ . & \end{array}\right\} \quad (31)$$

The estimate of demand per review period is taken as m/p, in an analogous way to that in the Intermittency model of section 6-3-3. The estimate x , of $|\epsilon_t|$ is analogous to the Mean Absolute Deviation of exponential smoothing (see p.44, ref.51). The current value of x is used within the model to set V_t and W_t automatically by the following equations:-

$$V_t = (1.25 \ x_t)^2 + 40 \ , \qquad (32)$$

$$W_t = \exp(-(x_t/65)^2) \ . \qquad (33)$$

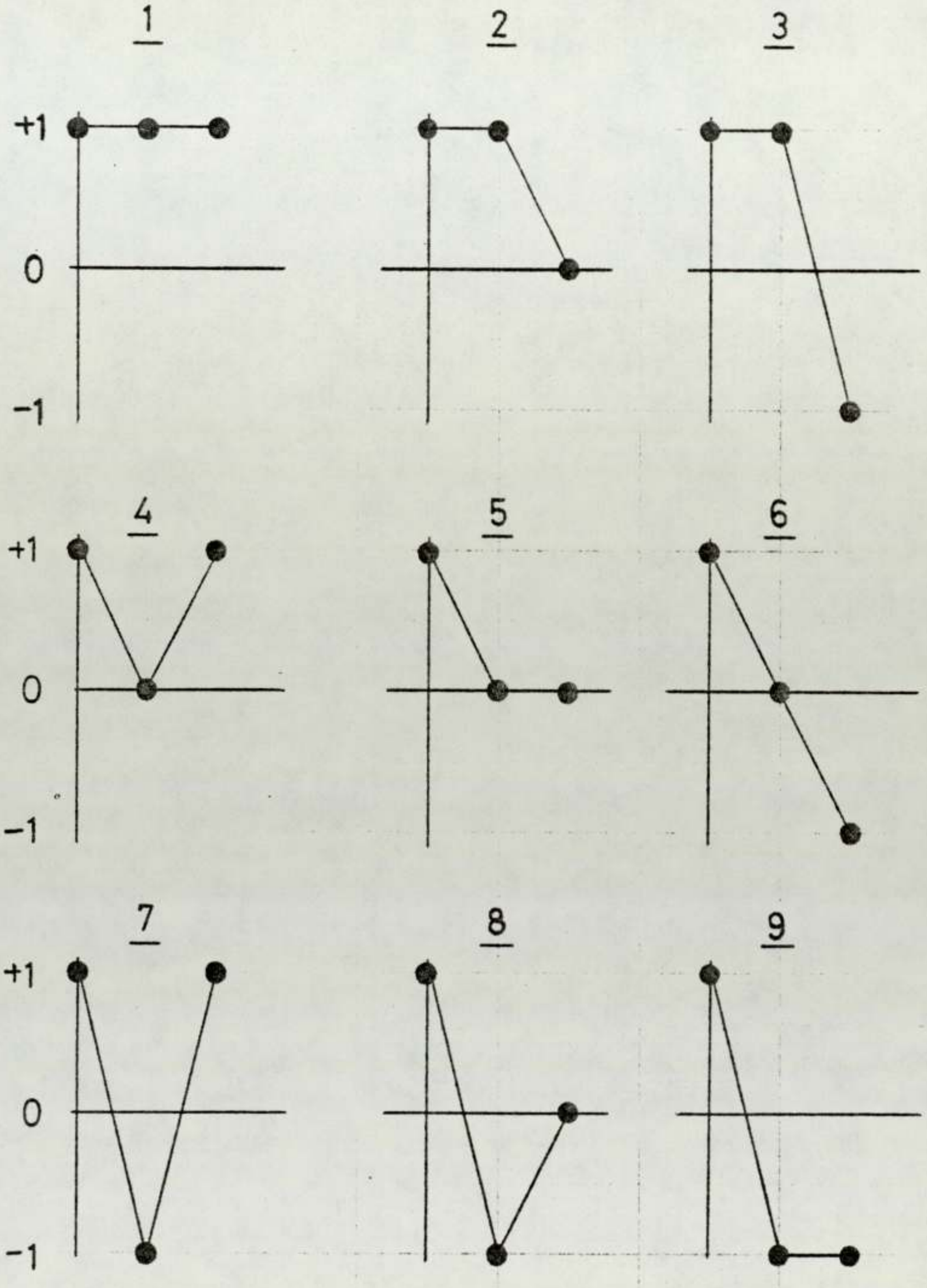
Simulation trials were conducted to choose suitable relationships, using a simple linear growth model with ranges of values for V and W. The time series used for the test was generated from a process with a varying trend and with pseudo-random noise superimposed. This was thought to represent the worst that could happen short of a major discontinuity. The criterion of performance was the mean squared error over fifty observations. The conclusion reached from these trials was that as long as V and W were of the right order of magnitude, the overall accuracy was not very sensitive to the actual values used. For the purpose of a system for Export demand, it was certainly not appropriate to make strong assumptions about the data, and the form of the equations chosen reflect this.

Default Values

The forecaster will probably use the interactive capability on only a small number of critical items, so it is necessary to specify default values for various parameters. These values can be used for

FIGURE 13

NINE DISTINCT FORMS USED TO DETECT DISCONTINUITIES



initialising the procedure, either for a new product or after a discontinuity. A set of values is given here which will provide a "cautious" response under these conditions.

$$\underline{m}^* = \begin{bmatrix} 10 \\ 0 \end{bmatrix} ; \quad \underline{C}^* = \begin{bmatrix} 6V & 9V/5 \\ 9V/5 & 3V/5 \end{bmatrix} ; \quad V^* = 200 ; \quad W^* = 1.$$

$$x^* = 10 ; \quad C_\epsilon^* = 400 ; \quad V_\epsilon^* = 100 .$$

$$p^* = 2 ; \quad C_p^* = 100 ; \quad V_p^* = 100 .$$

6-4-2 Detection of Discontinuities

A number of methods have been suggested for coping with discontinuities in time series. Trigg's tracking signal (51) , Super Exponential Smoothing (61) and cumulative sum techniques are dependent on detecting persistent bias in the forecast, and they trade off resistence to transients against reaction to genuine changes in level or trend. Since Export demand data was expected to be noisy and not to show strong trends, a method was devised which would deal specifically with the detection of transients, changes in level or changes in variance.

Under the assumptions of the model, the observation is expected to satisfy the inequality -

$$\{ y_t - 2.45 \; x_t \} < y_t < \{ y_t + 2.45 \; x_t \} \qquad (34)$$

with 95% confidence. Let the observation be classified as +1, 0, or -1 according to whether it is above, within, or below the confidence band. Suppose that, after a string of class 0 observations, y_t is of class 1. In this case, the normal revision of parameters is suspended, and the observation is stored. Figure 13 shows the nine possible forms for the classes of y_t , y_{t+1} and y_{t+2}, based on the confidence limits at time t. (N.B. If y_t were of class -1, a symmetrical set of possibilities exists.) Having detected one of these forms, an inference is made about the process, and action is taken as follows:-

(a) If the form contains both $+1$ & -1 classes, the process is assumed to have increased its variance. This applies to forms 3, 6, 7, 8, & 9. Notice that the last three can be detected at time t + 1. In this case the system responds by putting $C_\epsilon = C_\epsilon^*$, and goes through the revision procedure with the stored observations.

(b) If the outlying observations are on the same side of the confidence band, the process level is assumed to have changed, i.e. in forms 1, 2 & 4. In this case, the response is to put:-

$$\underline{m}_t = \begin{bmatrix} y_t \\ 0 \end{bmatrix} \;;\; \underline{C}_t = \underline{C}^* \;;\; x_t = \left| y_{t+1} - y_t \right| \;;\; C_\epsilon = 100 ,$$

and then revise the estimates from y_{t+1} and y_{t+2} only rejecting all previous information.

(c) Form 5 represents the occurrence of a sole outlying observation, and this is assumed to be untypical of the process. In this final case the outlier, y_t, is rejected, and the revision continues.

Two more minor refinements were added. First of all, it was thought reasonable to limit b_t to a maximum of 10% of m_t, reflecting the assumption that the data would not show dramatic trends. If this rule is invoked, it is assumed that the noise estimate is too small and the current value of C_ϵ is doubled to make the estimation more responsive. Secondly, two tests are used for outlying values of q_t, as suggested by Croston (20) -

(1) If $(1 - 1/p)^{q_t} < 0.01$, then q_t is significantly larger than expected.

(2) If $q_t /p < 0.2$, q_t is significantly smaller than expected.

In either case the system becomes more responsive by setting $C_p = C_p^*$.

6-4-3 System Behaviour

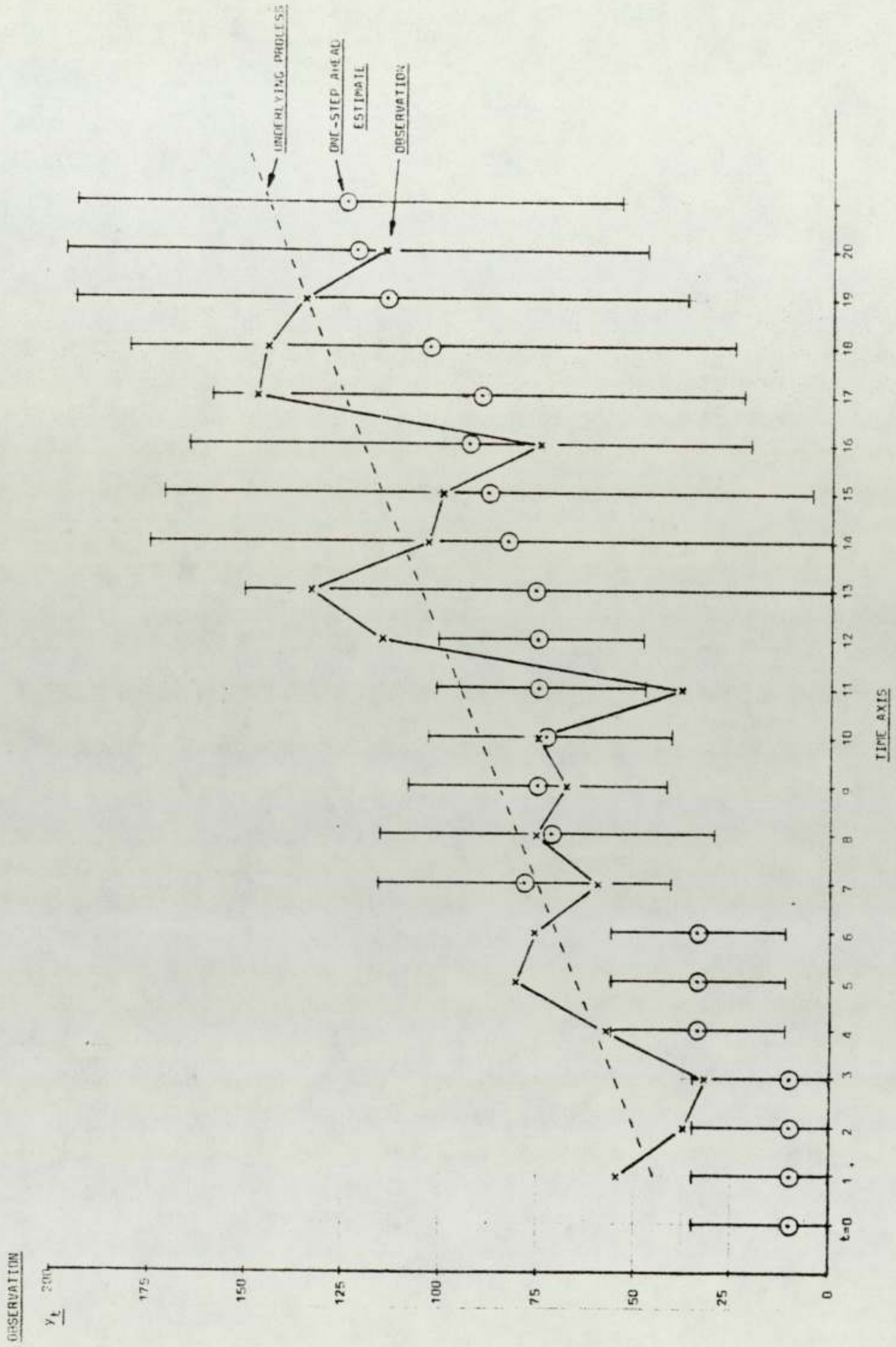
In this section, the behaviour of the automatic system is described by applying it to some artificial data. The data is a set of 20 observations generated by noise superimposed on an underlying process which begins at 40 units and grows at a rate of 5 units per time interval. The noise is normally distributed with a standard deviation of 11.5 units initially, increasing linearly to a final value of 40 units.

Figure 14 shows the observations and the one-step ahead estimates of the process level derived from the system in its automatic mode. The interval around each estimate corresponds to that defined by equation (34), so any observation within that interval is dealt with normally, and any outside invoke the exception procedure.

At time $t = 0$ nothing is known about the process so default values are used for all parameters. The first observation triggers the exception procedure and at $t = 3$ a "form 2" (a change in level) is detected. However, the estimate from the first three values is not satisfactory for the subsequent three, so the exception procedure is invoked again. At time $t = 12$, an increase in the noise level is detected (a form 9), and after this adjustment the system recognises the trend.

FIGURE 14

BEHAVIOUR OF THE AUTOMATIC SYSTEM ON ARTIFICIAL DATA



The FORTRAN programs for the automatic system and for this simulation are recorded in Appendix 6. The simulation is continued there, showing the response to discontinuities and to other noise distributions (truncated Normal and Lognormal). These trials demonstrate that the system produces a sensible forecast even when the data does not reflect the assumptions of the model. It is evident that no attempt has been made to judge the method on the basis of some quantitative comparison. Detailed comparisons between forecast methods are complicated even over a standard set of trial data, (57) so time would not permit this to be attempted. However, the main justification is that the system is robust and "good enough for the purpose", rather than optimal. There is certainly room for "fine tuning" since much of its design was intuitive and ad hoc.

CHAPTER 7

APPLICATION OF THE FORECASTING MODEL

7.1 The Demand Data

7.2 Seasonality

7.3 Distribution of Demand Over the Range

7.4 The Variability of Demand

7.5 Trial of the Automatic Procedure

7.6 Summary

CHAPTER 7

APPLICATION OF THE FORECASTING MODEL

7. Introduction

In this chapter, demand data from the European Selling Companies is analysed and its characteristics described. The analysis suggests which portion of the range is suitable for application of the forecasting model from chapter 6, and the model is demonstrated using actual product histories.

7-1 The Demand Data

Every Export order received at Fort Dunlop is recorded on a computer file, and is given a unique number by the computer system for internal identification. In general, each order consists of a number of separate "lines", one for each item required, and these lines constitute the elements of demand. The line is basically four pieces of information; the order number, the MPG ITEM code, quantity and date set up. Facilities currently exist for the extraction of information from any of the operational files used in the administrative process, and working reports are produced routinely. For accounting purposes, monthly sales data is accumulated for each customer, but apart from this, information is lost two weeks after the order has completed all its stages.

This data base was inadequate for the purpose of analysing demand over an extended period, so the Computer Centre supplied a set of records on daily, weekly and monthly bases, covering all orders from the European Selling Companies. By the end of the project, the files contained order information covering a period of fourteen months. The data were subject to a degree of inaccuracy, due to the operational nature of the files from which they were taken, and the urgency with which they were required. However, regardless of these inaccuracies, it was felt that they were representative of the demand processes.

7-2 Seasonality

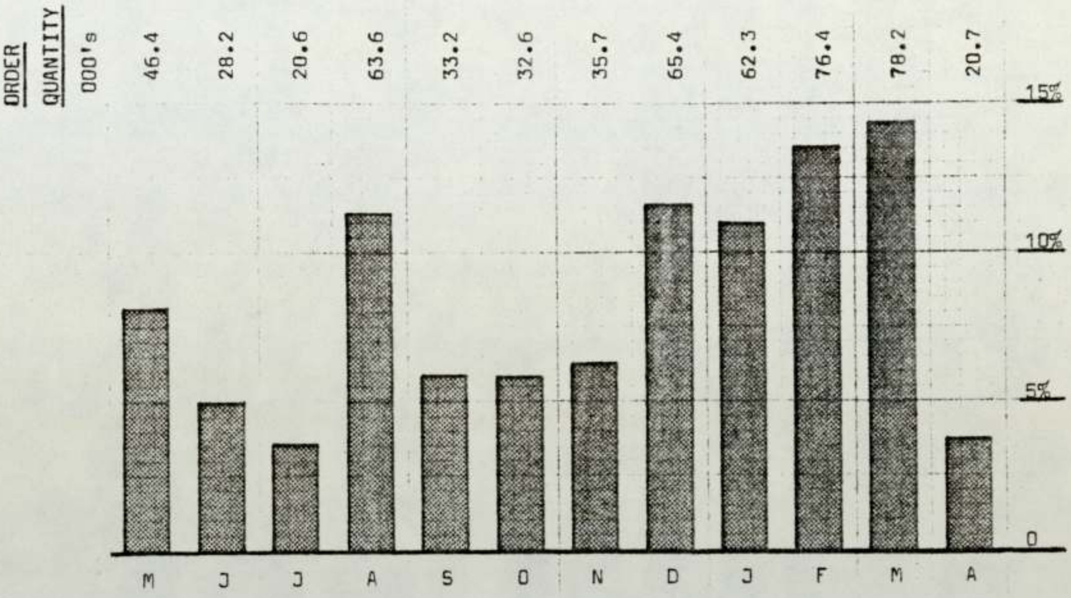
A seasonality is a pattern in demand which is related to the time of year in which the demand occurs. There are often good reasons for such patterns in consumer goods. In Europe, the main selling season for replacement car tyres is between Spring and Summer, while truck fleet operators normally replace their tyres before Winter, when a deep tread is an advantage. Tractor tyre sales tend to peak just before the ploughing and harvesting seasons.

A useful estimate of a seasonal pattern can only be obtained from several year's historical data. But it is important to look for an indication of such a pattern in the monthly data available because the forecasting model proposed has assumed that they are insignificant. The majority of individual items, and many of the major product groups, had such a low overall demand from E.S.D. that it was not sensible to look for seasonalities there. So for this purpose, the demand has been aggregated into "super groups", containing items classified broadly as car, truck, motorcycle, tractor, earthmover or land-road & implement. Figures 15, 16 and 17 show the seasonal variations over a period of twelve months from May 1976. The charts show the monthly totals as a percentage of the total for the group over the period. Figure 15 also shows the profile for the total monthly demand for all these products.

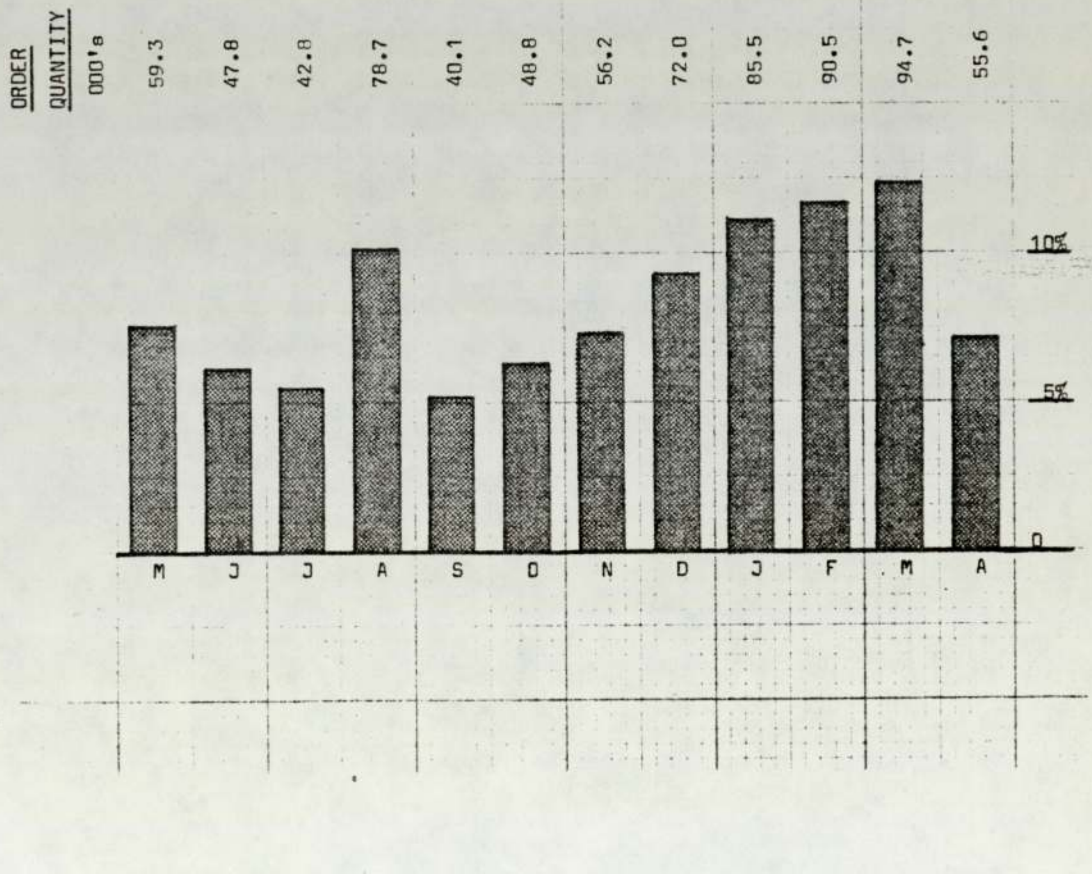
The "conventional wisdom" about seasonalities, outlined above, is certainly not contradicted by the shape of these charts, but the most significant aspect of them is the great variation from month to

FIGURE 15

SEASONALITIES



(a) CAR GROUP



(b) ALL PRODUCTS

FIGURE 16

SEASONALITIES

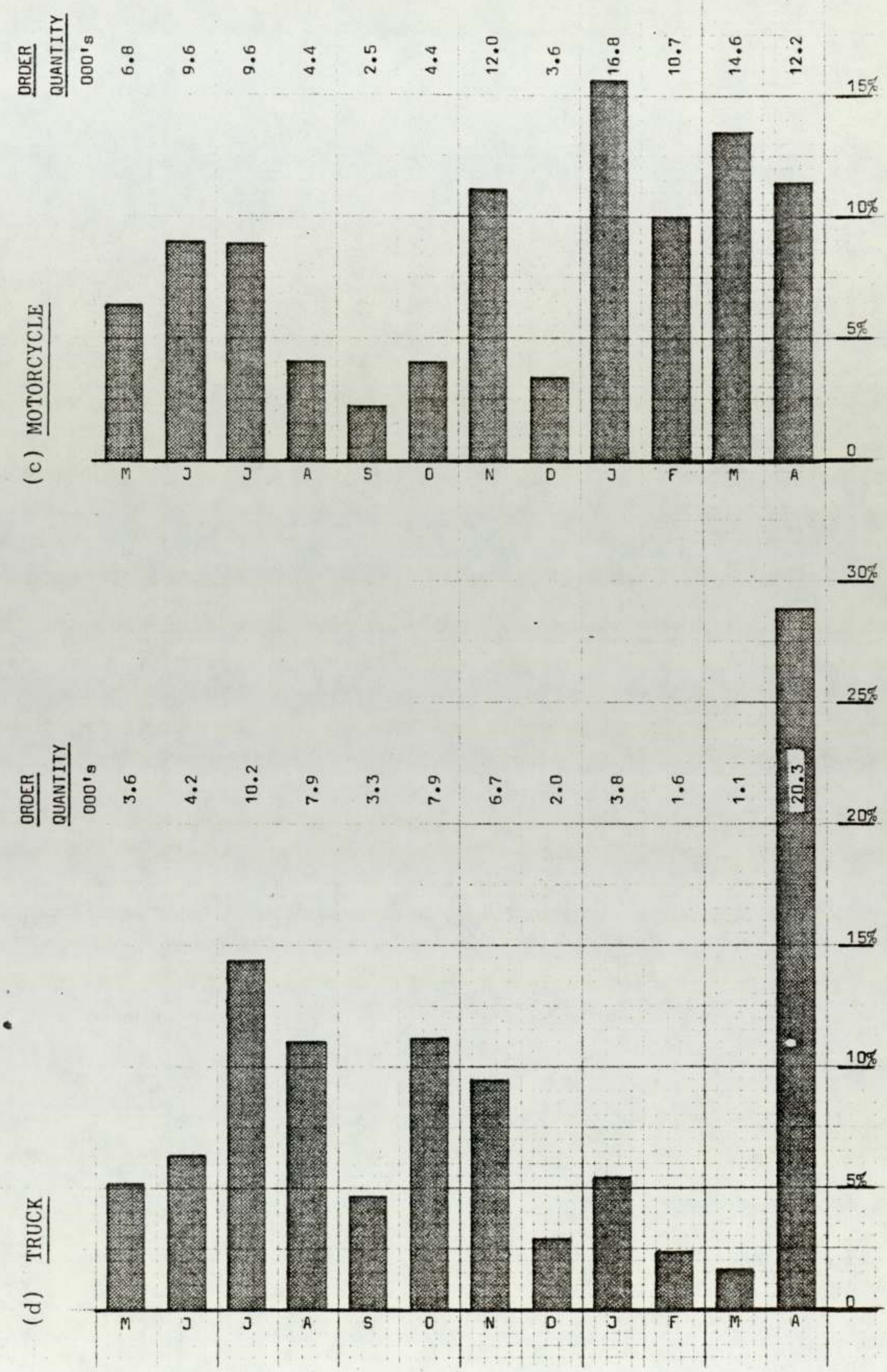
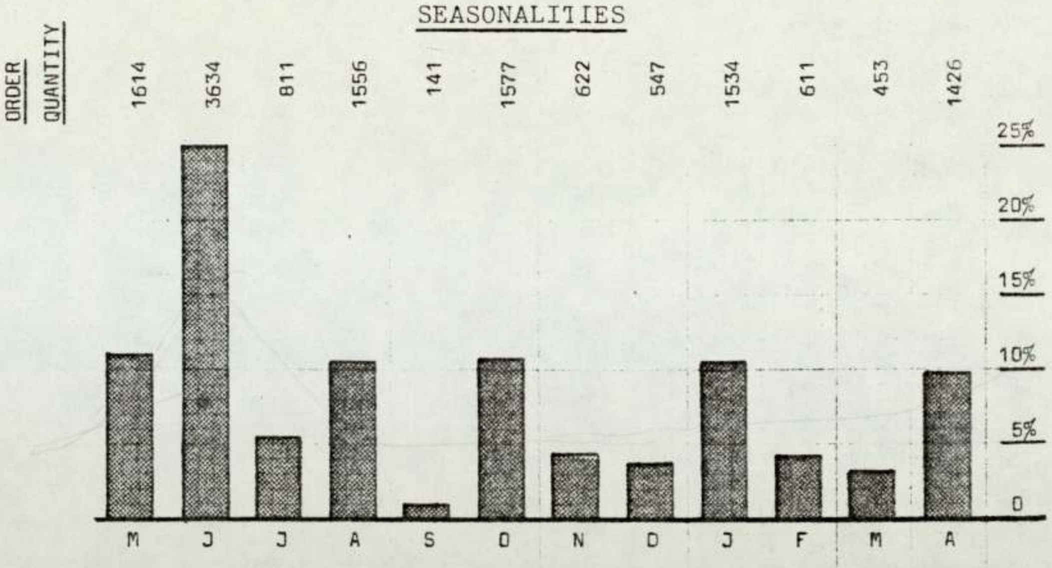


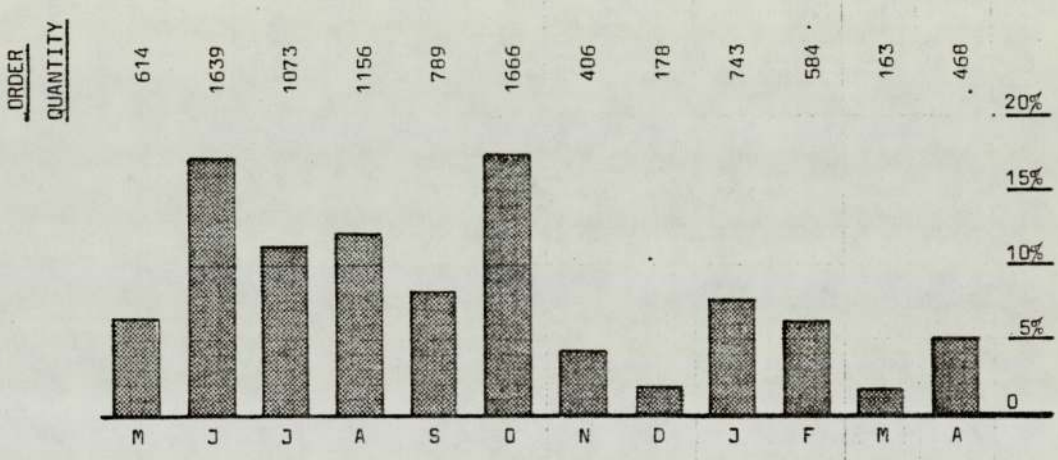
FIGURE 17

SEASONALITIES

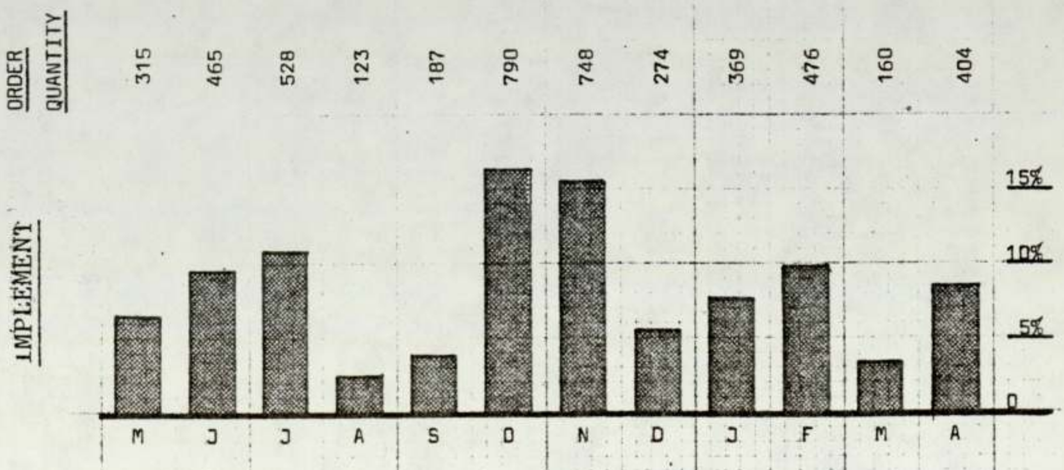
(e) TRACTOR



(f) EARTHMOVER



(g) LAND, ROAD & IMPLEMENT



month, even at this level of aggregation. The overall profile is mainly determined by that of the car group, and is highly suggestive of a sinusoidal curve. However, in my opinion, it would be stretching the bounds of credibility too far to suggest that successive years' data will conform to this pattern.

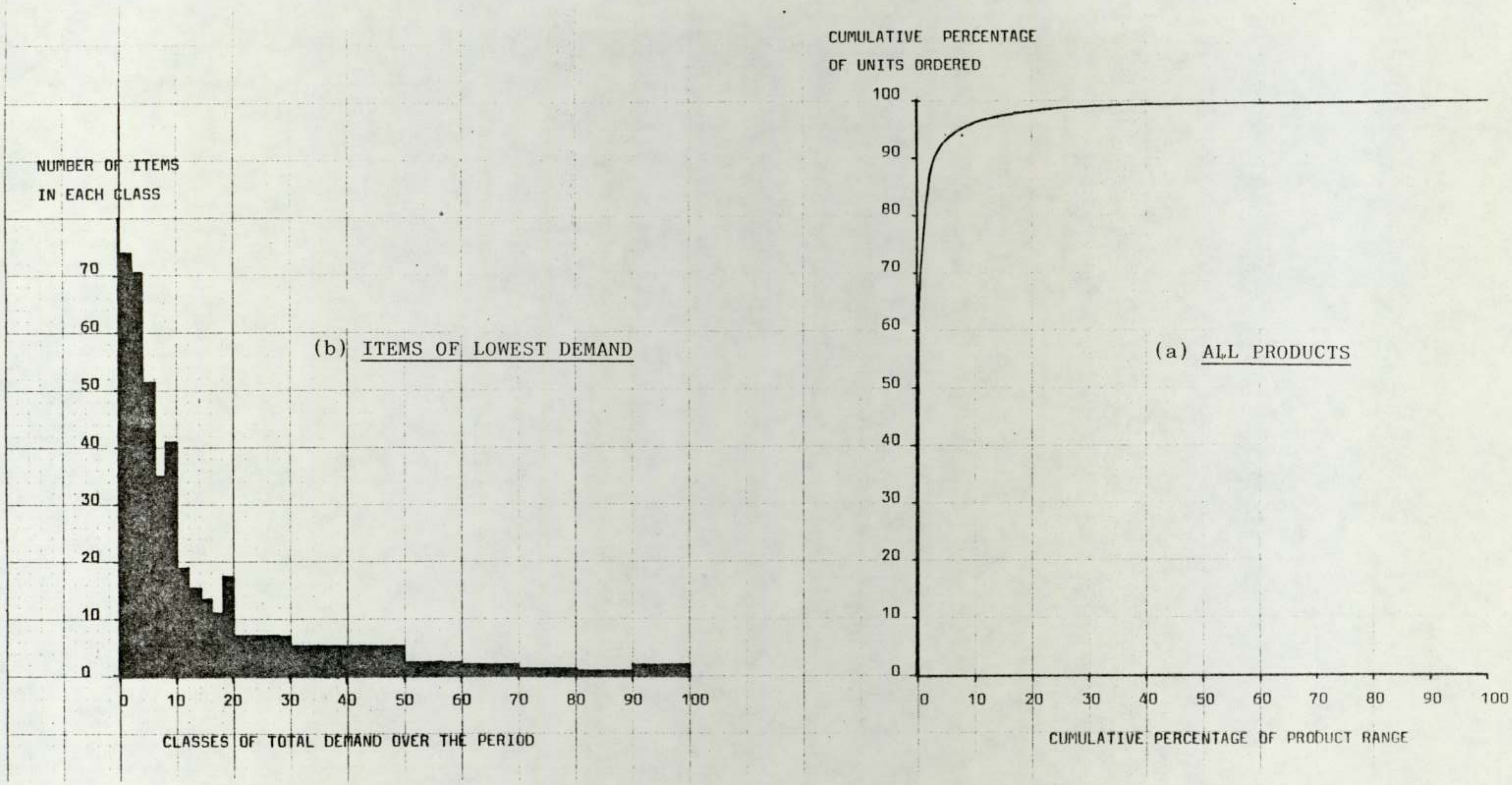
If smoothed urely seasonality suggested?

The general conclusion drawn from this data is that no worthwhile information of seasonality can be extracted by a formal process for use in short-term planning procedures. This essentially justifies the exclusion of seasonal parameters from the forecast model.

7-3 Distribution of Demand Over the Range

To gain an impression of the relative importance of items in the range, each item can be classified according to its total demand over the fourteen month period. Most of the 1200 items have relatively low demand, while 35 (= 3%) account for 90% of all units ordered. This is summarised in figure 18(a). (N.B. High demand items are important in terms of the ability to forecast, rather than turnover or profitability.) Figure 18(b) shows the distribution of items in the very lowest classes of total demand. Half of all items ordered had a total demand of less than twenty.

Since intermittency is a major part of the model, it is useful to get some idea of how often demand occurs for each item. If they are classified according to the number of weeks in which demand occurred, the resulting distribution turns out to be similar to that for demand, and this is presented in table 6. Over half the range was ordered on three occasions or less, while 350 were ordered only once. On this weekly basis, the most popular item was only ordered two-thirds of the time, so every item is intermittent from this point of view. (In fact, many more than 41 order lines were set up for this item).



(b) ITEMS OF LOWEST DEMAND

(a) ALL PRODUCTS

FIGURE 18
DISTRIBUTION OF DEMAND OVER THE RANGE

TABLE 7

WEEKLY CATEGORIES OF INTERMITTENCY

Number of Weeks in which Demand Occurred	Number of items in each Class
1	350
2	196
3	122
4	86
5	70
1-5	824
6-10	183
11-15	84
16-20	55
21-25	29
26-30	9
31-35	5
36-40	3
41	1
	1193

This analysis shows that even with the intermittency model, a forecasting procedure would not provide useful information for the majority of those items requested.

7-4 The Variability of Demand

It is sometimes useful to establish a relation between the level and variability of demand, for a group of products or product range. If such a "variance law" is valid, it can be used to simplify the estimation of variances for all individual items. R. G. Brown (16) and T.A. Burgin (18) have suggested these empirical forms:-

$$\sigma^2 = C\,\mu^P \qquad (1) \qquad \text{(Power law)}$$

and

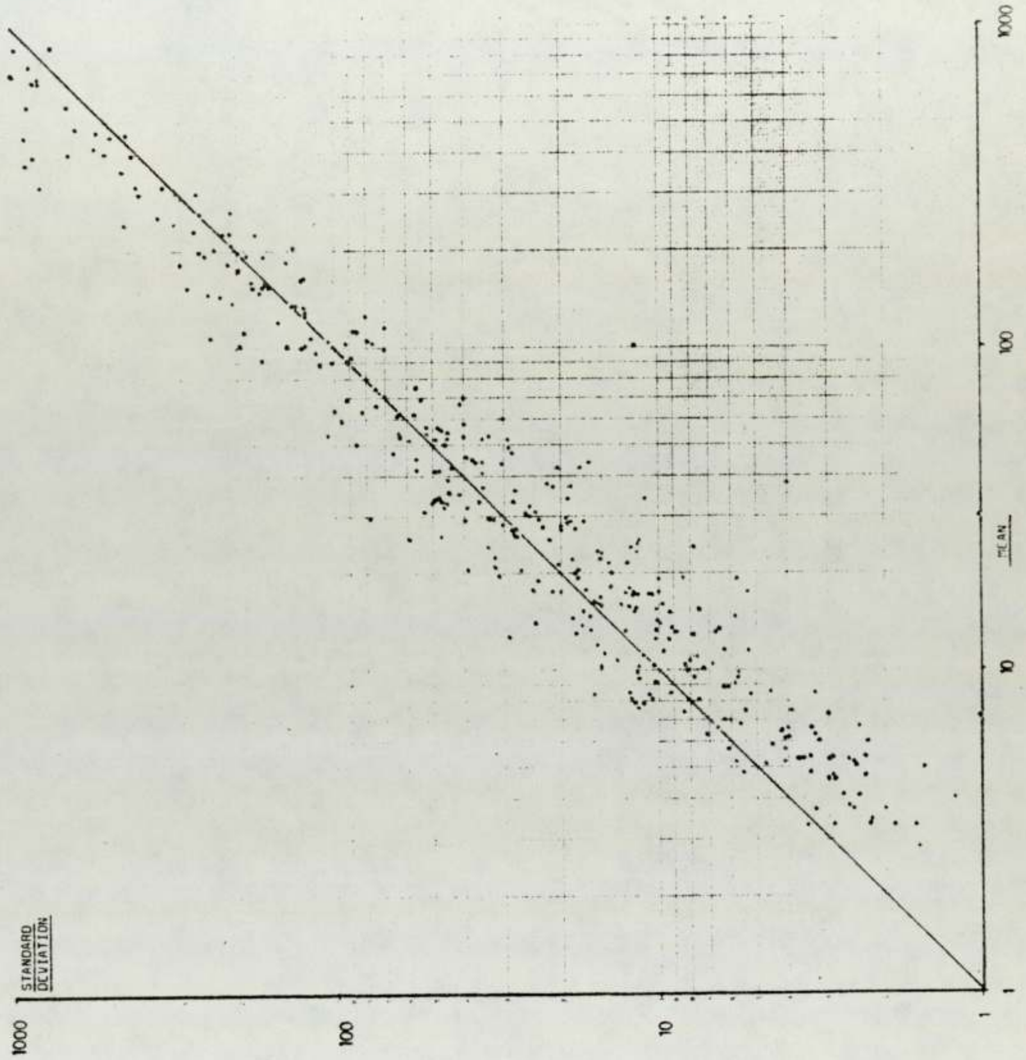
$$\sigma^2 = A\,\mu + B\,\mu^2 \qquad (2) \qquad \text{(Quadratic law)}$$

Stevens (67) has derived the quadratic law from a joint demand model for a family of items. He also points to the problems of parameter estimation for such a law, and gives a suitable algorithm for use with small sample estimates of level and variability.

Figure 19 shows a plot of sample mean against sample standard deviation of demand data for a selection of products throughout the range. The selected products are those whose sample mean demand was less than 100, and for which orders were placed during six or more weeks in the whole period. It is not worthwhile estimating the variance law for this set of data because the model actually includes a variance estimate for each item individually. But it is worth noting that the line shown, representing a variance law of the form $\sigma = \mu$ is not unrealistic, and this indicates a much higher general level of dispersion than is considered normal by Brown. In fact, Brown defines demand to be "lumpy" (14 p.245) if after fitting a forecast model, the standard

FIGURE 19

THE VARIABILITY OF DEMAND



deviation of the residual differences is greater than the level parameter of the model. Here, the sample mean can be considered to estimate the underlying process, and then all those points on or above the line $\sigma = \mu$ can be said to be lumpy. For this data, of course, this provides a rather arbitrary distinction, but it conveys the general impression of demand which is unstable and subject to discontinuities, as allowed for in the model.

Figure 20 shows a plot for a corresponding variance law for intermittency (measured in days). The 80 points were a random sample of all items for which there were more than six orders. It shows, predictably, that as the intervals between orders increase they become much more variable. The model's smoothing parameter for estimating intermittency was chosen to be 100, corresponding to an exponential weighting factor of roughly 0.1. This value is considered to be reasonable for data of such variability.

7-5 Trial of the Automatic Procedure

In this section the model is applied to four actual product histories, to give an impression of how the automatic procedure would have coped under real conditions. It is not claimed that this is in any sense the best forecast for this data. It must be realised that there is room for intelligent intervention at any time, and even room for fine tuning the automatic response. In a sense, the series shown are untypical because they are fairly long, but subjectively they do seem representative of the sort of things that happened.

Trials of the model described in chapter 6 were found to be unsatisfactory for items with high demand and variance. This was due to the form of V_t (see section 6-4-1, eqn. (23)). The forecasts were much too stable because V_t became too large under these circumstances.

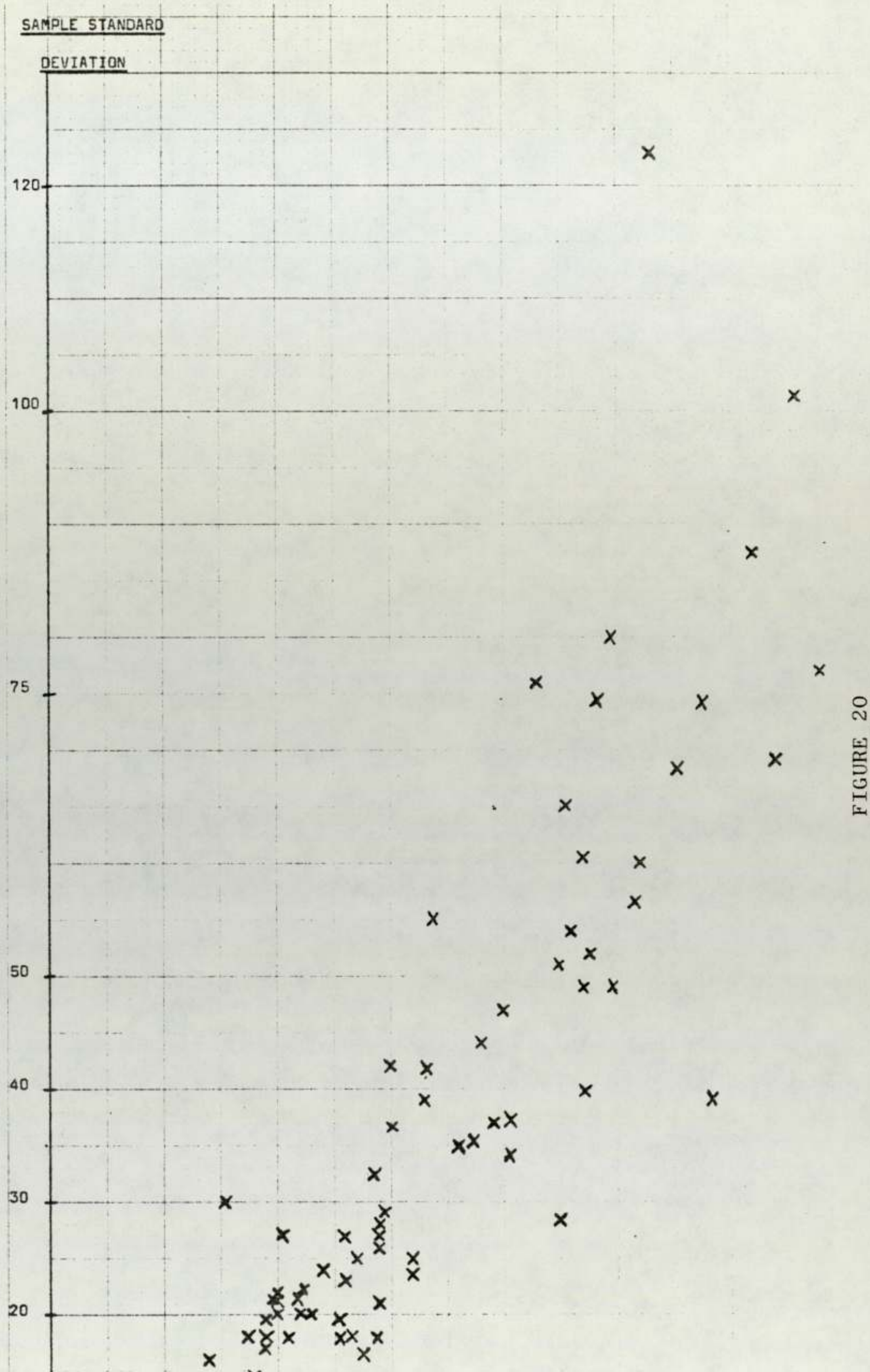


FIGURE 20

THE VARIABILITY OF INTERMITTENCY

To deal with this, the form was changed to -

$$V_t = 40 + 20000(x_t / m_t) \; (1 - \exp -(x_t/100))$$

This takes into account the general relation between mean and variance referred to in section 7-4, and that the stability of the forecast should be more closely linked to the "signal to noise" ratio.

Figure 21 shows demand and intermittency data (crosses) and the one-step ahead forecasts of level, intermittency and weekly demand (circled dots), for a 16" steel radial truck tyre. The mean demand is relatively low with an average dispersion. Initially the demand is rather wild and the model is uncertain about it until $t = 7$, and subsequently the pattern is fairly stable. The time between events is quite regular, and the model only detects one transient, at $t = 19$.

Figure 22 shows demand for a popular Dunlop D75 car crossply tyre. The intervals between orders are steady, but there are two major transients in the demand. After the first, at $t = 7$, the model senses a change in the variance, and it increases its stability accordingly. The second transient results in the detection of changes in level and variance, and the model becomes much more sensitive.

The demand for vintage car tyres is generally small and infrequent, and an example of this is shown in figure 23. The signal to noise ratio for both demand and intermittency is greater than unity, so it is reasonable to call this item lumpy. The abrupt changes in the weekly demand estimates are caused mostly by the variable intermittency estimates, while the model copes well with transients in the raw demand.

The final example in figure 24 is of a top quality SP4 steel radial. (Intermittency is not shown because it is fairly stable.) The first eleven points in the sequence show an unremarkable jump, which is interpreted as an increase in level. Subsequent observations are on a

FIGURE 21

FORECASTS FOR A RADIAL TRUCK SIZE

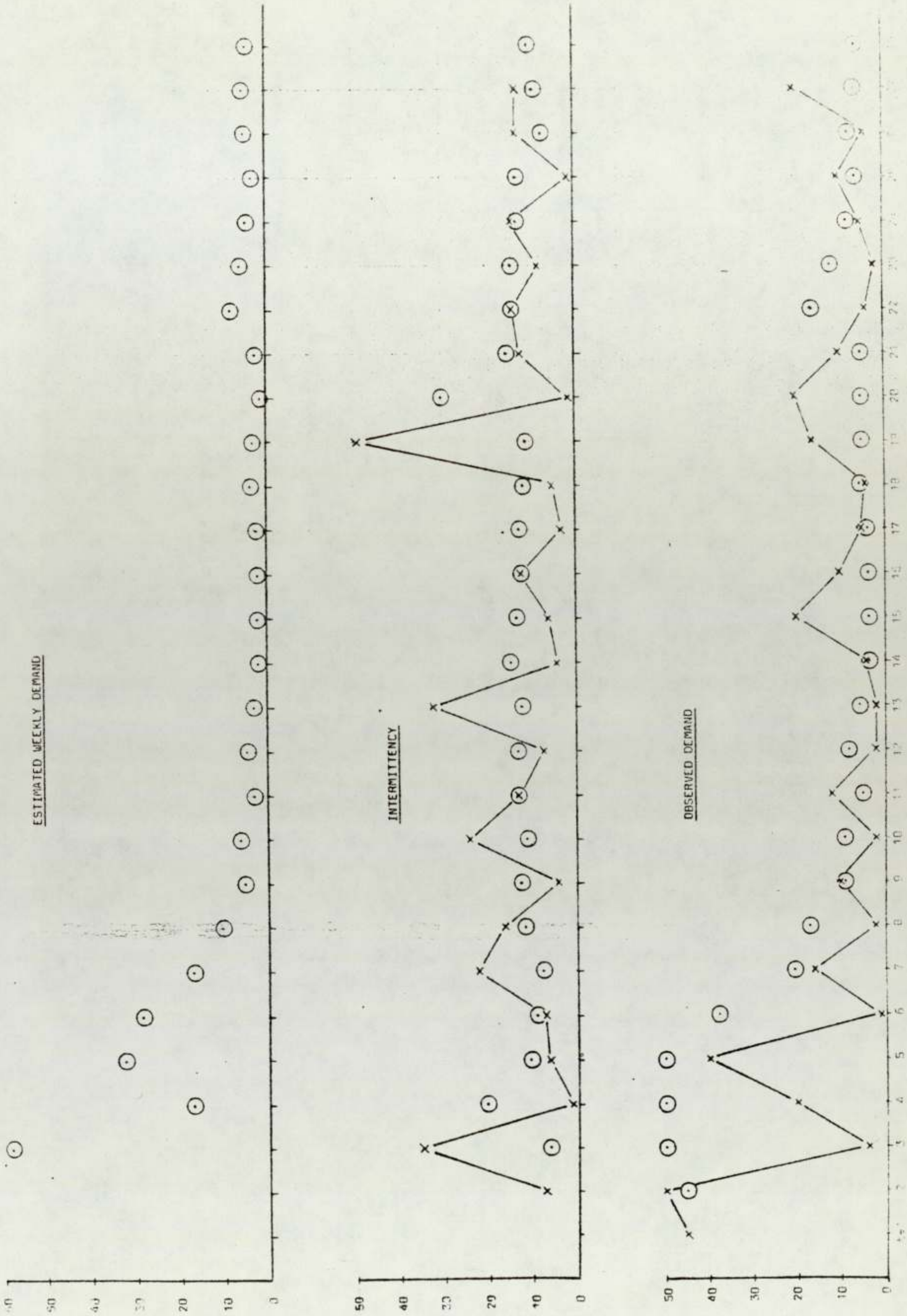


FIGURE 22
FORECASTS FOR A D75 CAR CROSSPLY SIZE

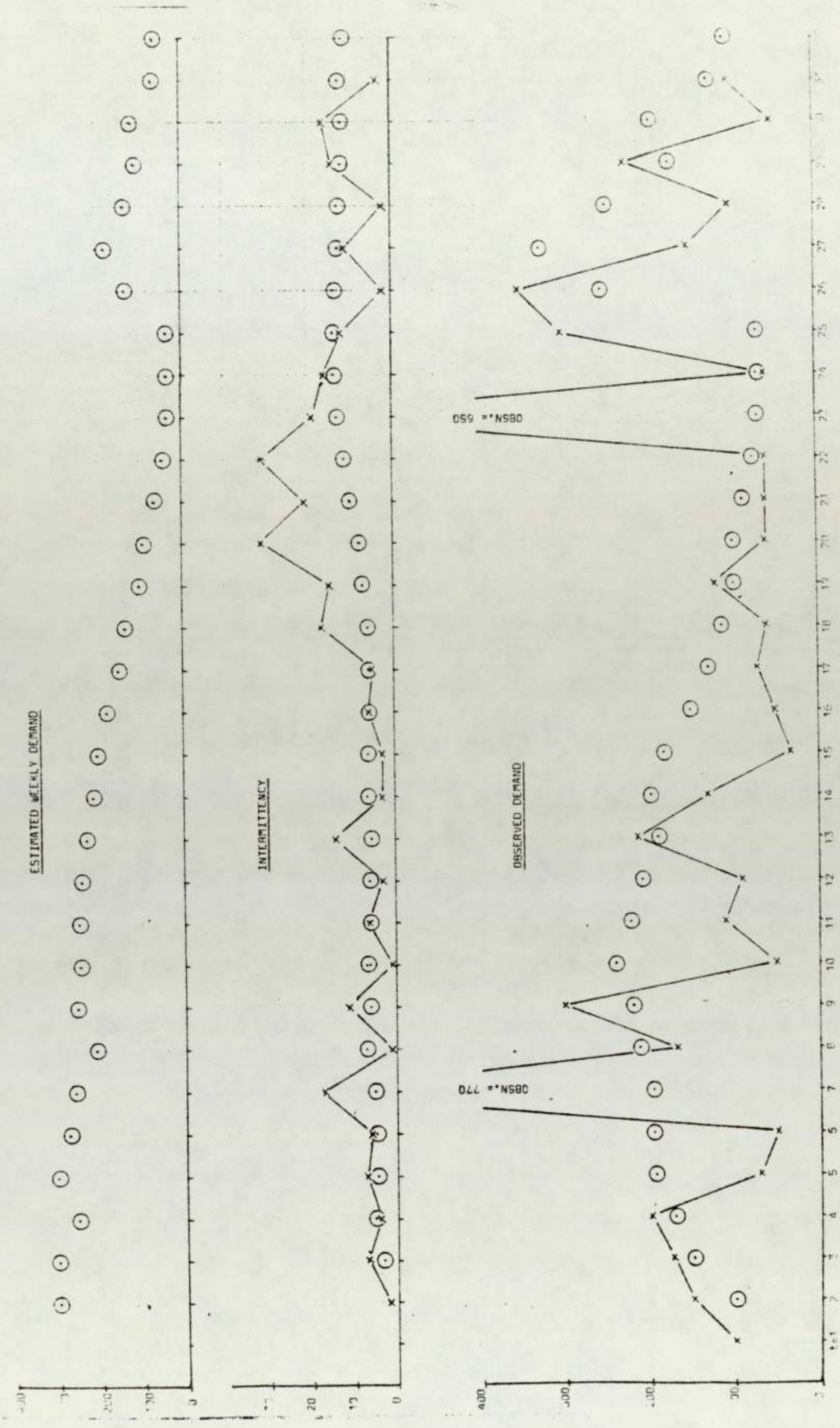
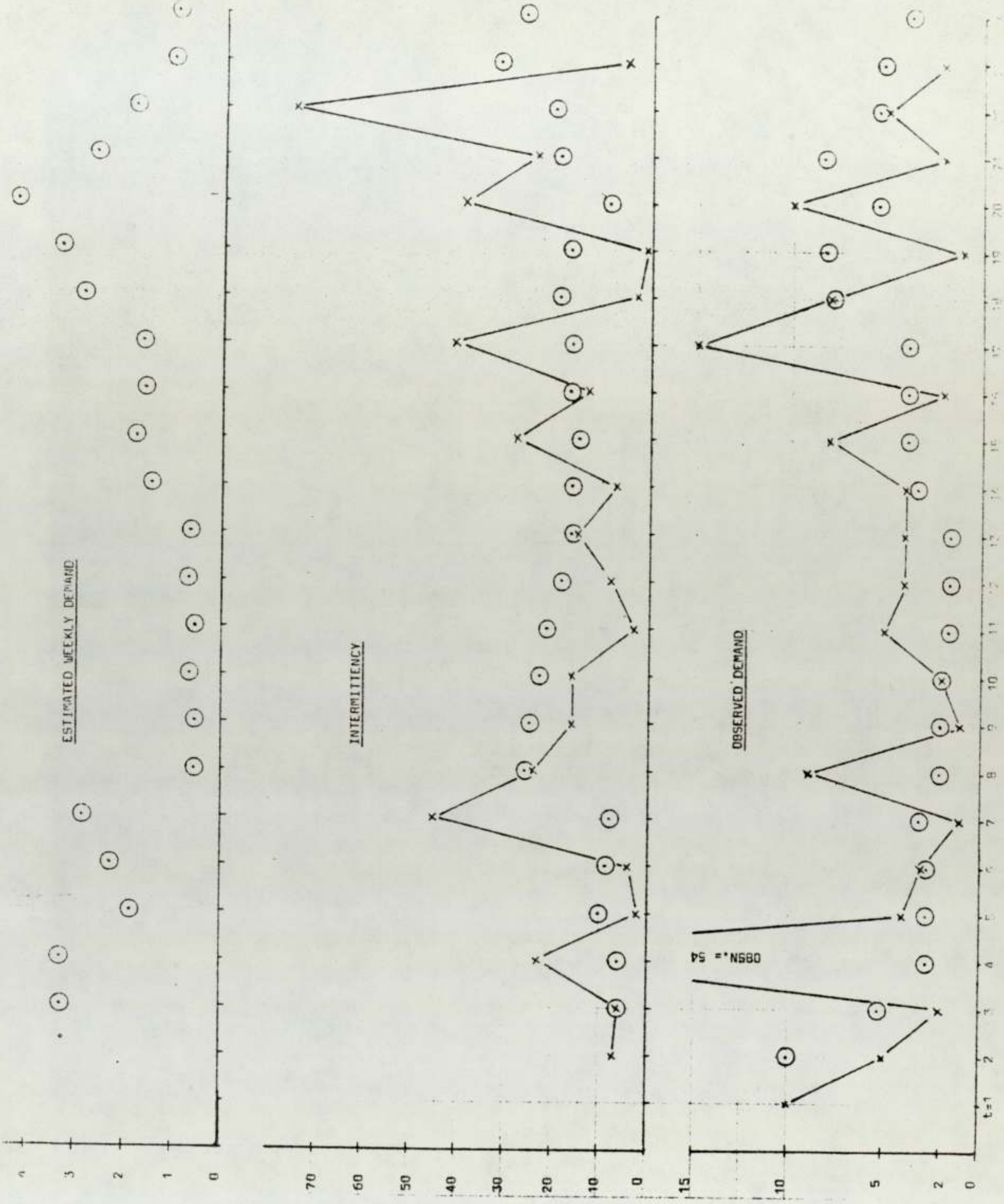
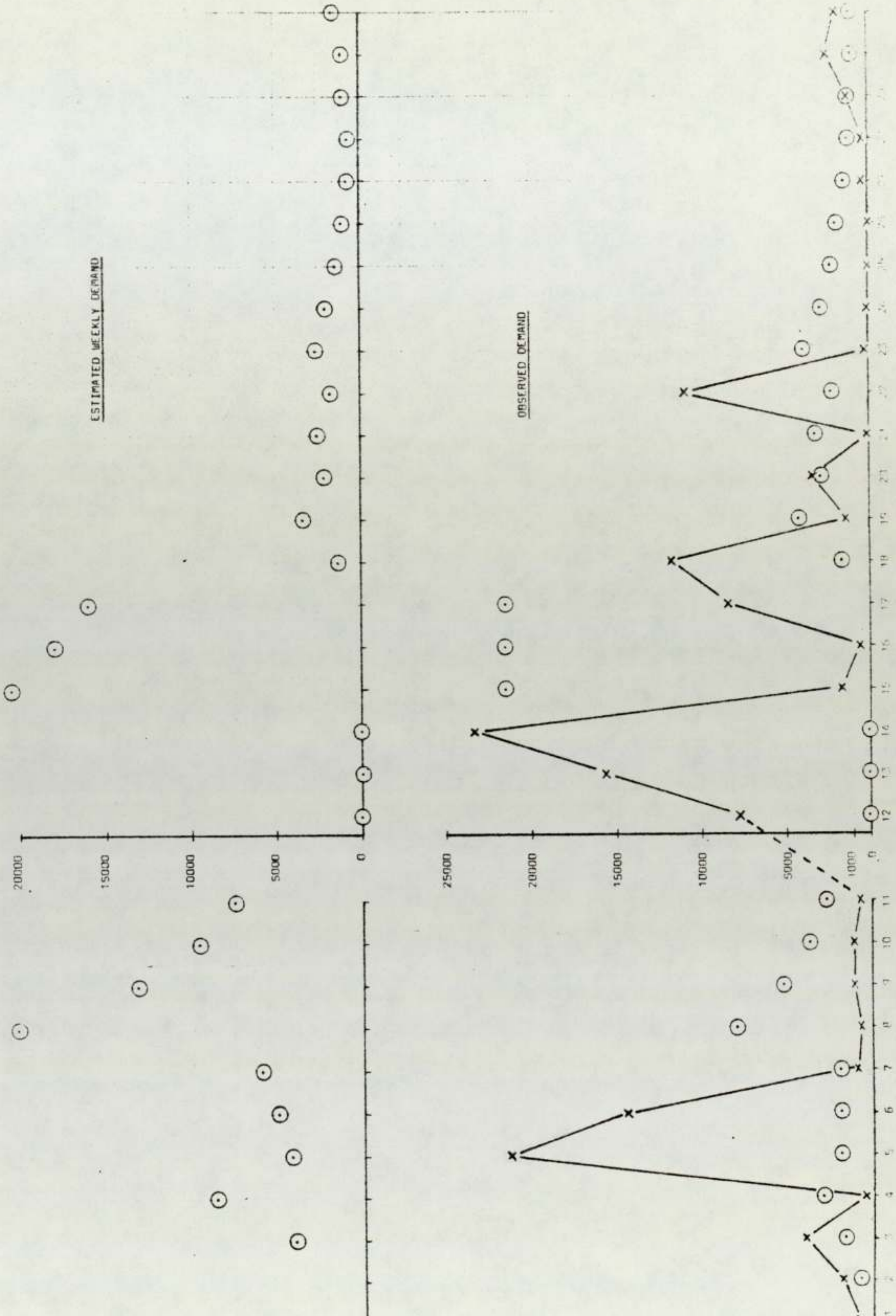


FIGURE 23

FORECASTS FOR A VINTAGE CAR SIZE



FORECASTS FOR AN SP4 STEEL RADIAL



scale which is an enormous factor of 20 times the initial scale. This jump in demand actually covered a period of 14 days when orders for a total of 46,800 units were recorded. The weekly demand estimates, which at first sight seem to have gone wild, are actually very moderate in response to such a change. Even after this, the data continues to be unstable, but the estimates settle down very quickly.

7-6 Summary

The demand data from European Selling Companies has been shown to be sporadic and often lumpy, but to correspond to the general assumptions of the model. The model gives a stable response to this sort of data, and provides useful information except when there is insufficient data.

CHAPTER 8

LEAD TIME OF THE PRINCIPAL PLANNING ACTIVITIES

CHAPTER 8

LEAD TIMES OF THE PRINCIPAL PLANNING ACTIVITIES

Introduction

Lead times are a fundamental element in any production-inventory system, and largely determine the level of customer service. This chapter describes the administrative process for export, and how lead times are monitored currently. An analysis is made of the lead times of supply and consignment planning covering a fourteen month period. As a result of this analysis, suggestions are made for improving operational and management reports, in order to improve the general awareness and liaison with customers.

8-1 The Export Order Administration Process

This section describes the basic operations of the Export Department as a background to the discussion in the rest of the chapter.

The major details of an export order are recorded in a log book in the Export Co-ordination section when it is first received. It is then sent to the Supplies office, where the appropriate MPG ITEM code is found for each product listed. (Note that at present this code is only used within the U.K. commercial systems, and that it is not understood in Europe. Communication between organizations invariably use descriptions of the product rather than a code.) If a product is in free supply, a note is made against it, showing at which warehouse ("stocking point") the goods are held. If an item is in short supply, a simple estimate of availability is made, based on the current factory programme and the quantity already on order.

After "coding", the order is recorded on a computer file ("set up") and the computer generates a serial number for internal identification. At this point the order is "outstanding" and items in free supply are "allocated" from available stock. All outstanding orders are reported weekly to the Supplies office by the computer. This is the basis of negotiation for allocation of short supply sizes between Supplies and Export Co-ordination. The progress of the order is supervised by a clerk in the Export Department responsible for a particular group of countries or territories. The "consignment planning report", also produced by the computer, shows the "territory clerk" all goods allocated to each customer, along with their weights and dimensions. From this report, the clerk decides on suitable consignments for his customers, and lists of goods to be "called off" are communicated to the Export despatch section in the stores. The goods are then brought together physically to be packed and despatched. At the same time, shipping is booked, and invoices and other documents are prepared.

Summary

An order received by the Export Department is processed through a number of stages before a consignment can be despatched. The territory clerk is the customer's point of contact with the organization, and so performs a liaison role as well as supervising the progress of the orders through the administration. The stages in this progress are registered on computer files, and the computer produces operating reports for a number of functions. The clerk often has information, over and above that held by the computer, which entails individual treatment for many orders.

8-2 Current Lead Time Reporting

The operation of the system has been left purposely flexible. For example, the quantity on order can be changed on request, or stocks can be "de-allocated" and diverted to orders of higher priority. The original customer order loses its identity for the purposes of supplies planning (and often consignment planning) and requirements are dealt with in aggregate, so the territory clerk often provides information of specific customer requirements in this process. The flexibility makes monitoring the performance and behaviour of these operations far from straightforward.

Before going any further, it is appropriate to be clear about what information of lead times is useful. As an element of "customer service", it is important to monitor the total lead time experienced by customers, and have some standard for comparison. It may be possible to analyse this further, by groups of customers or groups of products which are similar in this respect. It may also be useful to management to monitor the lead times attributable to the various stages of order processing. At the operational level, it is useful to provide warnings of excessive delay on specific orders (possibly judged against the norms of the management reports). This information would be used for corrective action, or chasing, and even passed on to the customer as acknowledgement of delay. Finally, it may be a necessary element of a systematic re-order policy.

The Export Territory Statistics and Lead Time Analysis report is currently produced to give a summary of the week's events, and a sample page is shown in figure 25. It is normally about 25 pages of computer print-out, showing the status of each (report of operations) group for every territory, the quantities processed through each stage, and comparing them with the corresponding data for the previous week. The average lead times are calculated as arithmetic means for all the transactions which took place.

On the surface, it appears that this report gives a large amount of detailed information, about groups of products on order from groups of customers. Although the information is detailed, the only specific order referred to (indirectly) is the oldest one in each group, and it does not refer to specific products. The lead times for each group are summarised over three processing stages (time outstanding, time to call off, and time to being packed), but because the averages are calculated from only one week's data, they do not provide a stable or representative impression of either the processing stage or the product grouping (look at the results for E.S.D. in figure 25).

Essentially, the report has been criticised because it neither provides a sensible summary of performance, nor gives specific information about problems or exceptions. This does not mean it is of no use. Since the Export Manager is familiar with current problems and has built up an intuitive appreciation of this method of reporting, it may well suggest to him areas which need further investigation. Without this intuitive appreciation provided by experience, it was necessary for the purposes of this research to take a more thorough look at these operations, and the Computer Centre provided a set of files recording the daily transactions on E.S.D. orders covering a period of fourteen months.

8-3 Analysis of the Lead Time Files

The aim in this section is to analyse and summarise the data collected by the lead time files for processes of allocation and consignment planning. These were chosen because they encompass the major planning activities involved in the administrative process. Making measurements from this data was not straightforward; several difficulties have been mentioned already. The original order quantity can be changed

```
REPORT NO. 0001                 EXPORT TERRITORY STATISTICS & LEAD TIME ANALYSIS        WEEK NO. 40  DATE 01 10 76   PAGE NO.   23

                     ------ POSITION AT WEEK END -------    ------ LAST WEEK/S TOTALS -------      -------- AVERAGE LEAD TIMES --------
                       QTY   OLDEST                CALLED           VOLUME        CALLED                         O/S REC/D-  C/OFF-   PACKED-   REC/D-
PRODUCT GROUP          E/S    ORDER    ALLOC    OFF  PACKED    REC/D  ALLOC    OFF  PACKED DSPTCHD  ORDERS  C/OFF  PACKED   DESPTCH   PACKED

    E.S.D.
CAR X PLY  TYRES       8823  29 01 76     527    342    2474     112-    659    429     790       0      75     64       7         0       66
CAR RADL TEXTILE      95137  14 08 75    4135   8757   20839     241-   4437   6249    4678       0      70     58      10         0       89
CAR RADIAL STEEL      17247  17 12 75    1383   3380   13053      170   2660   2860    3374       0      67     44      12         0      133
TRUCK XPLY TYRES       1646  23 07 74     111     92     729       24     84     97      32       0      81     79       5         0       62
TRUCK RADL TYRES       5092  22 03 76     707    976    2909      340    586    473     705       0      82     89      18         0       57
MOTOR CYCLE CVRS      10625  18 12 74    2575   4176    1749      135    180   1370     972       0      23     17       6         0       22
REAR TRACTR CVRS       1383  01 09 75     432    898    1651       11    105    255     520       0      86     64       9         0       45
LARGE EMVR TYRES        212  15 10 75      46    149     112        0     60    112      41       0      75     46       7         0       33
EXTRA LARGE EMVR         67  17 06 76       5     39      19        0      9     39       5       0      50     48      10         0       55
 OTHER  PRODUCTS      68632  23 07 74    9353   7681   27559     5540   6752   5923    5893       0      58    103      13         0       34

    EIRE
CAR X PLY  TYRES        315  20 05 76     205    100     250        8    305    100     250       0      94     13       7         0       75
CAR RADL TEXTILE      12701  20 02 76    1059    428    6874        3   1268    259    1480       0     105     64      11         0       59
CAR RADIAL STEEL         30  21 09 76       0      0       0        0      0      0       0       0      10      0       0         0        0
TRUCK XPLY TYRES        189  03 03 76      61     40      68        2     41     40      53       0     102      5      12         0      133
TRUCK RADL TYRES        870  26 05 76      95     55     980        0     75      0     150       0      26      0      23         0      125
MOTOR CYCLE CVRS         32  16 03 76       0      0      16       11      0      0       7       0      86      0      12         0       25
REAR TRACTR CVRS        561  09 05 74      22    287      31        0    199    287      20       0      44     21      12         0       75
LARGE EMVR TYRES         89  29 10 75       2     22       1       20      2     20       0       0      49      4       0         0        0
EXTRA LARGE EMVR          4  26 05 76       0      0       6        0      0      0       3       0     103      0      11         0       37
 OTHER  PRODUCTS      26204  23 04 75     580   3149    4784     2627   1179   1629     552       0      70      7      16         0       63

    EUROPE FACTORIES
CAR X PLY  TYRES        472  25 03 76      16     59      71       95     56     55       0       0      64     35       0         0        0
CAR RADL TEXTILE       3514  17 03 76     979    288    2814     1450    712      0     343       0      49      0       7         0      153
CAR RADIAL STEEL        800  25 06 76       0    700       0      300      0    400       0       0      14     67       0         0        0
TRUCK XPLY TYRES         35  03 02 76     181      0      90        2      0      0       0       0     147      0       0         0        0
TRUCK RADL TYRES        700  14 06 76       0      0       0     200-      0      0       0       0     105      0       0         0        0
MOTOR CYCLE CVRS       4322  16 09 75     664   1536    1518      300    873   1536       0       0      67     79       0         0        0
REAR TRACTR CVRS         20  23 06 76       0      3       0        0      3      3       0       0     100     53       0         0        0
LARGE EMVR TYRES          0  00 00 00       0      0       0        0      0      0       0       0       0      0       0         0        0
EXTRA LARGE EMVR          7  02 06 76       4      0      19        0      4      0       4       0      59      0       8         0       85
 OTHER  PRODUCTS       4572  22 07 74     222    908    1283      483    173    340     284       0      95     32      10         0       81
```

FIGURE 25

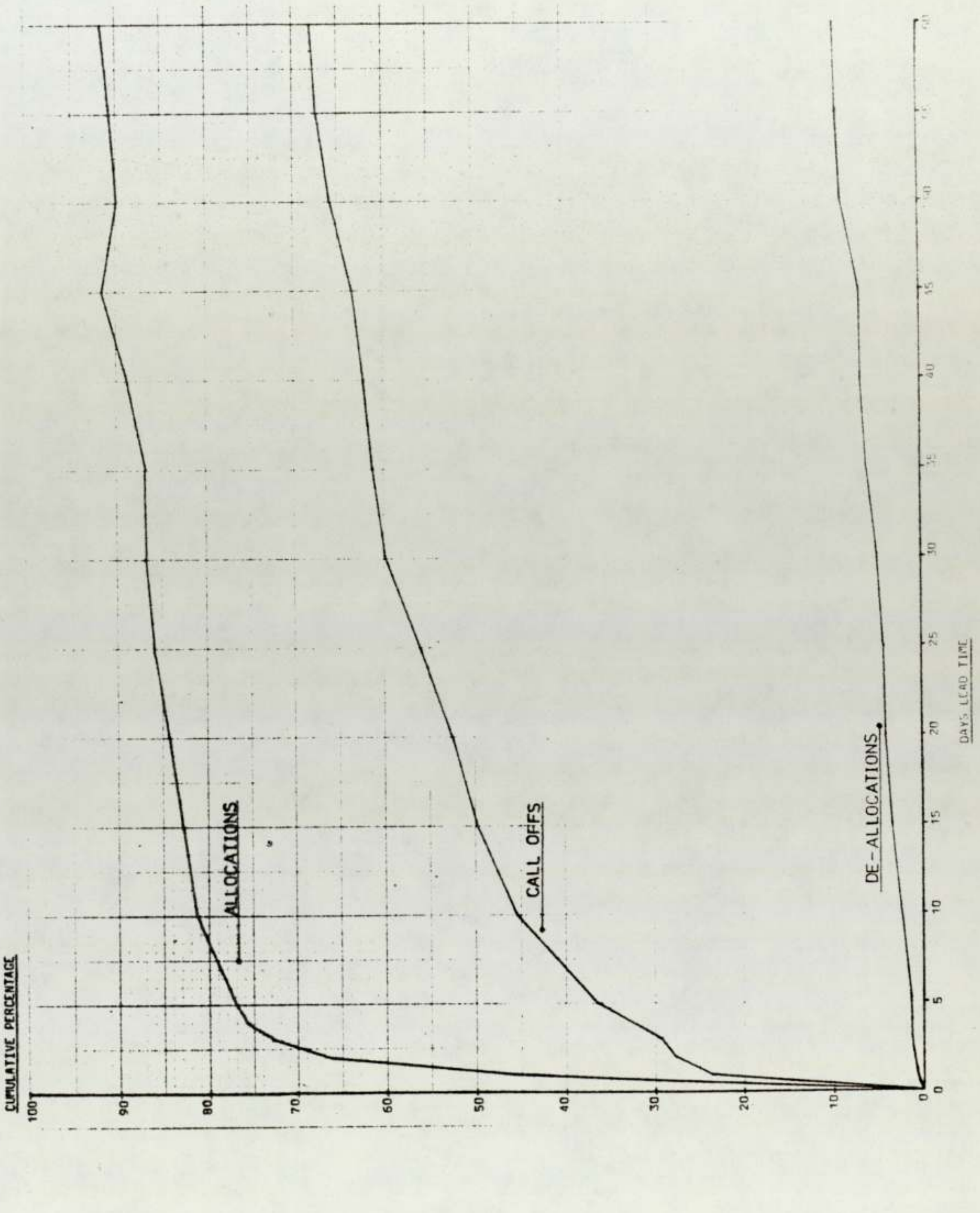
at any time on request, allocations can be withdrawn, sometimes even consignments have to be re-planned. But there were also inaccuracies in the actual data on file, which could not be allowed for. Allocations may not be formally registered if the goods are to be called off immediately, and compromises made to simplify the data collection and programming were later found to make some of the results meaningless. This has had the effect of limiting the power and scope of the conclusions, but the main results are unaffected.

8-3-1 Comparison of Supplies and Consignment Planning

In figure 26, the "Allocations" graph represents the cumulative effect of supplies for all orders for steel radial and tubed crossply car tyres over the whole period. It includes the effect of de-allocations (which are shown separately as a cumulative percentage of all positive allocations), so that between 45 and 50 days after set up the general tendency was for stocks to become unavailable. The graph clearly shows a distinction between freely available stocks and those in short supply. De-allocations in this group constituted 10% of all allocations, which was generally higher than other groups. The "call offs" graph is calculated as a percentage of net allocations, so that the area between the two graphs is indicative of the delay between the successive events. Interpretation is not straightforward here, because there are items in an allocated state at the end of the data collection period which are still awaiting call off, and neither has any account been taken of those still outstanding. Such distortions make the average time between the events look artificially high. (The graph was restricted to lead times of 60 days for the purpose of presentation. Actual lead times recorded were often far in excess.) The distortions are minimal just after set up, at the right hand side of the graphs. Here, 70% of allocations were made within five days after set up, and 47% of items allocated within five days

FIGURE 26

COMPARISON OF SUPPLIES AND CONSIGNMENT PLANNING



were called off within that time. Comparison with the major product groupings may be made from table 8. In general the performance is worse.

8-3-2 Comparison of Product Groups

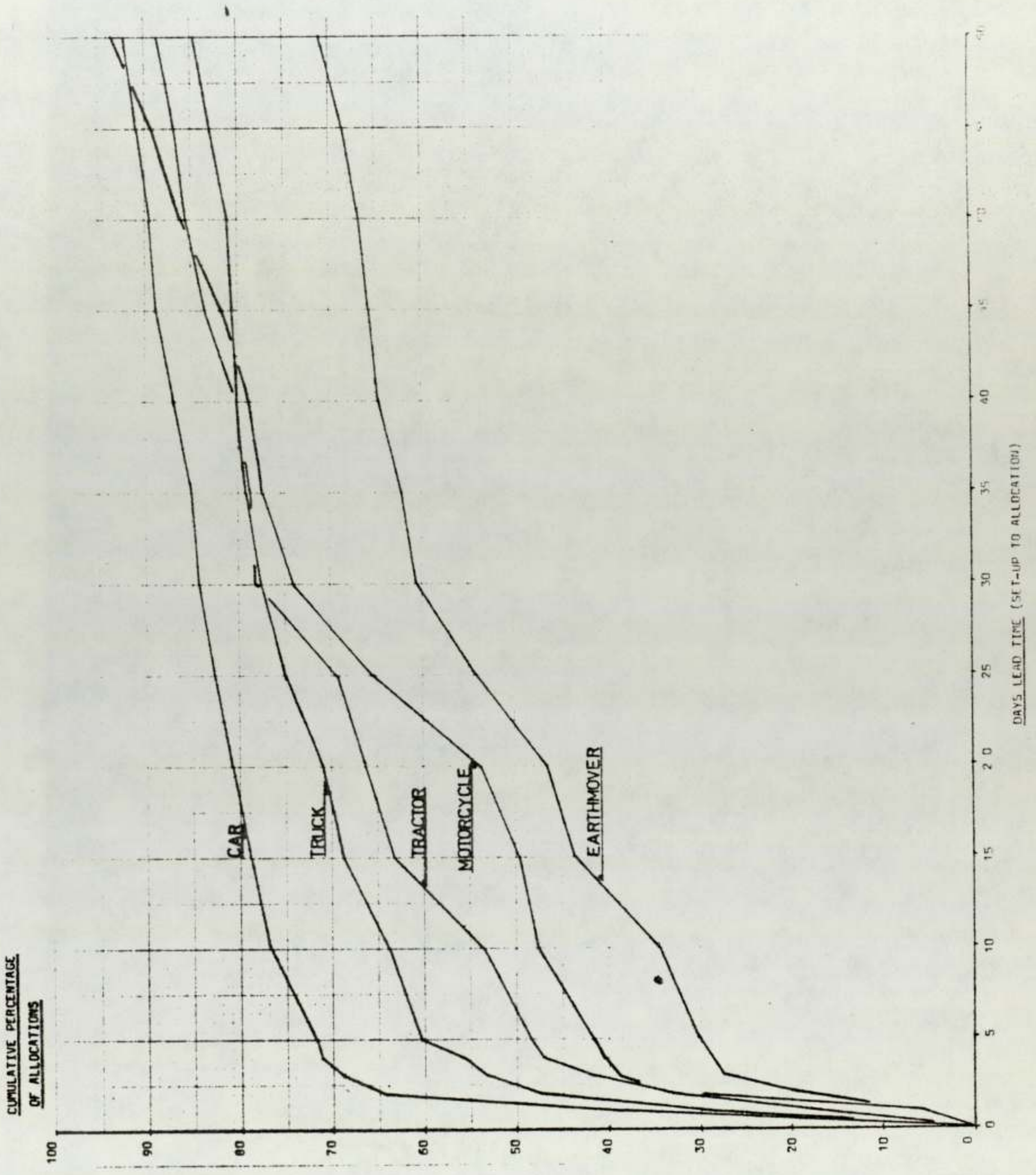
Figure 27 compares the lead time to allocation for five broad product categories. In all of them there is a clear distinction between free and short supply. The apparent hierarchy reflects (a) the extent to which the products are mass produced, and (b) the similarity between the European and home markets. For example, the majority of earthmover tyres are produced to order, while demand for motorcycle tyres comes much earlier in Europe than at home, so the U.K. factory is not geared up to those requirements.

Figure 28 shows cumulative call offs as a percentage of all call offs, again making the comparison between product super groups. The hierarchy appears to remain in tact except for motorcycle, and the reason for this is that the two alternatives for making up consignments (a container load) involve delay. Relatively large quantities are required to fill a container, but they can only be mixed with other goods when brought from the Liverpool factory to one of the Midlands stores.

Table 8 summarises these graphs, and compares the two processes more directly by showing mean values for their lead times. It also compares results for the first six months of data collection with those for the whole period. This initial period was one of general shortages for car and truck products, which improved dramatically over the remainder of the period. The important aspect of the comparison is that the reduced time to allocation is not only passed on, but it actually assists the consignment planning process. That is, the delays are not additive, but the <u>rate</u> of allocations affects the ability to make consignments quickly. The effect is not marked in other groups because other factors have a

FIGURE 27

COMPARISON OF SUPPLIES BETWEEN PRODUCT GROUPS



SUPER GROUP	6 MONTH'S DATA		14 MONTH'S DATA			
	MEAN LEAD TIMES				% ALLOCATED IN 5 DAYS	% ALLOCATED & CALLED OFF IN 5 DAYS
	SET UP - ALLOCATION	SET UP - CALL OFF	SET UP - ALLOCATION	SET UP - CALL OFF		
CAR	24	45	14	24	72%	45%
TRUCK	30	54	22	37	60%	19%
TRACTOR	20	36	22	41	49%	37%
EARTHMOVER	(39)*	(31)	39	41	30%	26%
LAND, ROAD & IMPLEMENT	(-)	(-)	(22)	(41)	68%	14%
MOTORCYCLE	13	44	22	45	42%	12%
BARROW & TROLLEY	(-)	(-)	(38)	(45)	(-)	(-)
TOTAL	-	46	-	28	-	-

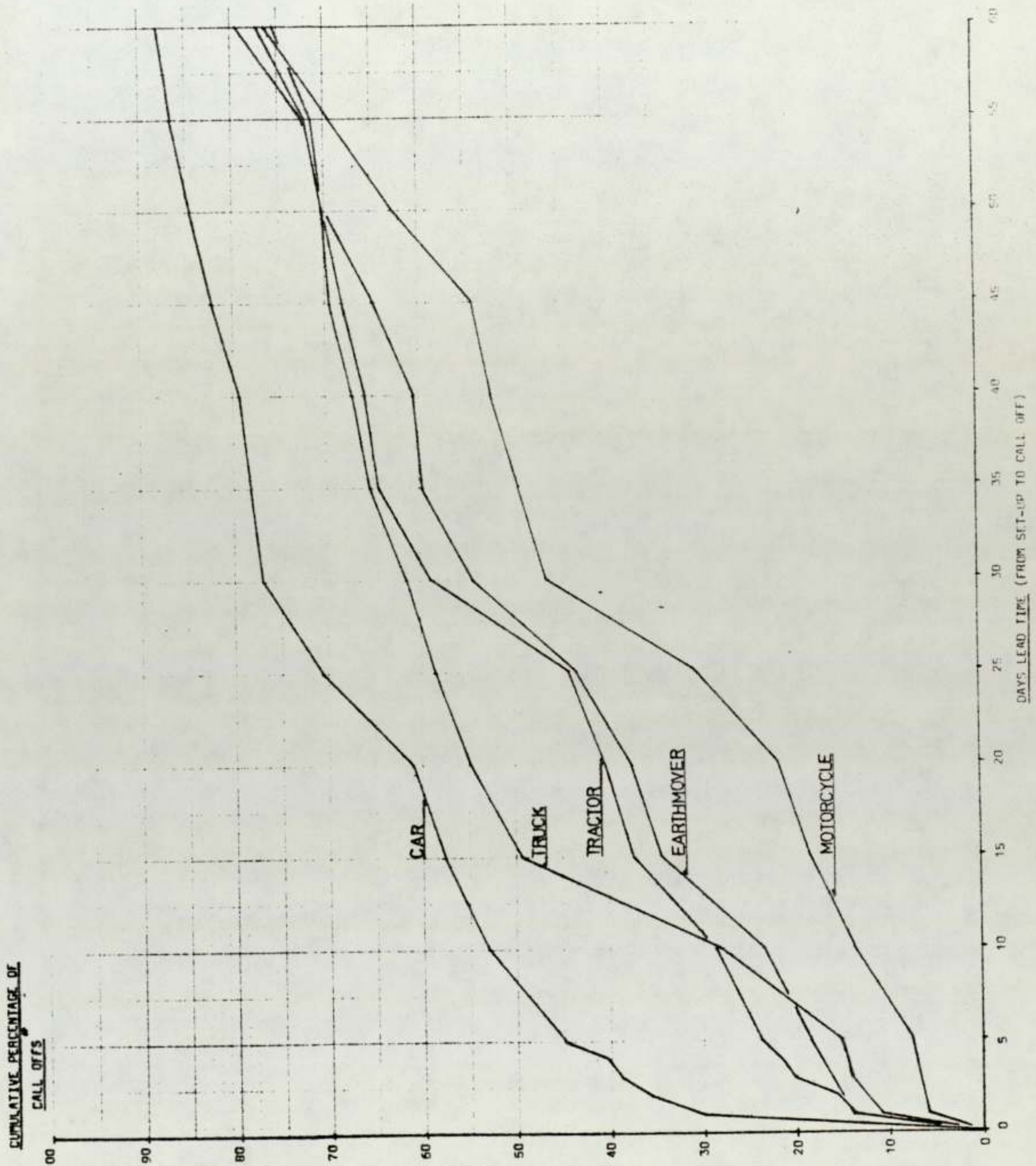
* Brackets imply limited amount of data

TABLE 8

COMPARISON OF SUPPLIES & CONSIGNMENT PLANNING

FIGURE 28

COMPARISON OF LEAD TIMES TO CALL OFF BETWEEN PRODUCT GROUPS



dominant effect. (Special considerations for motorcycle have been mentioned, while tractor tyre orders often include a specific date for shipment.)

8-3-3 Comparison of Service between Customers

Figure 29 and table 9 make comparisons of performance between the Selling Companies, on the basis of the lead times from set up to call off. The main influence is the volume of orders, as it affects the ability to make up container loads. Denmark suffers because its shipments are split between two warehouses which do not exchange supplies due to the cost of transport. Greece suffers abnormally long delays because each consignment requires an import licence. The dramatic improvement for Italy after the inital six months seems to be due to the changeover from 40' containers to 20' , which are easier to fill. So, generally, there are genuine differences between customers, for which there appear to be sound reasons. It is suggested that these differences only be monitored infrequently, and possibly only for specific excercises.

8-4 Proposals for Lead Time Reporting

The essential recommendation made here for the improvement of lead time reporting is to draw out the distinction between detail and summary, i.e. between operational use and management use. For operational use there are two suggestions. Firstly, that a weekly report should be issued for use by the territory clerks, showing details of all customer orders which have been outstanding for two months (in the week previous to the report). This report would be of use for reviewing the supply position, and possibly for notifying customers of delay. The second suggestion is that two statistics should be added to the on-line item status interrogation file (BSSI), which gives details of the factory

FIGURE 29

COMPARISON OF SERVICE BETWEEN CUSTOMERS

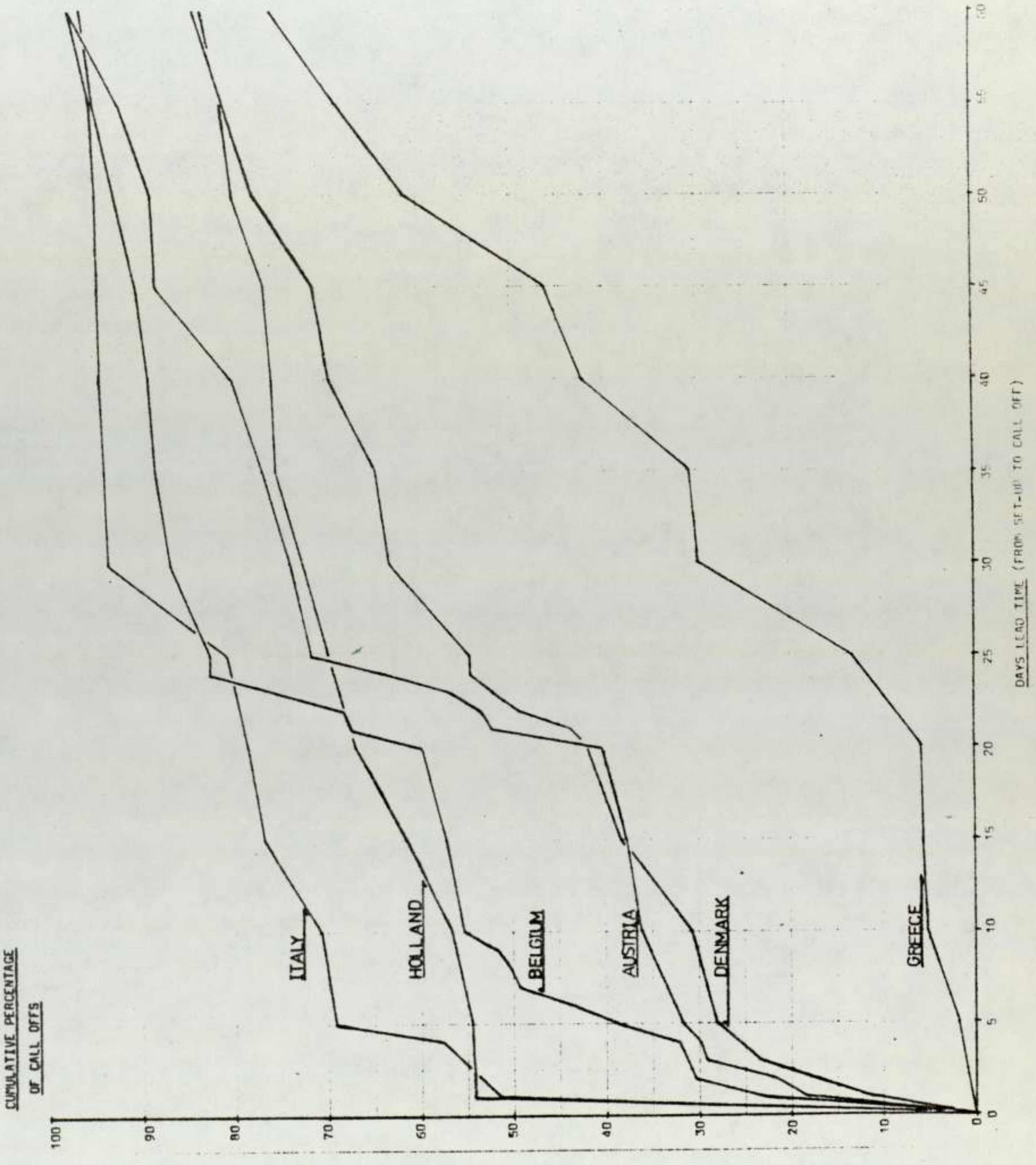


TABLE 9

COMPARISON BETWEEN SELLING COMPANIES OF LEAD TIMES TO CALL OFF

	6 MONTH'S DATA		14 MONTH'S DATA	
	DAYS LEAD TIME	RANK	DAYS LEAD TIME	RANK
ITALY	70	7	12	1
BELGIUM	44	4	21	2
HOLLAND	57	2	24	3
AUSTRIA	30	1	26	4
SWITZERLAND	62	6	32	5
DENMARK	37	2	35	6
SWEDEN	38	3	35	7
GREECE	83	8	53	8
TOTAL	48		27	

programme, stocks and outstandings for each item:-

(a) The percentage of allocations which were made within five days of order set up;

(b) The average time outstanding for those orders which took longer than five days to allocate.

These statistics should be based on three months' data of transactions, and updated monthly. This information will give a clear picture of each item's historical availability, when making quotations or planning consignments.

For management use, the main recommendation is to report average lead times every month, rather than every week, and to report by "areas" (i.e. Africa & Middle East, W. Europe, E. Europe, North & Central America, South America & Caribbean and Asia & Far East), rather than by territory. The format for average lead times would remain as in figure 25, but it is suggested that averages for the previous three months should also be shown so the current figures can be compared against a longer term view. It is also suggested that the statistics (a) and (b), above should be reported for each (report of operations) group.

The final suggestion is for an annual management report on the average lead times experienced by each of the major customers. It is envisaged that this would form the basis of a review and assessment of the service they receive.

8-5 Summary

The administrative processes of the Export Department have been described briefly, showing how information on computer files is used for the supervision of orders through each stage. General criteria for monitoring lead times were put forward, and the current lead time report was criticised on that basis. Lead time data, accumulated over 14 months was used to compare the supplies and consignment planning functions, concluding that the rate of allocations, as well as the pure delay, affects the time to call off. Genuine differences of performance were found between product groups and between customers, for which there appeared to be good reasons. As a result of this analysis, a number of suggestions were made for improving the information of lead times available to both operational and management staff.

CHAPTER 9

DESCRIPTION OF THE RESEARCH PROJECT

9-1 Initiation

9-2 First Thoughts

9-3 The First Approach

9-4 The Second Approach

9-5 Major Developments

9-6 Re-Appraisal

9-7 Contribution to the Sponsors

CHAPTER 9

DESCRIPTION OF THE RESEARCH PROJECT

9. Introduction

This final chapter describes the progress of the research from its beginning, showing the history of different approaches and explaining the value of the contribution to the sponsoring organization.

The project was set up under Aston University's Interdisciplinary Higher Degrees Scheme, which brings together the project's sponsor, a research student and supervision from the University's academic staff. A grant for the research was awarded by the Science Research Council, which was then converted into an "industrial studentship". This meant that the grant was given to the sponsor, (U.K. Tyre Division) who in turn employed me as a graduate trainee for the duration of the project. Mr. T. McNair, the Export Manager, was appointed "industrial supervisor" of the project and was my immediate superior in the organization. C.D. Lewis, Professor of Operations Management in the University's Management Centre, agreed to be the academic supervisor of the project.

9-1 Initiation

Coming directly from finishing my first degree in Mathematics, the Export Department was the first contact I had with the commercial side of industrial organization. I spent an initial period of six weeks' familiarisation with the department's operations and staff. Mr. McNair held a clear opinion as to how I should fit in. Basically he wanted someone to take a fresh look at the way things were done, without being involved in the day to day operations, or prejudiced by the conventional wisdom that had grown up.

TABLE 10

CHRONOLOGICAL TABLE OF THE PROJECT WORK

1975	AUG.-OCT.	Initial six weeks of familiarisation at Fort Dunlop.
	OCT.-DEC.	Attended:- (a) Management Centre M.Sc. Courses. (b) Dunlop's Graduate Induction Course. (c) I.H.D. Action Research projects.
1976	JAN.-MAR.	Continued work on "small orders" project. Put forward initial proposals for main project.
	APR.-JUN.	Completed report on small order policy (appendix 1). Wrote report on consignments to Denmark (app. 7(a)). Attended OTMA/IHD Communications course. Familiarisation with GPSS language.
	JUL.-SEP.	Continued sifting available data. Wrote summary report of the planning organization and the product range. Made initial approach about the Lead Time files.
	OCT.-DEC.	Gained approval for Lead Time files. Put forward revised proposals in 1st. annual review. Visited Dunlop A/S Denmark. Read Dunlop Internal reports on Depot Stock Control and the development of factory programming systems (app. 3). Read Croston's paper on Intermittent Demand.

(Continued)

TABLE 10

CHRONOLOGICAL TABLE OF THE PROJECT WORK

(Continued)

1977	JAN.-MAR.	Attended Bayesian Forecasting Event (app. 7(b)). Completed discussions with Computer Centre staff on specification of the Lead Time files. Attended conference on Distribution in Europe (app.4).
	APR.-JUN.	Discussed the push system with E.S.D. H.Q. personnel and Manager, Group Management Services. Commenced work on FORTRAN programs to analyse data files. Persued literature on the general theory of organization. Data collection commenced.
	JUL.-SEP.	Attended S.R.C. Graduate School Attended Dunlop internal course "Cost & Financial Information for Managers". Wrote outline thesis proposal for the 2nd annual review.
	OCT.-DEC.	2nd Annual Review Attempted first analysis of Lead Time files. Continued development of the forecasting model. Received copy of "Material Management Systems".

(Continued)

TABLE 10

CHRONOLOGICAL TABLE OF THE PROJECT WORK

(Continued)

1978	JAN.-MAY.	Continued data analysis and development of the forecasting model. Wrote the first five chapters of the thesis.
	JUN.-SEP.	Conducted trials of the automatic forecasting procedure on actual demand data. Completed draft of the thesis.

He devised the "small order policy" project primarily because it was a current issue for which they had no satisfactory answer, but also to provide a definite objective while learning about the company. I was introduced to the managers in the Planning and Distribution Division and then left very much alone in a spacious office to get on with my allotted task. I was at first surprised that I had not been given any explicit instructions as to how the problem could best be tackled, but I soon came to realise that this was actually part of the problem. Because I was left entirely responsible for developing the project, I quickly developed a reliance on my own judgement and a spirit of enquiry which is essential in the role of an I.H.D. student. While Mr. McNair did not give any instructions, he was available to give general advice about how to find specific information or to introduce me to an appropriate person within the company. I later learned that the Export Department staff had been briefed to "supply all the information he wants, but don't disillusion him".

After the initial six week period at Fort Dunlop, I sat in on a selection of M.Sc. courses run by the Management Centre on Operational Research and Industrial Administration. As a newcomer to the discipline, this was a necessary grounding in what Management Science literature has to offer, I also took part in two "Action Research" projects organised by the I.H.D. Department, and Dunlop's Graduate Induction course.

9-2 First Thoughts

Early in 1976, events were taking place which seemed significant at the time, while not actually affecting my work. Soon after the Director, Tyres U.K. was given responsibility for the whole of European tyre operations, the then Planning and Distribution Manager was appointed as Planning and Supplies Director, Tyres Europe. This was in fact the beginning of the Tyres Europe Headquarters organization, and the appointment of the Supplies Liaison Manager, Tyres Europe followed in June 1976. These moves confirmed that there was a positive interest in the general problems of integration in a European contect. The former Distribution Manager, Mr. F.J. Charlton, took over Planning and Distribution division and, consequently, responsibility for my project.

Resuming work at Dunlop after Christmas, it took until Easter to finish work on the small order policy. But at the same time I was thinking how to approach the main problem of integrating the stock control systems in the U.K. with those of E.S.D. At that stage I was familiar with the simple stock control models, and I also realised that the methods actually used to control stocks relied more on the human elements of experience, judgement and common sense, than the dictates of a well defined systematic policy. The approach I put forward was to formulate a model of the interactions between the two divisions, either by an analytical model or by simulation, and then use the model to test out alternative decision rules. The idea was to discover those policies which would be best suited to exports. The only other approach I saw at that time was to make a thorough review of the Export Department's administrative procedures and make commonsense recommendations about how the selling companies could be better serviced. Besides the fact that this ground had already been covered fairly thoroughly by the Computer Centre's systems analysts in developing their systems for exports, the staff had little sympathy either with graduates or those who tried to tell them how to do their job (although I had established good working relations by that time). So I considered this idea a non-starter.

9-3 The First Approach

I started work on the simulation approach by reviewing the literature on simulation methods and the computer languages written for the purpose.

One of these languages (General Purpose Simulation System) was actually available for use on the Fort Dunlop computer, and I even wrote a few programs to "get the feel of it". Without coming to any definite conclusion as to which language to use, I set out the discover the structure of the control systems at Fort Dunlop for representation in such a model. I tackled this by finding out more about the Supplies and Factory Programming operations, the complete product range and its characteristics, and by sifting existant computer files for relevant data or statistics. In particular, I was looking for representative elements of the process, or events which were relatively stable (if probabilistic) in aggregate, for use as building blocks in the model. Of course, this is one of the major challenges of the technique, requiring an understanding of the system's structure.

It was a disheartening investigation, not simply because I did not find what I was looking for, but also because I could not match the reality of the situation up to the theoretical approach. That is not to say that the people I spoke to were not helpful, or that the conversations were not informative. Indeed I was surprised by the interest shown in the project and the efforts made to assist. Looking back, I think there were three major difficulties. First of all, it was not possible to separate the allocation of supplies to export demand from the requirements of other markets for the purposes of modelling, because of the strong interactions between them. In effect, this meant a model was required for all supplies, export demand, and all the demand competing with exports. The system "as a whole" was so complicated that it was not reducible to a small number of simple components.

Secondly, it was difficult to communicate with staff on the basis of finding out about such a hypothetical model, because their understanding and appreciation of events has a very different basis. To perform a specific function, it is necessary to know about a wide range of possibilities for tackling every day problems, while any general understanding of it is intuitive and ill defined, derived only from long experience of the function.

The third difficulty lay in the available information and its interpretation. The various computer systems in operation had, quite naturally, been designed for specific tasks, (to provide operational information, various management reports and a certain amount of historical sales data for accounting purposes). They were certainly not designed to reveal the inner structure of events to a raw recruit, and since the systems were programmed in COBOL (a language I did not know) I could not write programs myself to analyse those files already available. (There was another language, QUEST, designed specifically for extracting and sorting file data, but since it had a limited capacity for manipulation and mathematical functions it was little use for my purposes.) Management reports were difficult to understand and interpret simply because I lacked the necessary experience of operations. The little I did glean from these files was that there was very little regularity in the demand, or in the subsequent administrative transactions (see, for example, appendix 7, working paper (a)), but it was not apparent how little until I analysed my own files.

9-4 The Second Approach

By the end of the first year of the project, I had been forced to think again, and I put forward a set of proposals in October 1976 which concentrated on the problems of one specific selling company. There were several reasons for choosing Denmark for the study. It had traditionally drawn most of its supplies from the U.K., through two ports, despite having direct road links to the French and German factories (which provided better service but more expensive goods). The market was thought to be fairly typical of Scandinavia, where competition is strong and high quality products are demanded. The basic proposal was to generate information about demand from Denmark in advance of requirements, for use by the supplies planning system, and the following outline programme was set out:-

1. Set up a suitable forecasting package for demand from Denmark;
2. Devise suitable rules for generation of forward requirements, derived from the forecast and the production schedule;
3. Consider a rationalisation of the stocking policy adopted by Denmark;
4. Set up a data base of lead times from the U.K. for at least two of the selling companies.

To me, at that time, the strength of the proposals was that they were a positive attempt to integrate the two operations of control in separate organizations, which could later be extended to the other selling companies. It also signified a change of approach from attempting a simulation (a very "academic" approach to the problem) to a practical, down to earth one.

On the basis of these proposals, I made a request through Mr. Charlton, Manager of Planning and Distribution, to have the lead time files (as in chapters 7 and 8) set up by the Computer Centre. Coming at a time when the Centre was suffering from an increasingly heavy workload, it was a measure of the commitment to the project that this work went ahead. However, the effect of the heavy workload was that the job had a low priority, and often had to be put off while more important work was attended to. Even though some concessions were made on the quality of the data, the programs which captured data off the live files were not operational until the following May, more than half way through the project.

Shortly after the first annual review, I arranged a visit to Dunlop A/S Denmark in Copenhagen (appendix 2) to get a first hand appreciation of their administrative systems and methods of stock control. It turned out that the company had had many problems with its computer which were only just being resolved. The operational systems were programmed for specific purposes and there was the same lack of flexibility of analysis as with the Fort Dunlop systems, only on a smaller scale. I could also see that there was much room for improvement of their stocking policy when more information of demand and supply leadtimes was available (as suggested in section 5-4), but that using their demand data for forecasting was impractical. I was beginning to understand that the implementation of a scheme which was straightforward in principle could be subject to serious practical limitations.

9-5 Major Developments

Two major developments came early in 1977. The first was from attending the Bayesian Forecasting Event at Warwick University in January (the report I wrote about it is exhibited in appendix 7, working paper (b)). The most attractive feature of Bayesian forecasting is the way it can be used to combine the skill of an experienced decision maker with information derived from data analysis. There were two areas already identified (production scheduling and the selling company's ordering procedures) where forecasting as a skill has very little assistance from any formal data analysis, and this was where I could see a much more positive role for the computer in decision making. The development work was concentrated on an automatic procedure because the formulation of the model allowed for an interactive facility to be added on later and tailored to the particular situation. I anticipate that the procedure could be of value in other situations of sporadic and variable data which I have not dealt with, so I can see it being developed by the Computer Centre as a general purpose facility for many of their users.

It is worth pointing out here that the term "forecasting" is often used to mean "anticipation of the future" in general, of the kind required for budgeting and drawing up the Management Plan. It is a popular fokelore in the division that if the distribution of car registrations and the percentage market share were known, it would be possible to derive a fairly accurate estimate of coming demand. There has also been a suggestion of forecasting export orders by measuring the proportion of quotations which are later placed as firm orders. The short term forecasting proposed in this thesis is "naive", in the sense that it disregards any casual structure in the demand. It will merely pick out a simple pattern in the demand, if such a pattern exists, and present the result for assessment by the decision maker.

The second development, from attending the "Distribution in Europe" conference (appendix 4), was the revelation that there was not only a general theory applying to multi-echelon systems, but that the software for controlling such systems had already been designed and implemented. On the one hand, this led me to look at the general theory behind the push system, and on the other hand I felt that it was necessary to open the eyes of the company to the possibilities.

I read the original papers by K.F. Simpson and then looked around for more insight into the general behaviour of organizations. The three major areas of Industrial Dynamics, Cybernetics and Organization Design (after J. Galbraith, 31 & 32) provided a wealth of literature and, more importantly, some very useful ideas, for understanding and explaining the behaviour of large companies. In fact, each of these ideas was a minor revelation which let in some light on the complicated muddle that previously I had been struggling to understand. The work of J. W. Forrester, in particular, had already derived general conclusions about the design of a multi-level warehouse chain, and that put the final nail in the coffin of the simulation approach to my problem. I was convinced that, when brought together, these three areas would provide a genuine conceptual framework for both the problem and the alternative solutions. However, it was not easy to see how each of these theories fitted into the schemes of the others. I spent a considerable amount of time and effort drawing them together and relating them to the Tyres-Europe organization, to provide the final coherent explanation and analysis contained in chapters 3 and 4.

I did not receive a copy of R.G. Brown's book "Materials Management Systems" until the end of 1977, but the basic ideas of the push system had come over so clearly in the conference that I was able to write a paper outlining the application of such a system to Dunlop's European operations (appendix 7, working paper (c)). With a certain amount of evangelistic zeal, I went to see some of the staff at Europe Sales Division Headquarters to discuss the issues raised by the push system, and made a request to see the General Manager. In turn, I was asked to provide a summary of all the work I had done on the project, but the summary was sent to the Manager of Dunlop's Group Management Services, presumably because they did not feel able to assess it for themselves.

I had an interesting conversation with him as a result, in which he pointed out some of the facts of life; i.e. that even if the funds and resources for such a major project were available, the impetus would have to come from the Divisions concerned. He received more requests for systems and O.R. work than his department could cope with, without going out of his way to propose major new schemes. Probably the most positive response to the idea of the push system came from Mr. McNair, who admitted he didn't know what to make of it, but thought it would be difficult to gain any political acceptance for the scheme.

9-6 Re-Appraisal

Towards the end of the second year it was appropriate to stand back and re-appraise the whole project in terms of what the sponsors really wanted from it, and what practical result I should aim to achieve. More specifically, an outline of the thesis was required for the second annual review. In terms of the theory, the project was asking "how can the two operations be better integrated?". The answer was equally straightforward that this could best be done with a push system. However, I had found by experience that it was simply unrealistic to expect such a sudden or dramatic change to take place in a large mature organization. It was also apparent that the "real" problem was not simply one of stock control, but of producing goods at the right time in an economical way. Bad service to European markets was most frequently blamed on production failures or on the economics of small batches in a "mass production" industry. The latter explanation was popularly summarised in this rhetorical questions:- "should we go out to sell what we can best produce, or should we make to order?". The ostensible answer was that the production schedule is <u>based</u> on outstanding orders, which means that the balance lies somewhere between the two. This problem can also be seen as one of integration, which was, nevertheless, outside the scope of my project.

The theory also showed that, of the organizing modes available for improving performance, the development of professionalised and liaison roles was already a clear strategy (it could even be said that this strategy was characteristic of the organization). The remaining alternative was the development of data processing and transmission in vertically integrated information systems (of which the push system is a specific example). Of course, using the computer was not new. Indeed, its ability to replace and enhance clerical functions was well appreciated, and it was widely and effectively used in this mode. In fact, the principle of planning from a centralised data base had even been applied to stocks and distribution from home depots. So, one of the principal objectives I set for the thesis was to provide an explanation of how vertical information systems could be used to improve the stability and control of inventories over a large area, and, in this way, describe the opportunties available for developing the use of the computer beyond the horizons which were already in view. I genuinely felt that the conceptual framework provided a good perspective for the problem as a whole.

My interest in forecasting led to the consideration of what it was really trying to achieve. In the business context, the aim is to summarise what has happened and provide a view of what will happen. By applying a "filter" to raw data, better quality information is produced. It seemed to me that the current reporting procedures were merely sorting, aggregating and averaging data, and if the principle of filtering was applied, it was not apparent. I could see there was real potential for development of computer applications in "active" roles for decision makers, as well as simply in reporting events. So, I decided that this was where I should make my practical contribution. The approach I adopted for the final year was to develop the forecasting procedure so it would work on real data, and apply these general principles in a re-examination of the major decision and reporting areas.

The majority of the final year was spent drawing the theoretical work together into a coherent framework, and filling it out with various views and observations of the company, for inclusion in the thesis. The rest of the time was spent on analysing the data files and developing the forecasting procedure. Ever since I had come across Bayesian techniques, I had been hoping to set up an interactive facility for general use. However, the Computer Centre continued to have difficulties with its workload, which meant there was no possibility of pre-empting their commitments to assist with the sort of development work required. In fact, some errors were found in the original programs for the lead time files, which took a considerable time to correct and added to the mild frustration that I had already experienced. The programs I wrote in FORTRAN to do the analysis started off being very sophisticated, attempting statistical tests of a number of hypotheses I wanted to examine. Over the extended period of building up sufficient data and running the programs, it became more and more obvious that there was very little point to such sophistication and that the original hypotheses were not very meaningful. The real world seemed to be much more random than is suggested in statistics books.

9-7 Contribution to the Sponsors

The three years spent on the project were of fairly obvious benefit to myself, gaining an appreciation of many of the theoretical insights into organizations, and at the same time having an unusual amount of freedom to study how a real organization functions and to make my own decisions. I have seen some of its internal politics from an almost independent viewpoint, while using my programming skills to develop a forecasting technique for its use. However, the value of the project must eventually be seen in terms of its contribution to the sponsor, Dunlop's Tyre Division.

The original statement of the project (to study the feasibility of developing a stock control and replenishment system covering European Selling Company requirements) presented a wide-ranging and "open ended" problem. The first two recommendations are also open ended, in the sense that a substantial amount of work will be required to put them into practice.

I am convinced that my recommendations are of great significance to the sponsors because I believe that, eventually, the Tyres-Europe organization will develop along the lines I suggest, regardless of the specific arguments that are actually used to justify them. However, I certainly cannot claim to have dealt with the current most pressing concern of Tyre Division; one need only look as far as the intended closure of the plant at Speke (which has received wide publicity) for an example.

The tangible result of the project is the thesis itself. It was, therefore, written to provide the sponsor with a concise description of the project work, as well as to satisfy the academic requirements. Obviously, the chapters on forecasting will be fully appreciated by only very few people within the company, but I have tried to compensate with with explanations and summaries in plain English. So, while it is not "easy reading", I feel that I have provided an analysis of the company's operations which can be read by many people in the organization, and especially those interest in its future development.

It is now appropriate to restate all the recommendations.

Recommendation 1 - The Long Term Development of European Distribution

The efficiency of the administration and distribution of finished goods throughout Europe will be improved by using information more effectively in more complex decision mechanisms. Suggestions have been made for such improvements in the areas of production scheduling and allocation, the selling companies' ordering policies, and information processing networks (chapter 5) towards the eventual objective of implementing an integrated push system. The following design strategy recognises the limited capability of a mature organization to develop rapidly.

Phase 1 Systematise the collection of demand, stocks and lead times data for each product in each selling company warehouse. Monitor the distributions of lead times and demand, and make forecasts for up to four weeks ahead of the combined demand.

Phase 2 Improve the stocking policy operated by each selling company, using the information generated in phase 1.

Phase 3 Extend the planning horizon of U.D. production scheduling to four weeks, as suggested in section 5-3.

Phase 4 Introduce programs from the "Multiple Warehouse Systems" to cover the replenishment of home replacement depots and selling companies.

Phase 5 Extend the use of the push system to all European distribution networks.

Phase 6 Centralise the management and co-ordination of European distribution, using an integrated push system to cover all Dunlop owned distribution points.

Recommendation 2 - A Short-Term Forecasting Facility

The automatic procedure for estimating export demand described in chapter 6 should be programmed for interactive use by production schedulers. Its flexibility and robustness will allow it to be applied to other markets and situations, while the current re-structuring of the computer's data base will allow it to be applied to selected product groupings at the discretion of the user.

Recommendation 3 - Operational Lead Time Reporting

The following information should be made available to Export Department staff for improving customer liaison.

(i) A weekly report issued to territory clerks, giving details of customer orders which have been outstanding for two months (triggered during the week previous to the report).

(ii) Two statistics added to the on-line item status interrogation file (BSSI), based on three months data and updated monthly:-

  (a) the percentage of allocations made within five days of order set up;

  (b) the average time outstanding for those orders which take longer than five days to allocate.

Recommendation 4 - Management Lead Time Reporting

Reporting lead times for management and control purposes should be on the revised basis of one month's accummulated data, and by "area" rather than by territory, while retaining the same format as the current report. For comparative analysis, average lead times for the previous three months should also be shown, and the statistics (a) and (b) above reported for each report of operations product group.

Finally, average lead times for each major export customer should be reported annually (or on request) to form the basis of a review of the service they receive.

Without exception, these recommendations are based on the use that can be made of computing facilities. The organization has many applications already, which have replaced and enhanced clerical functions where large amounts of data are handled. These are effective and well appreciated applications. The uses I suggest are directed more specifically at assisting the complex decision making roles, so that the computer is used as a tool as well as an efficient clerk. Bayesian forecasting techniques in particular have already been very successful in practical situations.

In chapter 8 I have demonstrated just how much uncertainty and variability there is in the ordering and despatch processes of export. Because such an analysis had not previously been attempted and the only representative data available was in the form of averages, any discussion disregarded the significance of such uncertainty. In fact it is precisely this uncertainty which can only be reduced by the use of vertical information systems.

At the end of the project, a final supervisors meeting was held to discuss its value from the point of view of the sponsor, represented by Mr. McNair. In general, Mr. McNair was very pleased with both the standard of the work that had been done and its presentation in the thesis. In his opinion, the right elements of the problem were picked out for study, and he was convinced that a push system for European distribution would eventually be adopted. He thought that short-term forecasting for production scheduling was a very new idea for the company, but that it was a necessary part of any future development. The techniques suggested would probably be sent to Group Management Services for evaluation. He considered the analysis of lead-time to be very valuable as the basis of some modifications to their current methods of reporting and to fit in with their customer centred approach to service, called the "Total Export Concept." The impetus for development in this area was strong.

APPENDIX 1

Small Orders Policy: Results and Recommendations.

Introduction

The original project was to develop policy guide-lines for the acceptance and handling of small orders and small accounts from E.S.D. and O.M.D., with the objective of establishing economic order criteria. This final report restates the results of the investigation and analysis completed, and examines the opportunities available for dealing with the problem.

Summary of the Results of the Investigation.

A study of a sample of orders and invoices processed by the Export Department has shown that there is a straightforward way of classifying them as "large", "medium" and "small" according to their value. Individual accounts can also be classified in a similar way according to their annual turnover. A closer look at a sample of small orders revealed that requirements for low valued products were not generally associated with small orders. Neither is there any association between small orders and items with a low contribution.

It has been shown that the revenue from each order can be compared with the nominal cost of administration to judge whether or not it is economic. However, the revenue from each order can only be calculated accurately from the contribution from each item, the factory constants and the direct and indirect expenses. The degree of variation in each of these factors means that it is not sensible to set a specific level and say :- "above this level orders are economic, and below it they are not". I have concluded that the concept of an economic order size is not very useful in this context.

If it was required to assess the worth of each order, I have suggested the use of "contribution to expenses" which can be compared simply and directly with direct and indirect expenses. The use of contribution would be much more involved.

The Need for a Small Order Policy

The following four statements are typical of attitudes relating to small orders, and illustrate the obvious conflicts inherent in trying to solve the problem:-

ORDERS: 1) Some orders are not an economic proposition.

2) Small orders as a whole are more trouble than they are worth.

ACCOUNTS: 3) Small orders are part of the overall service given to customers.

4) Dunlop values the business of some customers.

I will now consider the implications of what is behind these statements in relation to five alternative strategies:-

a) Improve service

b) Accept as usual

c) Surcharge the order

d) Refer the order to an agent or depot

e) Reject the order

1) Some orders are not an economic proposition

This view arises from the consideration of the order as a cost centre, i.e. it says the "cost of an order" compares unfavorably with the revenue from it, and this has not been taken into account in the price. In particular, the relevant or balancing factor seems to be the administrative cost (should this be the average or marginal cost of administration, or a compromise somewhere between the two?). Much of work of the Export Department is concerned with invoicing, documentation and updating accounts records. None of this is directly attributable to particular orders. For example, invoices are actually created by the consignment planning process, rather than as a response to an order. So orders are not natural cost centres.

Suppose a surcharge was added to the price of an order which was uneconomic. This could be a percentage of its value or a flat rate. It would eventually appear on an invoice, which may also refer to items from different orders, each one requiring a different charge. In practice, each item would have to be charged on reception of the order, and the information stored until invoicing. This would be a complicated manual operation. An alternative is to consider the invoice as a cost centre. But since they are created by the administrative system, surcharging an uneconomic invoice would penalise the customer for something beyond his control.

The implication of a computer assisted order entry system is that pricing items individually would be a mere technicality. Each item could be assigned its price at the time of set up, and held on the computer until required for invoicing. However, it is not likely that a an automatic pricing facility will be available in the near future.

2) Small orders are more trouble than they are worth.

This statement could mean that the time spent on small orders could be better used on other work, or that blockages are created because the system is overloaded, The first meaning suggests that there are too many orders for the system to cope with, so that an "alternative" cost should be considered in the economics of an order. It possibly arises from the feeling that a mass production industry should not be bothered with small orders, except in special circumstances, and therefore they should be referred to our distributors. This could be done directly, or by introducing a surcharge to act as a disincentive for placing small orders.

The second meaning suggests that by eliminating small orders, pressure on the administrative system would be relieved so that more attention could be given to the more "important" business. This assumes that the system is the correct size and that removing part of the workload would make it more effective. The implication being that it is not worth the capacity or capability of the system just for the sake of improving service. If this view could be justified, it would lead to a proportion of orders being being referred to agents, and that the important criterion for doing so is the current workload.

3) Small Orders are part of the overall customer service.

Some of the reasons apparent for small orders occuring are related to service levels. The reasons can be summarised as follows:-

(a) There is a demand for products which are at the beginning or end of their life cycle and are not produced elsewhere.

(b) Some customers want to deal with Dunlop direct rather than through an agency.

In as much as these are genuine reasons for small orders, the Export Department is providing a service to these customers. The approach to these orders should be in accordance with the service levels offered by Dunlop, and if this is a genuine extra service, it is reasonable to surcharge the customer for it.

4) Dunlop values the business of some customers.

This refers to prestige customers and potential markets. I do not think it is useful or practical to put a value on the business of these customers. Prestige is not something which is equivalent to money in an any well defined way, and it is only sensible to decide on the value of opening up a large market after it has happened. I think the problem should be approached more positively, by improving the level of service to these customers, possibly by placing a priority on them.

The Alternative Strategies

The table represents a summary of the previous section, relating each identified problem area to each possible strategy. A tick represents a positive approach, a dash represents a neutral strategy, and a cross stands for a negative or counter-productive approach. The rejection strategy is no positive use anywhere, so this will be discarded immediately.

PROBLEM AREA	STRATEGY				
	a	b	c	d	e
1	×	-	✓	✓	-
2	×	-	✓	✓	-
3	×	✓	✓	×	×
4	✓	-	×	×	×

The strategy strongly related to the economics of an order is the surcharge. Exactly what form it would take would depend on the economic climate and the objectives of the policy set by management. The objective may be to provide disincentives for small orders or to recove recover the administrative costs, or alternative cost of orders, or to recover a proportion of the annual turnover. Once the objectives were clearly defined it will be possible to devise rules for the calculation of the charge for each item as the order arrives. As previously stated, it would only be practical as part of a computerised procedure for pricing.

The treatment of prestige customers and potential markets is complementary to the surcharge strategy, because if a surcharge is introduced, there will be exceptions to it. Such customers will need to be categorised and listed, with procedures for revision. The only suggestion I have for improving service to these customers is to place a priority on them. However, if this positive approach is taken, it may well limit the number of customers exempted from the surcharge and prevent the degeneration of the policy as a whole.

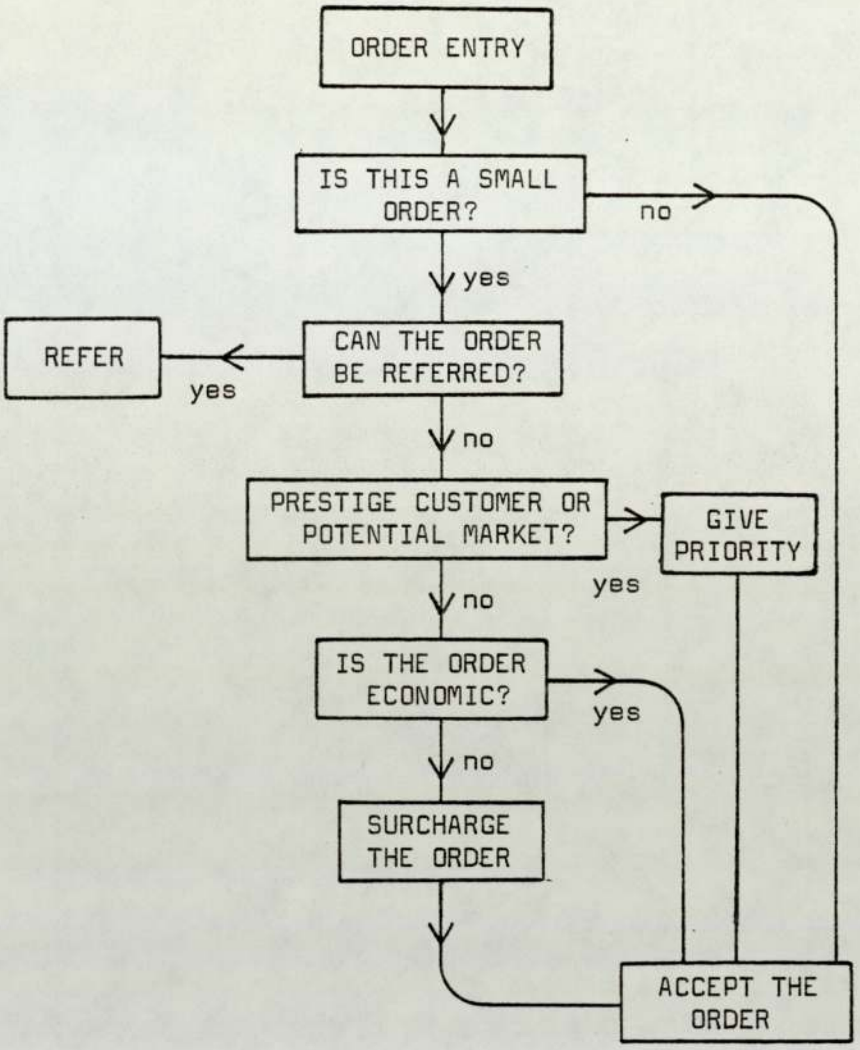
The strategy of referring orders to agents can be used independently of the surcharge strategy, although it may satisfy some of the same objectives. The process would require a considerable amount of information about the availability of particular items from alternative sources, and whether those sources are acceptable to the customers. Even if a store on the computer memory was used for this purpose, it would have to be reviewed and updated regularly.

The flow chart shows these alternatives in a logical arrangement suitable for application to an automatic order vetting procedure.

Summary and Conclusion

A simple means of classifying small orders has been suggested. However, the value of an order has been shown not to be a good indicator of whether it is an economic proposition. A method for evaluating the worth of each order has been proposed which is only suitable for computer operation because of the large quantity of information and calculation required.

The alternatives for dealing with small orders have been structured for application to a computerised order entry system, which, in my opinion, is the only reasonable alternative to the current "accept it" approach. While it has not been possible to evaluate the costs and benefits of such a system, I believe it would require more time and resources to implement and operate than could ever be justified by its benefits.



<u>Framework for Vetting Small Orders</u>

APPENDIX 2

18TH NOVEMBER 1976

I. H. D. - DUNLOP PROJECT

VISIT TO DUNLOP A/S, DENMARK, 10th - 12th. NOVEMBER 1976

1) INTRODUCTION

The purpose of the visit was to gain a first hand appreciation of the administrative system operating, and to determine whether the proposals I have put forward for the project are realistic and feasible. I also wanted to find out what lead times were being experienced for supply ex. U.K.

2) MARKETING

There are no car manufacturers in Denmark, and the import duty of 134% means that all vehicles are very expensive. As a result there is a large proportion of old cars on the roads and consequently there is a very wide range of products which have small and sporadic demand. Relative to wages and the cost of cars, tyres are not as much of an expense as in the U.K., and the market is very competitive in the popular sizes.

Dunlop's Customers are divided into four main types:-

TYPE	NUMBER	% OF T/O
GARAGES AND MECHANICS	4000	40
TYRE SPECIALISTS	250	20
CAR DEALERS	1000	20
PETROL STATIONS	2000	18
MISCELLANEOUS		2

A very substantial part of the business consists of garages and mechanics, who individually may not have more than two or three staff, and service all types of vehicles. So each has a very small turnover but they form a substantial share of the market.

contd.......

Tyre Specialists are the largest customers, and some hold consignment stocks. Many of them used to be in the retreading business which is now left to factories. They retain their thorough knowledge of tyres and the market. Some of them act as wholesalers and have a turnover of 20,000 + D.Kr. (Approx. £1 = 10 D.Kr.)

Customers value fast service and tend to expect a full range of products to be in stock. Back ordering is catered for by special forms but customers will usually only place back orders when the size is not available elsewhere. While I was there, I was shown a list of enquiries which had not been satisfied. It was compiled over a period of four months at the smallest Depot. The total value of these lost sales amounted to approximately 300,000 D.Kr., which represents more than 25% of its current turnover. It also emphasizes one of the dangers of forecasting from sales data as opposed to "demand".

3) DISTRIBUTION

Dunlop own three depots in Denmark, at Copenhagen, Aarhus and Odense. There are three more at Aalborg, Holstebro and Haderslev which are privately owned, receiving commission for what they supply.

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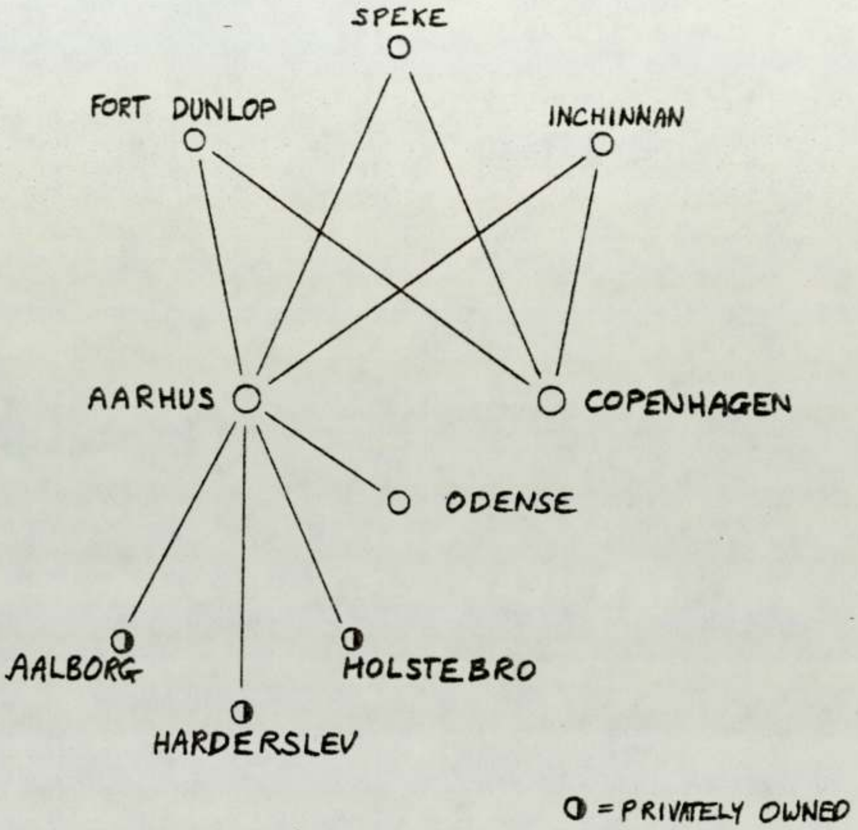
The stores at Copenhagen and Aarhus are supplied directly from the factories (mainly U.K.). The other four depots are supplied from Aarhus because there are road links.



There are seven salesmen covering Dunlop's marketing in Denmark. They visit major customers every month and take orders. Copies of all orders are sent to the office in Copenhagen for vetting and to be recorded on the Computer there. The computer holds all official records of transactions in Denmark.

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4) STOCK CONTROL POLICY

The method of stock control adopted by Dunlop Denmark is basically a Reorder Cycle Policy with monthly reviews, and a maximum stock level of 12 weeks. Stock is reviewed by computer report which lists current Stock, Quantity on Order, and a Suggested Reorder Quantity, for each item in the range. (Their range is much smaller then the U.K. range).

The crude Reorder Quantity is calculated as follows:-

$$\left\{(K \times (\text{12 MONTHS ROLLING SALES})\right\} - \left\{(\text{STOCK}) + (\text{QUANTITY ON ORDER})\right\}$$

The factor K is set for each Major Product Group ** by the Manager, Mr. R. Bryant, and is based on:-

1) the seasonalities revealed by the total monthly sales for each MPG, for the past 12 months.
2) the assumption that the lead time is 12 weeks.

So the crude Reorder Quantity allows for seasonalities which appeared in the past year for the MPG, and the trend exhibited in the past year for each item. Therefore, there is no attempt to include the seasonal characteristics of the individual item.

The figures from the computer are reviewed by Mr. Bryant and the Order Clerk, Mr. Beckman. This takes two days every month. The point of the review is to complement the crude figures with some of the characteristics of the item itself or, perhaps, some market intelligence. It is claimed that having a simple computer estimate gives a sound basis for "intelligent guesses".

** There is a different coding system in operation but the MPG is a similar classification to that used in UK.

An interesting refinement of the system is the distinction made, for a few items, between normal demand and special demand arising out of the ordering patterns of some major customers.

The Sales Manager, S.A. Carlsen, made the point that it is essential to have goods in stock in time for the major seasons exhibited by some types of product; in particular he mentioned truck and tractor.

SUPPLEMENTARY MONITORING

The computer report of Stock Status can be produced at any time, as a check on stock and to produce special orders. But apart from this, each customer order is vetted by the staff on arrival, so there is an informal check on sizes which are popular and on unusually high demand.

The four depots supplied from Aarhus review their stock cards and place orders every week, thus staff taking orders at the depots are continuously aware of current stocks. So there is a good warning system in case of stock running low. In general, I formed the impression that the smooth running of the company depended on senior staff having a very thorough awareness of the current market.

5 STATISTICS

I had intended to collect as much as possible in the way of statistics during the visit, which are essential for analysis of how effective the current stock control policy is.

/contd........

Some of the information I was interested in was just not available, and some could not be produced while I was there. I have arranged with Mr. R. Withey, Administration Manager, to send me a computer print out ofthe monthly sales by item. This will cover the previous 12 months and future months, and will be very useful for future work.

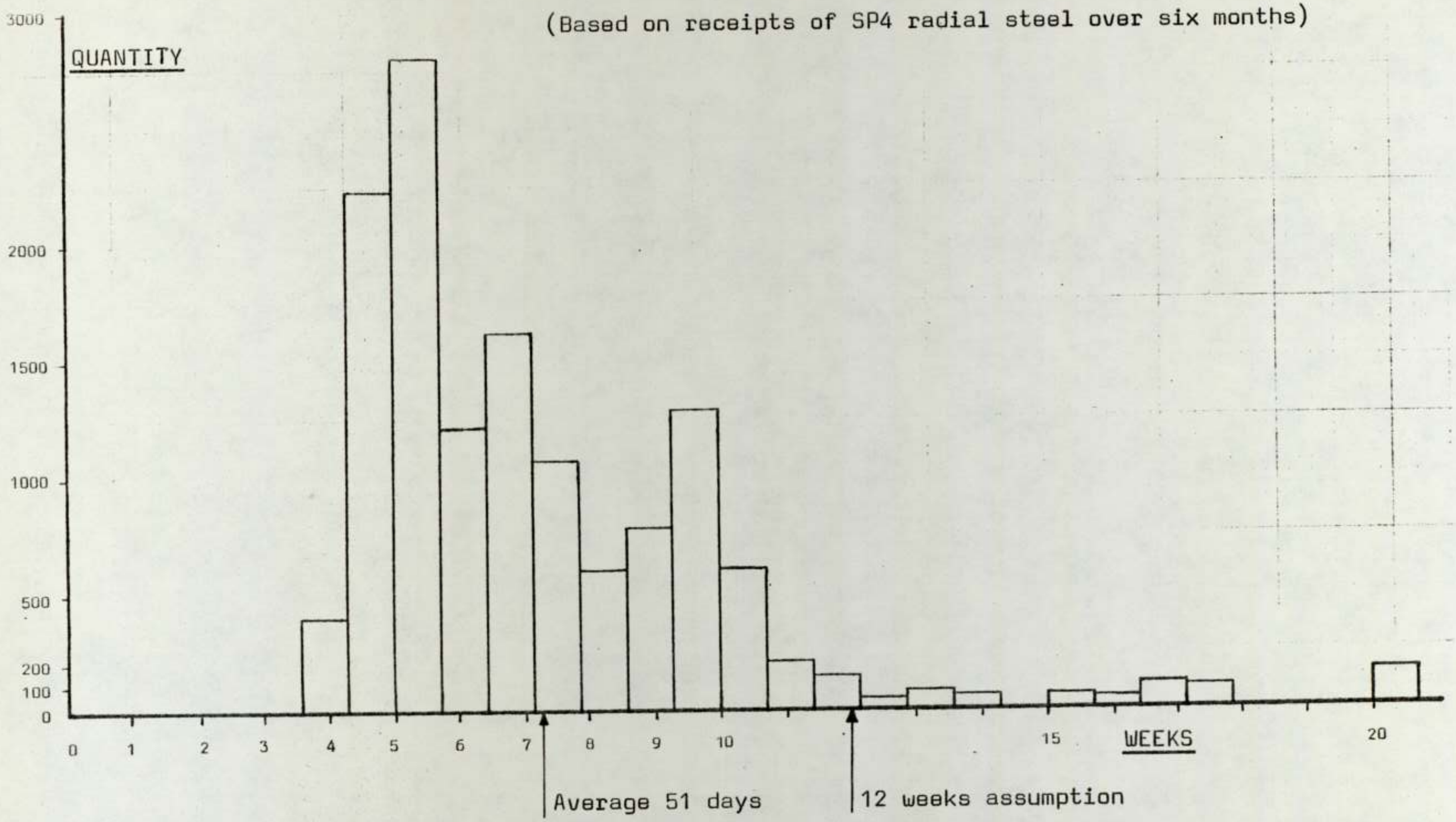
I have obtained lead times data for SP4 steel radials covering the past 6 months. This is summarised in the graph attached. The average lead time is approximately 51 days, and 4.3% of items arrived after the 12 weeks allowed for by the stock control policy

6) SUMMARY.

I am satisfied that the proposals I have put forward are reasonable, although I find it difficult to estimate how long the programme will take to complete. It was pleasing to get reliable data about lead times, even though it is limited to SP4. However, I am concerned about the apparent unreliability of supply and misleading estimates of availability received by staff in Denmark. This is an area which will be worth investigating.

I would like to record my thanks for all the assistance I received from the staff, and in particular Richard Withey.

N.T. CROUCH



(Based on receipts of SP4 radial steel over six months)

Distribution of Supply Lead Times Experienced by Dunlop Denmark ex U.K.T.D.

APPENDIX 3

An extract from a Dunlop Group Management Services report "Factory Programming Systems - Possible Lines of Development", January 1972.

3. PROBLEMS OF PERFORMANCE EVALUATION

If alternative approaches to the problem outlined in chapter 2 are to be considered, it seems essential to determine criteria by which they can be evaluated. The following criteria are at least implicitly used in current work

- stock level - customer service	"inventory performance"
- acceptability of schedule to production	"production performance"

The division indicated above roughly reflects the (conflicting) objectives of the two organisations interfacing in factory programming.

The Marketing/distribution organisation is responsible for inventory and customer service and therefore has an interest in optimising these two. The mechanics and logic of such stock control systems and the problems of evaluation are generally understood and will not be further discussed here. They concern the problems of forecastibility of demand, measurement of customer service etc.

It is when one turns to the "production performance" of a scheduling system that problems arise. This is because the definition given above is not in fact a criterion but covers a collection of criteria. If a schedule does not breach a series of known and agreed set of constraints it should by definition be acceptable. In practice however there seems to be a real difficulty in defining the constraints with adequate precision to be able to evaluate them in money terms. There is the further problem that there appear to be levels of importance of constraints. That is, in certain circumstances constraints cease to exist and are replaced by different ones. Such a situation might be stated as "Tyre A and B will not be cured in the same press at the same time because of different cure times". Subsequently, however, given adequate pressure of demand, it appears that A and B <u>can</u> be cured together provided the longer cure time is given. This leads of course to overcured (but acceptable) tyres in one of the sizes and a loss of capacity due to longer average cure times. In this instance we see an interaction between a quality constraint and a capacity constraint. Because of the inability to evaluate the constraints in cost terms it is impossible to attach any measure of validity to them. It is also possible that many of these constraints have only a short life and can be adduced as arguments for or against the acceptability of a schedule in a particular set of circumstances.

We thus have a situation when a factory programme is being simultaneously evaluated against reasonably well understood marketing criteria and a large variable set of production criteria which can change through time. As a result, in such a situation the evaluation becomes a comparitively subjective process.

It is arguable that one cause of problems in the development of Factory Programming Systems has been the reluctance or inability to set down in advance of development the exact constraints which must be respected and thus the criteria by which the resultant system will be evaluated. It is suggested that until this can be done, there will be difficulty in installing computer systems for Factory Programming which satisfy the planners.

4. EXAMINATION OF CURRENT WORK ON FACTORY PROGRAMMING

This chapter will not describe work being done in each country of the Dunlop Group as that is described in papers being circulated to delegates. It will attempt in the light of the scope objectives and problems raised above to appraise the line of development pursued in European Tyre Group.

Figure 2 shows in diagrammatic form the approach hitherto adopted in computerised Factory Programming Systems in European Tyre Group.

There is in UK and France for certain product groups a computer module drawing on files of stocks, issues, outstanding orders and plant and equipment availability and capacities. The term stock "issues" has been chosen because it covers any data on "demand" whether this be base stores issues or customer shipments. The choice between these can, it is suggested, be regarded as an independent question to be answered in the light of data availability and theoretical studies of the inventory performance of the model using the different data.

These data are then processed by a computer system in which are embedded some of the manufacturing constraints to produce a moulding (or making and moulding) program.

This program is then subject to a manual "review" and modified if necessary i.e. where, in the judgement of the planners, there are factors of demand or production which are not modelled by the system or where these are known data inaccuracies. It is noteworthy that this process in fact draws on the same data as the computer system in order to correlate it with other information at the planner's disposal.

The output of this phase is then passed as making and moulding schedules to factory planners who perform component breakdowns and check the component requirements against production capacity. In Dunlop Germany this breakdown and check is the computer system known as "Capacity Balance". There is at this stage a possible feedback to modify schedules if they breach capacity restraints on components.

The approach outlined above is, it is suggested a valid description of current and planned work in UKTG, France and Germany. The sequence of implementation is notably different however in that Germany have chosen to tackle first the problem of scheduling component production. In the other two countries the reverse has been done.

"COMPUTERISED" APPROACH

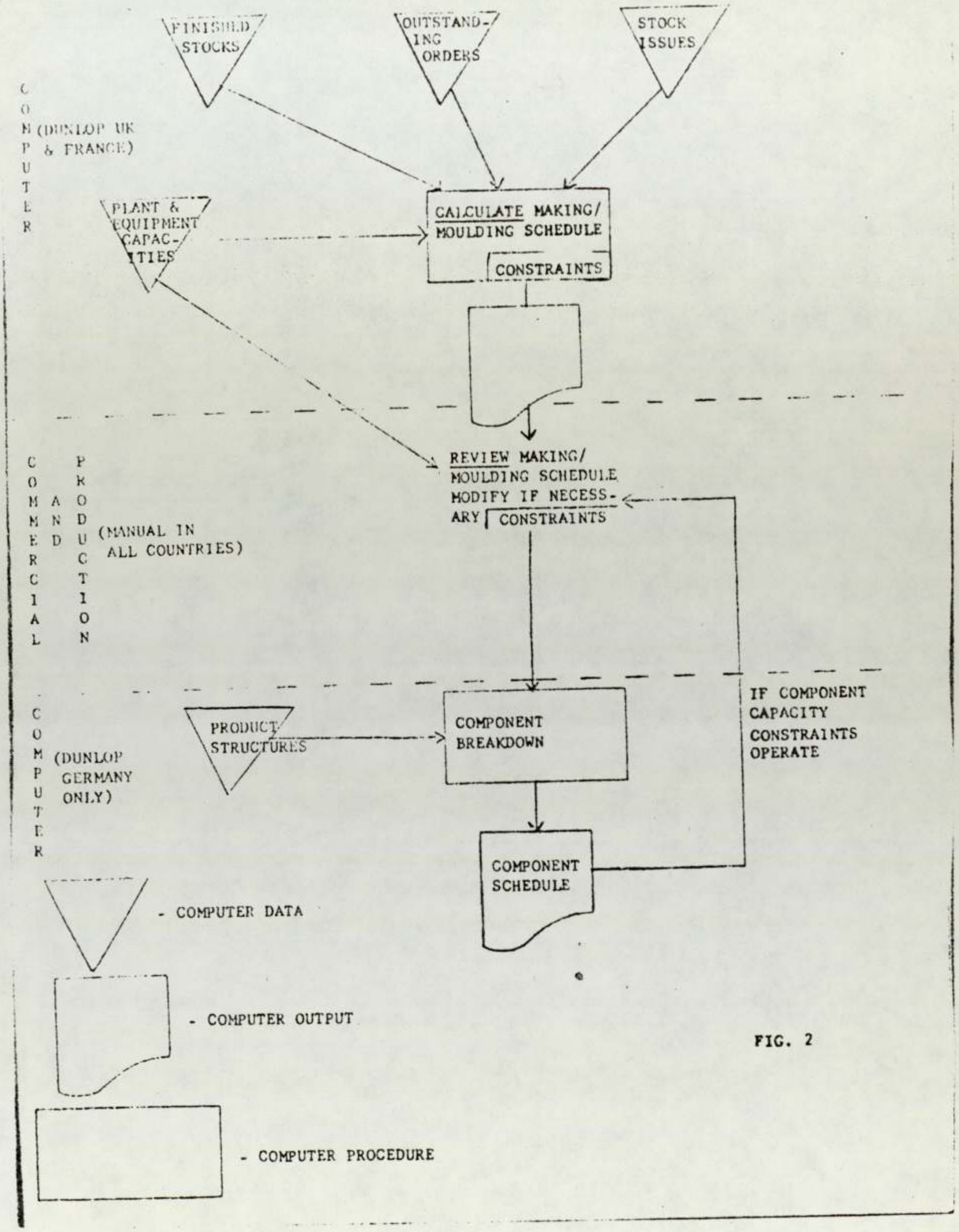


FIG. 2

One factor in this situation may be that Dunlop Germany had available at an early stage the necessary Process Issue and Routing files (BOMP) which enabled the component problems to be tackled.

It is interesting also to remark that there is a significant organisational difference between Germany and the other two countries. In Germany the planning function is totally the responsibility of one organisation with the split not between production and commercial departments but between a section responsible for the longer term aspects of capacity and planning (1 month and longer) and a section which produces weekly schedules for making, moulding and components and is also responsible for detailed short term control of moulds and materials to ensure that production management can meet schedule.

In UK and France on the other hand, the planning function is divided between a central function (Planning in the UK, Distribution in France) and a factory planning function responsible to factory management.

The computer system used in UK and France to calculate moulding and making schedules has encountered certain problems of implementation at organisational and technical levels but it is important to bear in mind its very real virtues. Principal among these is that, where applied, it uses the computer to provide a demand forecast and proposed schedules for all articles in the range being scheduled weekly for 4-5 weeks ahead. This is a task which would be impossible to do manually in the available time. Such a plan even if imperfect offers management an indication of the future patterns of production which can be extremely useful for instance in arranging in good time the production of samples for items which are made only rarely. It also allows a statistical check on the planners' estimates of future demand patterns and thus helps improve performance in this area.

The sub-system being implemented in Germany, on the other hand, though it represents a heavy calculational load, is in fact the easier to implement since it is of relatively straightforward computational nature if once the investment has been made in a Bill of Material Processor System.

In summary then it could be said that the "UK Approach" and the "German Approach" can in fact be seen as complementary parts of the same system. Of the two the UK work has tackled the part which is logically the more complex and for which there exist less well defined performance criteria.

5. FUTURE LINES OF DEVELOPMENT

In trying to formulate a policy for future development in this area, it is suggested that any strategy should lead to systems which can adequately reflect:

i) the organisational context of each division
ii) the role of the planner in the planning process
iii) the ability (or lack of ability) to construct comprehensive decision models

5.1 Organisation

A system however well executed will not function satisfactorily in an organisational environment to which it is ill-adapted. In such cases system objectives are likely to be incompatible with users' objectives, or the system will depend for the supply of information on people who receive no benefit from it. In either case, it will be difficult or impossible to assure system operation.

It is not the purpose of this document to evaluate in detail organisation structures in particular divisions. It is, however, reasonable to ask whether organisational problems are at all responsible for past difficulties in this area and to suggest that so far as possible future developments should lead to information systems and decision making organisation which are compatible.

5.2 The role of the Planner

Two of the most important aspects of the computer systems described earlier in this report were the lack of criteria for evaluation of the schedule and the reviewing role of the planner. If present work on radial tyre production programming models is indicative, there is a risk of developing systems of ever increasing complexity as the attempt is made to fully incorporate each successive constraint. One might thus have a model which is in a continuous stage of change and which needs to be redeveloped almost from scratch for any new product group or production facility to which it is applied. It might also tend to require a large and continuous maintenance effort and lead to a short overall life before systems require overhaul.

In such a situation, the planner is critical in his role of reviewer of schedules produced by the computer system. This in fact means that the planner is having to accept responsibility for maintenance of a computer system in addition to his operational role. At a psychological level, too, it is possible that this could lead to an adverse reaction from planners who feel that the computer is in this way adding to rather than reducing their workload.

In looking at this situation it is interesting to introduce a concept cited in the Diebold Research Program Document E75 on Production Scheduling. This is the notion of "programmed" and "non-programmed" decision making (P5). This says:

> "Decisions are programmed to the extent that they are repetitive and routine, to the extent that a definite procedure has been worked out for handling them so that they don't have to be treated de novo each time they occur...Decisions are nonprogrammed to the extent that they are novel, unstructured, and consequential. There is no cut-and-dried method for handling the problem because it hasn't arisen before, or because its precise nature and structure are elusive or complex, or because it is so important that it deserves custom-tailored treatment."

This notion is then pursued further implying that there is trade-off between the benefits in reduced effort and improved calculation from automation of decision making and the development and maintenance costs on the other hand. The relevant sections of the Diebold text are attached as Appendix A of this paper.

5.3 A model for future systems development

It is proposed that the above considerations lead to the development of a system which has as its central focus not a computer which is attempting the "unprogrammable" decision task of producing a factory program; there should instead be a system centred on the planner who can tackle the unprogrammable elements of the task but who is surrounded by a series of information systems which feed him information on which to plan. Such a system might be represented as in figure 3.

"PROPOSED" APPROACH

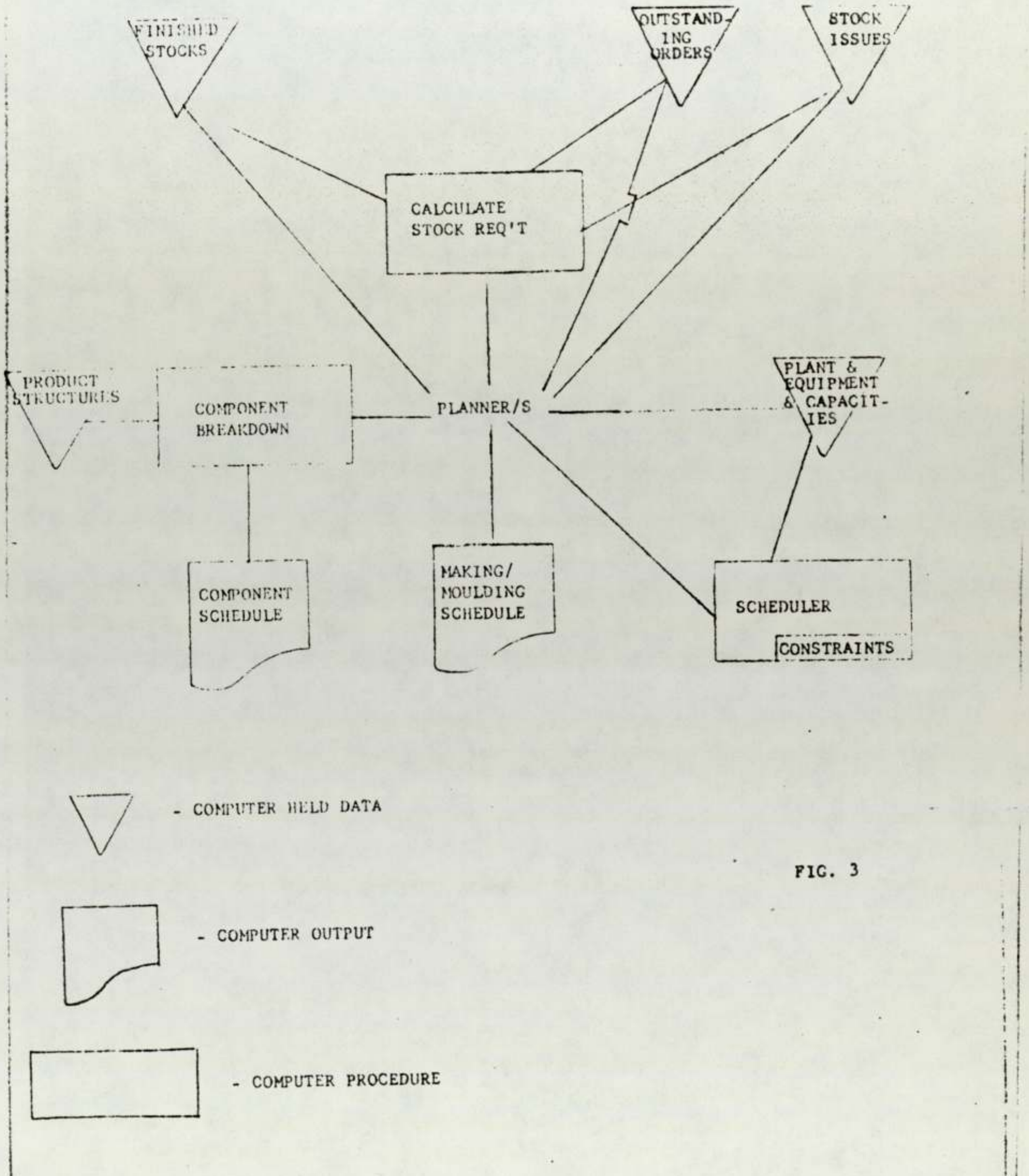


FIG. 3

We see here a system in which the planner has at his disposal (probably by computer terminal) stock positions of finished goods, outstanding orders and demand or issue rates for each item. Further, there is a computer procedure to process these three pieces of information to give a requirement by item to maintain stocks and service. Such a list of requirements would in effect correspond to the priority list of the UK Tyre Group Factory Programming System and indeed the form of presentation of priorities being adopted in the UK might be a desirable way to handle this. It should be noted, however, that in addition to this list of requirements, the planner is given the ability to access the data base(s) from which it is calculated, thus allowing him to reconsider any aspect of the list in the light of the facts at his disposal.

The planner is then provided with a "scheduler" module which is a system which accesses a data base of available plant and equipment and their capabilities and which incorporates some production constraints. This module would be used by the planner as a "scratch-pad" on which to try out his schedule decisions for compatibility with the items already scheduled in respect of the firm constraints.

This "scheduler" module would probably contain initially a large part of the logic of the scheduling part of the UK Tyre Group model though it might not necessarily do so. The exact content of this module would have to be decided by installation and by product group. It is however vital that in its execution it should be as modular as possible thus allowing it to be extended as or when the decision is taken that a particular constraint can be regarded as programmable. In the more distant future, too, it might be possible to include optimising routines to improve still further such things as curing schedules.

The final component of the proposed approach would be a sub-system invoked by the planner which would take a given schedule and perform component breakdowns both to ascertain component requirements and indicate component capacity bottlenecks. This would in effect be a capacity balance system as performed in Dunlop Germany.

5.4 The proposed approach in use

5.4.1 Organisation

With a system as proposed which makes explicit the different information flows and which omits "unprogrammable" decision making, it should be possible to work either with unified planning as in Dunlop Germany or with the type of organisation operating in the UK and France. In the latter type of organisation, the approach proposed could provide to both factory and central planners the same basic planning tools but would be robust enough to support their detailed negotiation of the schedule. In the former organisation this system would provide the kind of data flows and decision processes currently available but by use of computers a shorter planning cycle should be possible.

5.4.2 Access to the System

A system as proposed would, it is suggested, require real-time access almost certainly by visual display units to the data bases specified. Further, the "scheduler" module would desirably be developed as an interactive system where the user could "converse" with the computer to evaluate the implications of different scheduling decisions.

This it is admitted, calls for more advanced computer technology in systems, programming and hardware than has so far been brought to bear on the problem. However, sophisticated systems have already been proposed in installation development plans for other areas such as direct order entry or depot order processing.

5.4.3 How the Planner would use the system

This section aims to indicate in practical terms the work cycle of a production planner using a system of the type outlined above. Of necessity it cannot go into detail and there would inevitably be variations on the basic routine as individual planners adapt to the method of working.

Weekly the planner would use his computer terminal to set in motion the routine to perform demand forecasts and give him a statement of requirements (or priorities) for the period to be scheduled. At that point he might use the scheduler to produce a first draft of a program for his consideration. If he did this he would effectively be doing the same job as the current UK Tyre Group Factory Programming System. He would then review the proposed schedules calling by terminal on the background information in computer files and making additions or deletions of items which he wished to change.

With each such change he could use the scheduler to check out automatically the effect on the rest of the group being scheduled. In this way he would be using the computer to perform the routine calculation of schedule making but would retain the flexibility to change schedule if he wished.

To make the point that the planner's flexibility is maintained it should be noted that the system would work equally well if instead of immediately invoking the scheduler as proposed above he might chose to start producing a schedule by successive modifications of the existing week's schedule, taking account of the basic information at his disposition.

APPENDIX 4

TWO DAY CONFERENCE ON "DISTRIBUTION IN EUROPE"

9TH @ 10TH MARCH 1977

ORGANISED BY : The Centre for Physical Distribution Management and The Operational Research Society.

CONFERENCE CHAIRMAN : R.C. HORSLEY.

SPEAKERS : PROFESSOR R.G. BROWN
SIMON LISTER
DAVID BLACKLOCK

1. INTRODUCTION

The first two sessions of the conference were taken by Professor Brown, in which he discussed the "Push" and "Pull" methods of replenishment, the need for central visibility of stock status, allocation of stock and the Master Warehouse concept.

The final session was taken by Simon Lister and David Blacklock who presented three case studies illustrating the practical application of Professor Brown's approach to distribution in Europe.

More than one hundred delegates attended the conference. These included senior managers and consultants from a wide range of major and international companies.

2. THE "PUSH AND PULL" SYSTEMS

The traditional view of the replenishment system focuses on the warehouse, which holds stock to satisfy the requirements of its customers. The measure of service is often taken to be the percentage of orders filled from stock. Orders are placed on the supplier on the basis of sales, stock on hand and the supply leadtime, using a formula to calculate the re-order quantity or an economic order quantity. The warehouse may place its orders in competition with other warehouses, even if they belong to the same parent company.

So each warehouse is an entrepreneurial unit which controls its own stocks. This is the basis of the classical "Pull" system.

By contrast, the "Push" system is designed for use in the context of a large company which owns two or more tiers of a distribution chain. It gets its name from one of its major characteristics, which is to decide centrally what and when to replenish, on the basis of the total availability and the requirements of all customers. It is necessary, therefore, to centralise information about every product in every location within the system.

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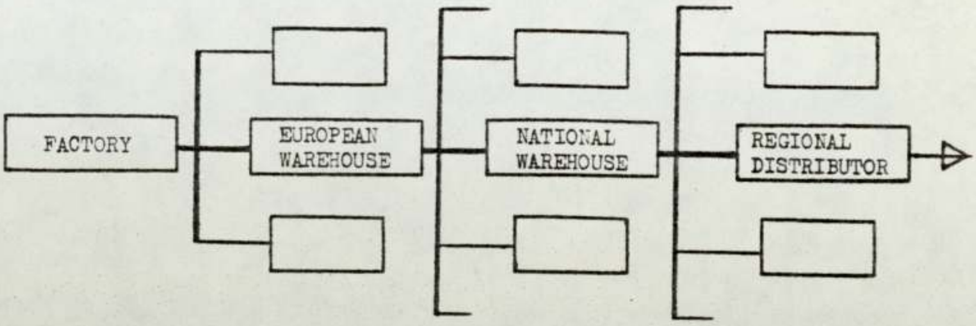
A TYPICAL COMPANY'S DISTRIBUTION CHAIN



3. THE PUSH SYSTEM IN OUTLINE

3.1 MOTIVATION

Professor Brown's intention was to explain how and why the push system works in general terms and to set us thinking about how it can be applied in our own organisations. He has introduced his ideas into many large organisations, not least of which was the Federal Supply Service. The savings in stock holding resulting from changing a pretty good pull system to a pretty good push system were typically 30% and he added that comparing it to a typical pull system was like shooting ducks in a barrel!

The description of the push system was based on a number of assumptions, which put the discussion into a context.

1) The number and location of warehouses is not at issue, because either there is no intention of reviewing the matter, or otherwise there are established techniques for such a study.

2) The best routes and modes of transport have been found from working experience.

3) Satisfactory methods exist for forecasting short term requirements and safety stocks, when the lead time is predictable.

However, despite these assumptions, he claimed that the push system is robust; i.e. it works even when all the assumptions are wrong! He also pointed out that; "things going well is an event of low probability."

3.2 FOUNDATION

Consider the question: "What is our distribution system trying to achieve?" A reasonable answer would be: "To achieve a level of customer service of 90% (say), while keeping the inventory of the whole system to a minimum."

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3.2 FOUNDATION (contd)

In 1957, K. Simpson examined the question of how this should be achieved in a multi - echelon system of warehouses, using a Linear Programming model. The result of this was that all the intermediate warehouses should give and receive perfect service, while all the risk of stockouts (10%) should be taken at the last points of supply.

Of course, this result needs to be translated into practical terms i.e. "If a company sets a Target customer service level for its distribution system as a whole, it can achieve that level with a minimum inventory provided any intermediate warehouse is replenished in a short and predictable lead time when it is in a stockout position."

Notice that this is a conditional statement. Nothing has been said about how this can be achieved, but it has emphasised the vital importance of dependable supply between suppliers. It is also worth saying that major customers can be included in this system if they are willing to co-operate.

3.3 CUSTOMER SERVICE LEVEL

Customer service level can be measured in a number of ways; e.g.

1) Percentage of complete order lines filled from stock.

2) Percentage value of orders filled from stock.

3) Percentage probability of not running out of stock.

4) Average lead time until orders are completed.

It is desirable to choose one which relates to the customer's view of the supplier's service, and to use it consistently. The first one satisfies this condition, and it is also appropriate to use this in the push system. So, the more order lines filled from stock, the better the service.

3.4 STOCKING STRATEGY

3.4.1 PRODUCT RANGE STRATIFICATION

The manager of the warehouse in a classical pull system is interested in which products out of the whole range he ought to keep in stock. There is a whole grey area of low turnover items which are a nuisance, but collectively form a major part of his business.

In the push system a different approach is taken. Instead of considering each warehouse individually, look at the whole distribution system and ask: "here is a product - where should it be stocked?"

Now the objective of the distribution system is to maintain the percentage of order lines filled from stock, so it is a good idea to look at which products are ordered the most. The chances are that, in many distribution systems, 5 - 10% of items account for 50% of all customer orders. More generally, they can be split-up as follows.

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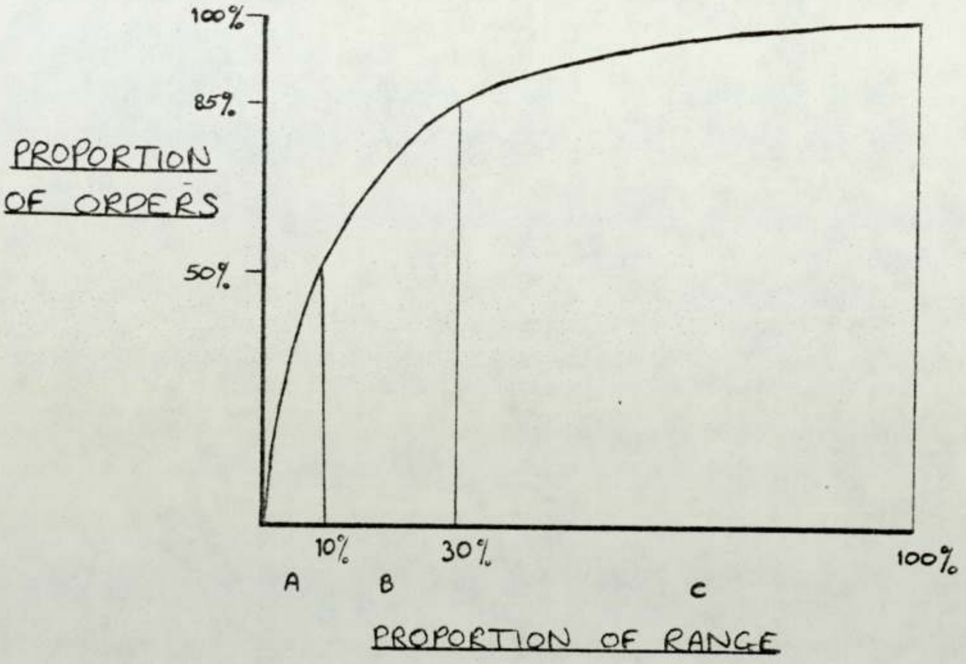

This is just like an ordinary ABC analysis with "Value" replaced by "Order Lines". It emphasises the importance of the A and B items from the point of view of the customer, and it would be sensible to keep stock of A items near to the market, B items at regional level, and C items at National level. When a B or C item is required, it can come on the next truck.

This is only one way, albeit important, to divide up the product range. It is not difficult to think up other good reasons for keeping a stock close to the market, e.g.

1) Products with a sales campaign.

2) High profit products.

3) Items critical to a piece of machinery.

4) Distributor is sole source of supply.

Suppose we have 5 such criteria. There are then 32 possible categories to which any product could belong; for example, the category of high profit items undergoing a sales campaign, but many of these categories will not actually contain any products at all, and the chances are that there will be 10 to 15 categories which make a lot of sense from the marketing point of view. This is the process of <u>range stratification</u> and these groups are a sensible basis for a stocking strategy covering all warehouses.

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3.4.2 THE NEED FOR STOCKS

There are four main reasons for carrying an inventory.

1) Stabilisation Stock is the buffer between production and the market. It arises because economic production runs do not coincide with the demand, due to seasonalities etc.

2) Pipeline Stock is that which is in transit between warehouses. Its magnitude depends on the rate of sales and the transit time.

3) Safety Stock minimises the chances of running out of stock during the supply leadtime. The amount required is dependent on the predictability of demand, the leadtime and the predictability of the leadtime. When these factors combine, and this effect is magnified by the number of warehouses and the number of products in a system, one can begin to appreciate the importance of controlling the leadtime.

4) Working Stock is the quantity in excess of the order level, which is related to the re-order quantity. The push system does not use this approach. Instead the concern is with load planning.

The first two reasons are not significantly affected by the push system, although with centralised information it may be possible to use available warehouse space more effeciently to cope with stabilisation stock.

3.4.3 THE MASTER WAREHOUSE CONCEPT

Safety stocks are considered from the point of view of the whole distribution system in the push system. Each product in the range is assigned one or more Master Warehouse locations. The Master Warehouse is simply a record of the quantity of safety stock which is available to all the Satellite Warehouses. Physically, the Master stock can be located in any warehouse, but often it will be central, for convenience of movement. There is no need for the Master stocks of different products to be at the same location.

The purpose of the Master Warehouse is to:-

1) Provide a last resort, if all the working stocks have been used.

2) Provide the essential buffer between the market and production.

3.5 INFORMATION

The fundamental advantage of the push system is centralised information and its strategic use. Along with short term forecasting, this enables the use of stock to replenish with minimal and predictable leadtimes.

Current sales data from all markets can be used to update production requirements, without the distortions inherent in the intermediate re-ordering procedure. (Effects of positive feedback). This ensures that production schedules are protected at the most stable level.

The push system has been made practical for large companies mainly because the cost of telecommunications and data processing has reduced so much in the last ten years.

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4. CASE STUDIES

The case studies provided illustrations of how some of these ideas were employed successfully in European distribution systems. I was pleased to see that the approaches I have made to my project were very similar to those of professional consultants with a more sophisticated technical knowledge.

A number of general conclusions were drawn from their studies.

1) European distribution must be managed centrally as a single entity.

2) Central information is vital.

3) A central warehouse is usually desirable.

4) Centralised stock planning is vital.

5) Transport should be regular and reliable, rather than cheap.

6) National frontiers are a significant barrier to trans-shipment between countries.

7) Systems should be as simple as possible.

8) The U.K. could be a natural base for a central information system.

5. CONCLUSIONS

Professor Brown offered some important insights into possible ways of structuring a distribution system, and put them over in a persuasive and enlightening way. The proceedings lent weight to the proposals I have put forward for my project and, at the same time, put them in a broader context. Therefore, it will be necessary to review the proposals to include a wider discussion of possible developments in Dunlop's distribution system.

Much more detail was discussed than I have presented here, but it will be possible to examine his ideas more thoroughly in his book:

"Materials Management Systems".

by Professor Robert G. Brown.

Publishers : Wiley Interscience, July 1977.

N.T. CROUCH

APPENDIX 5

A summary and an extract from a description of I.C.I.'s European Distribution System at an international seminar for the chemical and rubber industries, La Hulpe, June 1977.

I C I's European Distribution System

Summary

In 1973, ICI's Europe Division investigated the administrative efficiency of their organisation. This established the need for improved systems, so two major data-processing projects were started; the European Accounting System (E.A.S.) and the European Distribution System (E.D.S.)

The team studied the feasibility of a centrally - supported real-time order-processing and invoicing system, and concluded that such a system would achieve unity and coherence. It would improve the speed of communication and the consistency of information within the organisation. They proposed that system be limited in scope to Order Processing, Stock Recording, and Invoicing.

The alternative to this centralised system was the local development of administrative systems, because the existing ones would soon become overloaded. It was termed the "Stand Alone" alternative. Not only would piecemeal development have been more costly in total than the E.D.S., but it would also intensify the interface problems of multiple data transfers, complex communication, and incompatibility. This alternative would make it difficult to view the "European picture."

The other benefits from the E.D.S. were:-

1) Customer service would be a better competitive weapon. Order processing based on a consistent data base, would be faster, with fewer errors.

2) The cost of working capital due to stocks would be controlled by accurate, up-to-date, centralised information.

3) Savings would be made in staff and telecommunications.

Comments

I think the E.D.S. described is admirable for a number of reasons:-

1) The foresight to study a problem of such scale before its effects had become serious.

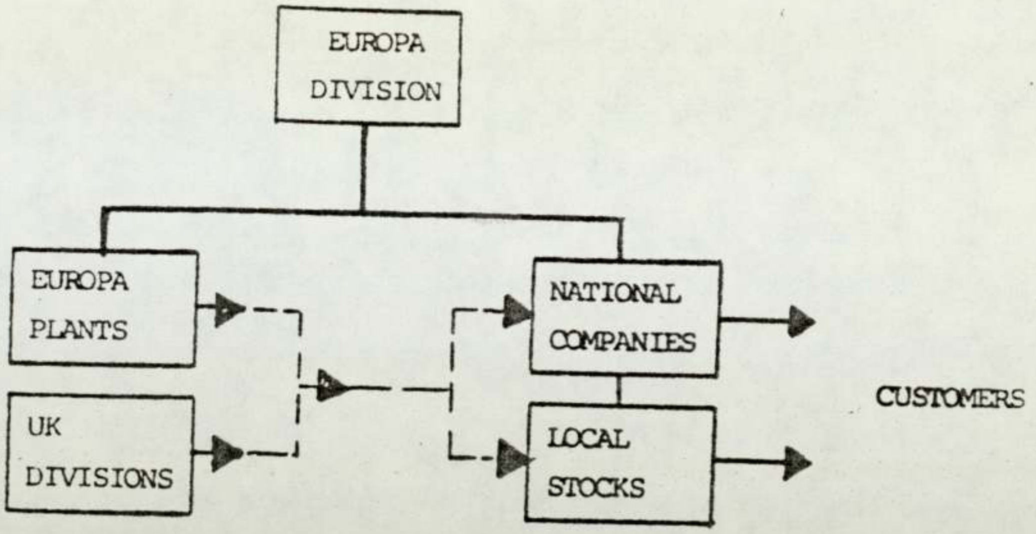
2) The speed of acceptance and implementation of the far reaching proposals.

3) The recognition of the importance of a centralised information system.

4) The recognition of the importance of an adaptable system.

Although it is recognised that centralised information can improve planning and stock levels, it is not apparent how this information would be used. Given a data-base like this, it is possible to systematize the strategic use of stock, and make product demand forecasting routine. Without such data, this is certainly not possible.

N.T. CROUCH



3. WHY EDS ?

The origins of the EDS project go back to 1973 when Europa Division set in train a number of investigations into the administrative efficiency of the organisation.

As a result, several needs were identified :-

(a) Ability to grow
ICI's business was expanding. Moreover, the pattern of the business was changing - (i.e. new products, new customers) - and it was seen as imperative that the sales-supporting systems should be capable of absorbing the consequent increases in throughput. The implications for order processing and accounting were seen as critical.

(b) Better customer service

It was felt that we needed to improve our service to the customer - not as an end in itself but as a competitive weapon. This called better communication and greater responsiveness throughout the organisation.

(c) Better planning data

In order to control distribution costs - (in particular, the cost of working capital tied up in stocks) - we needed data which was accurate and up-to-date.

(d) "One business" concept

Separate systems within separate parts of the organisation were creating complex interface problems and making it difficult - (or virtually impossible) - to view the business in a single European context.

(e) Reduction in cost

Order processing was a labour-intensive activity. Improved systems were seen as the only means of redressing the effects of progressive wage inflation.

In the situation which then existed we were reliant on a number of separate "stand alone" systems. That situation, if left unchanged, would not fulfil the needs set out above. It was characterized by multiple transfers of the same data, complex communication, and "non-transparency" - i.e. incompatibility between systems which made it difficult to look at the "European" picture.

In consequence, two major data-processing projects were undertaken.

The first was the European Accounting System (EAS). This was authorized early in 1974. Its objective was to provide a computerized accounting system which would generate (a) the legally and fiscally required accounts of the National Companies and (b) a uniform set of management accounts for Europa Division.

The second was the European Distribution System (EDS).

Initially, in 1973, a team was set up to study the feasibility of a centrally-supported real-time order-processing and invoicing system to serve the requirements of the National Companies and Europa Plants in the EEC "Six" plus Switzerland. The feasibility study team were drawn from a number of different National Companies. It was considered that as many of the National Companies as possible should contribute to the study, and should thereby participate in its decisions.

The team concluded that such a system would achieve unity and coherence in order-processing (because it would be a single system) and would improve the speed of communication and the consistency of data within the organisation. It would also achieve some direct cost savings - in particular a saving of about 30-40 staff. Moreover, while effecting reductions in staff number, it was thought that the system, (by automating the more tedious and mechanical aspects of order processing) would enrich the content of the human work requirement.

Accordingly, the system would respond to Europa Division's needs in the following way :-

ABILITY TO GROW	Adaptable & expandable system
BETTER CUSTOMER SERVICE	"One set of data" Fewer errors Faster processing
BETTER PLANNING DATA	Accurate up-to-date information on a cross-border basis
"ONE BUSINESS" CONCEPT	Simplified interface problem
REDUCTION IN COSTS	Staff savings Working capital Telephone/telex Improved physical distribution management

The feasibility study team recognized too that the alternative to EDS was not the "status quo". Some National Companies were already feeling the need to improve their existing order processing systems. In the absence of EDS, they would have felt obliged to develop their own systems locally. This would have resulted in the piecemeal development of separate systems throughout the Europa organisation, which would (in total) prove more costly than EDS, and which would intensify the problem of interfaces between systems - not only between the systems in Europa, but also between those systems and the UK-based systems of the other ICI Divisions.

APPENDIX 6

FORTRAN PROGRAMS FOR THE AUTOMATIC FORECASTING PROCEDURE, AND ITS APPLICATION TO SYNTHETIC DATA.

In the MAIN program, a set of observations is generated to test the general behaviour and robustness of the automatic procedure. Subroutine UPDATE contains the logic for detecting discontinuities and supervision of the system. It requires 13 pieces of information to be stored for each item it is used on, but no other historical data is required. Subroutine PROC updates the parameter values of the linear growth model, while VUP and PUP update variance and intermittency estimates respectively. Finally, GAUSS and RANDU together generate normally distributed random samples.

Figures (a) and (b) show the results of applying the procedure to truncated normal random samples, and figure (c) shows its application to a lognormal sample.

```
         CALL JOB(30)
         DIMENSION Y(3),OBS(100),IQ(100)
         EM=10.
         B=0.
         X=E 1
         V=(1.25*X)**2+40.
         C11=6.*V
         C21=9.*V/5.
         C22=3.*V/5.
         CF=400
         P=2.
         CP=100.
         IX=4734
         AM=0.
         DO 100 J=1,5
         DO 110 K=1,20
         IF (J.GT.1) GOTO 120
         S=10.+3.*K/2.
         CALL GAUSS (IX,S,AM,V)
         OBS(K)=40.+5.*K+V
         GOTO 110
   120    IF (J.GT.2) GOTO 130
         L=20+K
         S=80.
   125   CALL GAUSS (IX,S,AM,V)
         OBS(L)=V
         IF (OBS(L).LT.1.) GOTO 125
         GOTO 110
   130   IF (J.GT.3) GOTO 140
         L=40+K
         S=50.
   135   CALL GAUSS (IX,S,AM,V)
         OBS(L)=V-21.5
         IF(OBS(L).LT.1) GOTO 135
         GOTO 110
   140   IF (J.GT.4) GOTO 150
         L=60+K
         S=0.8333
         CALL GAUSS (IX,S,AM,V)
         OBS(L)=EXP(2.5+V)
   145   GOTO 110
   150    S=0.8333
         L=80+K
         CALL GAUSS (IX,S,AM,V)
         OBS(L)=EXP(3.+V)
   110   CONTINUE
   100   CONTINUE
         DO 160 J=1,2
         DO 170 K=1,50
         L=(J-1)*50+K
         S=20*J
   165   CALL GAUSS(IX,S,AM,V)
         IQ(L)=5*J+V+0.1
         IF (IQ(L).LT.1) GOTO 165
   170   CONTINUE
   160   CONTINUE
         WRITE (6,600)
```

```
600    FORMAT('1',21X,'OBS',11X,'LEV',
           11X,'SLO',10X,'DISP',10X,'LIM',11X,
      &'INTY',12X,'VW',12X,'WD')
        DO 99 J=1,100
        YT=OBS(J)
        QT=IQ(J)
        CALL UPDATE(YT,QT,X,CE,EM,B,C11,C21,C22,
           P,CP,I1,Y,V,W)
        WD=EM/P
        D1=EM+2.45*X
        D2=EM-2.45*X
        WRITE(6,610) J,YT,EM,B,X,D1,P,V,WD
610     FORMAT('0',8X,I2,8(5X,F9.2))
        WRITE(6,620) I1,QT,C11,C22,CE,D2,CP,W
620     FORMAT(' ',8X,I2,7(5X,F9.2))
99      CONTINUE
        STOP
        END
```

```
        SUBROUTINE UPDATE(YT,CT,X,CE,EM,B,C11,
                 C21,C22,P,CP,I1,Y,V,W)
        DIMENSION Y(3)
        N=CT
        VP=100.
        VE=100.
        IF(((1.-1./P)**N).GE.0.01) GOTO 2
        CP=VP
 2      IF((N/P).GE.0.1) GOTO 1
        CP=VP
 1      CALL PUP(CT,P,CP)
         E=YT-EM-B
        CLIM=2.45*X
        IF(ABS(E).GT.CLIM) GOTO 10
        IF(I1.NE.0) GOTO 20
        CALL VUP(E,EM,X,CE,V,W)
        CALL PROC(E,EM,B,C11,C21,C22,V,W)
        IF ((ABS(B)*10.).LE.EM) GOTO 5
        B=B*EM/(ABS(B)*10.)
        CE=2.*CE
 5      GOTO 98
 10     IF(I1.NE.0) GOTO 20
        I1=1.1*E/ABS(E)
        Y(1)=YT
        GOTO 98
 20     IF(Y(2).NE.0.) GOTO 50
        Y(2)=YT
        IF(ABS(E).LE.CLIM) GOTO 98
        I2=1.1*E/ABS(E)
        IF((I1*I2).GE.0) GOTO 98
        CE=VE
        GOTO 40
 50     IF(ABS(E).GE.CLIM) GOTO 70
        EX2=Y(2)-EM-B
        IF(ABS(EX2).GT.CLIM) GOTO 60
        Y(1)=Y(2)
        Y(2)=YT
        GOTO 40
 60     B=0.
        EM=Y(1)
        Y(1)=Y(2)
        Y(2)=YT
        X=ABS(EM-Y(1))
        V=40.+20000.*(1.-EXP(-X/100.))*X/EM
        W=EXP(-(X**2)/65.)
        C11=6.*V
        C21=9.*V/5.
        C22=3.*V/5.
        E=Y(1)-EM
        Y(1)=0.
        CALL PROC(E,EM,B,C11,C21,C22,V,W)
        IF ((ABS(B)*10.).LE.EM) GOTO 62
        B=B*EM/(ABS(B)*10.)
        CE=2.*CE
 62     E=Y(2)-EM-B
        Y(2)=0.
```

```
      CE=VE
      CALL VUP(E,EM,X,CE,V,W)
      CALL PROC(E,EM,B,C11,C21,C22,V,W)
      IF ((ABS(B)*10.).LE.EM) GOTO 64
      B=B*EM/(ABS(B)*10.)
      CE=2.*CE
64    I1=0
      GOTO 98
70    I3=1.1*E/ABS(E)
      IF((I1*I3).GT.0) GOTO 60
      CE=VE
      Y(3)=YT
      GOTO 90
40    DO 45 I=1,2
      E=Y(I)-EM-B
      Y(I)=0.
      CALL VUP(E,EM,X,CE,V,W)
      CALL PROC(E,EM,B,C11,C21,C22,V,W)
      IF ((ABS(B)*10.).LE.EM) GOTO 45
      B=B*EM/(ABS(B)*10.)
      CE=2.*CE
45    CONTINUE
      I1=0
      GOTO 98
90    DO 95 I=1,3
      E=Y(I)-EM-B
      Y(I)=0.
      CALL VUP(E,EM,X,CE,V,W)
      CALL PROC(E,EM,B,C11,C21,C22,V,W)
      IF ((ABS(B)*10.).LE.EM) GOTO 95
      B=B*EM/(ABS(B)*10.)
      CE=2.*CE
95    CONTINUE
      I1=0
98    RETURN
      END
```

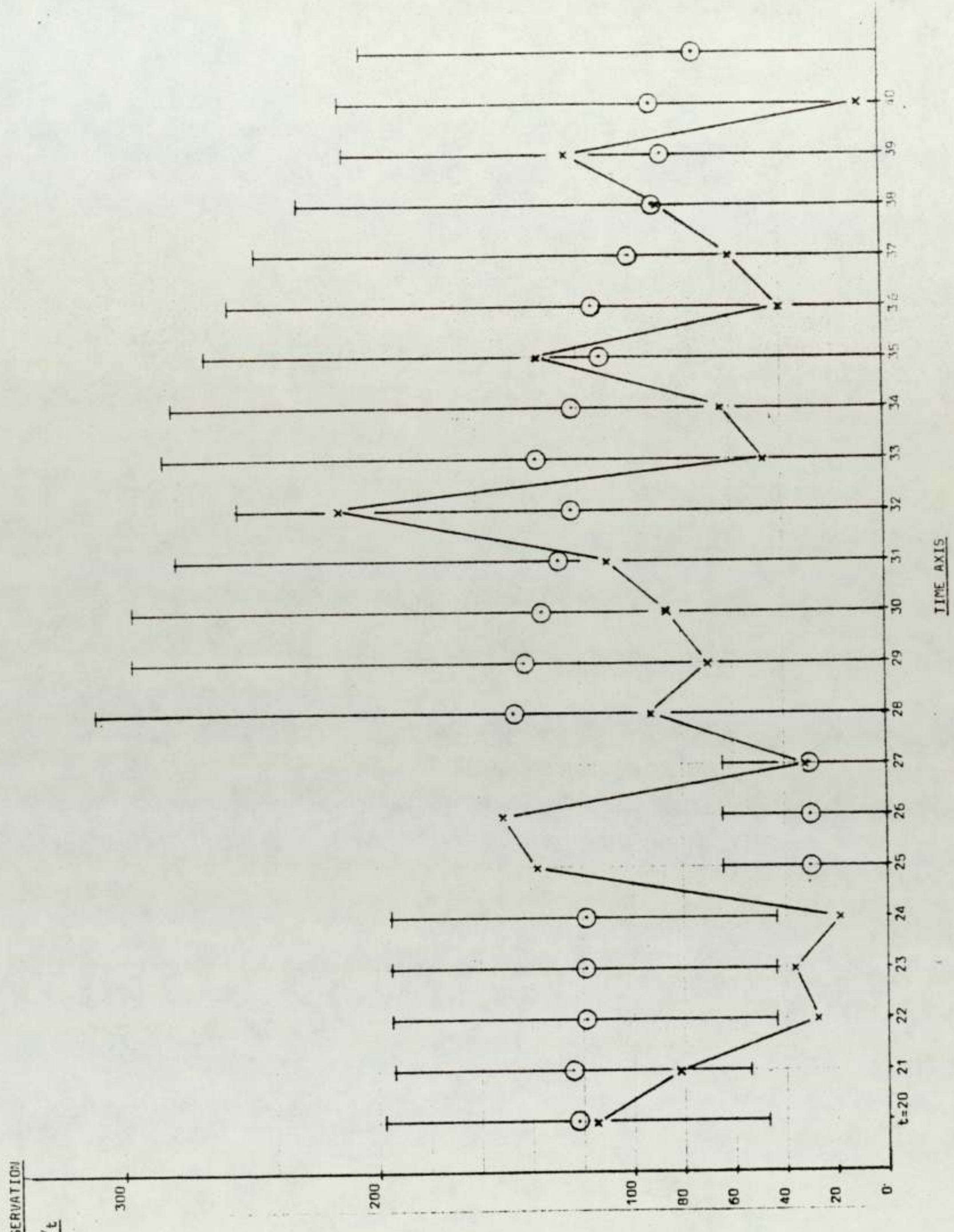
```
FORTRAN IV G LEVEL  21                     PROC

                    SUBROUTINE PROC(E,EM,B,C11,C21,C22,V,W)
                    R11=C11+2.*C21+C22+1.
                    R21=C21+C22
                    R22=C22+W
                    Y=R11+V
                    A1=R11/Y
                    A2=R21/Y
                    EM=EM+B+A1*E
                    B=B+A2*E
                    C11=A1*V
                    C21=A2*V
                    C22=R22-Y*A2**2
                    RETURN
                    END
```

```
FORTRAN IV G LEVEL  21                     VUP

                    SUBROUTINE VUP(E,EM,X,CE,V,W)
                    VE=100.
                    EPS=ABS(E)-X
                    RE=CE+1.
                    YE=RE+VE
                    AE=RE/YE
                    X=X+AE*EPS
                    CE=AE*VE
                    W=EXP(-(X/65.)**2)
                    V=40.+20000.*(1.-EXP(-X/100.))*X/EM
                    RETURN
                    END
```

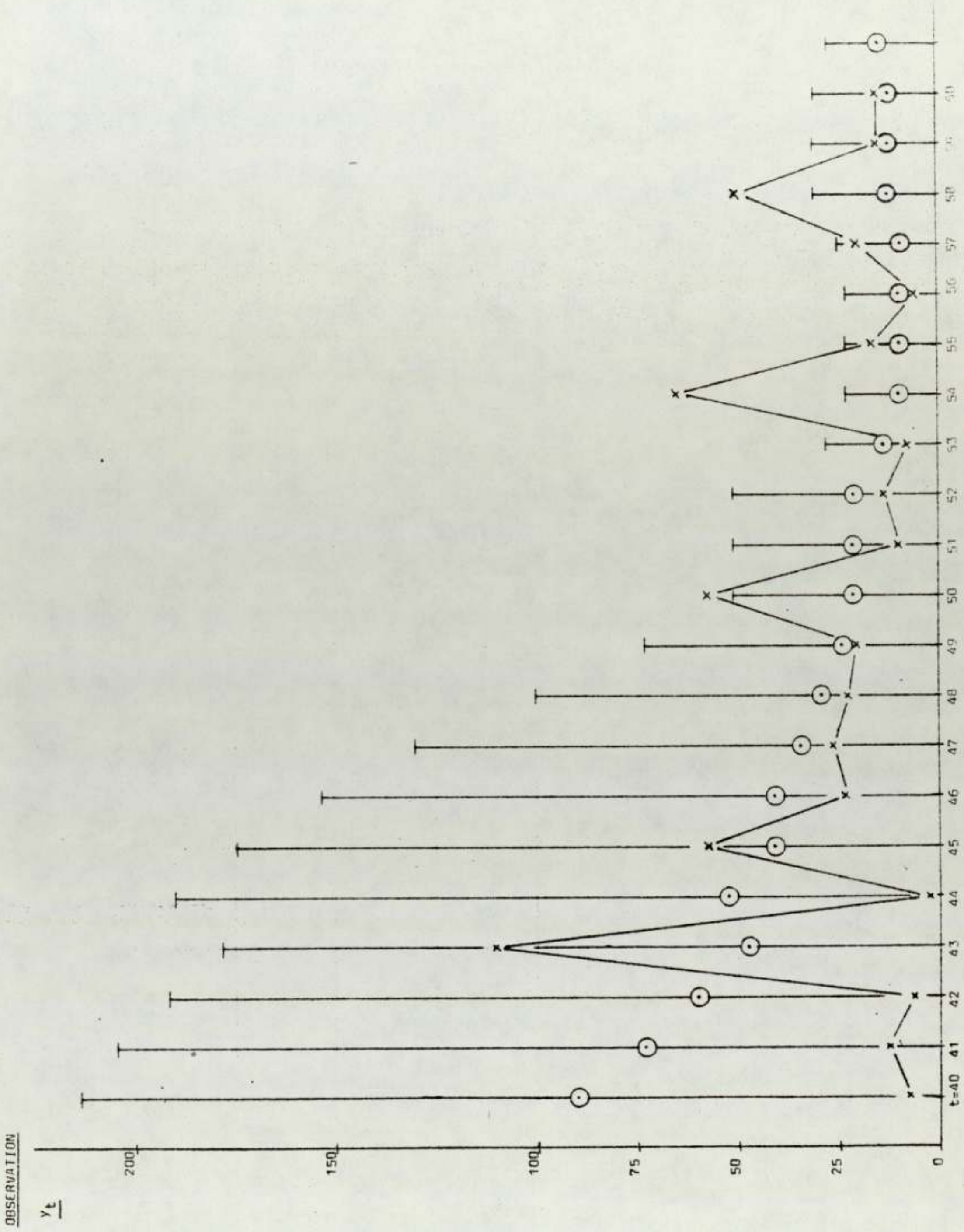
```
FORTRAN IV G LEVEL  21                     PUP

                    SUBROUTINE PUP(QT,P,CP)
                    VP=100.
                    ETA=QT-P
                    RP=CP+1.
                    YP=RP+VP
                    AP=RP/YP
                    CP=AP*VP
                    P=P+AP*ETA
                    RETURN
                    END
```

```
FORTRAN IV G LEVEL  21                         RANDU

                 SUBROUTINE RANDU(IX,IY,YFL)
                 IY=IX*65539
                 IF(IY) 5,6,6
          5      IY=IY+2147483647+1
          6      YFL=IY
                 YFL=YFL*.4656613E-9
                 RETURN
                 END
```

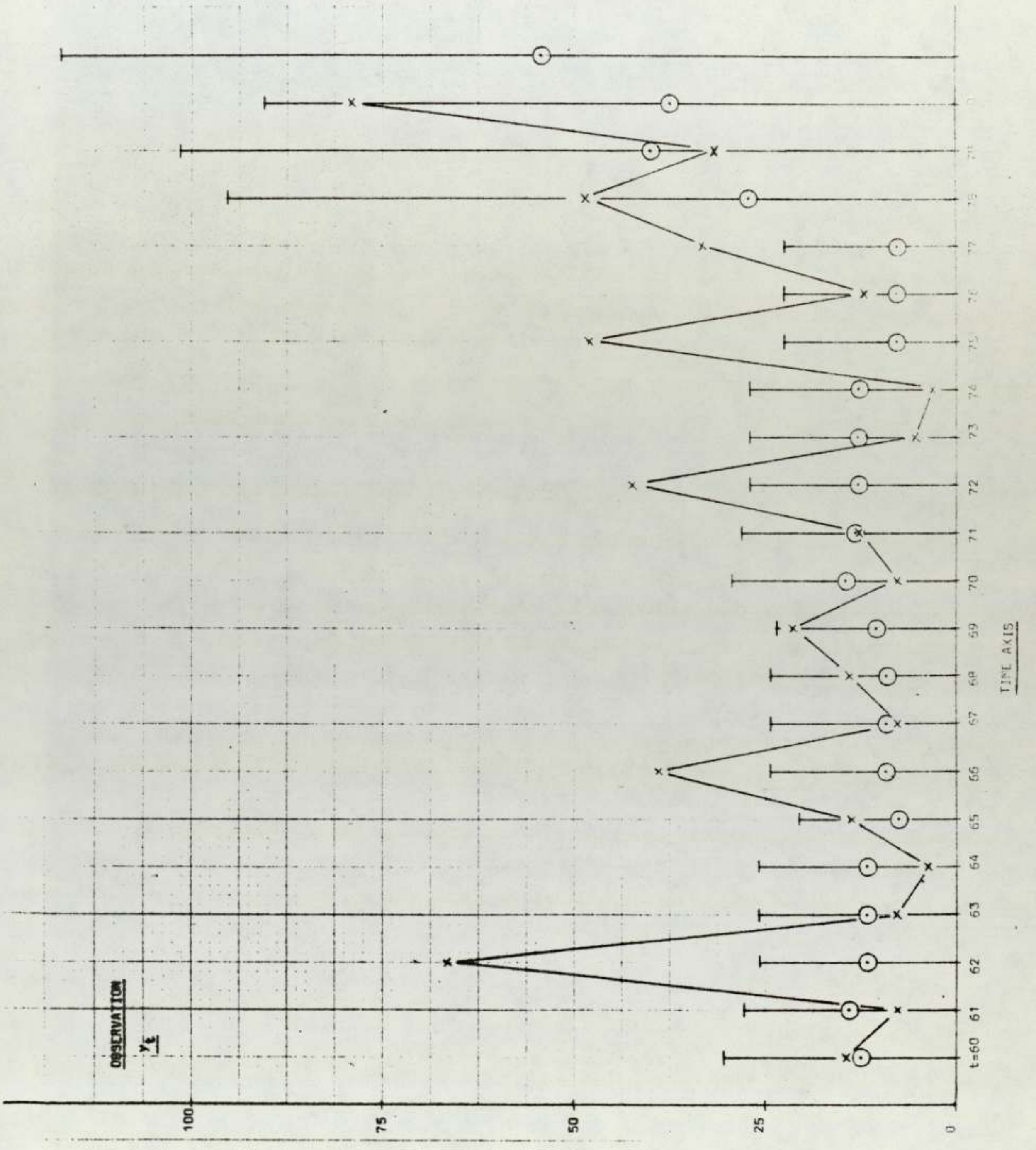
```
FORTRAN IV G LEVEL  21                         GAUSS

                 SUBROUTINE GAUSS(IX,S,AM,V)
                 A=0.0
                 DO 50 I=1,12
                 CALL RANDU(IX,IY,Y)
                 IX=IY
         50      A=A+Y
                 V=(A-6.0)*S+AM
                 RETURN
                 END
```



APPENDIX 6, FIGURE (a)



APPENDIX 6, FIGURE (b)



APPENDIX 6, FIGURE (c)

APPENDIX 7

This appendix presents three working papers written by the author during the project, for general circulation within the company.

Working Paper (a) A Summary of Consignments to Dunlop A/S Denmark in 1975.

(b) Report on the "Bayesian Forecasting Event" at Warwick University.

(c) Main Features of a Suitable Push System for the Supply of European Customers.

WORKING PAPER (a)

A SUMMARY OF CONSIGNMENTS TO DUNLOP DENMARK IN 1975

I am researching a project which is chiefly concerned with the problem of stock control between Fort Dunlop and Dunlop Denmark. I expect the main features of the project to be applicable to the other European Selling Companies.

This is the first of a series of short reports about aspects of my research, and their aim is to keep you aware of what I am studying. I will welcome your comments because they may reveal new aspects of the organisation to me. The reports will be short and factual, and I hope you will find them interesting.

The three tables are a summary of the invoice data recorded on computer files at Fort Dunlop.

Table 1 shows that 452 different items were supplied and the range of annual turnover to which they belong; e.g. 84 items had a turnover of less then £50. The column labelled "APPROX. VALUE" is an estimate of the annual turnover due to the corresponding range. (APPROX. VALUE = (NO. OF ITEMS) X (MIDRANGE). The cumulative percentage columns show that the relation between the frequencies and values follows the "20-80" rule. Because of this, I have classified the items by their annual turnover as follows:-

HIGH	TOP 5%	48% of T/O
MEDIUM	NEXT 15%	35% of T/O
LOW	BOTTOM 80%	17% of T/O

There are 20 Class A car and truck items, each with a turnover of more than £10,000.

These Top 20 items are shown in Tables 2 and 3 with their monthly consignment quantities. There is a marked peak in the total consignments during June. The natural question is whether this is a normal seasonality or the result of a specific "cause", like a change in priority.

The tables show an interesting tendency for strings of zero supply. I can think of two plausible reasons for this.

a) Items are in short supply during these periods, and the orders have a low priority.

b) The periods are covered by stocks, and orders for replenishment are not generated.

I intend to investigate the validity of these reasons by comparing these figures with ordering patterns. The order files are available in the Export Department but are not easily accessible.

Another interesting aspect of Table 3 is the fall off of shipments of these items from October. This could indicate a seasonality or a genuine trend away from these products.

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TABLE 1

DENMARK 1975

RANGE OF ANNUAL TURNOVER R (£)	NO. OF ITEMS IN RANGE	CUM %	APPROX. VALUE £000s	CUM %	
0 - 50	84	19	2.1	0.2	
51 - 100	62	32	4.7	0.8	
101 - 150	27	38	3.4	1.2	
151 - 200	24	44	4.2	1.7	
201 - 300	24	49	6.0	2.4	
301 - 400	26	55	9.1	3.5	C LOW
401 - 600	29	61	14.5	5.2	
601 - 800	23	66	16.1	7.1	
801 - 1000	20	71	18.0	9.2	
1 - 1.5K	31	77	38.8	13.8	
1.5 - 2K	16	81	26.0	17.0	
2 - 3K	25	87	62.5	24.4	
3 - 5K	18	90	72.0	32.9	B MEDIUM
5 - 10K	22	95	165.0	52.3	
10 - 20K	15	99	225.0	78.8	
20 - 35K	5	100	137.5	94.9	A HIGH
35 - 50K	1	100	42.5	100.0	
	452				

TABLE 2

MONTHLY DESPATCHES TO DUNLOP DENMARK 1975 TRUCK

MPG MONTH	101 3206	101 3216	101 3226	103 3241	TOTAL	%
JAN	-	-	-	-	-	-
FEB	-	50	60	20	130	5
MAR	-	-	40	160	200	8
APR	20	-	55	-	75	3
MAY	-	-	145	-	145	6
JUN	140	300	120	90	650	26
JUL	-	100	170	225	495	20
AUG	60	50	50	20	180	7
SEP	-	-	-	-	-	-
OCT	200	50	-	-	250	10
NOV	-	96	90	-	186	7
DEC	-	144	60	-	204	8
TOTAL	420	790	790	515	2515	
AV. PRICE	£36.1	£42.5	£52.1	£43		
TURNOVER	£15,159	£33,549	£41,170	£22,145	£112,023	

TABLE 3

MONTHLY DESPATCHES TO DUNLOP DENMARK 1975 CAR

MPG MONTH	131 1105	131 1112	131 1120	131 1132	139 0001	141 5070	141 5070	142 2800	142 2818	250 1801	250 1821	250 1841	250 1851	250 1861	250 2821	TOTAL	%
JAN	-	-	323	974	-	-	-	90	100	609	1028	310	500	1095	-	5029	9
FEB	775	589	310	646	-	-	50	230	180	84	600	195	670	437	-	4766	9
MAR	734	376	490	285	-	-	210	365	560	1273	144	296	1290	-	-	6023	11
APR	260	-	397	-	-	-	132	220	-	385	-	72	530	-	-	1996	4
MAY	60	-	262	1086	60	-	38	220	440	332	491	552	170	340	-	4051	8
JUN	1168	1024	578	1289	242	454	896	506	900	1228	24	322	326	364	1803	11124	21
JUL	142	-	60	41	150	658	-	204	350	250	-	464	-	296	1500	4115	8
AUG	430	-	450	1039	300	382	-	216	350	93	-	350	1097	350	577	5634	11
SEPT	-	620	-	1085	220	350	2512	-	370	-	-	-	217	-	296	5670	11
OCT	100	-	50	305	260	-	75	-	280	-	-	-	-	-	936	2006	4
NOV	-	200	25	300	-	63	-	250	300	-	-	-	-	210	179	1527	3
DEC	-	10	60	-	560	-	60	442	300	-	-	-	-	-	-	1432	3
TOTAL	3669	2819	3005	7046	1792	1907	3973	2743	4130	4504	2287	2561	4800	3088	5278	53373	
AV. PRICE	£4	£4.2	£4.1	£4.4	£6.3	£5.3	£4.7	£4.4	£4.8	£3.3	£4.5	£4.8	£5.3	£5.7	£4.7		
TURN-OVER	£14,675	£11,870	£12,189	£30,886	£11,233	£10,090	£18,566	£12,088	£19,769	£14,844	£10,233	£12,362	£25,639	£17,671	£24,572	£246,687	

WORKING PAPER (b)

BAYESIAN FORECASTING EVENT WARWICK UNIVERSITY

5th. & 6th. JANUARY, 1977

INTRODUCTION

The purpose of the event was to introduce workers in Operational Research to recent progress in short term forecasting techniques. The techniques have been developed over past years from work originally produced by R. E. Kalman in 1963. Roy Johnston and Professor P.J. Harrison of Warwick University took the course, giving numerous examples along with the step by step development of the theory.

There is little point in discussing the theory here, so I will describe the drawbacks of classical forecasting, and why this Bayesian method has significant advantages.

CLASSICAL FORECASTING

The standard, theoretically sophisticated, approach to forecasting starts off by analysing a batch of data which forms a "time series" e.g. weekly sales. A set of statistics is calculated which are used to choose a model (in the form of an equation) which relates one week's sales to those of previous weeks. Inherently, there will always be some uncertainty (or lack of knowledge) about what next week's sales will be, but the hope is that the chosen model will be closer than any other.

There are a number of practical limitations to this approach which are reasonably easy to appreciate. If a firm produces a new product, or starts selling one in a new region, there is no historic data which will provide the basis for choosing a suitable model. So the models are limited to use with a substantial quantity of data. If there were an advertising campaign, sales may start to grow and reach a new level, making the original model redundant. So the original work of choosing a model would need to be repeated. (Naturally, one would have to wait for sufficient data to accumulate, relevant to the new situation, and the model would probably not be available until after the forecasts could have been really useful). The market research department may be prepared to make a guess at what the sales would be, but it would not be possible to use this "subjective" information in the model. To sum up, these methods are unsuitable when:-

a) there is little relevant data about the time series;

b) there is a change in market conditions;

c) there is subjective information available with a corresponding degree of uncertainty.

After discussing these drawbacks, Professor Harrison remarked that in his experience these circumstances tended to be the rule rather than the exception.

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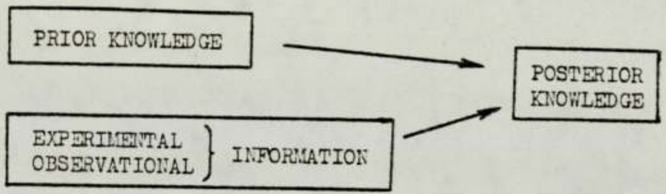
BAYESIAN FORECASTING

The Bayesian approach to forecasting is difficult to describe without discussing probability theory, but I will briefly introduce the idea behind it.

Suppose we describe our knowledge about a variable in terms of a probability distribution, e.g. with a certain mean and variance. Then if we perform an experiment (which will not give an accurate result) to determine the value of the variable, we can combine these two pieces of information to give a better idea about the variable than we would have had by relying on the experiment alone. That is, we have reduced the uncertainty about the variable, by combining both pieces of information.



Consider the case of a product being marketed in a new region. The Market Research Department estimate the weekly demand to be 500, but admit that it might be as high as 700 or as low as 300. This would constitute Prior Knowledge. Then after observing the first few weeks sales, one could calculate the Posterior Knowledge, in terms of a probability distribution.

The Prior Knowledge can be from any source (context, comparison, "executive opinion") as long as it is finally expressed in the form of a probability distribution. The Bayesian approach to forecasting means that this kind of knowledge about the model's parameters can be used throughout, but especially in initialisation procedures and with limited data.

The representation of the model is parametric as distinct from the functional model of the classical techniques. For example, if we are interested in a specific aspect of the data like "level" or "growth", then these ideas are incorporated explicitly in the formulation of the model, as parameters. As a result, a complex model can be built up easily from statements about individual parameters. Another consequence of this representation is that the forecaster can easily interact with the model, i.e. evaluate and understand inferences about the parameters, and import his own knowledge about them to the model.

Each of the parameters can be described as having their own time dependence and uncertainty. For example, the estimated growth in sales will be continually updated when there is new sales campaign or a price cut. There will also be an indication of how much confidence we can place in the estimate. So, the model "evolves" along with the data.

In the classical theory, the choice of models is limited to one, however thorough the selection procedure. The new techniques allow a number of alternative models to be considered with each new piece of data. Therefore it is possible to respond to sudden major changes in market conditions

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(e.g. a legal restriction) by switching to a more appropriate model. This switch will be automatic (apart, possibly, from adding some new market intelligence about a new level) and will soon settle down to give forecasts of the same reliability as before.

CONCLUSIONS

The course was excellent in its material and presentation, and turned out to highly relevant to the practical problems which I am faced with. I expect this work will have a considerable influence on my project and the progress I will be able to make.

N.T. CROUCH

WORKING PAPER (c)

Main Features of a Suitable Push System for Supply of European Customers

1. THE SYSTEM BOUNDARY

The advantages of the Push System are greatest for customers carrying a wide product range and whose primary source of supply is U.K. So it is aimed at the larger customers, and in particular the European Selling Companies. The system must run alongside the established order administration procedures at Fort Dunlop, so a gradual transfer of customers from one system to the other would be possible.

If, eventually, all tyre distribution within Europe is integrated, a push system of some sort will be employed. The push system I am advocating will provide very useful experience for it.

2. DATA RETRIEVAL

It is necessary to centralise information about every product in every location within the system. This means that every customer must report the weeks sales and deliveries, for each product, to Fort Dunlop. It may be a heavy commitment for a customer without E.D.P. equipment, and in that case the report could be made fortnightly or monthly.

3. FORECASTING

a) The sales data is used to revise forecasts for short term requirements of each product, in each location. The forecasts are projected 4 - 6 weeks ahead, depending on the supply lead time.

b) The sales data is combined with the orders set-up, in the corresponding week, for standard order processing. This combination is used to revise forecasts for each product, for the whole of export. These forecasts, projected forward 3 months, can be used to estimate the demands placed on production by all exports, and in revising the Management Plan.

4. WORKING REPORTS

a) The supply lead time, for each customer in the system, is monitored. The stock status for each product in each location is known. Combining this information with the short term sales forecasts of 3a), shows what the "most urgent" requirements of each customer are. (Here we could define "most urgent" to mean:- "Must be called off within 5 days"). The "Most Urgent Requirements Report" is used to make stock allocations for all the customers in the system.

b) After stock is allocated for the system as a whole, a report of Cumulative Net Requirements is used to make a "Fair Share" allocation between customers.

c) All allocations are then brought forward onto the Consignment Planning Report, as usual.

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5. EXCEPTION REPORTS

a) The basic objective of the push system is to maintain a specific level of customer service. Therefore it is highly desirable to decide on a suitable measurement of it, and monitor it. The most suitable measurement is "The Number of Order Lines Filled Ex-Stock".

b) The supply lead time, referred to in 4a), is the average time from Call-Off to Receipt of goods by the customer. It is a critical factor in the operation of the system and must be monitored. It is as important that the lead time should be predictable as that it should be short.

c) The model used to forecast sales will include a term to represent growth, or rate of increase of sales. The estimates of growth can be used to estimate "market potential".

6. STRATEGIC USE OF STOCK

a) The system holds in reserve a quantity of safety stock for each product - this is called a Master Warehouse, although it is merely a computer record. It is used only when current allocations fail to meet the most urgent requirements of all customers.

b) The policy towards what range of products should be stocked by each customer, is based on the order frequency for each product. This is a direct result of the measure of customer service level. (See 5a). A number of other factors can influence the final choice of product range e.g. Demand variability, Contribution, Length of the lead time, etc.

7. INTERVENTION

The routine of the system described above gives a fairly strict control over stock levels, which is where the main advantage of the system lies. There are three reasons for intervening in this basic routine.

a) An order for an item, which is outside the customers product range, must be dealt with by the standard procedures.

b) At some time, a customer may perceive an underlying change in demand for a product before it can be picked up by the forecast model. He is then able to change the "Bayesion Prior" forecast, and the system will adjust to this new level of sales.

c) During the initial period when a new customer is brought within the system, he can be advised of all shipments contemplated. If he wishes to alter the quantities, he may do so, as long as he is not exceeding his fair share. When he has built up confidence in the system he may then choose not to receive prior notice of consignments.

N.T. CROUCH

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