CONSTRUCTION OF MARKET AND
PRODUCTION MODELS AND AN EXAMINATION
OF THEIR INTERACTION AND USE FOR
PLANNING DECISIONS.

A Thesis, submitted for consideration for the award of Doctor of Philosophy,

by Peter Lawrence Bubb,
June 1974.

Construction of Market and Production Models and an Examination of their Interaction and Use for Planning Decisions

SUMMARY

The research was carried out in the New Metals Division of Imperial Metal Industries. The Division's primary business activity is the manufacture and marketing of semifabricated titanium. At the time of the initiation of the research, the Division was beginning to experience changing market conditions which threatened its monopoly position as a supplier of titanium in the United Kingdom. The need was apparent for a thorough evaluation of the Division's situation. Exploratory studies of the marketing and production of titanium identified areas for further research effort.

The behaviour of the Division's manufacturing costs were investigated in detail. As a result, the use of multiple regression analysis was put forward as an improved method for calculating cost absorption rates. The analysis of aggregated costs resulted in the development of a model of costs of different product mixes. This in turn led to a financial forecasting and cost monitoring system which was subsequently used by the Divisional Accountancy Department.

A model was developed which described the source selection decision of the titanium customer. This was built as a logical flow chart. It is based on the concept of a list of acceptable suppliers from which suppliers are successively eliminated by a sequence of decision rules.

A simulation model of the titanium market is built, combining the cost and decision models with models for various other aspects. This simulation is sufficiently general to be used to describe different segments of the titanium market. The simulation model has been used in exploratory long-range surveys of the total titanium market and for examining specific business opportunities.

Construction of Market and Production Models and an Examination of their Interaction and Use for Planning Decisions

CONTENTS

Appendix B cont'd

PREFACE

I am grateful for the generous help and assistance of a number of individuals and organisations. The Interdisciplinary Higher Degrees Scheme at the University of Aston in Birmingham provided me with the opportunity to study for a degree while involved in industry. The author was employed by Imperial Metal Industries Limited while carrying out the project. They provided the problem and also paid my salary. The Science Research Council contributed through a Research Studentship.

Dr D J van Rest, as the main supervisor of the project, spent many hours from an already full diary discussing the work with the author. Apart from co-ordinating the team of supervisors, he contributed many useful insights from his wide experience. Mr M K Hussey, as one of the two associate supervisors, took a great deal of effort to view the project as a whole, and to offer guidance on the modelling and mathematical parts. Mr J E Smith was always willing to offer the benefit of his extensive experience in industry, as well as helping the author to cope with the accounting problems he came up against. Mr I Winterbottom, of IMI, as the industrial supervisor, made sure that the project was always aimed at the Company's problems. He too gave freely of his time to discuss the work. Professor S L Cook, although not a supervisor, was involved throughout the project. He helped by kindly offering an "arms-length" view of the work as it progressed.

Many people in IMI, especially within the Sales and Accountancy Departments, spent a good deal of time helping me. Mr J R Willetts of Training and Education Services kindly commented on earlier drafts of the thesis.

Secretarial assistance on the project was provided by the IHD Scheme, and various parts of IMI, including the Secretarial School. I am grateful to Lynda Winchurch, who typed the dissertation to a tight schedule.

A final word of thanks to my wife, Fiona, who undertook many of the tasks I neglected while preparing this thesis.

This volume covers a good deal of information of a commercially valuable nature. All such data has been disguised. However, every effort has been made to preserve the internal consistency of the work.

PLB

CHAPTER 1

INTRODUCTION

1.1 The Organisational Environment for the Research

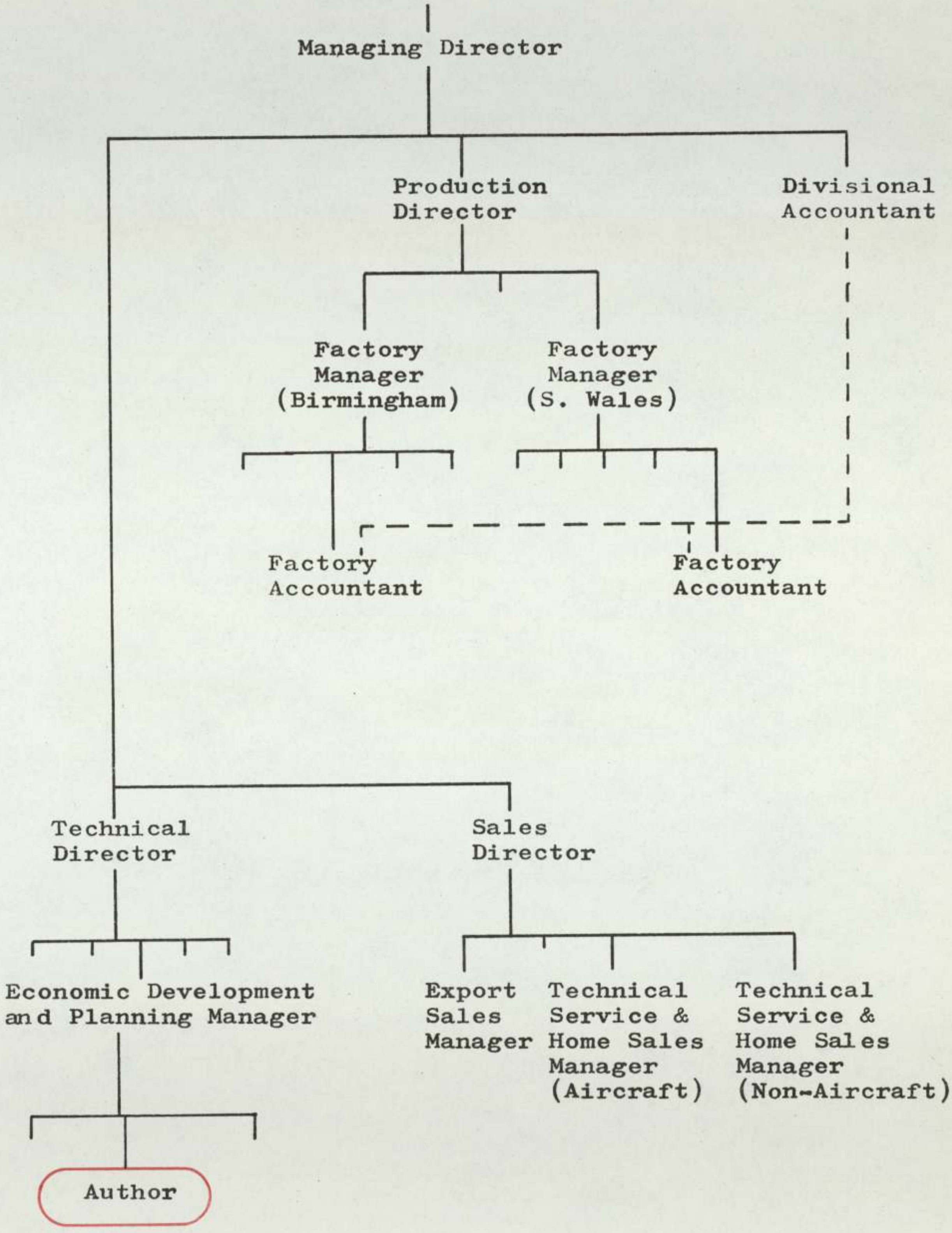
The research described in this thesis was carried out while the author was employed within the New Metals Division of Imperial Metal Industries (Kynoch) Limited. This Division forms a major operating unit of Imperial Metal Industries Limited, the majority of whose equity is held by Imperial Chemical Industries Limited. The author worked in the Economic Development and Planning Department, as indicated in Figure 1.1, which shows part of the Division's organisation structure. Much of the work was carried out in close collaboration with the Accountancy and Sales Departments.

The research formed part of Aston University's Inter-disciplinary Higher Degrees Scheme and was supervised by a team of four. The main supervisor was a University management scientist, and the others were an accountant and a statistician from the University, and the Division's Economic Development and Planning Manager.

Figure 1.1

ORGANISATION STRUCTURE OF PART OF THE

NEW METALS DIVISION



1.2 The New Metals Division of IMI

The New Metals Division is a largely autonomous part of IMI (Kynoch) Limited. It is engaged in the semifabrication and selling of titanium, zirconium, and various other of the "newer" metals. The research reported here has been concerned solely with the Division's titanium activities. Titanium represents the great majority of the Division's business, and largely utilises separate manufacturing and marketing facilities. It is produced in a variety of alloys in product forms ranging from wire to billet. Table 1.1 gives some examples of the product range. The major raw materials entering the Division's factories are pure titanium granules, and various powdered alloying elements.

The Division's products are sold to a large number of customers in most parts of the world. The industries which purchase the largest amounts of titanium are aerospace and process plant manufacturing. The material is used for aircraft and space vehicles largely because of its good strength/weight ratio, while it finds favour in process plant applications owing to its good corrosion resistance. Table 1.2 gives some typical uses for titanium products.

1.3 The Problem Identified

The project was set up at a time when the titanium market seemed about to enter a period of rapid change. The serious over-capacity in the United States Titanium Industry, the

Table 1.1 **AN INDICATION OF THE TITANIUM STANDARD PRODUCT RANGE**

		ALLOYS														
Alloying Additions	Vanadium						●									
	Oxygen	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
	Molybdenum	●	●	●	●	●						●				
	Copper										●					
	Palladium									●						
	Aluminium	●	●	●	●	●	●	●	●							
	Manganese							●	●							
	Iron							●								
	Tin	●	●	●	●	●		●								
	Silicon		●	●	●	●										
	Carbon				●											
	Zirconium	●		●												
Billet	4"-7" dia	◆	◆	◆	◆	◆	◆			◆	◆		◆	◆		◆
	8"-11" dia	◆	◆	◆	◆	◆	◆	◆		◆	◆		◆	◆		◆
	12"-16" dia	◆	◆			◆	◆				◆			◆		
Rectang-ular Bar	1"-2.9" thick		◆		◆		◆				◆			◆		◆
	3"-8" thick		◆		◆	◆	◆				◆					
Plate						◆	◆				◆					
Slab										◆	◆			◆		◆
Square Bar	4.5"												◆	◆		◆
Sheet	.014"-.1"gauge						◆			◆	◆			◆	◆	◆
	.1"-.625"gauge						◆			◆	◆			◆	◆	◆
Rod	.32"-1" dia	◆		◆			◆		◆	◆	◆		◆	◆	◆	◆
	1.1"-2" dia	◆		◆	◆	◆	◆				◆		◆	◆		
	2.1"-4" dia		◆		◆	◆	◆		◆	◆	◆		◆	◆		◆
Tube	.38"-.99" OD														◆	
	1"-2" OD									◆					◆	
Wire	.056"-.1" dia						◆			◆	◆	◆	◆	◆		◆
	.11"-.265" dia						◆			◆	◆		◆	◆		◆
Extrusions							◆				◆					
Strip	.008" gauge													◆		
	.036" gauge															◆

Table 1.2

SOME APPLICATIONS OF TITANIUM AND ITS ALLOYS

Industry	Application	Reason for Use
Aero engine manufacture	Gas turbine discs Gas turbine blades Pipework	Good strength/weight ratio up to about 400°C
Airframe manufacture	Nuts and bolts Heat shielding	Good strength/weight ratio up to about 400°C and resistance to corrosion in the atmosphere
Process plant manufacture	Heat exchangers in chlorine plants. Water cooler tubes in power stations	Resistance to corrosion in some aggresive environments
Prosthetics manufacture	Structural surgical implants, e.g. bone plates, heart valves	

emergence of very large multi-national aerospace projects, and the reduction of some obstacles to international trade in titanium were each making the industry much more competitive than it had been previously. The Division seemed about to be forced out of its position as the monopoly supplier of titanium in the United Kingdom. These factors suggested that many of the Division's approaches to its business problems might have to change to cope with the new situation.

The Titanium Industry is highly technological, and the sophisticated plant used for production is very expensive. This makes capacity change decisions extremely important to the Division.

The Division's Economic Development and Planning Department had been formed a few years before the research project was set up. The Department's aims were to undertake business analysis, and to develop a series of planning tools to help with various decisions taken by the directors and senior managers. The project was conceived as part of this activity of the Department.

The research project was intended to investigate the interaction between production and marketing activities in the Division, and to develop a tool for helping with capital investment and marketing strategy decisions. As the research progressed, it did, in fact become necessary to construct various models in each of the production and sales areas, and the interaction between these models was examined.

CHAPTER 2

THE SYSTEM AND THE PROBLEM

2.1 Chapter Preview

This chapter describes the production and marketing activities of the New Metals Division. Models and procedures in use in these areas are described critically. A description of the planning processes in the Division indicates the background for this project. The development of a model which shows the interaction between the Division's production and marketing areas is identified as the major interest of the work.

2.2 Titanium Production Facilities

The New Metals Division uses a wide variety of production processes to convert its raw materials to final products.

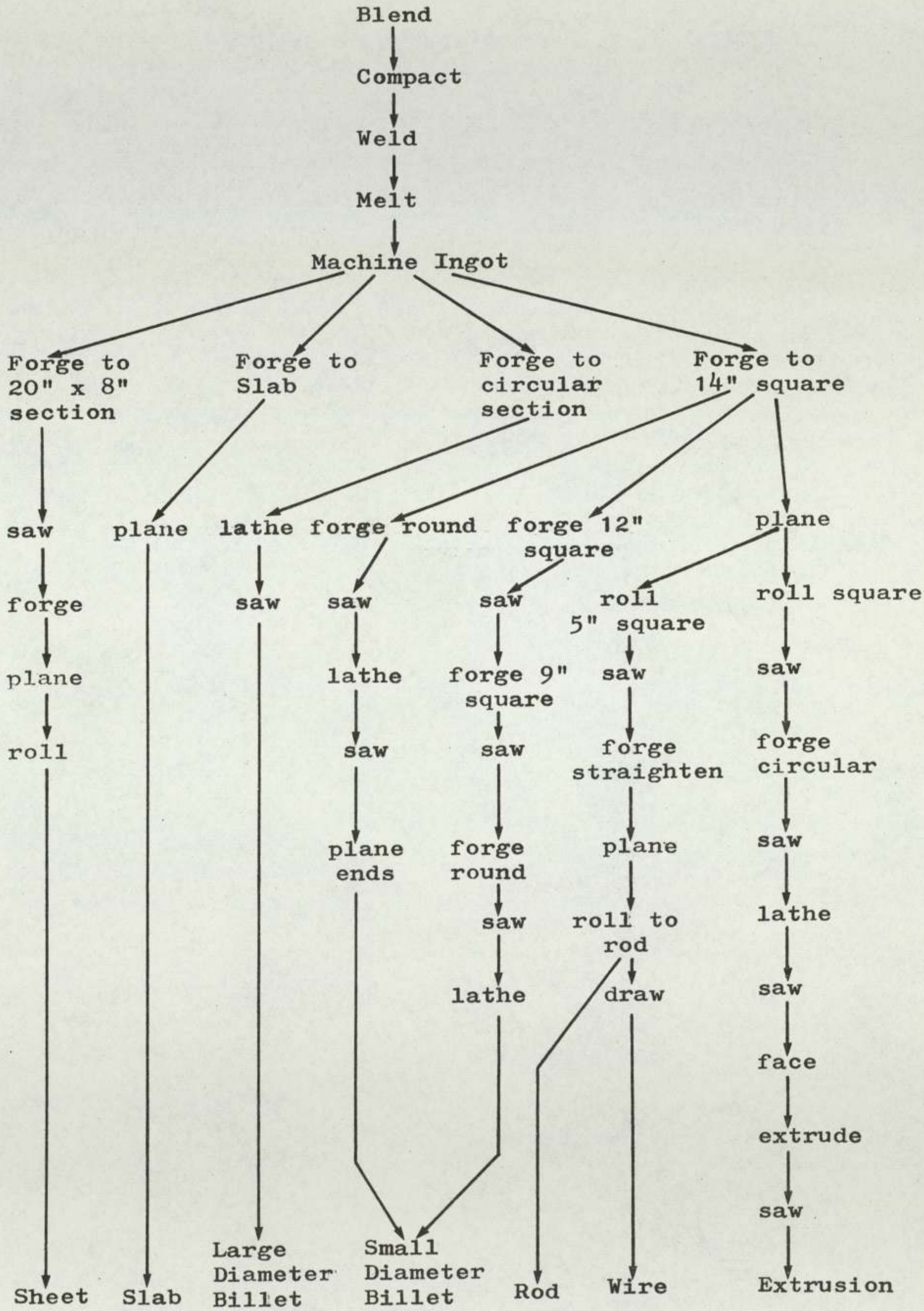
Although the majority of work is carried out within the Division, specialist sub-contractors are used for some processes.

Each product has a specific production route, which indicates the manufacturing operations to be carried out to produce it. Although these routes vary greatly from product to product, the first few stages, from raw materials to ingot, are common to each product form. The various raw materials are blended in appropriate proportions, and then compacted and welded to form an electrode. The electrode is melted to an ingot in a vacuum furnace. Impurity-rich parts of the ingot surface are removed on a lathe.

From this stage, the routes diverge markedly. The various deformation processes used include forging, rolling, tube reducing and wire drawing. The Division's machining facilities include lathes, planers, saws and grinders. Many other operations are carried out, such as shot-blasting, annealing and chemical etching. Testing of various types is applied at several stages in each product route. Figure 2.1 gives an outline of a few production routes.

Most production is initiated by a specific order for a product from a customer. A small number of products are stocked, however, and stock replenishment orders initiate their production.

Figure 2.1 THE MAJOR PROCESSES IN SOME PRODUCTION ROUTES



2.3 Production Procedures and Models

2.3.1 The Divisional Accounting System

The Divisional Accountancy Department reports financial data describing the Division's current and forecast operations to the Company Accountancy Department. The system can be regarded as a descriptive model of the financial aspects of the Division. The Divisional Accountancy Department also provides management control information of various types. As part of this activity a budgetary control system is operated, and standard product costs and cost absorption rates for centres of production are calculated.

Most of the planning carried out in the Division is very dependent on information obtained from the accounting system. This data is open to criticism on two counts: it is based on cost behaviour assumptions which have not been verified, and it is derived for stewardship purposes, and so not initially obtained for planning.

2.3.2 The Divisional Linear Programming Model

A linear programming model of the Division had recently been developed, which described the Division's activities in considerable detail (it used a representative 350 or so products). It was intended to be used mainly for showing which disposition of production resources would give the highest profit in a planning period. The model is formulated as a set of constraints which describe maximum demand for each product, maximum capacity available in production centres, and attributes such as costs of production and production routes.

The data used for the model was obtained from three major sources. Demand and price information was obtained from the Sales Department, plant capacity and production route details from the Production Department, and variable cost absorption rates from the Accounting Department.

Although the model was based on accepted data and production systems, it had not yet been fully accepted as a planning tool. Just how long it would take to gain complete acceptance from all the necessary personnel was not clear. However, it was obvious that some of the Divisional management lacked confidence in the model's formal treatment of data (especially the cost data).

2.4 Titanium Marketing Activities

The Division actively markets titanium by various means. It has sales engineers in the field, arranges promotional conferences, attends trade shows, and carries out applications and product development work, both on its own and jointly with customers. Part of the sales organisation deals with routine enquiries and orders.

Historically, the Division has had little competition in titanium in the U.K., and has also made significant sales into Western Europe. This situation is now changing, as some applications for titanium become routine, tariff and other barriers to international trade are reduced, and, outside the U.K., over-capacity in titanium is common.

2.5 Marketing Procedures and Models

The Division's sales organisation regularly produces sales forecasts. These are made, for different lengths of time up to several years, in a variety of detail. They are produced, essentially, by a process of summation of different experts' views, each for a different sector of the total market. The forecasts are of sales, and so have as an upper limit, IMI's expected production capacity.

The Planning Department have recently introduced a routine for improving the summation process, so that a measure of the forecast's precision can be obtained.

No large scale attempt to produce sales forecasts by any other approach had apparently been made. The current forecasts relied almost solely on experts' judgments. Although these forecasts were obtained in such a subjective way, they were surprisingly accurate. They achieved generally better accuracy than would be expected of statistical forecasts because they were able to take account of specific aerospace projects. These forecasts were however, consistently pessimistic, the pessimism (measured as the excess of actual over forecast sales) increasing with the distance into the future of the forecast period. (For more details about this phenomenon, please see Appendix A.2).

A formal model or estimate was not available which would show how these forecasts would change if given environmental conditions altered from those assumed. This factor severely limited the usefulness of the forecasts, which had to be revised frequently.

2.6 The Production/Marketing Interface

There is much informal contact between members of the Production and Sales Departments. This is often about particular problems concerning specific orders. Various committees exist which consider more general problems, and which have a membership including both sales and production personnel.

The various procedures and two models already described do in fact take account of this interface. The accounting system uses as one of its "inputs" the sales forecast. All the budgets, and thence standard costs, depend on the current sales forecast. The forecasts in turn reflect the expected interaction of IMI's capacity on the orders it will obtain. The linear programming model reflects the interaction of production and marketing in a richer way. Demand constraints (which indicate the maximum sales achievable of each product) are used with constraints describing the production set up, to describe the Division's environment. The LP model then selects the optimum product mix. There is no explicit planning procedure with the power to show the effect on demand of other market factors such as lead times, price or quality.

2.7 A Detailed Identification of the Problem

2.7.1 Planning Activities in the Division

Historically, the Division has not been strong in the strategic planning area. Although a planning department has now existed for a few years, a strong commitment to planning is still lacking from some departments. The LP model, the only major planning aid developed, still lacks credibility in some quarters.

The long term policies which the Division has operated during its existence seem to have arisen by force of circumstance. The business was developed from the research activities of the Metals Division of ICI (IMI's predecessor), as a monopoly supplier in the U.K. Sales effort was devoted to developing uses for the metal. As a major use developed in the aircraft industry, the Division was able to expand its capacity to take the bulk of this highly profitable business. In 1967 IMI took over Jessop Saville, the Division's only U.K. competitor, to strengthen its monopoly.

Capital expansion decisions were taken against the aircraft industry expecting good returns. The Division was for some years out-performing the rest of the Titanium Industry. However, no formal capability existed for assessing the risks of the large number of aerospace projects against which the Division was committing large amounts of capital. This led to the situation where the Division had little feeling for the risk in its annual profit forecasts.

In fact, on occasion, its forecast level of profit was not achieved for this reason.

Over recent years, the U.K. Aerospace Industry has become rationalised, and the home titanium market less protected. These factors led to the Division's dependence on fewer aircraft projects than hitherto. These projects are in turn controlled by a smaller number of aerospace companies.

The Division is now in the position where most of its output is taken by two British aerospace companies - Rolls Royce (1971) and the British Aircraft Corporation. The risk of this situation was forcibly demonstrated when Rolls Royce collapsed in 1971, resulting in a considerable amount of idle manufacturing capacity for IMI.

These factors seem to indicate that there could be great benefit to the Division if it was able to continuously re-appraise its business strategies. This project aims at providing a tool to help such a process.

2.7.2 The Proposed Work

The major aim of this project is an attempt to model the interaction between IMI's production resources, and its market for titanium. Although this interaction was modelled by the accountancy system and the LP model, neither of these considered the effects of variables other than price and sales weight. The object of this project is to try to include the effects of other variables significant in the production/sales interface. A simulation model is proposed for this purpose.

To develop such a model, two types of "building block" are necessary: models of customers, and models of suppliers. These models must include all the important elements and be mutually compatible.

The models of customers had to be developed from scratch, since no formal statement existed which indicated the effect of the various market factors. After exploration of a number of types of model, a model of a "typical" customer was developed by generalisation from IMI's customers. This took the form of a flow-chart which broke each buying decision down into its component parts.

Various aspects of the titanium supplier were modelled, based on a detailed knowledge of IMI. The major contribution was to indicate how costs varied with production levels. In IMI this was useful per se. Other aspects such as production lead times and capacity expansion were modelled. To examine the behaviour of the titanium market, these models were combined in a communication structure.

2.8 Chapter Review

The activities of the production and marketing departments have been briefly described. The models of aspects of these departments' work have been summarised.

The central area for study in this project has been identified as the production/sales interface, which would draw together the results of existing parallel activities in the Division.

Various models of supplier behaviour, including a logical flow model of customer behaviour are required for the study of interaction. It is proposed to study market behaviour using a simulation model.

CHAPTER 3

A PREVIEW OF THE THESIS

3.1 The Work

All the work carried out as part of this research project was designed to contribute to the planning process. It was further aimed at the production of a tool which would help strategic planning in the Division, by showing how IMI's production processes and markets interacted, and enabling experiments to be conducted in the market.

With these objectives, a variety of work was carried out. Wide ranging surveys of market behaviour from IMI's point of view led on to the study of the titanium buyer, and his behaviour is described in terms of a flow chart.

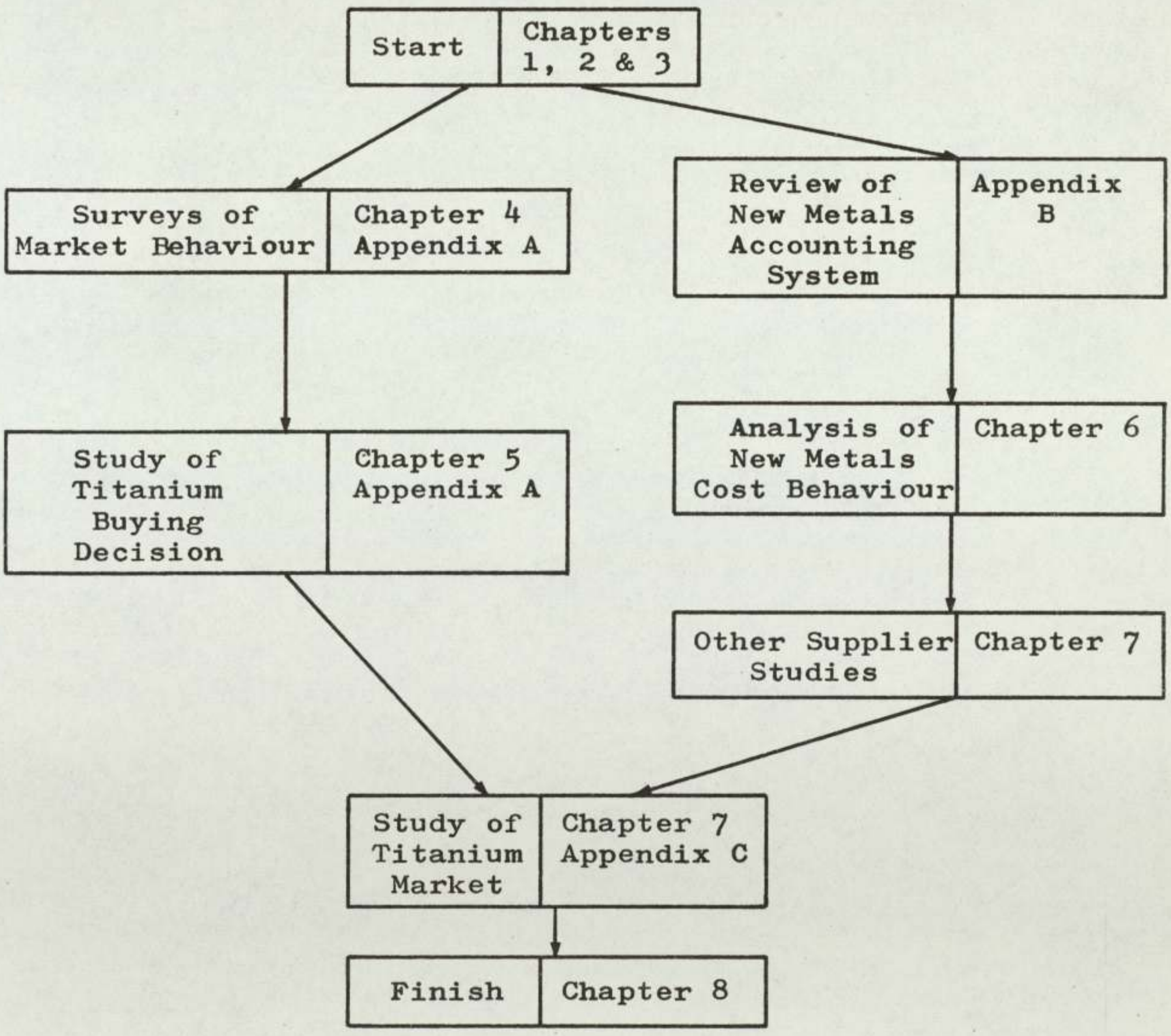
Cost behaviour was identified as one of the most important aspects of titanium suppliers. After an extensive review of the Division's accounting system, a scheme for describing the variation of the manufacturing costs for titanium was developed. Study was made of other aspects of IMI as a titanium producer: how long it took for delivery, how quotations were made, etc. Similar behaviour was deduced for other suppliers. These aspects of behaviour were combined by a study of the European titanium market.

A structure of suppliers and customers was put together and market behaviour predicted. This agreed well with the observed behaviour.

The major use of the work is seen in systematic planning and ad hoc studies made possible with this market study. Figure 3.1 indicates the structure of the research.

Figure 3.1

THE STRUCTURE OF THE RESEARCH



3.2 The Thesis

The thesis is structured round the problem solving approach used in this research project. After the first three introductory chapters, Chapter 4 presents some results of the introductory survey of the titanium market. The other introductory work in the marketing area is described in Appendix A. The development of the work concerning the titanium customer's buying decision is described in Chapter 5.

Chapter 6 presents the study of manufacturing costs in IMI. The preliminary survey of the accounting system is briefly described in Appendix B. Chapter 7 shows how the supplier and customer aspects of the titanium market are put together. The necessary minor studies of titanium suppliers are described in this chapter. The extensive usefulness of this part of the work is described. Chapter 8 reviews the work and sets it in its practical and academic context.

The appendices are used to show the different behaviour studied: Appendix A concerns customer behaviour, Appendix B, supplier behaviour and Appendix C shows work in the market interaction of customer and supplier. The appendices in general include detailed material which will be of use only to those readers with a special interest. All the literature surveys are placed within appendices. Appendix D contains an (as yet) unpublished working paper cited as a reference.

CHAPTER 4

A STATISTICAL PROFILE OF THE DIVISION'S CUSTOMERS

4.1 Chapter Preview

This chapter describes an exploratory investigation of IMI's titanium customers. The results are discussed from the point of view of their use to IMI, and for their application to the rest of this project.

4.2 The Investigation Carried Out

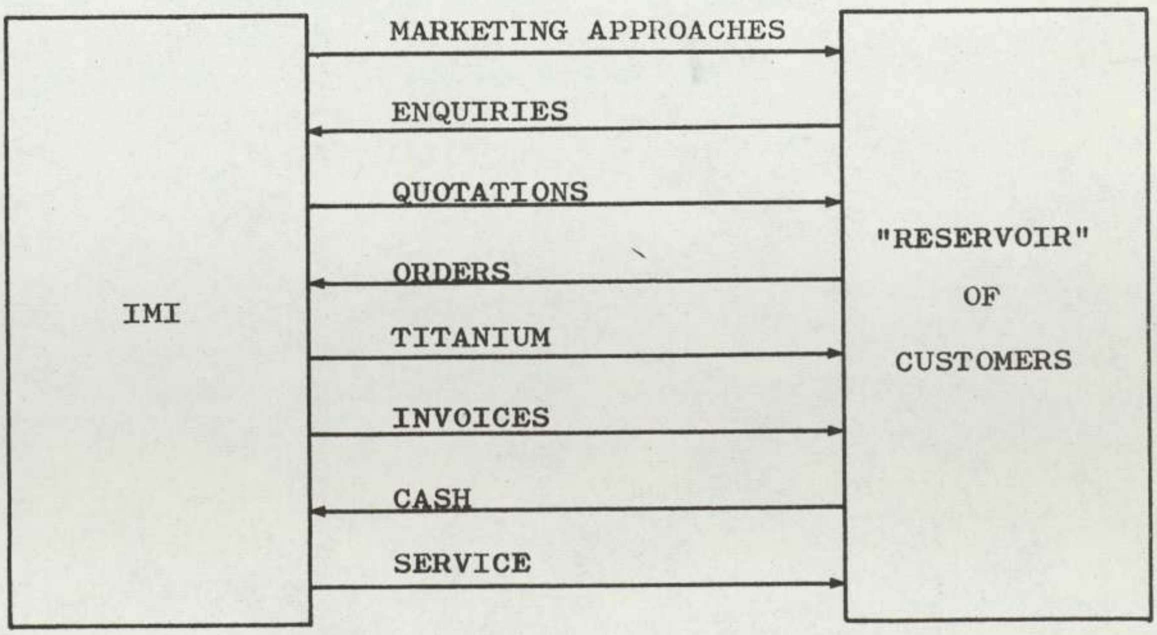
4.2.1 The Intention

In order to give the author a feel for the behaviour of the market, a survey was carried out of IMI's titanium customers. As a secondary objective it was hoped to identify the key market factors which IMI was able to control. Since the routine dealings with the customers largely took place in the Divisional Sales Office, the investigation was based on that Department.

The approach taken was to regard the Division and its customers as two "black boxes". It was possible to identify flows of various types between them. These are indicated in figure 4.1. There were certain aspects about these flows which were measurable: others were not.

The investigation concentrated on the measurable quantities; these were largely weights, dates and numbers of occurrences. It did not prove possible to measure factors such as loyalty, other suppliers' quotations, or quality.

Figure 4.1 FLOWS BETWEEN IMI AND ITS CUSTOMERS



4.2.2 IMI's Procedures with Customers

The Sales Office is the department in the Division which controls the quoting and ordering process.

The office receives product enquiries from potential customers by telephone, mail and telex. If the product is outside the Division's range the customer is immediately notified that the Division is not in a position to sell that product.

For products within IMI's product range, reference is made to the plants for a delivery indication, and then a delivery and price quotation sent to the enquirer. The quotation is usually telexed within one day and a confirmation sent by post.

The customer decides whether or not to place an order[1] based on this quote. Orders are also placed by customers without prior enquiry. The system is shown diagrammatically in figure 4.2.

When an order is placed by a customer, the Sales Office places an order on the Production Department, and confirms the order with the customer. When the titanium has been manufactured, the Production Department arrange delivery of the goods and simultaneously (normally) send an invoice to the customer. Cash payments are received by the central Company Accountancy Department.

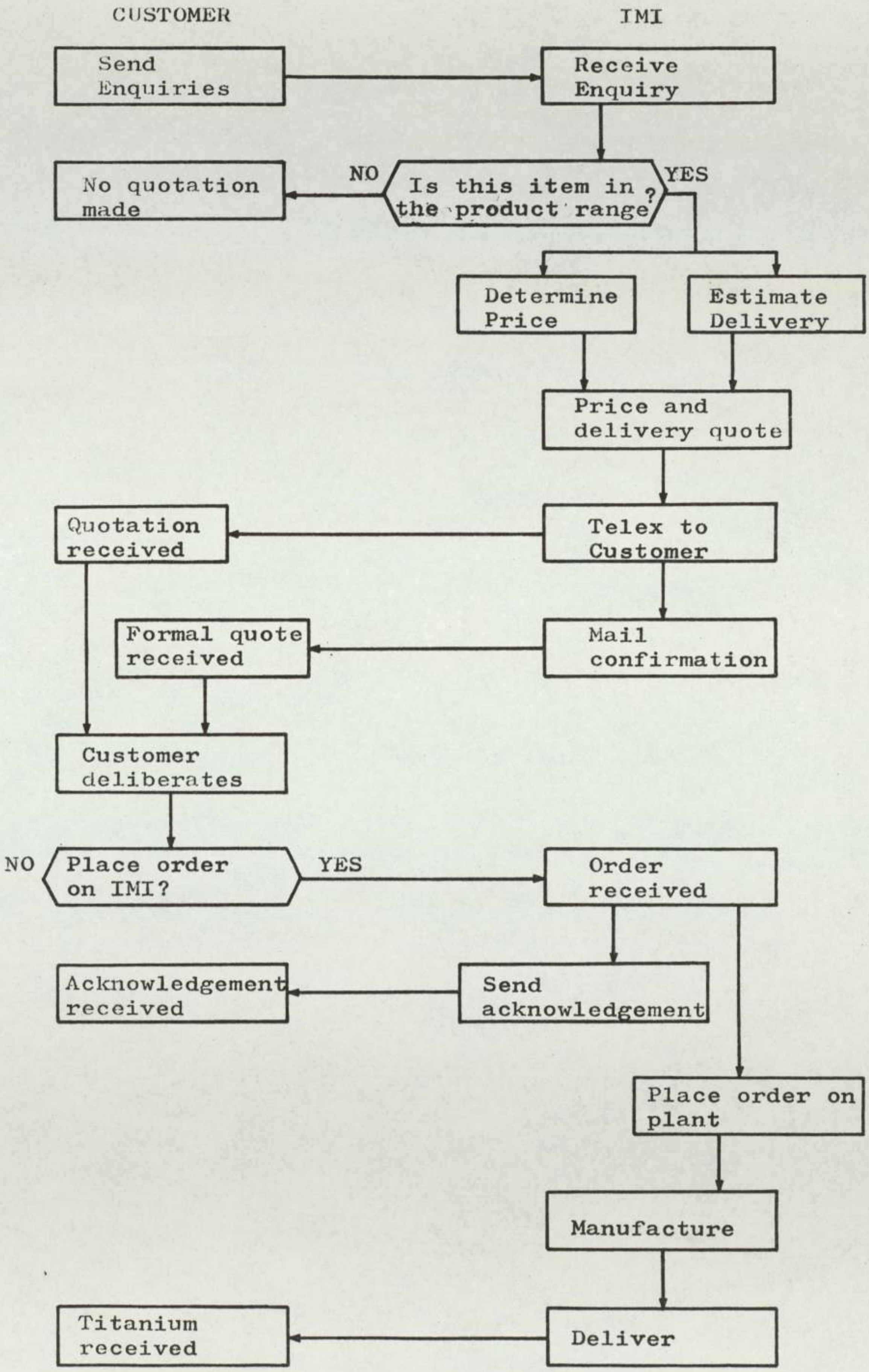
---

1. The definition of order used in this survey followed internal IMI practice. An order was regarded as that quantity of one product ordered by the customer at one time.

   When multiple orders or enquiries were received, Sales Office personnel were under instructions to treat each item separately. Industry practice was for each order decision to be made independently, so that quotations for one product did not affect the buying decisions for other products.

   The sales management's belief that there are no important cross-elasticities between the demands for the various products is backed up by examination of the technical design procedures which generate titanium demand.

Figure 4.2 THE ENQUIRING, QUOTING, ORDERING, AND DELIVERING SYSTEM



There are cases where this sequence of events is altered somewhat. For some customers, payment is required by IMI before despatch. In these circumstances, the invoice is issued when the material is ready for despatch. In other cases, order modifications and cancellations are received after the original order has been placed. Some orders are despatched as several separate items.

4.2.3 Information Sources

A search of files in the Sales Office yielded a substantial amount of data. Records of enquiries received were kept. These showed the number and sizes of enquiries on each day. Similar records were available for orders. Files of "dead" orders were kept which showed the order, despatch and invoicing details for each delivery. It was not possible to establish whether specific enquiries led to orders, or whether a given order was placed as a result of a prior enquiry. However it was feasible to find out the delivery date for most orders from Production Department files. The date of payment of invoices was also obtainable, for U.K. customers only, from records kept by the Company Accountancy Department. Samples were assembled of the following quantities:

Number of enquiries per day

Number of orders per day

Sizes of enquiries

Sizes of orders

These related to the first six months of 1972.

A random sample of 80 orders was selected and where possible the progress of each of these was traced through from enquiry to cash payment. This was only possible for some orders from British customers, and principally yielded information about time intervals in the system.

4.3 Sample Distributions

The distributions of the various quantities observed are described in this section. Where the distributions are similar to theoretical statistical distributions, this fact is noted. Although histograms are shown here to describe the distributions, the reader who desires more information will find, in Appendix A.1, the data and results of comparisons with theoretical distributions.

4.3.1 Enquiry and Order Frequencies

The distribution of the total number of enquiries received on a day is shown in figure 4.3. Its mean and standard deviation are 19.8 and 9.4 respectively. The order frequency distribution (figure 4.4) had a mean of 19.7 per day and a standard deviation of 8.0 per day.

4.3.2 Enquiry and Order Sizes

The distribution of enquiry sizes (measured by weight) is shown in figure 4.5. A mean of 439 kg. and a standard deviation of 1559 kg. were calculated.[1] The order size

1. The standard deviations of enquiry and order sizes are calculated to draw attention to the similarity of the dispersions of the two distributions. As a measure of absolute spread, the standard deviation is of little use with such skew distributions.

Figure 4.3 THE DISTRIBUTION OF THE NUMBER OF ENQUIRIES ARRIVING ON A SINGLE DAY

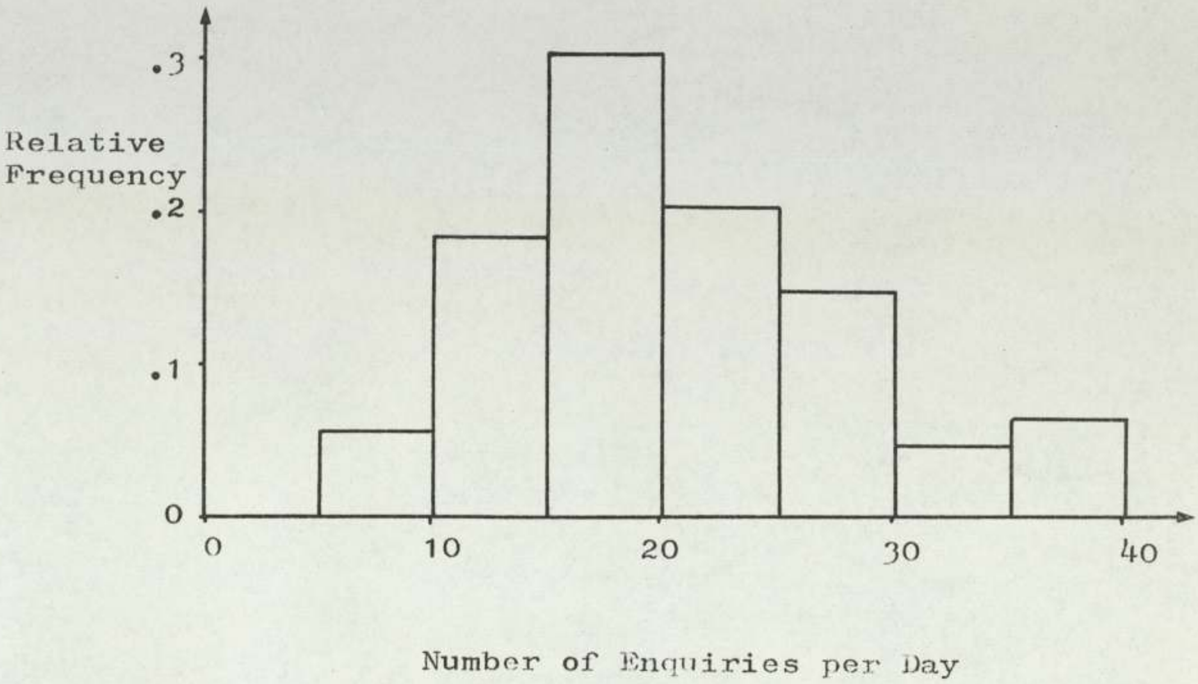


Figure 4.4 THE DISTRIBUTION OF THE NUMBER OF ORDERS ARRIVING ON A SINGLE DAY

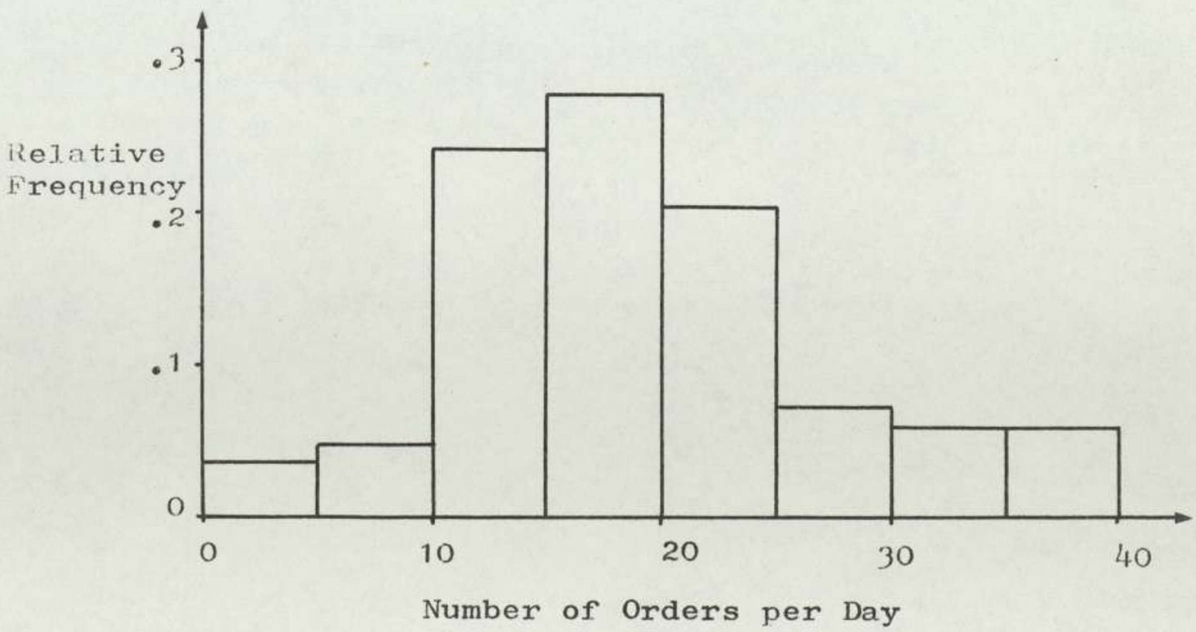
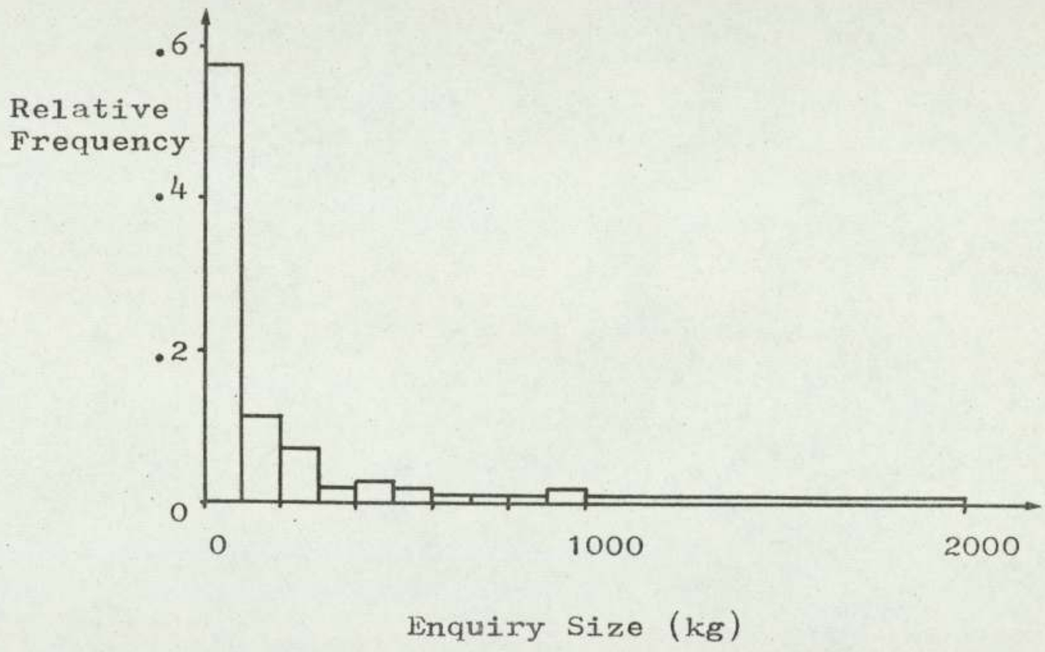


Figure 4.5 THE DISTRIBUTION OF THE WEIGHT OF ENQUIRIES



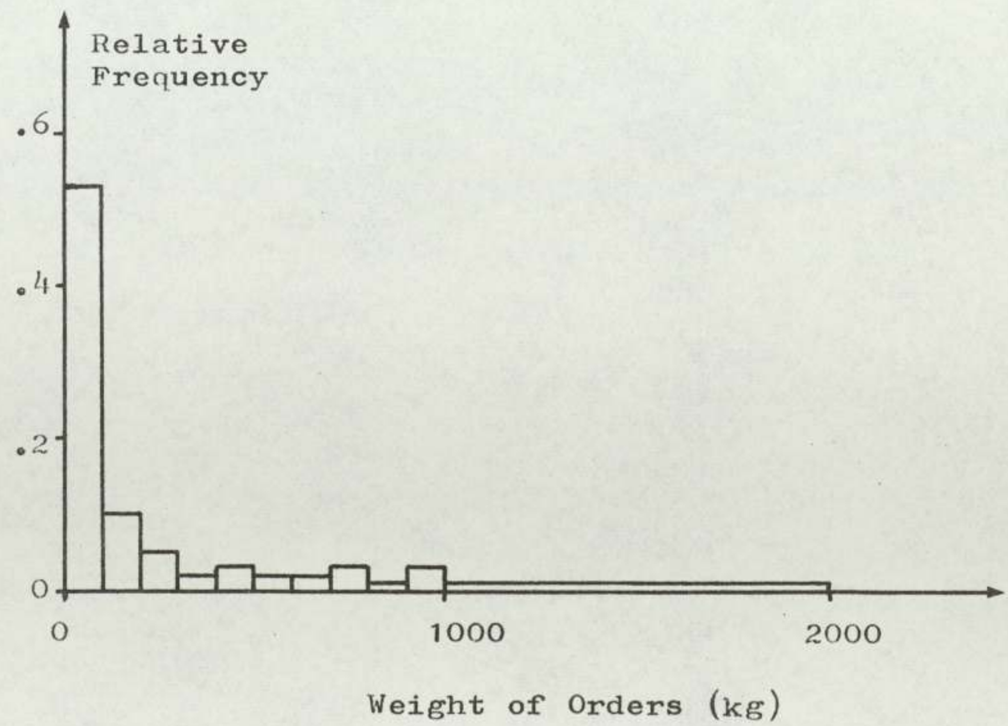
distribution (figure 4.6) had a mean of 561 kg. and a standard deviation of 1510 kg. Both of these distributions were strongly affected by a few very large items. The two distributions are very similar.

The sample of order weight against order price (figure 4.7) suggested an underlying linear relationship. This was estimated as:

$$P = 27.6 + 5.05 W \quad (r^2 = .989)$$

where P represents the order value in £ and W the order weight in kg.

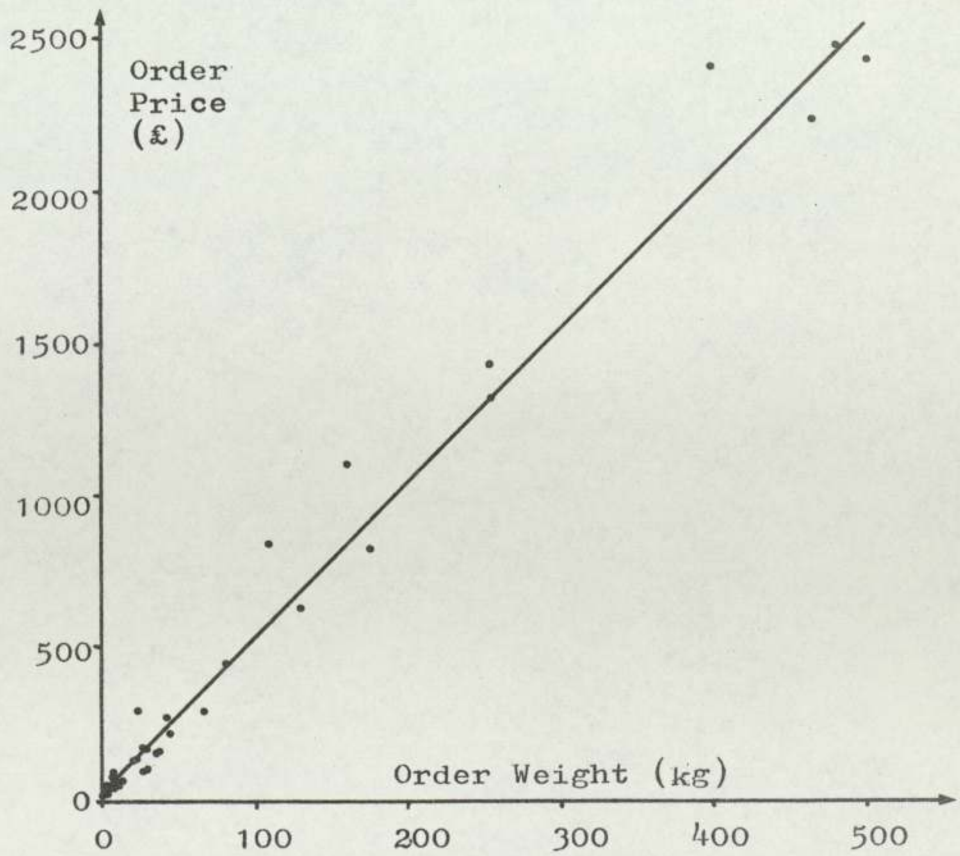
Figure 4.6 THE DISTRIBUTION OF THE WEIGHT OF ORDERS RECEIVED



The relationship in itself is interesting, since the Division operates a policy of adding "extras" to small orders. For this reason one would expect the positive constant in the equation. However, this constant is so small in relationship to the value of most orders (the average order value was about £ 500) that this suggests that the price extra policy might not be functioning well.

Figure 4.7 also shows a surprisingly low amount of spread, since the points represent widely varying products. Perhaps this suggests that the Division charges low prices for its products with high work content (such as wire), compared to products at the other extreme.

Figure 4.7 THE RELATIONSHIP BETWEEN ORDER PRICE AND WEIGHT



4.3.3 System Time Intervals

Three intervals were examined: enquiry to order time, order to delivery time, and delivery to payment time. The sample of enquiry to order "delays" was rather too small at 8 orders to afford any useful conclusions, but the other two distributions are shown in figures 4.8 and 4.9. The time between order and delivery had a mean of 48.3 days. The distribution was similar to an exponential distribution. Although it appeared that invoices were normally sent on the same day as the delivery was made, no specific check could be made. The distribution of delivery to payment times had a mean of 64 days and a standard deviation of 37 days. It was similar to a normal distribution.

The time between order and delivery, the production lead time for the product, is subject to fluctuation as the production situation varies. The sample was taken over a short enough time period to avoid such fluctuations but the distribution will not necessarily be appropriate for other periods. It is of note that about two thirds of the orders are delivered in a time less than the average.

Figure 4.8 THE DISTRIBUTION OF ORDER TO DELIVERY TIME

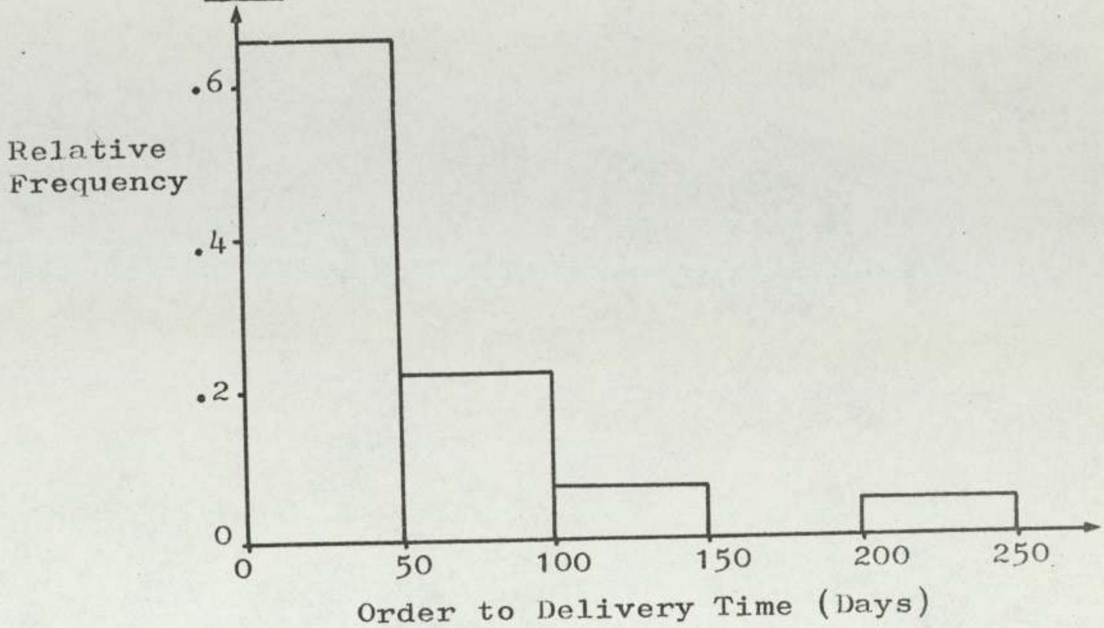
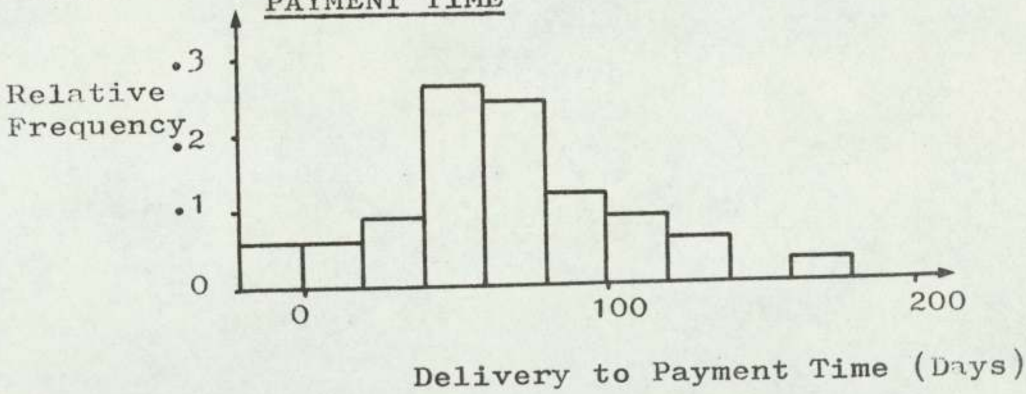


Figure 4.9 THE DISTRIBUTION OF DELIVERY TO PAYMENT TIME



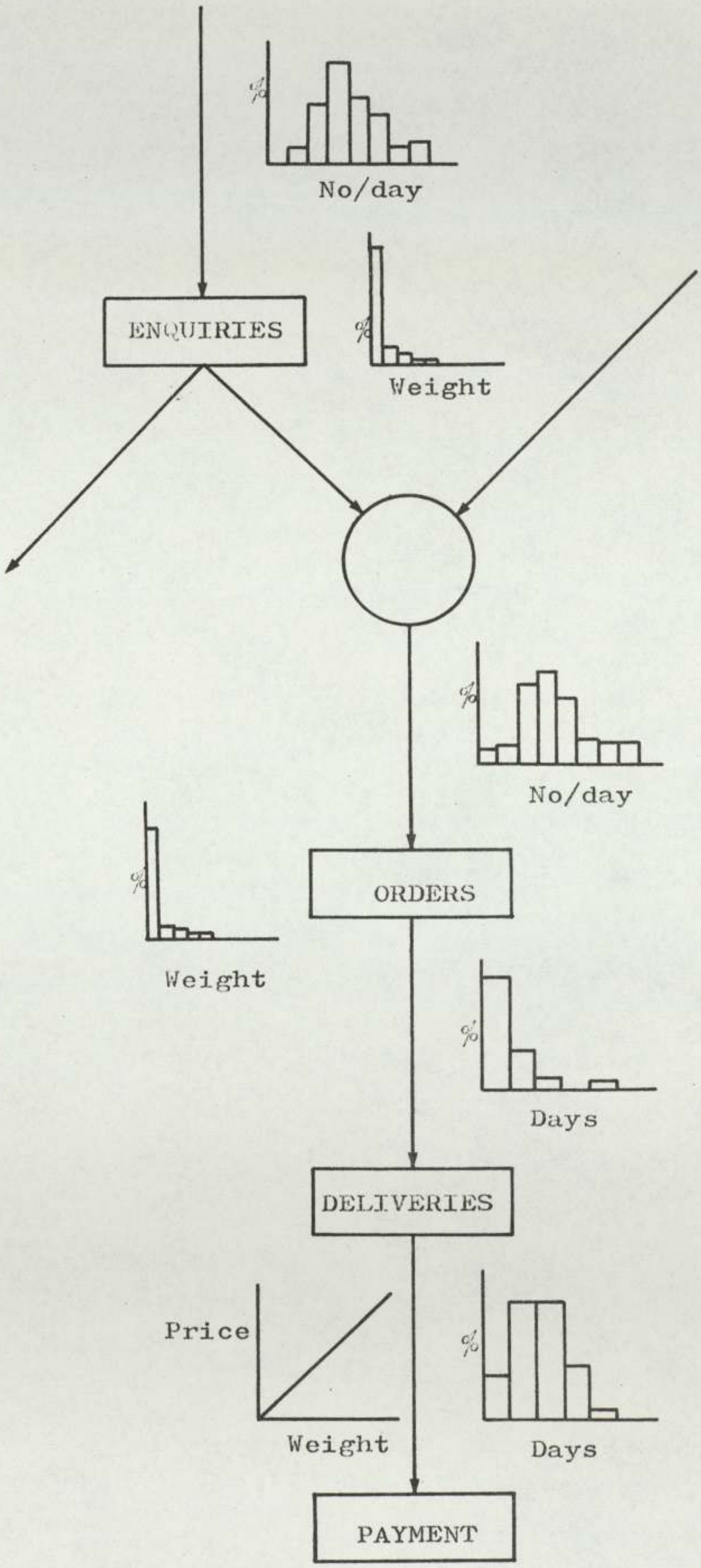
4.4 The Statistical Profile

4.4.1 Combining the Observed Distributions

Figure 4.10 shows in diagrammatic form, the empirical distributions obtained in this study. Each graph indicates a characteristic of the process shown, or of the link between two processes. Since few of the distributions obtained could be characterised by theoretical models, it was not feasible to combine them analytically. However,

Figure 4.10

THE STATISTICAL PROFILE



it would be easily possible to combine these empirical distributions using a simulation technique to show the behaviour of the entire system. This could be done by selecting values at random from each distribution, and thus following enquiries and orders through the system. It would then be possible to compare the behaviour of this system with independent measures of its gross behaviour, such as the monthly value of despatches, prepared by the Accountancy Department.

Such a course was not considered worthwhile as part of this project as it would contribute to neither of the objectives of this part of the work.

However, two exercises of this kind were carried out, since it was apparent that they would give a useful insight into the system, and have immediate uses elsewhere. The theoretical distributions for order to delivery and delivery to payment times were combined using the approach outlined above.[1] This gave a distribution of order placing to payment time which is shown in figure 4.11. Another study was carried out which gave a distribution of cash flow (or payment) attributable to single days (figure 4.12). A sample was taken of the distribution of orders per day. The appropriate number of samples were then taken from the order weight distribution, and for each order, its value obtained by using the regression relationship found

1. The independence of the observed distributions is demonstrated in Appendix A.

between order value and weight. To take into account the spread of points around the regression line, a sample from a normal distribution with the appropriate standard deviation was added to the value. The probability of an enquiry becoming an order was estimated to be 0.38. This was computed using the mean rate of arrival of enquiries and orders, and the relative frequency of enquired orders, out of all orders.

Figure 4.11 THE SIMULATED DISTRIBUTION OF ORDER TO PAYMENT TIME

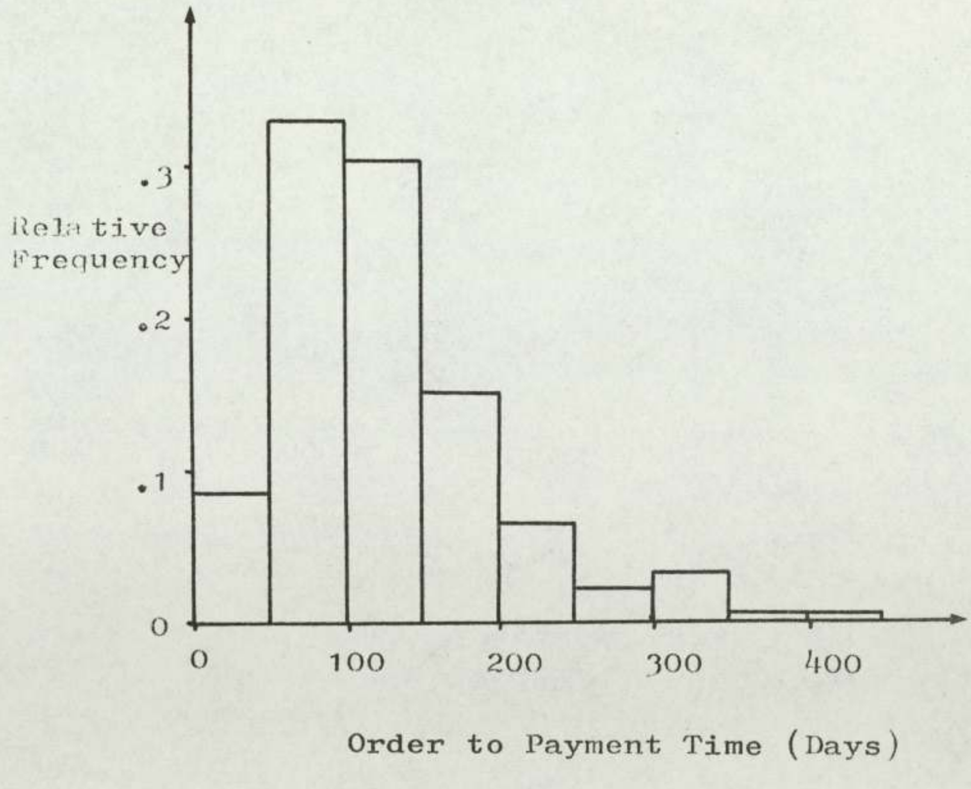
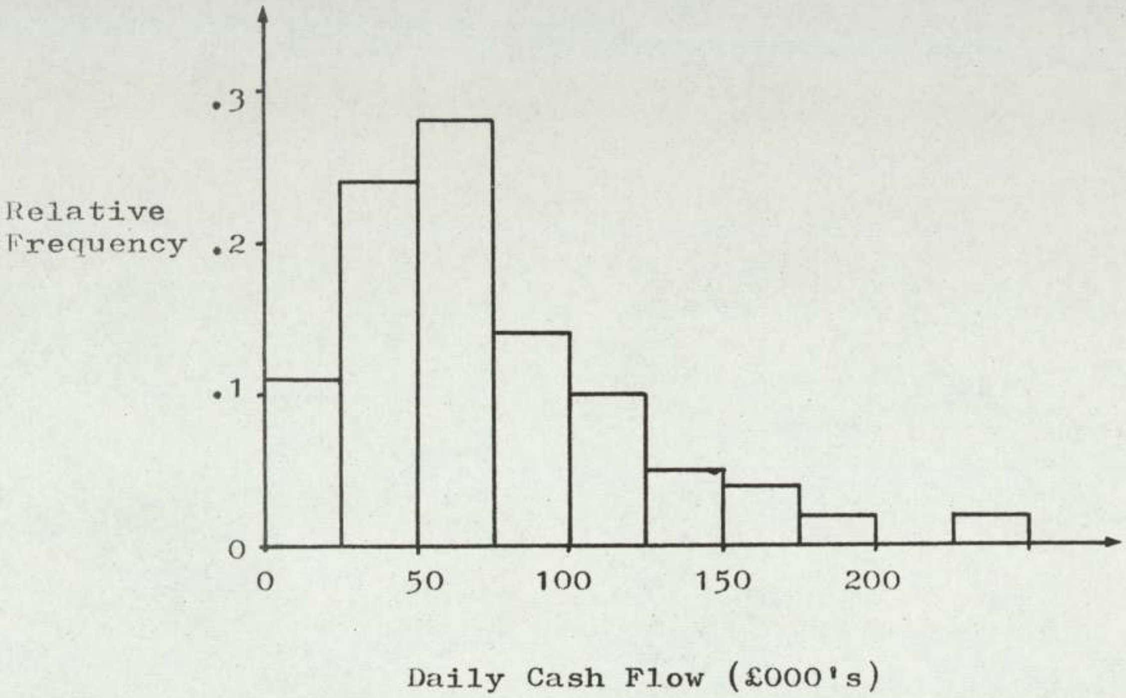


Figure 4.12

DAILY CASH FLOW DISTRIBUTION



4.4.2 Uses of these Findings

This study was aimed at giving the researcher an insight into the behaviour of titanium customers. It achieved this aim. As a secondary objective, it was hoped to identify the factors important to the titanium buying decision. This was not achieved, for two major reasons. No measures could be obtained for some factors, while for others, such as the influence of price on enquiry success rates, a much larger sample would be required to estimate the behaviour. Such a large effort seemed somewhat inappropriate in the context of this project and since there were still going to be factors which could not be measured.

Certain aspects of the work however could lead to improvements of planning and control procedures in the Division. The distribution showing the number of orders and enquiries received on a day could be of use in planning any change in Sales Office organisation: if its capacity is measured by its order and enquiry processing rate, then the capacity required to always give the appropriate speed of processing can be determined. The measures of elapsed time between ordering and delivery afford a useful measure of production lead time. A check could be kept on this quantity to monitor plant efficiency. The delivery to payment time details should be useful in cash flow budgeting. Since the length of these delays directly affects liquidity, it might be considered worthwhile to set up a system for monitoring this aspect of the system. Currently, this information is not made available to the Division. It could be of great benefit to the Division to keep a careful check on the ordering and enquiring pattern of its customers as both the daily frequency, and the sizes of such items are of interest. One way to do this would be to set up statistical control charts. Regular samples of each quantity could be taken. Where the number of enquiries on a given day fell outside a "control interval" set using the empirical distribution, the cause might be investigated. The control limits would be set at levels such that one would be surprised if the number of enquiries fell outside the range, given stable market conditions. One crucial factor of Sales Office procedures is the conversion of enquiries to orders. It would enable more control to be affected on the system, if the variation of the "conversion probability" could be measured, and monitored. It would thus be useful if the record keeping procedures could be changed to note which enquiries become orders.

4.5 Chapter Review

This chapter has described an investigation based on the Division's Sales Office. Enquiries and orders were studied from the point of view of their size and frequency. Time lags from enquiry to cash payment were examined.

The results gave a useful insight into the market, but the investigation was not able to identify and measure all of the important market factors. The distributions obtained gave useful information for Sales Office planning and control, and some worthwhile guides for cash flow budgeting emerged.

CHAPTER 5

A MODEL OF THE INDIVIDUAL TITANIUM BUYING DECISION

5.1 Chapter Preview

This chapter describes the behaviour of the individual titanium buyer in terms of a flow chart of his decision. The development and uses of this model are set out.

5.2 The Need for Such a Model

The major aim of this project was to produce a tool for evaluating realistic business strategies. To achieve realism it appeared necessary to be able to show or model the effects of all the important factors influencing buying decisions. The investigation described in the previous chapter was not clearly able to show the effect of some factors apparently influencing each buying decision.
A different approach was thus required, from the analysis of aggregate buying behaviour. The work described in this chapter thus aims to build up an explanatory model

of the individual buying decision, based on the behaviour of the buyer.

5.3 The Structure of the Model

A literature review of explanatory models of individual industrial buying behaviour forms part of Appendix A. This showed that most models of this type have been constructed by considering the individual buying decision as a series of sequential sub-decisions. Models built on these principles generally consisted of a flow chart with a number of alternative routes through it.

The building blocks of these flow charts generally consisted of either branching or non-branching processes. The path taken out of these blocks branches if it depends on the answer to a given question.

These blocks can be put together to perform various types of behaviour. A survey of decision models (Moore (1969b)) has classified the functions carried out by parts of the models into categorization, choice and computation. Categorization involves each supplier being evaluated against some fixed criterion. Choice involves the selection of some "best" subset of suppliers, while computation is a situation where no alternatives are considered.

One feature of models of this type is feedback or memory behaviour. If a decision is modelled as being dependent on past outcomes as well as current inputs to the decision process, then inertia or loyalty[1] will be apparent in the outcome of successive decisions.

The model of titanium buyer behaviour used a flow chart to describe the activity of the buying centre.[2] Although most work has been done concerning a single individual decision-maker, the model was structured around the decision rather than the decision-maker or makers.

5.4 The Model Building Methodology

Two major techniques have been used to build such models in the reported studies. One method involves the decision makers describing their behaviour to the model builder, by answering questionnaires, being interviewed, or "thinking aloud" while making the decision. The other technique used is for the model-builder to observe the decision-maker at work in his normal environment. These two methods, often used together, serve to model the decision maker's decision rules. Such a study of actual buying decisions would prove difficult in the Division's context.

It was, however, decided that it would be more appropriate to model the perception which the Division sales managers had of their customers' buying behaviour. Although this

---

1 Please see Bubb and van Rest (1973) for a discussion and literature review about the concept of loyalty.

2 The buying centre is that group of individuals exerting an influence on the decision outcome.

would entail possible "errors" from "real" behaviour, it was regarded as superior in two areas: because it would fit in with the managers beliefs, it would stand a much greater chance of being used by them, and it would involve no difficulties in customer relations.

The author made a study of the various files and reports available in the Sales Department. These were scanned particularly for reports of customers' buying behaviour. Table 5.1 indicates the types of comment made in the most appropriate reports. The Monthly Sales Managers' reports were the most useful for anecdotes of market behaviour. These reports were searched for a period of about a year to find all references to competition and buying behaviour of customers. Although the reports presumably consisted of exceptions to the rule, these references turned out to be capable of generalisation. Some 70 anecdotes were collected from these reports. Some typical comments are shown in Table 5.2.

Already the researcher seemed to be getting a "feel" for some of the decision rules which the customer operated.

Next a series of interviews were conducted at which each of the anecdotes were discussed with the appropriate sales manager. His explanation of the behaviour experienced was noted.

Table 5.1

THE MORE SIGNIFICANT ROUTINE SALES REPORTS LOCATED

1. Reports of Representatives to Technical Sales Managers

   Monthly reports from each sales representative, detailing visits, and describing market activity.

2. Sales Managers' Monthly Reports

   These monthly reports describe the important events in the market place, and also pick out instances of competitive activity.

3. Reports of Sales/Commercial and Sales Director's Meetings

   These reports cover the market area generally in a less detailed fashion than those above.

Table 5.2

EXTRACTS FROM SALES MANAGER's REPORTS

1. "Competition
   1) Customer A worried that our industrial dispute should delay material despatches have ordered material from supplier X.
   2) There is a possibility of losing some IMI 155 sheet business at Customer B due to their material shortages because of late ordering."
2. "Concerning competitive activity, we have clearly lost some metal finishing business from Customer C and others during the last year, as a result of our higher prices, and this has gone mostly to supplier Y and supplier Z. We are now offering Customer C special prices for jig section and wire, and this has already resulted in some small orders for wire."

The researcher next described each of the amplified anecdote descriptions in terms of a separate flow-chart. Some examples of these form figure 5.1. These, however, showed only one path through each decision point. A flow-chart was next produced which attempted to generalise from these individual models. Where the individual models were not compatible, decisions based on the customer's identity were used to incorporate the various types of behaviour. By this means a flow-chart was obtained which described general customer behaviour.

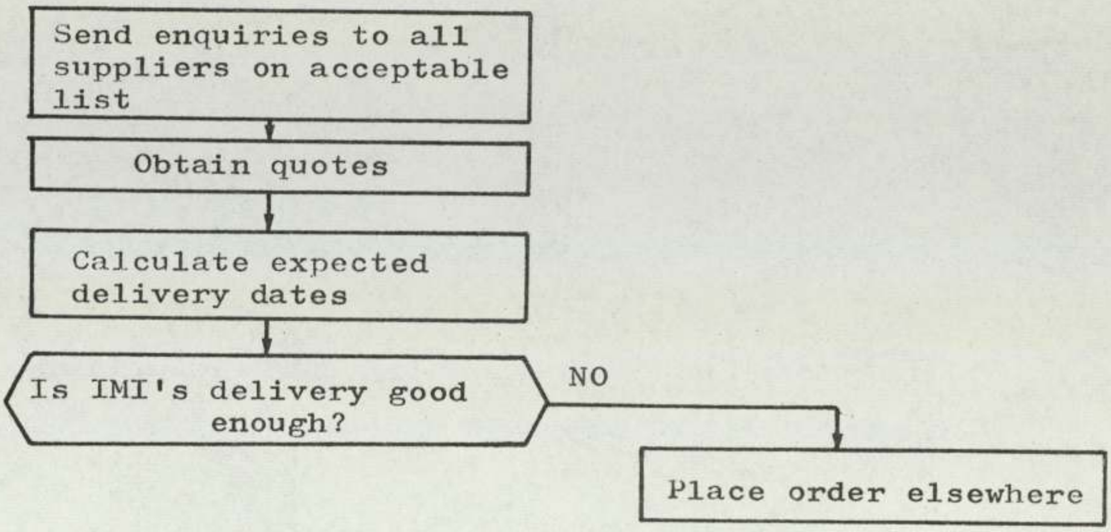
A slightly simplified version of the model was written in prose, and circulated to the sales managers for comment. This description forms figure 5.2. At a further series of interviews the comments made by each sales manager were discussed with him. These suggestions were incorporated into a further version of the model, which forms figure 5.3. By this stage, the sales managers were in a position to agree that the model had generalised from the exceptional cases of their reports, to the behaviour of the "general individual buyer".

5.5 A Description of the Model

The model may perhaps best be described as a "list processing" system. A list is initially set up, using current data, of the acceptable suppliers to the buyer. Enquiries are placed on these suppliers. A list is then produced of quoting suppliers. The quotes are used, along with

Figure 5.1 FLOW CHARTS FOR INDIVIDUAL DECISIONS

Example 1



Example 2

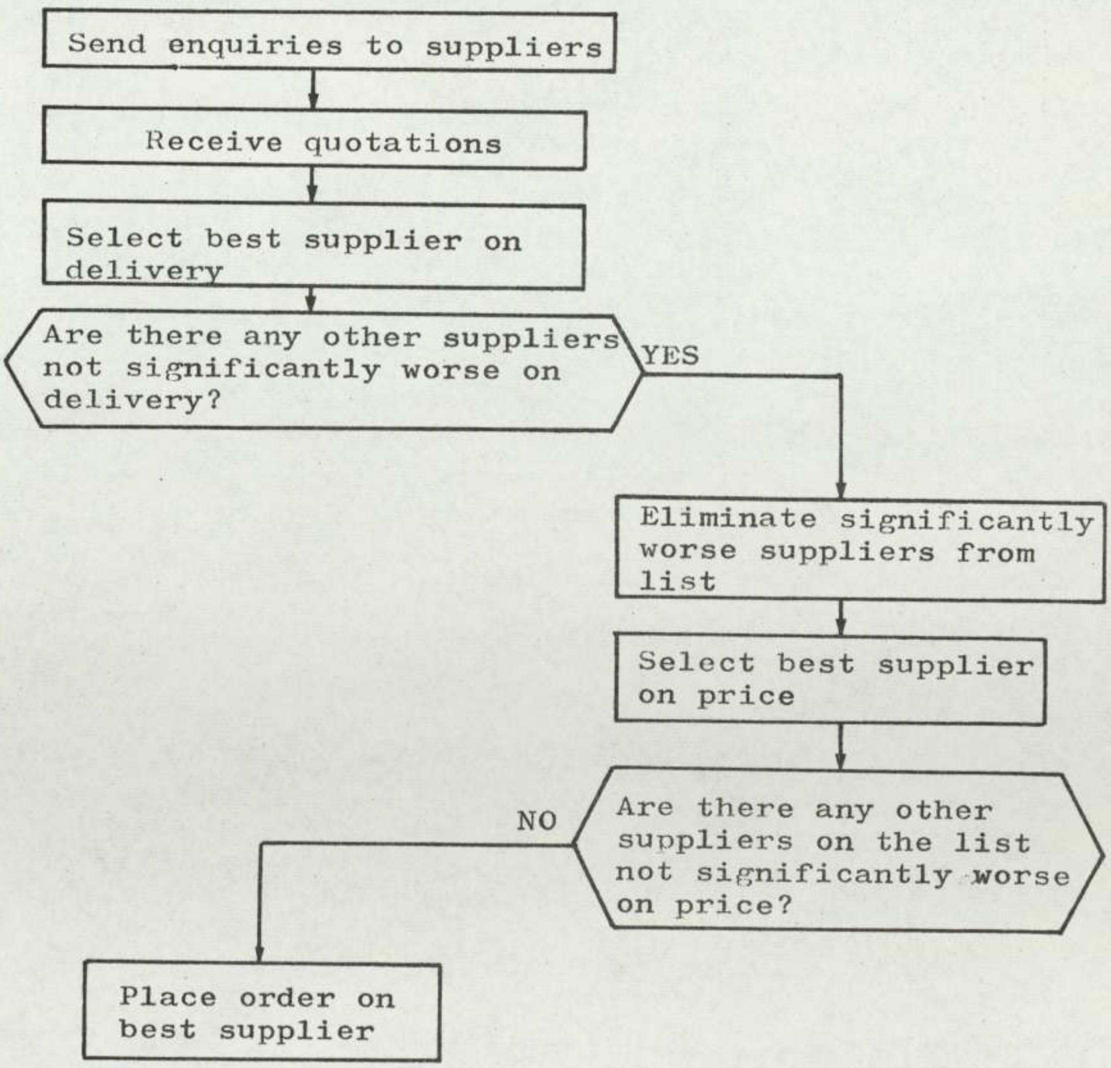


Figure 5.2 VERBAL DESCRIPTION OF PURCHASER FLOW CHART SENT TO SALES MANAGERS

Titanium Purchaser Behaviour

1. I have made the decision to buy a given quantity and product of titanium.

2. I prepare a list of suppliers of this product, from whom I would be willing to buy.

3. Enquiries are made of these suppliers.

4. Quotations are received from suppliers.

5. From these, I calculate when I expect deliveries would actually be made.

6. Eliminate from consideration suppliers who:-
   (a) would be expected to deliver after the deadline, or
   (b) quote a price above my absolute maximum.

7. If there are now no suppliers left, relax these constraints until at least one supplier is acceptable. If only one supplier is left, go to step 12.

8. I make a list of the following factors in order of their importance to me: price, expected delivery lead time, product quality, loyalty to supplier, pressure from my customer.

9. Select the supplier who performs best against the factor at the top of this list. If this performance is significantly better than any other supplier's, go to step 12.

10. Eliminate from consideration those suppliers with a significantly worse performance. Move the most important factor to the bottom of the list. If I have not considered each factor on the list, go back to step 9.

11. If more than one supplier is still being considered, make a list of the preferred suppliers at this stage.

12. Release details of preferred supplier or suppliers to selected suppliers.

13. Receive their response in the form of requoting and activity from their salesmen.

14. If the response was insignificant, place the order with the preferred supplier or suppliers.

15. If I am convinced, alter the expected delivery time from one or more suppliers.

16. If I am persuaded, alter the maximum price and delivery deadline.

17. If I am persuaded, alter my ranking of some of the important factors (in step 8).

18. If I am persuaded, alter the significance level for step 9.

19. Carry out steps 5 to 12 again.

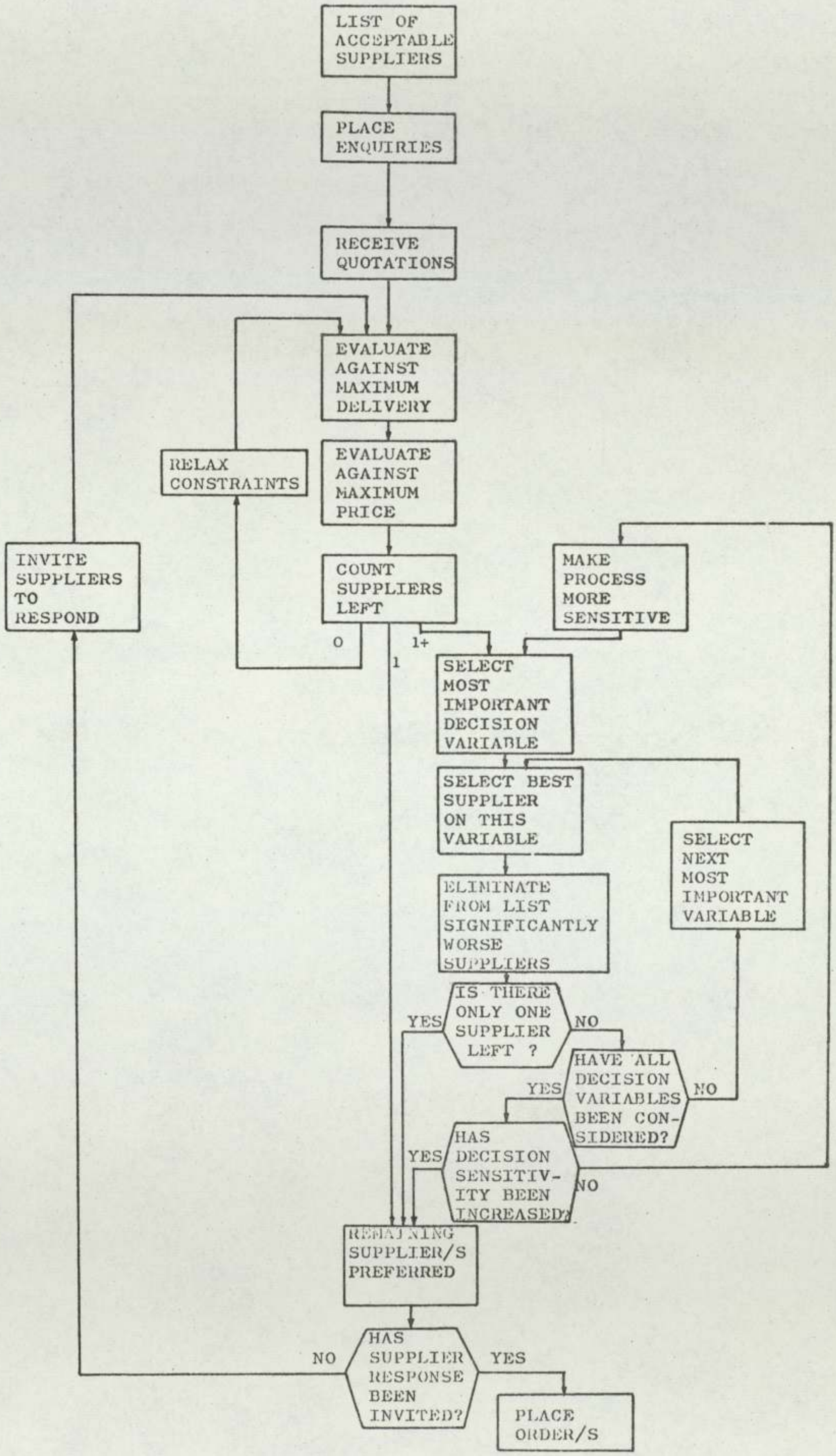
20. Place the order on the preferred supplier or suppliers.

21. Receive titanium.

22. Evaluate supplier against his quotes.

23. Update my impression of his performance and credibility.

Figure 5.3 THE BUYING DECISION MODEL



the customer's requirements, to eliminate those suppliers from the list who do not meet the required delivery deadline, or maximum price.

Providing there is still more than one supplier on the list, further suppliers are eliminated using the following process. Each customer is considered to have a priority decision variable from the following list: price, delivery, loyalty to his customer, his expected product quality, and pressure from his customer for which the order is destined. All suppliers are then compared on the basis of this variable. Those who perform significantly worse than the best supplier are eliminated. The same procedure is carried out for the next most important variable, and so on until either only one supplier remains or the list is exhausted. If more than one supplier remains, the process is repeated with the decision sensitivities increased.

The remaining supplier or suppliers on the list are regarded as preferred. This information is transmitted to the various suppliers who then have a chance to respond, by re-quoting, or persuading the customer to alter his order of importance of decision variables, or persuading the customer that he will perform better than previously expected in some respect.

After the responses have been received from any suppliers, the list processing procedure is carried out in precisely the same way, from the quoting stage onward. After the preferred supplier or suppliers have been determined, the order is spread equally among them.

The flow-chart model was programmed in FORTRAN for use on a computer. It was written with prompts so that it would be suitable for use from an on-line terminal. The major difficulty at this stage was the necessity for refining some quantities (such as loyalty and quality) not previously measured to provide quantitative data for the computer model. This scaling process, although clearly arbitary, was carried out in an intuitively reasonable way. The author's estimates of these parameters were used to check the system with the previously discussed anecdotes.

5.6 Model Validation

Since all the available anecdotes had been used to build the model, it was not immediately possible to check the model against an independent set of market incidents. Two validation procedures were used, however, both of which were appropriate in that they would clearly help to demonstrate to IMI personnel that the model was a reasonable description of reality.

One test[1] concerned the structure of the model: it was discussed with people inside and outside IMI, who agreed that it seemed a reasonable way to structure the decision. For another test, some hypothetical situations were specified to various knowledgable people in IMI, and their expectations

---

[1] This procedure is known as face validation.

of the decision outcome noted. These were compared to the outcomes obtained from the model, and good agreement between the two was noted[1].

It did not seem to be appropriate to estimate empirically the distributions of the decision variables, in order to check the model outputs.

As time progressed, more anecdotes became available from the market. These were checked with the model, and good agreement again obtained.

5.7 The Uses of the Model

The development of this model involved extensive computer programming. The resultant model was straightforward and so would be readily useful to management. In fact two out of three sales managers expressed an interst in using the model for rapid analysis of particular situations. This is seen as its major immediate use.

The model also forms a major part of an extensive simulation model of the titanium market. It is of limited use in isolating the key influences in individual decisions.

5.8 Chapter Review

A model of the general titanium customer was developed after interviews with the Division's sales managers. This shows the customer as working to a list of acceptable

---

1 This test is known as a Turing test, after its originator (Turing (1956)).

suppliers for each order. Suppliers are eliminated from the list if they fail to perform satisfactorily on price, delivery, or quality, or as a result of the customer's loyalty or pressure from his customer. The model was written as a flow chart and programmed for use on a computer.

Its principal uses are as a tool for evaluating individual market situations, and as a component of the titanium market simulation developed later.

CHAPTER 6

THE MEASUREMENT OF COST BEHAVIOUR

6.1 Chapter Preview

Extensive analysis of the Division's cost behaviour leads to an examination of aggregated costs. This is carried out using multiple regression analysis. The results of this analysis are useful for the project and to the Divisional Accountancy Department.

6.2 The Requirement for a Model of Cost Behaviour

The market simulation developed as part of this project requires a model which will indicate the costs of producing different mixes of a small number of product groups. The Divisional Accountancy Department routinely predicted costs for forecast sales mixes, but were reluctant to specify precisely how they did this. Their reason was that the process involved some informal adjustment, based on the accountants' experience. However, the Department felt that its assumptions about cost behaviour could be usefully checked. An exercise to independently assess the behaviour of manufacturing costs was thus conducted with the co-operation of that Department.

The Accountancy Department currently produced its estimates of costs, based on a classification of costs into fixed and variable. Fixed costs are characterised as remaining constant for each period, while variable costs are directly proportional to the appropriate measure of production. The budgeting process involves the aggregation of budgeted costs up to Divisional level, while maintaining the integrity of fixed and variable costs.

From the point of view of this project, some four product groups were required to be treated separately. This level of detail corresponded to that of Divisional level financial statements. So there appeared to be two approaches to obtaining the desired information on product group cost behaviour: either to investigate basic cost information, and aggregate this, or to analyse aggregated data directly. Both methods were attempted, using historical actual cost information.

6.3 Investigation of Basic Cost Information

6.3.1 The Cost Centre Approach

The Division is organised into a series of cost centres. A cost centre budgetary control system is operated in the Division's plants. Actual costs in each plant cost centre are compared quarterly with those bugeted for the year. These costs are broken down into a number of headings. An example of an annual budget forms figure 6.1.

A product standard costing system operates which is based on the annual cost centre budgets. All the plant overhead budgeted costs are allocated or apportioned onto cost centres where production is actually carried out. These budgeted costs are then absorbed (by machine hour) by the products budgeted. Divisional and Company overheads are absorbed directly by products on a per ton basis. In this way, standard product costs are calculated by absorbing cost at each production cost centre in the product route.

The Division had recently developed a linear programming (LP) model. This was designed to indicate the optimal disposition for the Division's production resources.

Figure 6.1 A HYPOTHETICAL ANNUAL COST CENTRE BUDGET
NEW METALS DIVISION

Budget for S.O. 149 - Year 1972, Lathes

	BUDGET 1971	ESTIMATED 1971 ACTUAL	BUDGET 1972	REMARKS
ACTIVITY	62712		81821	Ingot kg
DIRECT WAGES	71458	46632	49707	Different shift pattern
VARIABLE ONCOST				
Indirect wages	18060	10226	11818	
Overtime Prem. & shift allce.				
Labour charges	17380	11144	12170	
Ordinary Maintenance (incl. fork lift truck)	13000	9272	12300	
Consumable stores	11000	8654	13200	£9000 for cutting fluid
Gas				
Water				
Electricity	19900	14270	14920	
Manufacuring steam				
Research Chrgs.		110		
Transport incl. cranes				
TOTAL VARIABLE ONCOST	79340	53676	64408	
FIXED ONCOST				
Salaries			880	
Dependent staff charges				
Funded plant maintenance	625	465	400	
Funded property maintenance				
Insurance				
Rates				
Travelling expenses				
Miscellaneous				
Heating steam				
Control Lab/Rsrch				
Office Cleaners				
Sewing Room & Laundry				
Design charges				
Abnormal Maintenance	2450		500	
TOTAL FIXED ONCOST	3075	465	1780	
TOTAL WAGES & ONCOST	153873	100773	115895	

The model could however be used to determine the financial outcome of producing a given product mix. One of the major inputs required by this model was data on the variable (or marginal) cost absorption rate for each production cost centre.

The intention of part of this project was to come to an independent assessment of the cost accountants' assumptions of cost behaviour. The marginal cost absorption rates obtained from this exercise might then be aggregated using the LP model for different assumed product mixes. This would yield an indication of how total Divisional costs varied with product mix in the detail required.

An accounting procedure known as accounts classification (please see Appendix B for the different approaches which have been used) had been used to determine cost behaviour. A parallel analysis of costs within cost headings was thus commenced. The cost headings into which all cost centre costs were split are indicated in figure 6.1. Three cost headings, (direct wages, indirect wages and consumable stores) and some six cost centres were selected. These headings were assumed by the cost accountants to be respectively variable, fixed and variable.

Figures showing the quarterly costs incurred in each of these headings were available from the accountants' records. However, some difficulty was experienced in obtaining suitable measures of activity in the cost centres concerned. The measure selected was derived from a "payment by results" scheme recently introduced into the Division. As part of this scheme, measures of work output by sections of the factories were available for 28 day periods. In most cases these sections included several cost centres, although in one instance the section was just one cost centre. The payment scheme had been installed around the end of 1969, and the analysis was conducted during 1971. The data was made compatible by adjusting the 28 day output measures to refer to calendar quarters (using linear interpolation).

Graphs were plotted for each cost heading within each cost centre, which showed the appropriate section's output, and the actual costs incurred, for ten quarters. Inspection revealed few obvious relationships between cost and output, either for the same month, or lagged. For the cost headings which appeared best behaved, the costs were plotted against output. The points did not fall very close to the expected straight line.

Both the wage cost headings were broken down into monthly figures, based on data kept by the wages office. With appropriate output data the points were plotted but no linear relationship was apparent. The wage payment system was then examined in rather more detail. Direct wages and some indirect wages were paid using a group payment-by-results system. This involved the calculation, for each 28 day period, of an index of production for each section. The wages were paid in a given week, based on the hours attended during the previous week, at an hourly rate determined by the latest 28 day index. The index formed a linear measure of work output, but the hourly wage rates did not bear a linear relationship to the index.

Various attempts were made to demonstrate a linear cost/output relationship. The first stemmed from the observation that wage payments in month t were determined by the index in month (t-1) and the hours worked in month t. The output in month (t-1) was related to the index in that month. The hours worked in month t were likely to be related to the output in that month. Thus the wages cost in month t was plotted against the product of outputs in months t and (t-1), for all the available data. This yielded no useful relationships. Wage payments were adjusted to their effective rates at a constant index as a further approach. Also outputs were adjusted to a constant level, but still no useful models became observable.

It was possible to break down the indirect wage costs into their component parts. Each was examined for a linear relationship with output, but none emerged.

The costs classified as consumable stores included machine lubricants and other items expected to be used in direct proportion to the output. A plot of cost against output did not give an obvious straight line however. One hypothesis for this failure was that the operators might keep local stocks, so moving average costs were plotted against output. This gave only marginally better results.

These disappointing results suggested that it would be more productive to examine the behaviour of costs aggregated to some level. It appeared that if output measures could be found which were more appropriate than those used this would improve the usefulness of the work.

6.3.2 Behaviour of Total Costs in Cost Centres

The investigation of aggregated cost centre costs was carried out using the same six cost centres previously studied. Aggregations of costs were used at two levels: the total costs incurred in each cost centre, and the total fixed and total variable costs within these. These actual cost figures were only available quarterly, since much of the information used in their preparation was derived from somewhat inflexible computer systems.

There seemed to be no alternative to the use of the output measure from the payment by results scheme. These measures tended (as noted earlier) to be effectively averages over several cost centres.

Initially the behaviour of costs with output was studied graphically. The points plotted (of cost against output) suggested that a simple relationship between cost and output might well exist. It was not clear whether a straight line or a curve would best describe the underlying relationship. It was therefore decided to use a computer polynominal regression program to fit various relationships to the data. For each cost centre studied relationships of the following forms were assumed in turn:-

$$C = a$$

$$C = a + bW$$

$$C = a + bW + cW^2$$

$$C = a + bW + cW^2 + dW^3$$

where C represents the cost, W the output measure, and a, b, c and d constants. The computer program, for each assumed relationship, obtained the estimates of parameters a, b, c and d by a least squares technique. It also calculated some statistics[1] which were used to examine the quality of the fit of the relationship to the data. In general, the quadratic and cubic curves did not fit the data significantly better than the straight line.

---

1 The principal uses of these were in evaluating the improvement of fit observed as the more complex relationships were used. F-tests were used for this purpose.

The coefficient of determination (R^2) of each fit was also examined. Since there were only 10 observations this coefficient was artificially increased with the complexity of the assumed relationship. The values were corrected using a method described by Huang (1970):-

$$\bar{R}^2 = 1 - (1 - R^2)\,\frac{n - 1}{n - k - 1}$$

where $\bar{R}^2$ is the coefficient of determination, corrected for degrees of freedom, n the sample size and k the degree of the polynominal. The $\bar{R}^2$ represents the proportion of the variance in the data which is accounted for by the relation used.

The curves did not seem suitable for describing the cost behaviour since outside the range of the data, they tended to follow intuitively unreasonable paths. Wide ranges were indicated, for, say, the 95% confidence limits.

It was felt that possibly inflation was a factor influencing cost behaviour. An appropriate price index was thus selected (the index of wholesale prices input to manufacturing industry) and a multiple regression program used to fit the following models to the data:

$$C = a + bW + cI$$

$$\text{and } C = (a + bW)\, I \quad \text{———— A}$$

where C represents the cost, W the output, I the index, and a, b and c the model parameters. These relationships fitted the data much better than the previous attempts.[1]

The major drawback of this approach, for predicting costs, was that the Government index used was not available for several weeks after the end of the quarter concerned. It was thus not easy to use the relationships established for control purposes. A time series was therefore sought which could be used in this relationship, but lagged, so that the appropriate figure would be available well in advance. Three such time series were seriously examined, and, of these, U.K. car production (after Coen et al (1969))

---

1 The fits were compared using coefficients of determination (R^2). The second of these relationships had more degrees of freedom than the first and consistently gave R^2 higher than .8.

and U.K. bank advances chosen for detailed examination. These two time series were each used instead of the index in relationship A. Each series was lagged by between 1 and 12 quarters.

The case which gave one of the best fits[1], and was acceptable from a causal point of view was U.K. bank advances, lagged by 3 quarters. A test on the data revealed no seasonality.

Using this lagged relationship, all the various costs under study were predicted. In general this regression approach gave rather closer predictions than the traditional accounting approach.

6.3.3. Cost Absorption Rates

The work on individual production cost centre costs appeared likely to be useful in the budgetary control process. It did, however, suffer from one major disadvantage when being used to provide input data for the LP. The use of the accounting conventions when apportioning overhead cost centre costs looked as if it might swamp the underlying behaviour of the costs.

The rates were calculated in the following way. The set of plants cost centre budgets were taken, and by a process of allocation and apportionment, all costs shown against one of the production cost centres. In general, after all

---

1 The values of the coefficients of determination were used to find the best fits.

directly attributable costs were allocated, the other costs in overhead cost centres were spread arbitrarily out over the cost centres (of both types) which they were regarded as serving. The bases for these apportionments were either direct wages, personnel, or floor area. Throughout the process, the Accountants' fixed/variable assumptions were recognised (although the majority of apportioned costs were fixed). Thus, it was possible to form "gross" production cost centre budgets. The total budgets were divided by the predicted machine hours in each production cost centre, to obtain hourly absorption rates. These rates were split into the variable and fixed elements. Since no comparison was made between actual and standard absorption rates, it was not possible to evaluate them directly. The apportionment process was the only (implicit) definition of overhead cost behaviour.

It was feasible, however, to apply the linear assumption about cost behaviour to actual costs. It seemed reasonable to propose the model:-

$$C = a + bH_1 + cH_2 + \dots\dots\dots\dots pH_n$$

where, C represents the total cost for the whole plant in a given time period, and the H_is the machine hours used in each production cost centre i. The total fixed cost for the period is represented by a and b, c .... p represent the variable cost absorption rates in each of the n production cost centres.

If a large enough stream of data could be assembled, of values of C and the corresponding Hs, the parameters a, b, c .... could be estimated statistically using multiple least squares regression. In practice there was not enough data for this to be carried out. The concept did, however, prove applicable. An independent part of the factory was selected with four production cost centres. Machine hours figures were obtained for those cost centres for some 12 quarters. The total costs (deflated using a price index) were obtained for all (overhead and production) cost centres in that sector of the factory. Values for the model parameters were obtained using a multiple least squares regression package.

The analysis demonstrated that it was possible, in principle, to measure the actual cost absorption rates. The factory could be split into a set of independent blocks, and each treated separately. The fixed costs were not attributable in any way to the output by this analysis.

The pilot study did not convince the Plant Accountants of the advantage of using this technique for two major reasons. The multiple regression analysis did not offer any help in apportioning fixed costs, and the confidence intervals were wide on the calculated cost rates. The second objection will hopefully be overcome by an exercise to break down the data into monthly figures. However there seems little point in carrying out such an exercise until the first obstacle can be overcome.

There are, however, convincing reasons why this approach could be worth using in some environments[1]. The process will enable a saving of effort compared to the traditional approach, and yields statistically more reliable results.

6.3.4 Use of Low Level Cost Behaviour Data

Although this approach, i.e. to measure low-level cost behaviour by multiple regression, and to use those results as input to the LP model seemed promising, it involved a great deal of work in obtaining the data for analysis.

Neither the author nor the Accountancy Department were able to devote the time required to complete the data collection task so that the results would be available for other parts of this research project. This factor led to another approach being used to model the production cost behaviour of the Division.

6.4 Determination of Cost Behaviour using Aggregated Financial Data

6.4.1 The Accountancy Approach

The Divisional Accountancy Department frequently made forecasts of costs for the Division as a whole.

Their approach to predicting how costs would vary with differing output, was to use the Division's annual budget. This was an aggregation of the budgets for all the cost

---

1 The case is made more fully in Bubb and Smith, (1972b).

centres in the Division. The profit forecast (i.e. the Divisional budget) statement issued by the Accountancy Department showed costs in some 20 categories. They were classified into fixed and variable costs on this statement.

The total product range (for which one summary statement was issued) was broken down into 5 product groups. So profit (or loss) was shown for each product group. To estimate results for levels of activity other than those initially budgeted for, the Divisional budget was flexed. However, it was not flexed in the "normal" way, by keeping the " fixed" costs constant and adjusting the "variable" costs in direct proportion to the activity. The "fixed" costs were broken down into two parts, one of which was flexed while the other was not, and the same procedure used on the "variable" costs. The accountants were thus acknowledging that their "fixed" and "variable" classifications were not accurate so far as total costs were concerned. In fact they readily admitted that they were not too sure how costs were really influenced by output. Hence the investigation of cost behaviour at Divisional level was of interest to the accountants and they were keen to be involved.

6.4.2 The Data Available

As part of the Division's management control system, quarterly statements are prepared forecasting financial results. Actual results are reported quarterly and annually for comparison with these. Figure 6.2 gives a hypothetical

Figure 6.2 **A HYPOTHETICAL STATEMENT OF ACHIEVED FINANCIAL RESULTS**

MAIN TRADING ACCOUNTS

NEW METALS DIVISION

TRADING RESULTS FOR 12 MONTHS TO DECEMBER 1972

	Total Ti & Zr		Titanium Sheet		Titanium Rod		Titanium Other & Hire Work		Zirconium		Special Metals	Total Inc. Special Metals	
SALES WEIGHT (Kgs)	137,000		14,000		79,000		42,000		2,000		-	137,000	
	£	£/lb	£	£/lb	£	£/lb	£	£/lb	£	£/lb	£	£	£/lb
SALES REALISATION	168,000	1.226	28,000	2000	13,000	.165	79000	1.881	48,000	24.000	22500	190,500	1.391
Less Variable Selling	16000	.117	2000	.143	1000	.013	7000	.167	6,000	3.000	2500	18,500	.135
NETT SALES INCOME LESS DIRECT COST	152000	1.109	26000	1.857	12,000	.152	72000	1.714	42,000	21.000	20,000	172,000	1.255
Metal	85500	.624	14500	1.036	5500	.070	37000	.881	28500	14.250	2000	87,500	.639
Less Scrap Profit	10500	.077	1500	.107	500	.006	7000	.167	1500	.750	-	10,500	077
Nett Metal	75000	.547	13000	.929	5000	.063	30000	.714	27000	13.500	2000	77,000	.562
Direct Wages	34500	.252	2500	.179	2000	.025	14000	.333	16000	8.000	4500	39,000	.285
Oncost (part)	5700	.042	1700	.121	500	.006	2500	.060	1000	.500	200	5,900	.043
Premiums	2800	.020	1300	.093	-	-	1000	.024	500	.250	300	3,100	.023
Tools	2600	.019	500	.036	500	.006	1000	.024	600	.300	400	3,000	.022
Packing & I.W.T.	3900	.028	1000	.071	500	.006	2000	.048	400	.200	200	4,100	.030
S E T / R D G	(7400)	(.054)	(500)	(.036)	(400)	(.005)	(3000)	(.071)	(3500)	(1.750)	(900)	(8,300)	(.061)
Excess Premiums	3100	.023	1500	.107	600	.008	1000	.024	-		-	3,100	.023
Extramural Costs	3300	.024	2000	.143	800	.010	500	.012	-		-	3,300	.024
TOTAL	123,500	.901	23000	1.643	9500	.120	49000	1.167	42000	21.000	6700	130,200	.950
CONTRIBUTION	28,500	.208	3000	.214	2500	.032	23000	.548	-	-	13300	41,800	.305
LESS FIXED CHARGES													
Oncost (Part)	4700	.034	1500	.107	200	.003	2500	.060	500	.250	200	4,900	.036
Depreciation	3100	.023	500	.036	300	.004	1700	.040	600	.300	300	3,400	.025
Overheads	3800	.028	1000	.071	300	.004	2300	.055	200	.100	100	3,900	.028
R & D	5200	.038	500	.036	-		4000	.095	700	.350	500	5,700	.042
Selling Expenses	4300	.031	600	.043	200	.003	2000	.048	1500	.750	200	4,500	.033
Royalties	(1400)	(.010)	(300)	(.021)	-		(600)	(.014)	(500)	(.250)	(100)	(1,500)	(.011)
Management Services	2800	.020	700	.050	300	.004	1600	.038	200	.100	300	3,100	.023
TOTAL	22,500	.164	4500	.321	1300	.016	13500	.321	3200	1.600	1500	24,000	.175
PROFIT FOR 12 MONTHS	6,000	.044	(1500)	(.107)	1200	.015	9500	.226	(3200)	(1.600)	11800	17,800	.130
TOTAL PROFIT FOR 12 MONTHS TO DECEMBER 1972	6,000	.044	(1500)	(.107)	1200	.015	9500	.226	(3200)	(1.600)	11800	17,800	.130

example of one of these statements of achieved results. Sales weight and realisation are reported, along with costs, broken down into a substantial number of headings. Separate accounts are produced for the different product groups, and these accounts are summarised at various levels of aggregation of the product groups. Figure 6.3 shows the product groups, with their aggregation for financial reporting.

Actual quarterly cost data was obtained from these statements for some six years. The "Wholesale Price Index of Inputs to the Mechanical Engineering Industry" was obtained for the same quarters. A further measure of inflation was obtained; the price paid for the Division's major raw material (titanium granules) over the same period.

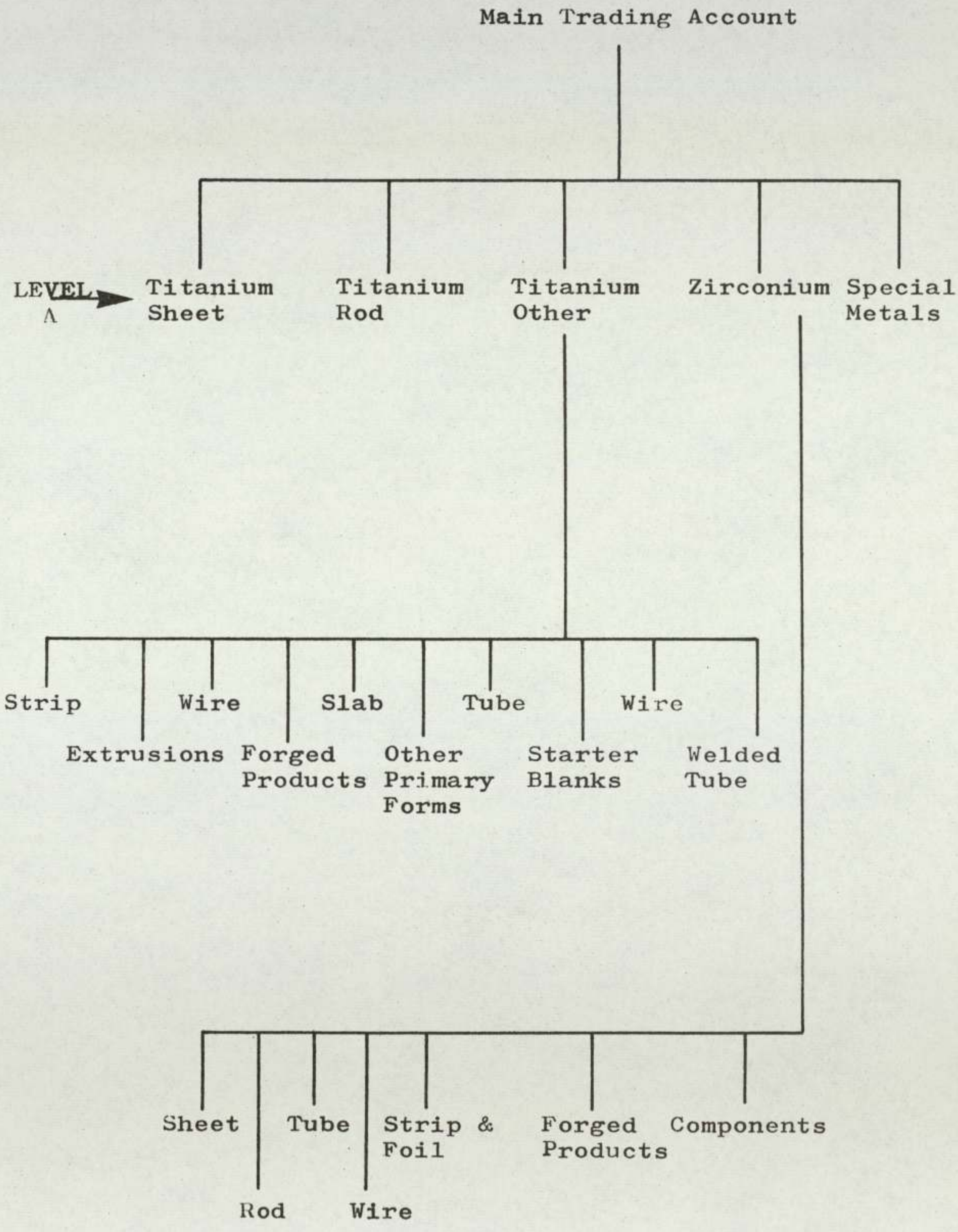
6.4.3 The Analysis Performed

The most appropriate method of analysing of the available data seemed to be multiple least squares regression. For any particular cost heading (e.g. wages), a relation was postulated of the form:-

$$C = a + b_1W_1 + b_2W_2 + \dots b_nW_n$$

Where C represents the cost; a, the "fixed" element of it; the b_is the marginal cost rates associated with the W_is , the sales weights in product group i. It appeared that this model would be most compatible with the market model

Figure 6.3 THE BUILD-UP OF PRODUCT GROUPS FOR FINANCIAL STATEMENTS



(described elsewhere) if a small number of product groups were used for the analysis, and accordingly, four were chosen (level A in Figure 6.3).

This approach would have the advantage that it would carry out its own assignments of costs to product groups.

The appropriate figures were used as input for a computer multiple regression package. Since it appeared that cost inflation might confound any underlying relationship the cost data was initially deflated using the wholesale price index. In a later version of the analysis, an attempt was made to account for inflation using indices calculated directly from the Division's own experience.

6.4.4 Results of the Analysis

The regression results showed some strong relationships between costs and sales weights. These were in some cases markedly different from the assumed cost behaviour which the accountants had used in preparing forecasts of financial results. Comparison of costs estimated by regression with actual costs and those forecast by the Divisional Accountancy Department showed that the regression yielded rather more reliable estimates than the Accountancy Department were able to produce.

A summary of the relationships obtained is shown in Table 6.1.

Table 6.1

REGRESSION RESULTS FOR DIVISIONAL FINANCIAL DATA

COST		TOTAL "FIXED"	TOTAL "VARIABLE"	TOTAL COST
"Sheet" regression coefficient	'S'	1.917	3.969	5.886
standard error[1]		.566	1.423	1.560
"Rod" regression coefficient	'R'	- .920	3.367	2.448
standard error[1]		.447	1.124	1.232
"Other" regression coefficient	'O'	.209	2.488	2.698
standard error		.132	0.331	0.363
"Zirconium" regression coefficient	'Z'	-41.835	2.692	0.857
standard error		1.313	3.301	3.620
Intercept	'I'	353000	364000	717000
standard error		5690	14300	15700

The estimate of cost, £C, is given by:-

$C = ST_s + RT_r + OT_o + ZT_z + I$ where T_s, T_r, T_o, T_z are tonnes sold of sheet, rod, other and zirconium.

---

1. In general, there is about a .95 probability that the estimate will lie within two standard errors of the true value.

6.4.5 Uses of these Results

The relationships obtained were primarily of use in this project. However, the Accountancy Department found the results useful since they predicted total costs well. The analysis was carried somewhat further at their request, and cost relationships were obtained for each separate cost heading. A system was designed which produced forecast financial statements given sales weight forecasts, using an on-line computer. A control scheme was also developed to keep these regression relationships up to date[1].

6.5 Comparison of Low and High Level Cost Analysis

6.5.1 Level of Detail

The two approaches both aimed at giving cost behaviour in a suitable level of detail to fit in with the marketing model in this project. The analysis of Divisional financial summaries yielded the appropriate level of detail directly. The cost centre work did not give the required level of detail immediately, but it was originally hoped to obtain it through the LP or some other aggregation process.

6.5.2 Assumptions Necessary

Several assumptions were necessary for least squares regression techniques to be used for analysing the cost data. For the most part these assumptions were identical at low

---

1 This is described in Appendix B and in Bubb, Hussey and Smith (1973).

or high levels of cost aggregation. The differences mainly arose from the accounting procedures. Where a relation was obtained for each cost centre by regression, and then several of these relations summed to derive cost behaviour for the group of cost centes, the errors (between recorded and predicted costs) must be statistically independent. In the work in the Division, the available data was not considered sufficient to make any testing of such independence possible.

With multiple regression used on total Divisional level data, this problem did not arise. It is important that costs in a time period relate to the output measured for that time period. Whilst this assumption was not investigated in any detail, it is an accounting convention that this correspondence applies in financial statements. While this assumption was largely taken for granted because of the accounting convention, it seemed rather more plausible at Divisional than cost centre level.

6.5.3 Implementation

Within the timescale of this project, it was not possible to work through the complete factory carrying out regression at cost centre level. The accountants were not convinced of the case for relying solely on multiple regression for apportionment of overhead costs. They consequently did not devote much effort to the implementation of such a system.

At the more aggregated level, however, the Divisional Accountancy Department was more interested. Effort, and money (computer time) was forthcoming from this section to develop a system of continuous measurement of cost behaviour. A system has been developed which regularly updates the equations describing each cost on the profit forecast, and enables a new financial forecast to be rapidly prepared given any new sales weight forecast.

6.6 Chapter Review

Analysis of cost centre costs using regression techniques yielded suggestions for a revision of the cost apportionment procedures. Although useful results of cost behaviour were obtained, such analyses did not directly yield results helpful in the titanium market simulation. Analysis of aggregated costs had led to useful relationships for the market simulation. This work also led to a cost forecasting and monitoring system in use by the Divisional Accountancy Department.

CHAPTER 7

A TITANIUM MARKET SIMULATION

7.1 Chapter Preview

A simulation model of the titanium market is developed. This is largely based on the buying decision and cost models described earlier. The simulation model can be used to make studies of various sectors of the titanium market.

7.2 The Need for Such a Model

A simulation model for the titanium market represents the focal point of this research project for two major reasons. It is the method used to draw together all the other work in this project, and it performs the main task of the research: that of providing a strategic planning tool. Since the development of an analytic description for the titanium market did not appear feasible in the appropriate breadth and detail, a simulation approach was selected.

Since any strategies which might be considered would involve the interaction between suppliers and customers in the market, and sales and production functions within the firm, a model was required which would take account of each of these interactions. As the titanium market consisted of a small number of suppliers, it was necessary to model each of these separately. The simulation model would also be useful in further validation of the model of the buying decision.

7.3 The Structure of the Simulation Model

The model was initially structured on the European market for titanium. It was designed so that it would be possible to use it in any other market with a similar structure so that it could be used to analyse world markets and the markets for specific titanium products.

Although the structure of the model is based on that observed in the actual market, a number of simplifications had to be made to reduce the model to a manageable size. The model is based on representations of several titanium suppliers and a number of market sectors. Communication occurs between each supplier and each market sector. This communication is effected by the enquiring, quoting, ordering, delivering and payment processes, each depicted in the model.

The passage of time is modelled as discrete steps, each representing one month of "real" time. The complete order placing process from enquiry to order placement is completed within a single month. This, apparently coarse, description of time is justifiable for two reasons: the major interest of the model is its long term behaviour, and tests[2] have shown that this behaviour is not sensitive to the choice of time-scale.

Customers are represented in the model in terms of monolithic market sectors, In each month, each sector can only place one order for each of a small number of products[1].

---

1 These "products" are taken to represent groups of similar products.

2. The tests referred to were carried out in an adaptive fashion, as model development progressed. The model was initially written using a one-week timescale. As development proceeded, it became apparent that action was required to reduce the running time of the computer program. The model was then redesigned with a time-scale representing one month. It was found possible to obtain precisely the same annual summary data from the redesigned model as with the weekly version. This action constituted the test, which is in some ways similar to a sensitivity test.

Work in information theory (Shannon (1948)) suggests that if the interest is in annual statements, as here, an internal frequency is adequately high if it is at least twice the annual frequency. Thus one month is quite fast enough from that point of view.

The model, described in Chapter 5, for the individual buying decision is used directly for each market sector's decision. This simplification is reasonable since if one order is placed of weight equal to the sum of two other ones, and all the decision parameters are the same, the outcome of the former will be the same as the sum of the outcomes of the other two.

These two major simplifying assumptions are made to economise on storage and running time when the model is implemented as a computer program.

The total annual demand for each market sector is derived externally and is an input for the model. This ensures flexibility so that different market sectors can be depicted. This has also been done because it is not clear whether automatic sales forecasting is as effective as the experts' forecasts already prepared by the Division. This approach means that the decision whether to purchase titanium or a competing material is never specifically considered within the model. The buying decision thus becomes simply the process of source selection.

In each month, each market sector carries out this routine:-

1. Send enquiries to suppliers for each product.
2. Receive their quotations.
3. Select (and communicate) the preferred suppliers.
4. Receive any response from suppliers.

5. Select preferred suppliers.
6. Place order/s.
7. Receive any deliveries.
8. Update impression of suppliers.

Each supplier carries out the following sequence:-

1. Receive enquiries from market sectors.
2. Decide whether to issue quotations.
3. Issue quotations.
4. Receive information about sectors' preferences.
5. Apply sales pressure.
6. Receive any orders.
7. Manufacture and deliver any orders.

The model depicts all of these processes, and a number of other less important actions. Periodically, summaries of order placing and financial behaviour of the suppliers are produced.

The model was developed as a program for use on the University ICL 1905E computer. The extensive programming was mainly carried out in FORTRAN. This helped to speed up the program development, and made the program easily transferable to other machines.

The program was written as a set of modules, or sub-programs, each of which described part of the market, so it was a simple matter to carry out "experiments" with the model, by merely altering sub-programs, or the interconnections among them. The modular concept was later extended, so that a "library" of alternative sub-programs is now being built up.

Various output was derived from the model, to show behaviour in the market. The principal output consisted of regular reports on the financial behaviour of the suppliers to the market. These were designed to be in a form immediately useful to IMI's management.

7.4 Construction of the Model

Since the structure of the model has already been described, as a set of interconnected modules, this section is essentially devoted to description of the various modules themselves.

7.4.1 Demand Quantities

The mean monthly demand of each market sector for each product group is input externally to the simulation model. These quantities change each year. The actual demands of each sector are selected by sampling from a normal distribution whose mean is equal to the figure input. This random "noise" is intended to model the effect of differing quantities being required at different times by the actual customers. The use of the normal distribution follows from[1] aggregating a number of size distributions as in Chapter 4.

---

1 This approximation appeals to the Central Limit Theorem for its justification.

7.4.2 Supplier Selection

The model for the behaviour of an individual customer for titanium which is described in Chapter 5 is used in this process. The customer model is used as if each market sector was a single customer. The tendency is therefore for the monthly demand from each sector for each single product to be satisfied by a single order placed on one supplier. In each month the supplier selection routine is used by each sector once for each product group which it requires.

The parameters which are used to define the customer's behaviour are, in general, updated during the course of the simulation.

7.4.3 The Quoting Model

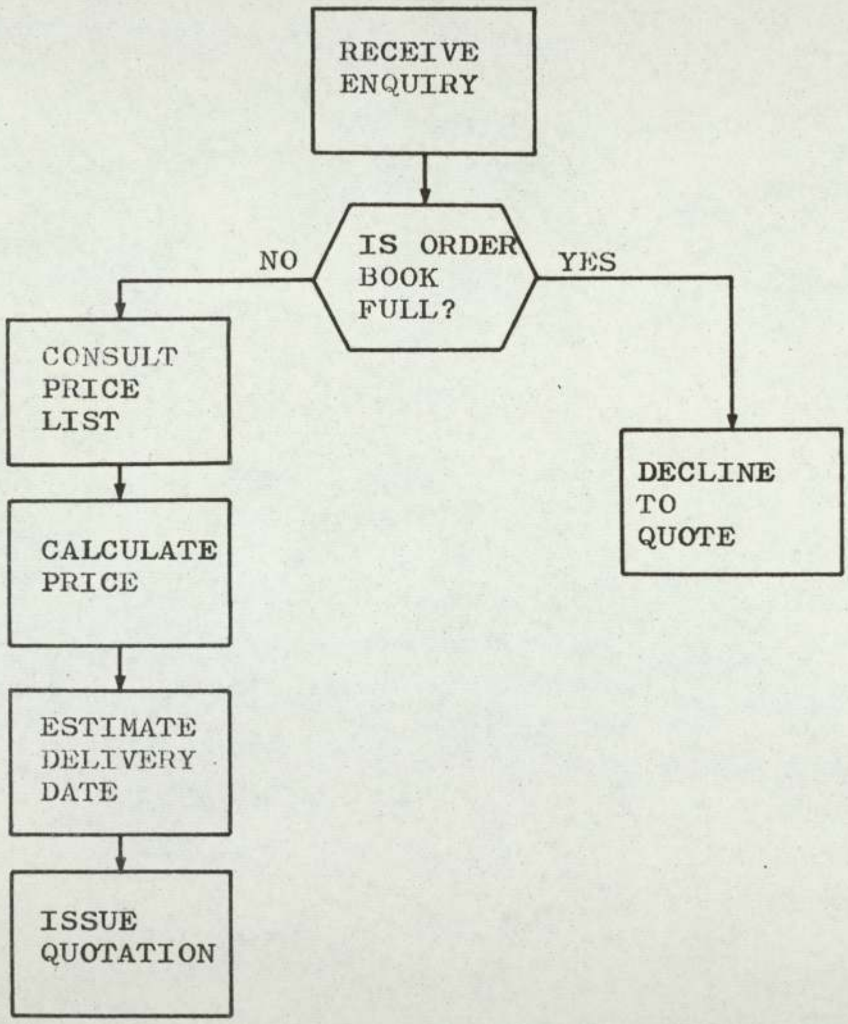
This is based on the behaviour observed and described in Chapter 4. The following rules describe the model which shows the quoting behaviour of each individual supplier. When an enquiry is received, count the number of current orders on the order book. If the book is full, decline to offer a quotation[1]. Otherwise, estimate the delivery lead time from the orders on hand, and look up a price for the current product group, adding some

---

1 This check is only used to limit the computer storage required by the model.

normally distributed "noise"[1] to obtain a unit price (i.e. £/kg). Issue this price and delivery indication to the customer as a quotation. This process is summarised in figure 7.1. The sizes of the suppliers' order books are large, so suppliers normally do issue a quotation.

Figure 7.1 THE QUOTING MODEL



---

1 This is added to model the effect of differing product prices within the product groups, and also of varying price quotations among suppliers. It is normally distributed for the reason discussed with demand weight. In fact, the price will never be below the marginal production cost.

7.4.4 The Sales Response Model

This model is shown in figure 7.2. It was obtained in a similar fashion to the customer behaviour model, by constructing flow charts to describe some real market incidents discussed with the sales managers. The model takes the following action (from the point of view of each supplier).

1. Decide whether the order is large enough to be worth applying sales effort.

   If not, Go to Step 8.

2. If so, Determine if I am the single preferred supplier.

   If not, Go to Step 4.

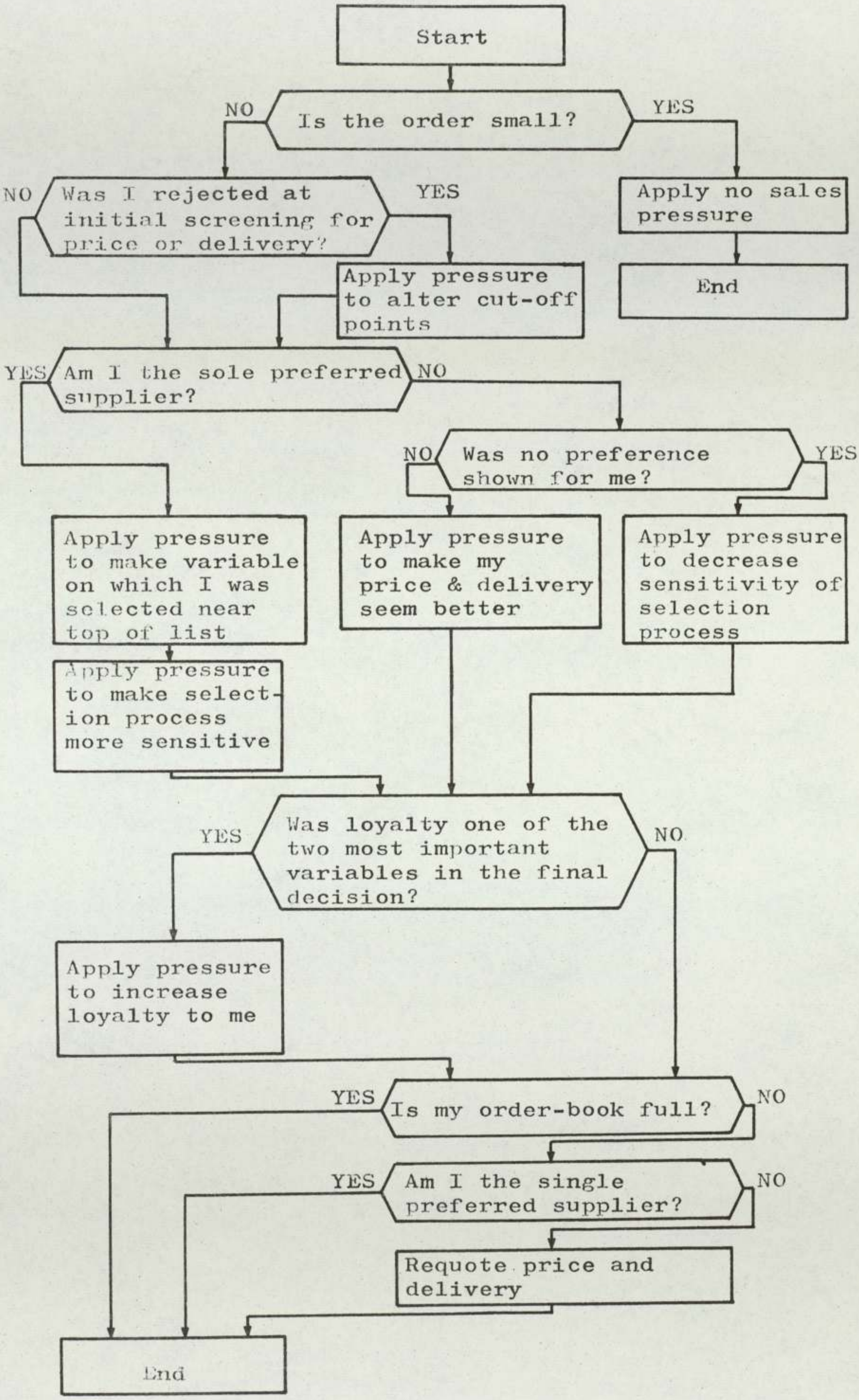
3. If so, Apply pressure to move the deciding factor (out of price, delivery,loyalty, quality and customer's customer's pressure towards the top of the customer's order of consideration. Apply pressure to make his decision more sensitive to differences between suppliers. If loyalty has been considered, try to increase the customer's loyalty to me.

4. Determine if I am one of several preferred suppliers.

   If not, Go to Step 6.

5. If so, Apply pressure to make my delivery quote seem shorter (i.e. to reduce the extra time the customer expects to wait). If loyalty has

Figure 7.2 SALES PRESSURE FLOW CHART



been considered, try to increase the customer's loyalty to me, If my order book is not full for the next month, requote price and delivery[1].

6. Determine if I am not a preferred supplier.

If not, Go to Step 8.

7. If so, Apply pressure to alter the order of consideration of price, delivery, loyalty, quality and customer's customer's pressure, so that factors not considered will be. Try to make the customer less sensitive to differences between suppliers. If loyalty has been considered, try to increase customer's loyalty to me. If my order book is not full for the next month, requote with price and delivery better[1].

8. Finish.

7.4.5 Order Placing and Sequencing

When the market sector places an order on a supplier, the order is entered in t he supplier's order book. The record shows the various order details, such as quantity, month placed, quoted delivery month and price. At this

---

[1] Requoting is done by reducing price and delivery by fixed proportions. Most of the work has been carried out with these proportions both at 20%.

stage, orders are never refused, although suppliers decline to quote if their order books are full. The order numbers are used to decide which order to produce next, so that the manufacturing process of each supplier operates on a "first in, first out" basis.

7.4.6 Manufacturing and Delivering

During each monthly cycle of the model, each supplier is able to deliver some titanium. He scans his order book, delivering orders up to the limit of his monthly manufacturing capacity (measured in tonnes of titanium). If he runs out of orders, he does not manufacture for stock. If he has some capacity left, at some stage in this process, but not enough for all of the next order, he delivers part of that order.

This model is intended to represent the production and delivery operations of the European titanium manufacturers. Although very simple, it shows the major features of these suppliers. One capacity limitation for all products is intended to model the melting bottleneck which seems to be present for each real supplier. The first-come, first-served servicing situation, although not demonstrably true in individual instances, where particular orders may receive preferential treatment, must be reasonable overall, since a very small amount of titanium is highly overdue.

The model does not include any physical limit to the manufacturing lead time, since this is in reality less than one month.

7.4.7 Capacity Changes

This part of the model was formulated by an examination of IMI's record of capacity installation. The decision to buy the expensive items of capital equipment is only taken in reality after extensive forecasting and planning activity. The capital expansion case is prepared, based on a discounted cash flow (DCF) analysis. Since it was not possible to include such specialised forecasting or DCF analysis segments in the market simulation without significantly increasing its complexity elsewhere, the following grossly simplified model was designed.

At the end of each year, examine the utilisation of capacity over that time. If it was at least a given level[1], increase capacity, otherwise keep it constant.

This followed the previous capital acquisitions policy of IMI reasonably well, when used in the simulation model.

When suppliers increase their capacity each increases it by a characteristic proportion (e.g. 40%). These were measured historically for all suppliers in the European market.

---

1 This level was fixed for all suppliers. The precise value was 98%, although the effect of varying it has been investigated.

7.4.8 Costs of Capacity Changes

Changes in installed capacity would, in general, be expected to engender several alterations to the Division's cost structure. Production costs would be affected by the technologically different capacity. No evidence of this was noted for previous capacity expansions. However, as the new plant tended to be in the melting and machining areas, of similar type to that already installed, it was not surpising. The act of purchasing the plant implies an instant increase in Fixed Asset capitalisation. This in turn causes an increase in the annual depreciation charges which the Division sets against profits.

At each increase in capacity each supplier's fixed costs were increased by an amount proportional to the original (i.e. non-depreciated) fixed asset figure, and also proportional to the absolute capacity increase.

7.4.9 Price Changing

At the end of each quarter, each supplier has the opportunity to reduce his average price. He will reduce it by v% if his capacity has been used less than w% during the preceding quarter[1]. The price will never however be

---

1 These percentages have been varied when looking at different market areas. For the general case, they have been fixed at v = 5%, w = 95%.

reduced below a level x% higher than the marginal cost of producing the product[1].

The suppliers have the opportunity to increase their mean prices at the end of each year. A supplier will increase his price level by y% if his capacity has been at least z% full for the preceding quarter[1].

7.4.10 Financial Data

A few rules serve to generate financial data to characterise each supplier. Each supplier depreciates his fixed capital by a constant proportion each month. This is identical to the reducing balance method used by accountants.

Analysis of IMI's actual data for working capital suggested a useful characterisation would be to regard working capital as composed of two parts. One proportional to the capacity (in tonnes), and another proportional to sales output (also in tonnes).

7.4.11 Routine Updating

During each month, various quantities are updated in the simulation. The most important of these is loyalty[2]

---

1 These percentages have been varied when looking at different market areas. For the general case, they have been fixed at x = 5%, y = 5%, z = 98%.

2 For a discussion of the concept of loyalty in industrial purchasing, please see Bubb and van Rest (1973).

which is one of the determinants of each "where to buy" decision. Each month, the proportion of customer's orders which are placed on each supplier is calculated. The loyalty between each customer and each supplier is altered to a weighted average of this proportion, with the previous value of their loyalty.

7.5 Data Estimation and Collection

Much of the data used in this simulation consists of subjective estimates of quantities which are not measurable in a "scientific"way. All these data have been estimated, by the author in collaboration with various IMI personnel. This largely concerned the loyalty of customers to IMI's competitors, and their prices, lead times and capacities. The Division had a good knowledge of these factors. Less was known about competitors' cost structure, and these estimates were made by a comparison of their plant with IMI's. All the supplier models have an identical structure to the model of IMI.

7.6 Validation of the Model

The sub-models encompassed in the simulation were each based on the most suitable data. In many cases it was possible only to validate these models against the same data used for their construction, since there was such a shortage of data available.

In order to perform an overall validation of the model, data was collected which described the behaviour of the European titanium market from 1967 to 1971. Sales of each supplier into each market sector in each year over that period were obtained by the Sales Department. The behaviour over this period was known in much more detail for IMI. These data were used to derive starting values for use in the simulation model.

The model was started running two years before the period it aimed to simulate. Demand data was used for each year of the simulation, but this was the only input data used during running apart from the initial values. Good agreement was obtained between simulated and actual sales. The model's performance is indicated by Table 7.1 which shows simulated sales as percentages of actual sales.

The purpose of the validation was to ensure that the model was close enough to reality to be suitable for giving useful insights to IMI management about business situations which were likely to arise. These included the kinds of effect which particular actions might have. As currently developed, the model is not expected to give accurate quantitative predictions of future events or effects of specific policies. For this reason, the rigorous validation appropriate to such use (Van Horn (1971)) is neither suitable nor feasible.

The validation procedures selected were largely chosen to demonstrate the reasonableness of the model. It was considered that the "absolute" test of validation was to convince the user that the model was reasonable for use in the specific situation. A subset of models passing this test would be those whose structure was reaonable, and whose predictions were as good, or better than experience has shown IMI's sales forecasts to be.

This approach to validation leads to a "face" validation[1] of the structure of the model. If the model is deemed to pass this test, a first stage validation for credibility of its output is to compare the accuracy of its output (expressed as a percentage of actual sales) to the accuracy of sales forecasts. If the accuracy of the simulation (characterised by the mean and standard deviation of the ratio) is as good, or better than the sales forecasts, then the test is deemed to be passed. Otherwise, the model must be validated by direct appeal to management, to establish the credibility of its predictions.

Such a two stage procedure depends for its justification on the fact that IMI's sales forecasts are credible to its managers. The test was devised, based on sales forecasts (for IMI's sales only) up to three years ahead. This showed that the mean accuracy (forecast sales/actual sales) was 93.6%, with a standard deviation of 23.8%. Thus, to pass this test, the model should have a mean

---

[1] Please see page 49.

accuracy between 93.6% and 106.4%, with a standard deviation of 23.8% or less. The test is very stringent, since one would expect IMI's forecasts of its own sales to be more accurate than those of other suppliers, while other suppliers' data is used to establish the simulation accuracy mean and standard deviation. No weighting by market share is applied, which, since IMI accounts for over 50%, makes the test tighter.

The accuracy (and its standard deviation) of the simulation output (table 7.1) were found to be 97.8% and 22.8% respectively. Thus the model passed this test, and it was not considered necessary to submit it to direct testing by the managers.

The model was thus seen to be validated adequately for its objective. However, validation is probably more appropriately regarded as an adaptive process continuing hand in hand with model development. Thus it would be hoped that the model will become "truer" to life as it is used more. One of the model's envisaged uses is in exploring the consequences of assumptions about the market. For this function, validation is not appropriate, since (as Bonini (1963) points out) there is no reality to compare it with. As it stands, validation has shown that the model's forecasts tend to be more accurate than sales forecasts have been, and so the model clearly has made a contribution. This factor has helped to "sell" the model, so that it is now in use by managers (thus demonstrating its credibility).

At this stage the data used was sales by each of the six major titanium suppliers to the European market: IMI, Contimet, Krupp, Pechiney-Ugine-Kuhlmann, Avesta and Vereinigte Deutsche Metallwerke (VDM). It seemed appropriate to regard the market as being composed of three market sectors - U.K., the rest of Europe non-aerospace, and the rest of Europe aerospace.

This validation was considered adequate, since the model was designed only to explore possible long-term policies and behaviour in the market. To demonstrate close agree -

Table 7.1

COMPARISON OF SIMULATED AND ESTIMATED ACTUAL SALES IN THE EUROPEAN MARKET

Supplier	IMI	Contimet	Krupp	P.U.K.	Avesta	V.D.M.
Year						
1967	84%	98%	100%	100%	100%	95%
1968	112%	113%	104%	108%	103%	108%
1969	105%	127%	109%	115%	84%	120%
1970	94%	95%	85%	101%	69%	102%
1971	94%	31%	104%	101%	28%	145%

Figures represent simulated sales/actual sales.

ment with historical market behaviour was necessary to "sell" the model to its users. Since the many simplifying assumptions made had apparently not detracted from the accuracy with which the model represented reality, these had, to a large extent, been vindicated.

After the model was built and used, data became available describing the sales in 1972. The model was used to compare its prediction with the sales estimates for each supplier into Europe, for that year. The comparison forms table 7.2. It was not possible to obtain data on other aspects of all the suppliers' behaviour for the year.

The comparison of actual and simulated sales shows a strong discrepancy for Contimet. In part, this is explained in reality by that supplier's rapid penetration of the U.K. market. Changes in its policy resulted in substantial sales in that market in 1972 after very low sales in 1971.

The data did not meet the first stage validation test by comparison with historical forecasts. They were then discussed with sales personnel who were convinced that the model showed a reasonable result, since IMI's own forecasts for 1972 had not been very accurate. However, it should be noted that more accurate predictions for 1972 would be achieved by initialising the model at 1971 instead of 1965, as the case in the validation. When in use, the model has been initialised with the latest available data.

7.7 Exploring the Future

The long term behaviour of the model was examined with three different future demand conditions: constant, linearly increasing, and geometrically increasing. Each case was examined from 1971 to 1975, and the demand data is shown in figure 7.3.

Table 7.2 COMPARISON OF SIMULATED AND ESTIMATED SALES FOR 1972

Supplier	Simulated/Estimated Sales
IMI	103%
Krupp	81%
Contimet	38%
P.U.K.	136%
Avesta	110%
V.D.M.	161%

The model was started off from the stage it had reached after validation from 1967 to 1971. The results of the simulation are shown in figures 7.4 to 7.6, which indicate how each supplier fares. Since each supplier is modelled as an identical structure, it is surprising that such divergence among suppliers develops. In general, the large suppliers improved their market share, while that of the smaller suppliers declined. This was mainly because the large suppliers were able to achieve lower lead times than the smaller ones.

In the geometrically increasing market, suppliers who were able to attract sufficient orders were limited by their production capacity. Over the market as a whole, capacity was not able to expand fast enough to keep up

Figure 7.3 THE TOTAL DEMAND FOR THE GROWTH PATTERNS EXAMINED

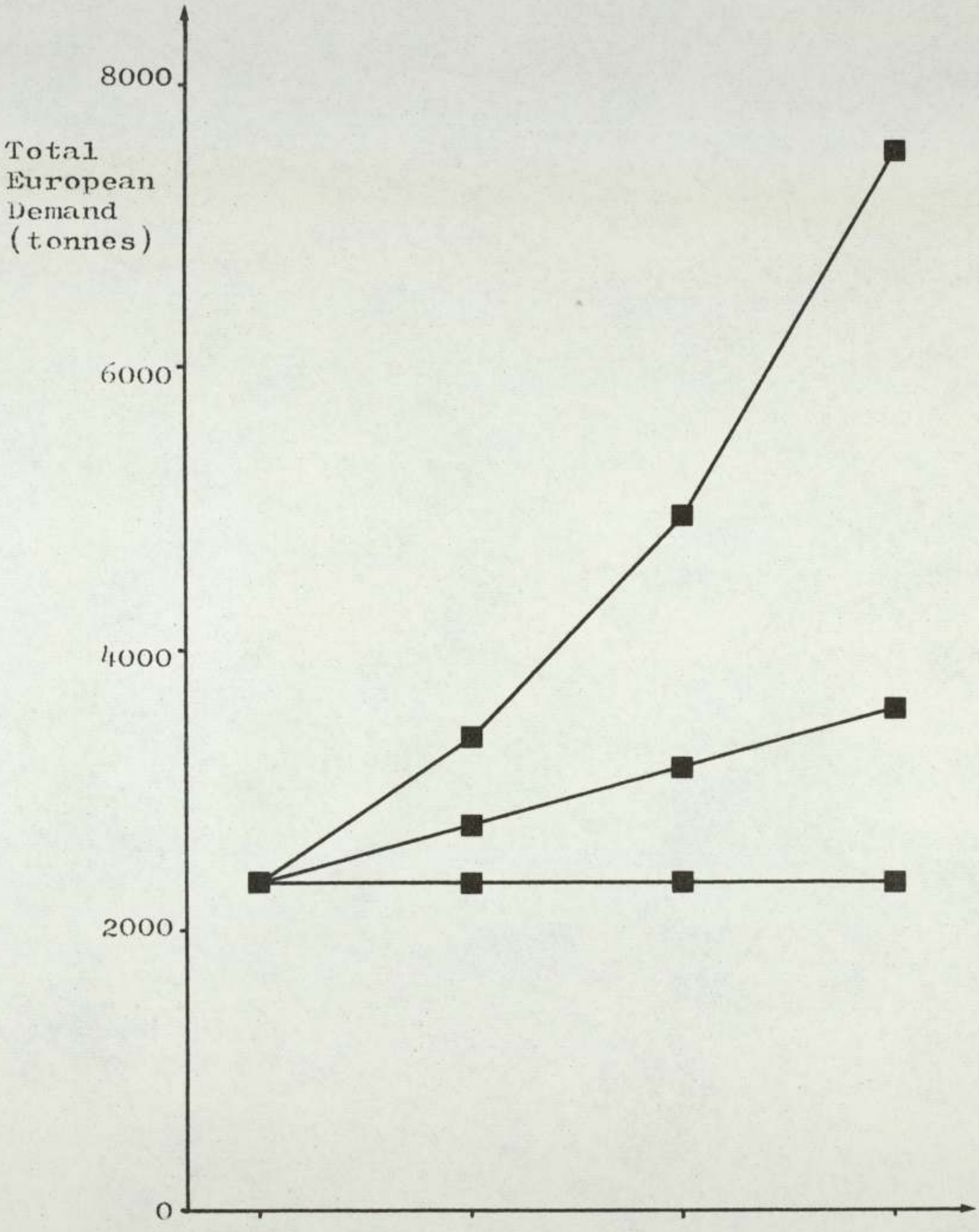


Figure 7.4 TITANIUM SALES WITH CONSTANT ANNUAL DEMAND

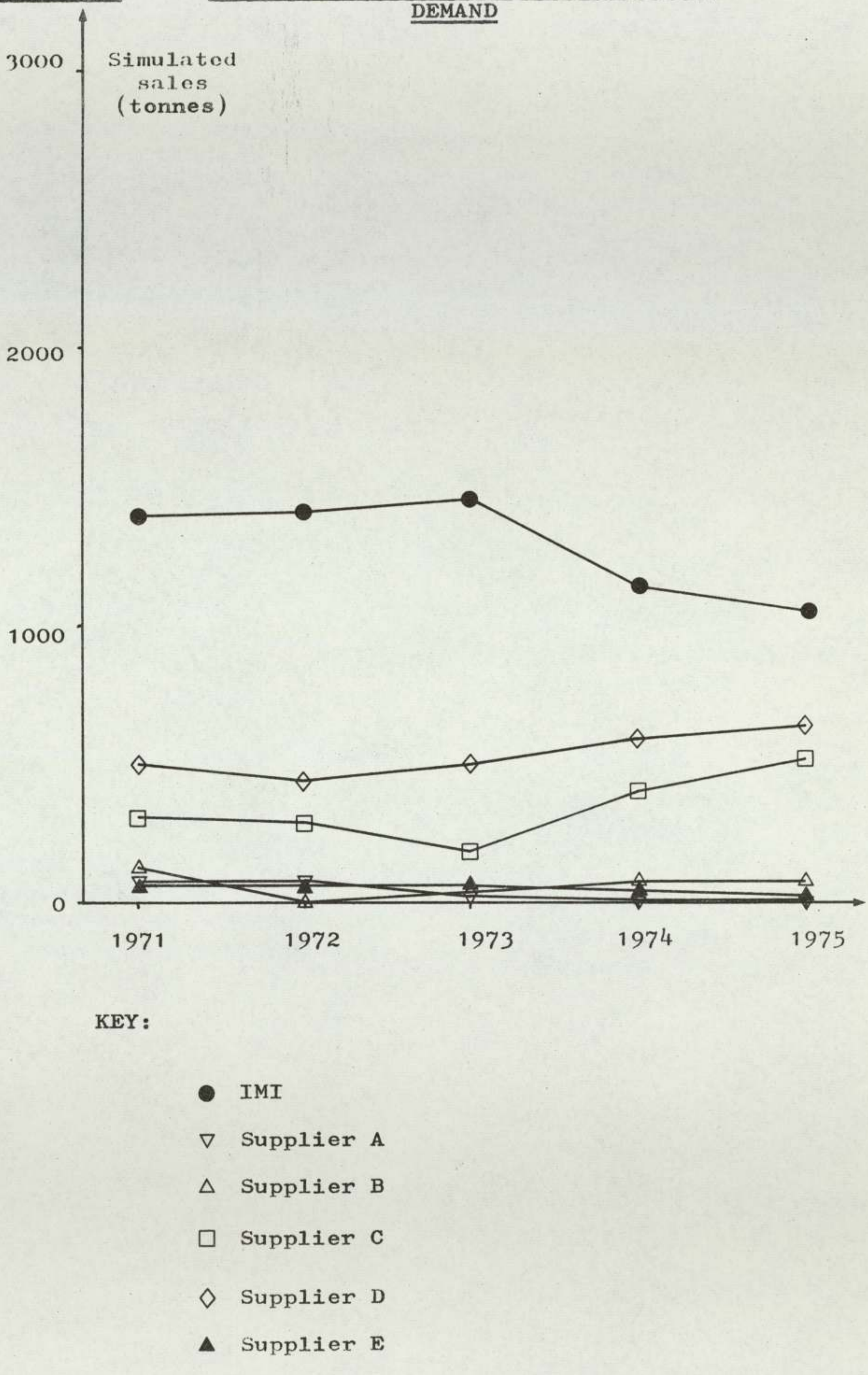


Figure 7.5 TITANIUM SALES WITH STEADILY INCREASING ANNUAL DEMAND

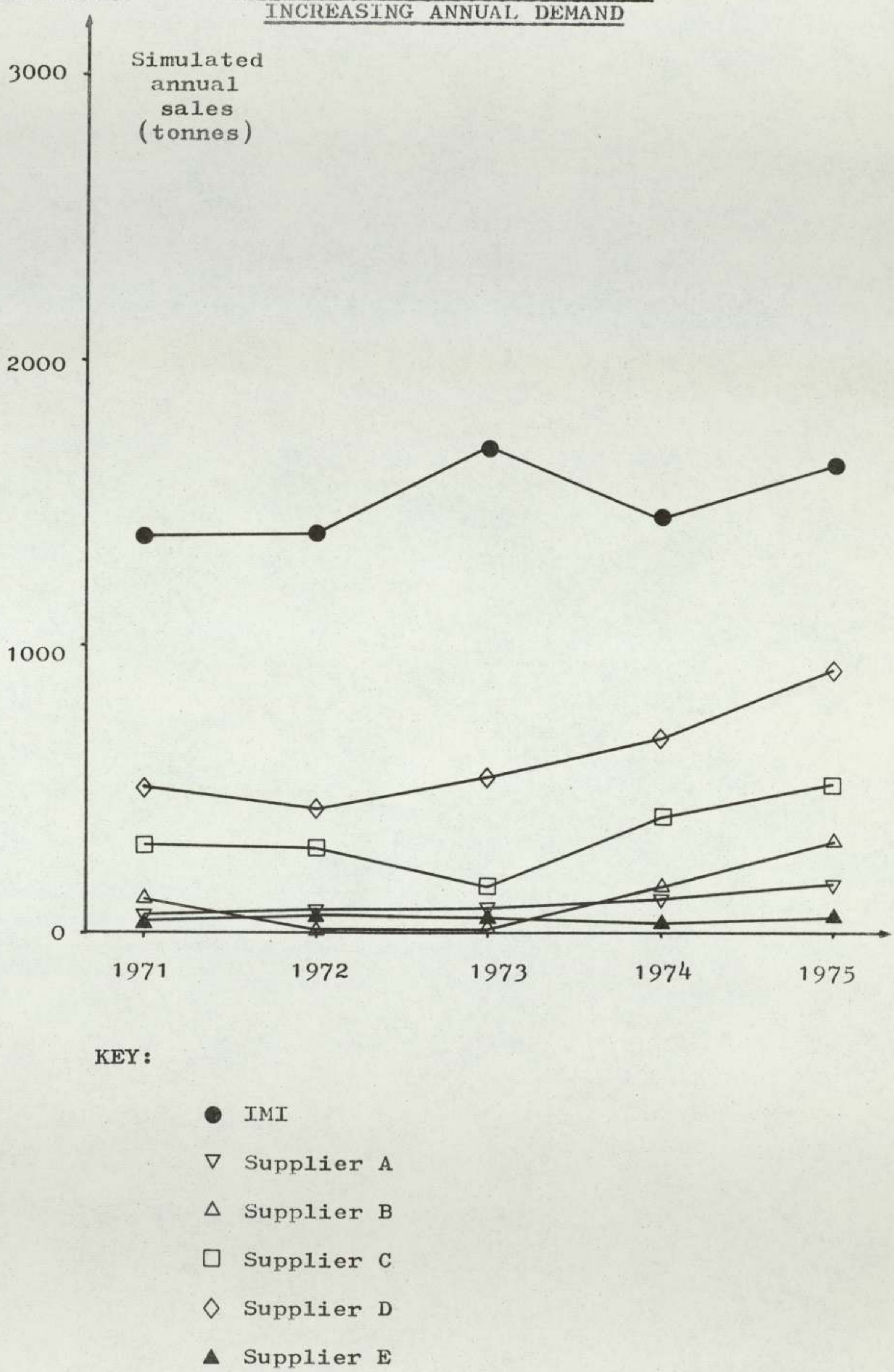
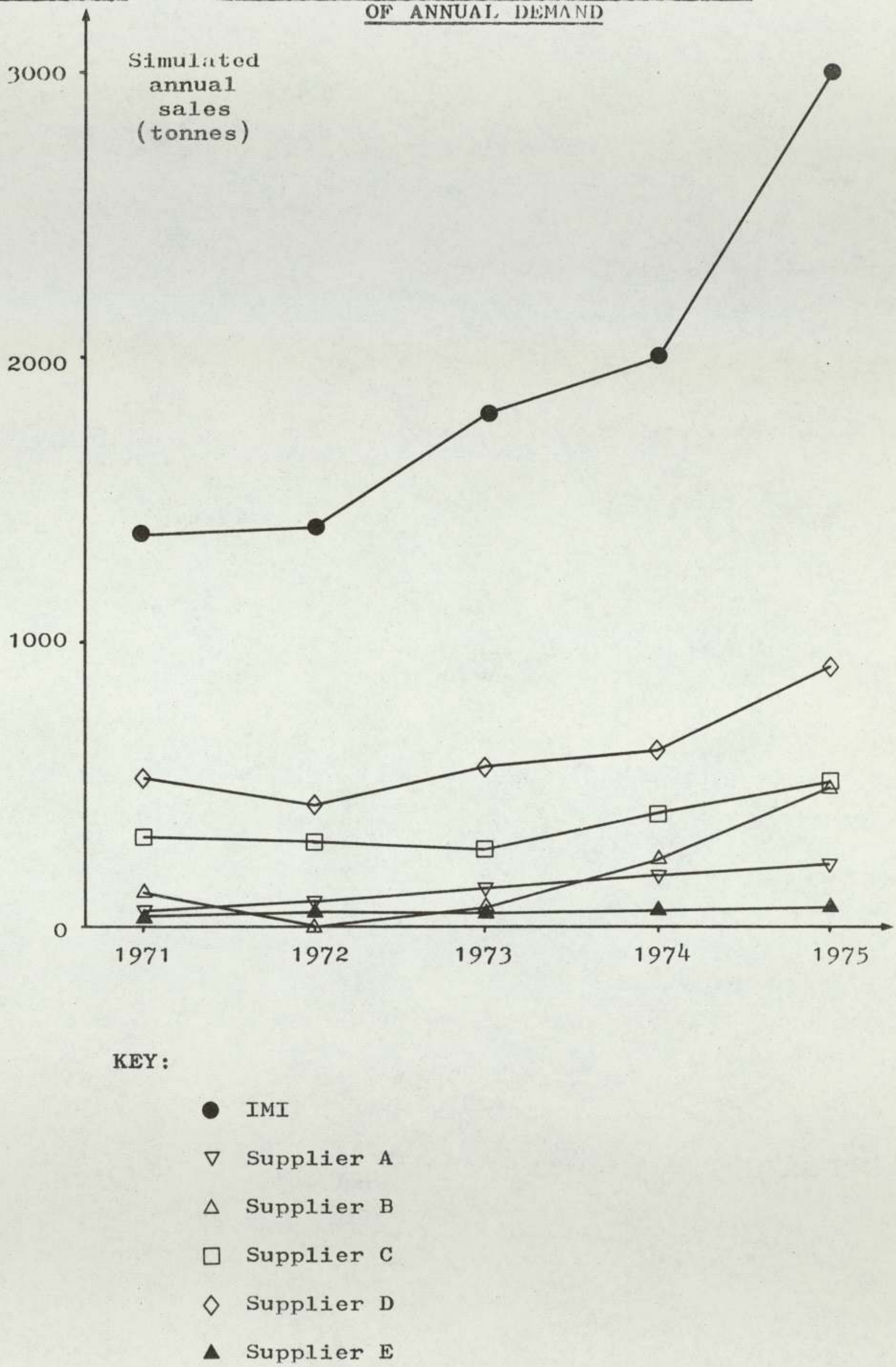


Figure 7.6 TITANIUM SALES WITH GEOMETRIC GROWTH OF ANNUAL DEMAND



with the demand growth. Even with this situation, some suppliers were not always able to fill their capacity. In this market, IMI was able to expand faster than any other supplier, and so increase its market share. Its initial strong loyalty was useful in this respect, and was strengthened as time progressed. Supplier B starts off with high prices and long lead times. These factors turn away orders, which results in a decreasing loyalty, and so the effect persists for a few years.

In the two other market situations, IMI's market share declines. This appears to be due to slowly declining loyalty, resulting from lower prices by other suppliers. It is interesting to note that supplier D fares well in each market situation. Initially low prices take orders which improve the loyalty of the sectors to this supplier. This in turn strengthens future growth. Supplier D is well known as a very aggresive competitor of IMI.

Although the larger suppliers generally increase their sales as time progresses through the model, they only do so at the expense of steadily declining prices. The smaller suppliers are able to take orders at slightly higher prices. Since the larger suppliers are expanding faster, they have higher fixed costs resulting from the higher depreciation provisions of newer capital expenditure. Thus the larger suppliers are seen to have low profitability (and in some cases, small losses), while the smaller suppliers make good returns on their capital. It would clearly be in IMI's interests to establish in more detail why these phenomena occur, and to look for alternative expansion strategies.

7.8 Uses of the Model

One major use of the model (the exploration of widely varying market conditions) has already been indicated, but it is also suitable for other types of investigation. The model is designed to facilitate studies of the "what-if?" type. To show how these investigations might be carried out, an example is given below of how one has actually been carried out.

IMI had developed two novel products for use in the electro-refining industry. The products, if priced appropriately, should capture a very large market competing with the currently used materials. As far as was known, IMI had a strong technical lead with these two products for the electro-refining industry which both used the same production facilities. IMI was already acknowledged as the world leader for the sale of titanium starter blanks, which, in many cases, were sold to the potential customers for these new products.

In order to use the model to examine the potential market for these products, data was collected to characterise the situation. The variable cost of manufacture for IMI was estimated. It was apparent that the laying down of some new plant by IMI would serve to reduce these costs considerably. It seemed that IMI might be able to participate in similar cost savings by sub-contracting this work. Costs for other (probable) suppliers were estimated at this lower level, since the equipment necessary is used in steel-making and each of the other suppliers had a strong connection with a major steel manufacturer. IMI was modelled as having a fixed capacity, while the other suppliers were depicted as having very large capacity. Loyalty and initial price levels were set after examining the suppliers' behaviour in the starter blank market.

The model was used to examine the market for these products. It appeared that IMI would fill its capacity easily, and make good profits. IMI was then allowed to expand its capacity in a further run of the model[1]. This suggested that although the policy would be profitable in the short term, reducing profit margins in the model in the long term would result in inadequate profits in later years of the project.

A different module of the model was designed, in which IMI did not reduce its prices so fast, when capacity was not

---

[1] This was achieved by altering the capacity expansion factor in the model, for IMI.

fully utilised. When used in the model this gave apparently more realistic behaviour. The capacity expansion rule for IMI was next altered, so that expansion would only take place when capacity was full and profit margins were good.

These changes indicated a way in which IMI could make continuously acceptable profits while maintaining its market leadership.

This example serves to indicate the two ways of using the model to answer what if? type questions: Parameters can be varied, or the structure altered. The program was written to facilitate both types of change.

The capacity expansion module, written as a FORTRAN sub-program was added to the "library" of alternative modules for use in the model. Thus, as the model receives more use, this "library" will expand, and render the model more useful. Although formulated essentially for use by the planning function, the output from the computer program has been designed to be in a form which will be immediately useful (and familiar) to management. Figure 7.7 shows an example of the major program output.

It is difficult to envisage broad strategies which cannot be examined by the model. It seems to fall short where

Figure 7.7 **THE MAJOR OUTPUT FROM THE SIMULATION PROGRAM**

COMPARATIVE FINANCIAL RESULTS FOR YEAR 3

SUPPLIER	1	2	3	4	5	6
CAPACITY (T)	491	90	65	84	81	10
SALES WT (T)	491	90	65	84	81	10
REALISN (£K)	2750	482	348	470	456	51
VAR COST (£K)	1963	360	259	336	324	38
CONTRIBN (£K)	787	122	89	134	132	13
DEPRECN (£K)	216	43	26	37	36	5
PER COST (£K)	337	62	45	58	56	7
TO FX CO (£K)	553	104	71	95	91	11
PROFIT (£K)	233	17	18	40	41	1
FIXD CAP (£K)	2049	404	250	349	339	44
WRK CAP (£K)	229	42	30	39	37	4
CAP EMPL (£K)	2278	446	280	388	376	48
PROF/CAP (%)	10	4	6	10	11	3

more detail is required of either products or production than is available in the model. It can be used to test many sorts of marketing strategy against demand growth of various types, action by competitors, effects of supplier mergers and customer reaction.

7.9 Chapter Review

This chapter has described the development of a simulation model for the titanium market from models described earlier. The structure and construction of the model has been set out. The extensive usefulness of the model for exploratory planning, investment appraisal, and strategy selection has been indicated.

CHAPTER 8

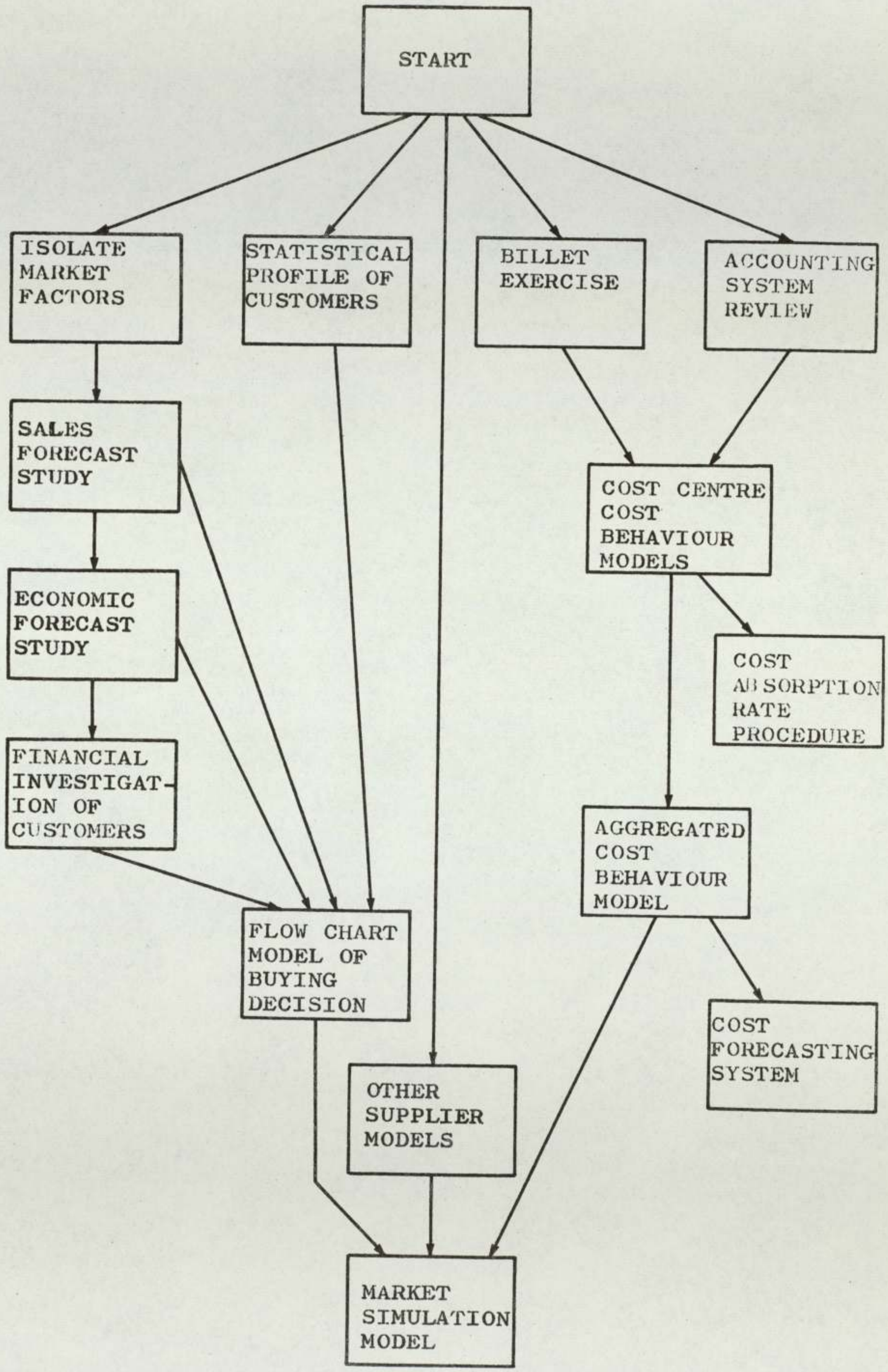
A REVIEW OF THE WORK

8.1 The Research Project

The work described in this dissertation has investigated various aspects of the New Metals Division of IMI, and the world titanium market, to develop a tool for strategic planning. The major integrating activity has been the building of a market simulation model. This put together the models of supplier behaviour and customer action. While integrating the modelling work, it also served to bring together the practical aspects: although the separate parts of the work were useful per se, the market simulation offered the major planning tool. Figure 8.1 shows the inter-relation of the various aspects of the work.

The work on cost behaviour started with an exploratory review of the Divisional Financial System (briefly described in Appendix B) and a specific investigation of the financial consequences of altering the production route for billet (also Appendix B). Although this work was of value in itself, and suggested various research approaches which were examined, it did not lead directly to the major effort

Figure 8.1 THE STRUCTURE OF THE RESEARCH



in cost behaviour determination. Rather it served to set the scene, and give the researcher a broad perspective which was necessary to carry out the specific examination of costs.

The behaviour of cost centre costs was investigated in considerable detail. Although little success was achieved by investigating cost headings, the analysis of total cost centre costs proved profitable. Good cost forecasts were obtained using leading economic indicators. A novel method for the calculation of cost absorption rates, which obviated the need for arbitrary overhead apportionment was put forward. Within the time available in this project, it was not possible to carry out similar cost behaviour studies for the complete Division, and consolidate the results into the appropriate detail.

When it became clear that an alternative method for modelling Divisional costs was required, aggregated Divisional financial results were analysed. A model which was proposed, and fitted to the data using multiple regression proved to be a good forecaster of total costs. This led to a system for forecasting financial results now in use by the Accountancy Department, which uses a novel approach to updating the regression relationships.

The market studies commenced with some attempts to isolate key factors in the buying decision, a review of sales and economic forecasts, and the statistical review of IMI's customers. Although useful in themselves, these largely served to give the author an appreciation of the marketing environment.

The flow charted model of the individual titanium customer was developed after an initial exploratory survey of IMI's marketing activities.

Models describing various aspects of titanium suppliers (the most important being cost behaviour), and customers are all put together in the simulation model of the titanium market. This model serves to further validate the customer flow-chart model. However, its main emphasis is as a tool for strategic planning for the Division.

8.2 Use of the Work

The project has been a useful source of ideas for IMI. Some of the insights obtained in the various models have already been used, while others await implementation. The major aim of the project: to develop a tool to help assess possible strategies, has been demonstrably achieved, as the simulation model is beginning to be used for that purpose.

The cost behaviour studies have resulted in action on several fronts. The author has been involved with Divisional Accountants in a refinement of their assumptions on cost behaviour, at cost centre level. A system is in use by accountants at the Divisional level, where a computer terminal is used to prepare "instant" financial forecasts using some of the author's regression results. A novel control[1] system for updating these regression formulae is also being used. The author has also been involved in the determination of cost behaviour elsewhere, using some of the ideas obtained here.

Although a pilot study to show the proposed system for the calcualtion of cost absorption rates has been carried out, this has not yet been implemented for the whole Division. The study of billet machining resulted in action by sales and production management.

The statistical survey of the sales office suggested various limited planning and control applications which would be possible. These suggestions have not yet been acted upon. Although the flow chart model of the titanium customer only represents a formalisation of sales managers views, two sales managers have asked to be able to use the model to assess individual opportunities. Various studies led to possible rules for adjusting Divisional sales forecasts, and using published economic forecasts to derive sales forecasts for titanium. Little use has yet been made of this work, but it would be useful with a modest amount of development.

---

1 This is described in Appendix B.3.

The simulation model has already been used to examine a few business situations: in exploration of IMI's strategies in different types of market, and in the investigation of an "ad hoc" planning situation. It does however, have very extensive usefulness. It has been developed in a form which is flexible enough to be directly useful for many subsets of the world titanium market. Different policies, suppliers, and market situations can be simulated by carrying out two types of change in the model. Input parameters, and the program structure can both be easily changed. The model is suitable for comparing different strategies and environments, and for many types of exploration.

8.3 Relationship of the Work to the Literature

The cost behaviour work represents an extension to the few published studies of the use of statistical techniques for that purpose. The work is unusual in that the outcome is managerially significant. Three publications have resulted from the study[1]. The use of regression analysis for the calculation of cost absorption rates is, to the author's knowledge, novel. The control scheme used to update the regression relationships represents a simple, effective and new use of quality control procedures.

---

1 Bubb and Smith (1972a), Bubb and Smith (1972b), Bubb, Hussey and Smith (1973).

The development of the flow chart model of the titanium customer adds one further study to about a dozen reported in the literature. Some aspects of this study are unique: it is based on sales manager perceptions, and is validated by inclusion in a model of the whole market. While these approaches will not commend themselves for their objectivity they were appropriate in the context of this project. One outcome of the work was a report seeking to clarify the concept of loyalty in the industrial buying situation.[1]

The development of the other models, although specific to the present situation, do not represent the major use of any novel concepts or techniques.

8.4 Suggestions for Development of the Work

The major development of this work seems likely to be in implementation. Although parts of it are already in use, commitment to the planning approaches possible with the simulation model is still somewhat lacking from the Division's policy-makers. As the model is used more, it will become possible to improve its structure.

The model describing the buying decision has been demonstrated to apply to various areas of the titanium market. It appears likely that the model would be applicable to some other industrial markets. A worthwhile extension of the

---

1 Bubb and van Rest (1973).

work would be to investigate the applicability of the model in other markets.

The extension of the multiple regression approach to obtain cost absorption rates would be of direct relevance to IMI. This would enable useful data to be provided for the Divisional Linear Programming Model. This work is also likely to have relevance outside the Division.

The titanium market simulation is likely to be worth considerable development and refinement from its present form. This will probably not be possible however, without extensive experience of using it. The "library" of alternative modules now being built up may make worthwhile some "automation" of selection of these, to form the computer program. This would make the model more useful for management. The insight into the concept of loyalty gained in the research suggest that the importance of loyalty as an input to the buying decision has been somewhat neglected in the literature. This is a further area where the work can be developed profitably.

APPENDIX A

TITANIUM CUSTOMERS

A.1 The Statistical Profile

This section of the appendix largely consists of the sample distributions referred to in Chapter 4. Since the data collection is described there, that description is not repeated here.

Enquiry Frequencies

Table A.1 shows the number of enquiries received on each day of the sample. None of the more popular theoretical frequency distributions were found to be reasonably compatible with the data. (Although the Poisson seemed most likely, it proved inadequate).

Order Frequencies

Table A.2 shows the sample of total number of orders per day. No theoretical model was indicated.

Table A.1 DAILY FREQUENCY OF ENQUIRIES

Enquiries per day	Number of days	Enquiries per day	Number of days	Enquiries per day	Number of days
0 - 6	0	18	2	30	3
7	3	19	9	31	2
8	0	20	3	32	2
9	1	21	4	33	0
10	2	22	3	34	0
11	3	23	6	35	1
12	2	24	3	36	1
13	7	25	6	37	3
14	4	26	3	38	2
15	4	27	2	39	0
16	10	28	4	40	1
17	9	29	4	over 40	0
				Total	109 days

Table A.2 NUMBER OF ORDERS RECEIVED PER DAY

Orders per day	Number of days	Orders per day	Number of days	Orders per day	Number of days
0 - 3	0	16	3	29	2
4	1	17	5	30	0
5	2	18	6	31	1
6	0	19	4	32	2
7	0	20	5	33	2
8	2	21	4	34	0
9	1	22	3	35	0
10	1	23	2	36	1
11	4	24	4	37	1
12	3	25	4	38	2
13	4	26	1	39	0
14	5	27	1	40	1
15	4	28	2	Total	83 days

Enquiry Sizes

The sample distribution of enquiry sizes (measured by weight) is shown in table A.3.

Order Sizes

A sample of orders received yielded the distribution shown in table A.4.

Enquiry and Order Sizes

Although theoretical distributions were not found to describe the two samples obtained, their similarity of shape seemed striking. A chi-squared[1] test confirmed this strong similarity.

The chi-squared statistic was calculated using table A.4a. This gave

$$\chi^2_{14} = 15.76,$$

which does not refute the hypothesis that the samples were from identical populations, at the 20% level.

Order Weight and Price

The data obtained from the small sample comparing the weights (W) and prices (P) of some orders forms table A.5. The regression relationship,

$$P = 27.6 + 5.05W$$

had a coefficient of determination 0.989, and the standard error of the regression coefficient (5.05) was calculated as 0.121.

Table A.3 SIZE DISTRIBUTION OF ENQUIRIES RECEIVED

Weight (kg)	Number	Weight (kg)	Number
0-49	178	800-899	5
50-99	53	900-999	8
100-149	30	1000-1999	28
150-199	16	2000-2999	8
200-299	29	3000-3999	7
300-399	9	4000-4999	3
400-499	12	5000-9999	1
500-599	7	10000-14999	0
600-699	3	15000-19999	1
700-799	4	Total	402 Enquiries

Table A.4 SIZE DISTRIBUTION OF ORDERS RECEIVED

Weight (kg)	Number	Weight (kg)	Number
0-49	186	800-899	6
50-99	45	900-999	11
100-149	26	1000-1999	42
150-199	18	2000-2999	15
200-299	20	3000-3999	5
300-399	10	4000-4999	4
400-499	11	5000-9999	1
500-599	10	10000-14999	1
600-699	9	15000-19999	2
700-799	11	Total	433 orders

Table A.4a CALCULATION OF CHI-SQUARED STATISTIC FOR ENQUIRY AND ORDER SIZE DISTRIBUTIONS

Class	Observed frequencies			Estimated	Expected frequencies	
	enquiries	orders	total	prob-ability	enquiries	orders
0 - 49	178	186	364	.436	175.24	188.76
50 - 99	53	45	98	.117	47.18	50.82
100-149	30	26	56	.067	26.96	29.04
150-199	16	18	34	.041	16.37	17.63
200-299	29	20	49	.059	23.59	25.41
300-399	9	10	19	.023	9.15	9.85
400-499	12	11	23	.028	11.07	11.93
500-599	7	10	17	.020	8.18	8.82
600-799	7	20	27	.032	13.00	14.00
800-899	5	6	11	.013	5.30	5.70
900-999	8	11	19	.023	9.15	9.85
1000-1999	28	42	70	.084	33.70	36.30
2000-2999	8	15	23	.028	11.07	11.93
3000-3999	7	5	12	.014	5.78	6.22
4000+	5	8	13	.016	6.26	6.74
Total	402	433	835	1.000	402.00	433.00

Table A.5 PRICE AND WEIGHT OF ORDERS

Price £	Weight kg	Price £	Weight kg
69.22	9.6	2400.19	400.7
103.64	31.0	41.28	9.3
152.0	35.0	633.74	130.4
162.35	38.0	1201.5	160.2
55.13	12.5	99.6	7.65
50.0	2.99	74.76	8.9
60.0	13.4	220.32	45.9
17.0	2.0	2362.72	496.4
292.88	24.5	2235.36	465.7
79.55	7.8	1318.4	256.0
18.0	3.8	1419.14	255.7
19.4	4.0	264.38	41.7
15.75	2.1	40.53	2.72
32.5	4.0	170.5	30.5
57.07	10.1	175.8	28.4
31.5	4.2	134.55	23.4
835.03	110.6	2471.07	504.3
100.0	27.0	443.09	81.3
781.46	176.8	132.25	21.4
295.26	66.8	19.52	3.2
43.71	2.1		

Sample size: 41 orders

Order to Delivery Time

This sample is shown in table A.6. A theoretical exponential distribution with mean 53.5 was fitted to this data. The hypothesis that the sample was taken from such an exponential distribution was not refuted by a chi-squared test.

Table A.6a shows the calculation of the chi-squared statistic,

$$\chi^2_3 = 2.32$$

This test does not refute the hypothesis at the 20% level. It was felt, however, that the chi-squared test may not be very sensitive with such a small sample, so the hypothesis was also subjected to a Kolmogorov-Smirnov test. This gave a test statistic of 0.106, which did not refute the hypothesis at the 20% level. Table A.6b gives the calculation of this statistic.

Delivery to Payment Time

The data is shown in table A.7. The hypothesis that this data was a sample from a normal distribution with the same mean and standard deviation was tested by a chi-squared test. The hypothesis was not refuted.

Table A.7a shows the calculation of

$$\chi^2_3 = 1.095$$

Thus the hypothesis was not refuted at the 50% level. Since this test was also carried out with a small sample, the Kolmogorov-Smirnov test was used on this data. The test statistic (calculated in table A.7b) was calculated as 0.052 which did not refute the hypothesis at the 20% level.

Table A.6 DISTRIBUTION OF ORDER TO DELIVERY TIMES

Time (days)	Number of Orders
0 - 20	16
21 - 40	10
41 - 60	1
61 - 80	5
81 - 100	4
101 - 200	3
201 - 300	2
Total	41 orders

Table A.6a CALCULATION OF THE CHI-SQUARED STATISTIC FOR ORDER TO DELIVERY TIME

Order to Delivery Time (days)	Expected frequency	Observed frequency
0 - 20	13.08	16
21 - 40	8.69	10
41 - 100	12.96	10
101+	6.27	5

Table A.6b CALCULATION OF KOLMOGOROV-SMIRNOV STATISTIC FOR ORDER TO DELIVERY TIME

Order to Delivery Time (days)	Cumulative Probability		
	Expected	Observed	|Expected-Observed|
20	.307	.390	.083
40	.528	.634	.106
60	.674	.659	.025
80	.777	.780	.003
100	.846	.878	.032
200	.977	.951	.026
300	.996	1.000	.004

Table A.7 DISTRIBUTION OF DELIVERY TO PAYMENT TIMES

Time (days)	Number	Time (days)	Number
-19 to 0	3	81 to 100	4
1 to 20	1	101 to 120	3
21 to 40	3	121 to 140	2
41 to 60	9	141 to 160	0
61 to 80	8	161 to 180	1
		Total	34 orders

Table A. 7a CALCULATION OF CHI-SQUARED STATISTIC FOR DELIVERY TO PAYMENT TIME

Delivery to Payment Time (days)	Expected Frequency	Observed Frequency
-19 - 40	8.466	7
41 - 60	6.902	9
61 - 80	7.140	8
81 - 180	11.050	10

TABLE A.7b CALCULATION OF THE KOLMOGOROV-SMIRNOV TEST STATISTIC FOR DELIVERY TO PAYMENT TIME

Delivery to Payment Time (days)	Cumulative Probability		
	Expected	Observed	|Expected-Observed|
0	.042	.088	.046
20	.117	.118	.001
40	.258	.206	.052
60	.456	.471	.015
80	.666	.706	.040
100	.833	.824	.009
120	.934	.912	.022
140	.980	.971	.009
160	.995	.971	.024
180	.999	1.000	.001

Thus, with such a small sample (only 34 orders), a normal distribution of time delays seems reasonable. Since many 'natural' processes yield normal time distributions, such a model seems reasonable for this process.

Order to Delivery and Delivery to Payment Times

The independence of the two distributions was tested initially using a $2\sqrt{N}$ test. This test gave a score of 1 which was lower than 11.5, which would have indicated dependence. This test thus showed no dependence at the 5% level between the distribution.

The correlation coefficient for the data was calculated as 0.129. The t-statistic for this value is 0.724, with 31 degrees of freedom. This indicated at the 5% level that the correlation coefficient was not significantly different from zero. The data is shown in table A.7c.

The first test requires no assumptions about the form of dependence between the two times. The calculation of the correlation coefficient is based on the assumption that any relation between the times is linear, while the t-test assumes that deviations from this line are normally distributed.

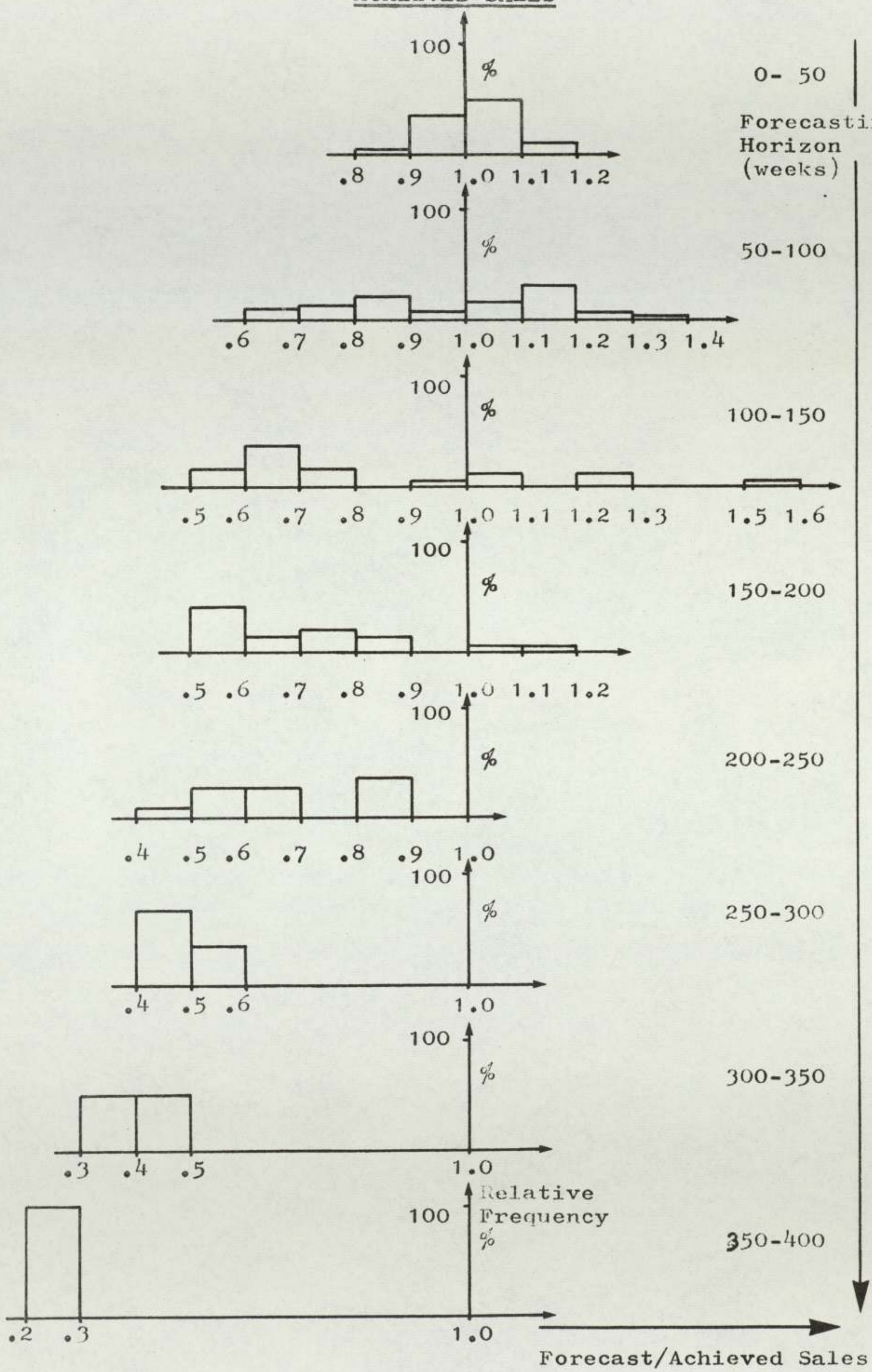
A.2 Other Exploratory Studies

The accuracy of forecasts made by the Division's forecasting expert were assessed. These were found to have a consistent bias which increased as the forecasting horizon increased (as shown in figure A.1).

Table A.7c RELATIONSHIP OF ORDER TO DELIVERY AND DELIVERY TO PAYMENT TIMES

Order to Delivery Time (days)	Delivery to Payment Time (days)	Order to Delivery Time (days)	Delivery to Payment Time (days)
122	110	15	63
2	53	22	63
5	-2	27	51
3	84	68	65
129	101	78	55
3	64	83	50
22	11	76	50
37	21	15	85
1	-6	28	68
10	0	31	65
1	161	33	91
1	47	227	74
46	57	36	115
91	37	95	123
70	46	13	97
23	126	1	39
264	56		

Figure A.1 A COMPARISON OF FORECAST AND ACHIEVED SALES



A rule was thus obtained for adjusting these forecasts.[1]

A measure of the variability of these forecasts was also obtained. The variability of the forecasts was found generally to decrease as the forecasting horizon increased (apart from the bias).

An attempt was made to predict sales by using regression analysis on historical data. Although some statistically reliable fits were obtained, polynominal regression was necessary in most of the cases tried. These curves made somewhat volatile forecasts, which were intuitively unreasonable. Since the maintenance of the ceteris paribus conditions were doubted, this approach was not taken further.

Consideration of the structure of the Titanium Industry (described in Appendix C.1) helped to focus attention on the parts of the system interacting with IMI. IMI is a melter and semifabricator of titanium, and (as shown in figure C.1) the major flows across its boundary are of titanium sponge, scrap, and mill products. An assessment of the

---

1 The rule was:-

$$F_n = F_o / (1.127 - .00229W)$$

where F_n was the corrected forecast, F_o the original one, and W was the mean length of time ahead (in weeks) for which the forecast was made.

There is evidence from a survey of American firms (Hirsch and Lovell (1969)) to suggest that a firm's sales forecasts are likely to be either consistently pessimistic (as in the case here) or consistently optimistic. The same study concludes that, in general, short range forecasts will be more accurate than longer range ones.

Work in the subjective estimation of probability (Hampton, Moore and Thomas (1973)) indicates a strong tendency for estimates of low probabilities to be understated, and high probabilities over-stated. This effect could explain the consistent decreasing bias of IMI's forecasts: at long range it is forecasting the sum of outcomes of many low probability events, which become high probability events when the horizon is short enough.

future development of each of these flows was made.

Sponge costs represent a substantial part of the costs of the final product, and are the principal raw material cost. IMI purchases the majority of its sponge on long term contracts, at a fixed price. This policy has resulted in only one change in sponge prices over the past six years. Since the majority of sponge is sold under long term contracts, this policy is unlikely to change within the next ten years. The major part of sponge costs are involved in conversion from the ore, and this expensive process shows no sign of being superseded by a dramatically cheaper one. Sponge prices are not expected to change significantly as a result of ore price movements.

Scrap circulates around the Titanium Industry. By management policy, IMI sells some forms of scrap, but does not buy titanium scrap. IMI does, however, recycle some of its own process scrap. Scrap is of various types, only some of which are suitable for incorporation into titanium ingots. At the present time, there is a technical limit on the proportion of process scrap which can be used in this way (since such incorporation reduces the strength of the compacted electrode). Despite intensive research effort, there is no sign that an imminent technological breakthrough will affect this proportion drastically. Thus IMI's interaction with the scrap market is not expected to change significantly in the next ten years. Scrap forms a relatively small proportion of IMI's raw materials.

The vast majority of sales of titanium mill products are destined for aircraft manufacture. The same is true for IMI's sales. IMI's sales forecasts are based largely on the expectation of numbers of different types of aircraft built. An examination was made to establish whether sales of titanium into this market could be forecast by linking through to forecasts of passenger-mile demand, and air freight forecasts. However, this was not useful because of the various factors influencing the links between them. A good deal of titanium (about 50% historically for IMI) is incorporated into pre-production planes, which are never sold to airlines. It is not clear how aircraft sizes and speeds will develop, as these have a critical effect on the number of aircraft required. Aircraft purchase decisions appear to be made largely with respect to internal financial criteria of the airlines. Most airlines have recently had liquidity problems which have depressed the demand for new planes. Owing to the stringent safety requirements for aircraft operations, which result in long testing programs of aircraft development, aircraft lead times are long. This effect meant that IMI's current forecasts of aerospace titanium demand were of more use than technological forecasts over a ten year planning horizon. As a further approach to examine the cross elasticity of titanium, a normative model of the design process for a jet engine disc was developed. This attempted to show how the prices of the various possible materials would affect their demand, by treating the disc as a simple mechanical structure, and only considering the stresses and temperature limitations. The approach was not taken further because the model was not able to show reasonable agreement with the true life process, because so many other factors are important in the design of a real disc.

Examination of the demand for titanium in space and missile systems indicated that, owing to the curtailment of the American space programme, sales would decline somewhat from their 1970 level.

Approaches taken to look at the non-aerospace market for IMI's titanium included interviews with technical sales personnel. No completely new products with large potential were put forward during these. A survey was made of the various applications (such as jewellery, surgical implants and ultra-centrifuge rotors) which took a small but growing share of the market. This indicated that such growth was likely to be swamped over the planning horizon of the work, by aircraft sales. Economic forecasts for user industries were studied, and markets examined, to draw this conclusion.

Thus the structure of the Titanium Industry, although complex, is largely isolated from IMI's point of view. The significant interactions which IMI experiences in the Industry are with its customers. The various technological forecasting approaches examined in IMI's markets were less useful and credible to IMI's management than currently produced forecasts. For these reasons, the promising approaches outlined above had to be rejected for the purposes of this project.

Some investigations were made of companies buying IMI titanium. These took the form of financial appraisal, and an assessment of their management and business position.

This was done largely using ratio analysis, an approach which needs careful use. Although tentative forecasts of their titanium consumption were made, the method would apparently not yield accurate forecasts. It served however as a useful approach to looking at customer industries. The data collection for this work involved obtaining both published and unpublished financial and other information from a variety of sources. A number of useful insights into the customers selected were obtained, and found useful by the Sales Department.

A survey of the files available in the Sales Department was carried out to find suitable information sources for planning purposes. Sales Managers' Monthly Reports were found to be reliable extractors of important information from reports circulating in their departments.

A.3 Literature Review on Flow Chart Models of Industrial Buying

A.3.1 Introduction

The reported investigations of buying decisions in industry have been classified (Moore (1968)) according to whether they describe how decisions ought to be made (i.e. normative models) or how decisions are actually made (i.e. descriptive models). This section concentrates on studies of actual decisions in the belief that only such work will be of use in modelling titanium buyer behaviour.

Since the real industrial buying process is complex (Wind and Robinson (1968)), there is little analytical work in the field. The majority of the published studies have used a simulation technique known as heuristic programming (H P)(Kuehn (1962)). Moore (1968) describes the HP approach as:-

" a) analysing the actual, step-by-step cognitive process which an individual consciously or unconsciously follows in arriving at a given decision,

and b) developing an explicit flow diagram model and computer program which will produce the exact same output as the human counterpart."

This description would seem to have some limitations in the industrial context. As Wind (1971) points out, many industrial purchase decisions are influenced by several individuals. For a model to be useful it should presumably include all substantial influences on its outcome, and so model the group decision behaviour. Massy and Savvas (1964) point out that computers are only an expedient in the modelling process. Clearly, a model which produces the "exact same output" will be valid. However, one which produces a similar but non-identical output may be almost as useful as an absolutely true model.

Thus an operational version of Moore's definition, which is suitable for examining the buying decision might read:

" a) analysing the actual step by step process followed in arriving at the buying decision,

and b) devloping an explicit flow diagram model
to produce the same output."

A.3.2 HP Model Building Methodology

The building of flow-chart models has been described by Massy and Savvas (1964), but the actual derivation from "field data" is left to the studies of some decision-makers. Moore (1969a), in a study which generalises from several independent buying decision-makers, describes how flow models are produced by seeking commonality from a large collection of anecdotes. Morgenroth (1964) and Howard and Morgenroth (1968) obtained flow charts more directly by interviewing managers, and obtaining their articulations of their own decision rules (termed protocols). Schussel (1967), in a study of photographic dealer film buying behaviour, similarly interviewed dealers and asked them to describe their ordering policies.

Models based on the Behavioral Theory of the Firm (Cohen, Cyert, March and Soelberg (1963) and Cyert, March and Moore (1963)) have been designed originally from a normative viewpoint, but have stood up to later validation surprisingly well.

Wind (1966) describes a two-stage process for initially deriving decision models: a first stage consisting of unstructured interviews with "key" people in the decision process, which is intended to uncover the relevant decision variables, followed by the second stage where protocols are obtained by asking participants to "think aloud". Although not stated, this apparently refers to anecdotal data, and not direct transcription of the participant's protocol.

Little has been written comparing these three methods of initially setting up a flow chart, although one study (Massy and Savvas (1964)) states:-

> "Individuals can rarely describe all the details of their jobs with great accuracy."

Similarly, Moore's (1968) definition of an HP implies that the researcher ought to investigate anecdotes, and himself work out protocols from them. However, Morgenroth's (1964) work, which is based on an apparently weaker approach, yielded extremely accurate results, when the model was compared to previous decisions. There seems to be little to favour the normative approach.

It seems to be fairly well established (Massy and Savvas (1964), Cohen, Cyert, March and Soelberg (1963), Morgenroth (1964), Howard and Morgenroth (1968) and Wind (1966)) that, once established, the protocols should be verified by submitting them to a large scale comparison with previous historical decisions, using the firm's existing data. A further test suggested in Morgenroth (1964) and Wind (1966) is to validate the models by reference to other involved personnel (e.g. other buyers).

A.3.3 HP Model Structures

The use of flow-charts to describe buying decisions results in the treatment of the buying decision as a system of sequential sub-decisions. Apart from this, there are many other similarities in the models of different decisions reported in the literature. Moore (1969b) in a survey of HP models, classifies their decisions into functional types:-

i) Categorization, where each supplier is evaluated against a fixed measure.

ii) Choice, where a subset of suppliers is chosen, by selecting the "best" performers on some criterion.

iii) Computation, where no alternatives are considered (e.g. a sales forecast made).

Cohen, Cyert, March and Soelberg (1963) have derived a model which shows a hybrid of the two first functional types. If an adverse condition is produced by categorization, a localised search is carried out to produce choice behaviour. These three functions therefore form the "building blocks" of an HP model.

Loyalty, or memory is a frequently occurring concept in HP models[1]. Wind (1966 and 1970), and Webster and Wind (1972)

---

1 A more complete discussion of the concept of loyalty and how it is shown by other writers is found in Bubb and van Rest (1973).

have concluded that source loyalty[1] is a factor in organisational buying behaviour. Moore (1969a) treats similar behaviour in a rather different way. He finds, in a general model, that buyers tend to select suppliers from those on an "acceptable list". A feedback system is operated to keep the lists up-to-date. Since this feedback tends to be slow in comparison to the order decision frequency, it produces source loyalty. Forrester (1961) shows similar behaviour in a feedback or memory system.

---

1. Rao (1969) has put forward a measure of the brand loyalty of a consumer of a frequently purchased food item. This measure is developed to characterise the response of a consumer to advertising , and is in terms of three market variables: the number of competing brands, k, the proportion of his purchases satisfied by his favourite brand, p, and the maximum length of time (in years) the consumer has favoured any brand, L. Loyalty, Z, is given by:

$$Z = \frac{Lp - L/k}{100 - 100/k}$$

This measure thus summarises past behaviour in the market, and exhibits a loyalty which is not specific to a brand. Rao uses the measure in determining the response to advertising strategies.

As pointed out in Bubb and van Rest (1973), in industrial buying loyalty is more usefully,for modelling and predictive purposes, regarded not only as a summary of buying decision outcomes, but as an input to each decision.

The model developed in this thesis requires such a measure of loyalty which is specific to each supplier/customer pair, and which can reasonably be used as an input to the decision. The definition proposed by Rao is unsuitable for use in this situation, since it depends on the number of brands: in our case we do not wish loyalty to change if other suppliers come or go. Also the measure is not specific to a particular supplier.

A.3.4 Summary

While many studies have been written describing industrial buying rationale, there does not, of yet, appear to be a theory which can be directly applied to a specific market (Moore (1969b)) (in our case titanium).

The suggestions for obtaining protocols, although sketchy, are useful. Similarly, reports of specific models are useful in that they give help in obtaining protocols from reports of anecdotes.

Little help is given with validation of the models, which, according to Moore's (1968) definition are either valid, and describe reality perfectly, or invalid. This type of validation must surely be tempered by the model's usefulness. It is surely better to have a so called invalid model used, than an unusable, but valid model. The major although some models describe the process well, no report of the use of any model is presented.

A.4 The Flow Chart Model of the Titanium Customer

This model is described in Chapter 5, and has been programmed in FORTRAN. Since the program listing forms the most detailed specification of the model, that is attached here as table A.8.

Table A.8 THE CUSTOMER MODEL PROGRAM

```
      LIBRARY(ED,SUBGROUP CSL)
      LIST(LP)
      PROGRAM (EXXX)
      INPUT  1 = CR0
      OUTPUT 2 = LP0
      INPUT  3 = TR0
      INPUT  5 = CR1
      OUTPUT 6 = LP1
      COMPRESS INTEGER AND LOGICAL
      TRACE 2
      END
      TRACE 1
      READ FROM (CR)
      MASTER XX
      REAL Q,PB(10),EXP(10),QUP(10),EXD(10),QUD(10),TRD(10),COP    ,COD
     A    ,IM,PM,INTM,INT(3,10),BEST       ,SEN(5),PREFS(10),TP,SPI,PCO,PLP,
     BSPL(5),PV(5),LPS,SCPX,CPX(10),TSP,SP(5),TSF,SF(10),ORD(10)
     C,MFP,ATR(10,5),ADFP,             PSEN(10),PLOY(10),REQ(10),PCPL(5,10)
      INTEGER X,J,TW,DA(10),EX(10),AS(10,5),CLI(10),OG(10),ALI(10),JC,MP
     C,CPL(5),FP,B(5),PRS,RT,NUM,SPA    ,ADEQ(10)
     D,PCOP(10),ORBK(10),ORDPROD
      COMMON Q,PREFS,PCOP,PCPL,CPX,PSEN,PLOY,REQ,ALI,CPL,ORBK,TW,EX,AS,PB
     C,TRD,ATR,SEN  ,X,QUP,QUD,COP,COD
C INPUT ROUTINE FOR NOW
    7 CONTINUE
      DO 73 J=1,10
      PCOP(J)=0
   73 REQ(J)=1.
      CALL GENINP
      CALL ORDINP
      CALL GENPRI
      CALL ORDIPR
      DO 12 J=1,TW
   12 CLI(J)=1
COMMENT======== REQUIREMENT FOR PRODUCT
COMMENT======== PREPARE LIST OF ACCEPTABLE SUPPLIERS
      SPA=0
      KJ=0
  300 DO 301 J=1,10
C                                 TW=TOT SIZE OF WORLD LIST
      IF(J.GT.TW) GO TO 303
      IF(EX(J).EQ.0) GO TO 303
C                                 EX(IC,J) =0 IF CUST IC HAS NO EXPER OF SUP
      IF(AS(J,X).EQ.0) GO TO 303
C                                 AS(J,X)=ABILITY OF SUPP J TO SUPP PROD X,1
      IF(PB(J).LT.0.2) GO TO 303
C                                 PB(IC,J)=PREPAREDTOBUYINDEX CUSTIC SUPPJ 0
      CLI(J)=1
C                                 CLI(J)=CURRENT LIST INDEX  1=ALIVE  0=DEAD
      GO TO 301
  303 CLI(J)=0
  301 KJ=KJ+CLI(J)
  302 CONTINUE
      IF(KJ.EQ.0) GO TO 8989
COMMENT======== CLI AT THIS STAGE SHOWS IF GOING TO ISSUE ENQUIRY
      WRITE(2,305)(CLI(J),J=1,10)
  305 FORMAT(10X,18HENQUIRY DECISIONS ,10(1H,,1X,I1,1X))
      DO 310 J=1,TW
      IF(CLI(J).EQ.0)GO TO 311
      GO TO 314
  311 OG(J)=0
      GO TO 310
  314 CALL ENQ(J,KQ)
      OG(J)=KQ
  310 CONTINUE
COMMENT======== DEDUCE PRICE + DELIVERY EXPECTATIONS FOR EACH SUPPLIER
 8888 FORMAT(30X,I2)
  600 DO 601 J=1,TW
      IF(OG(J).EQ.0)GO TO 601
      EXP(J)=QUP(J)
C                                 EXP(J)=EXPECTED PRICE FROM SUPPLIER J
C                                 QUP(J)= QUOTED  ---------11----------
      EXD(J)=QUD(J)+TRD(J)
C                                 EXD(J)=EXPECTED DELY  ------ 11 -----
C                                 QUD(J)= QUOTED  -------- 11 ---------
C                                 TRD(J)=ADJFACTOR-------- 11----------
  601 CONTINUE
  602 CONTINUE
      WRITE(2,605)(EXD(J),J=1,10)
  605 FORMAT(10X,20HEXPECTED DELIVERIES ,10(1H,,1X,F6.2,1X))
      WRITE(2,606)(EXP(J),J=1,10)
  606 FORMAT(10X,16HEXPECTED PRICES ,10(1H,,1X,F6.2,1X))
COMMENT========SET UP ATR FOR NOW
C                ATR(10,5) = ATTRIBUTE MATRIX
C                ATR(  ,1) = EXPECTED PRICE
C                ATR(  ,2) = EXPECTED DELIVERY
C                ATR(  ,3) = LOYALTY
C                ATR(  ,4) = QUALITY
C                ATR(  ,5) = PRESSURE FROM BUYER'S CUSTOMER
      DO 312 J=1,TW
      ATR(J,1)=EXP(J)
      ATR(J,2)=EXD(J)
  312 CONTINUE
COMMENT======== EVALUATE EACH SUPPLIER AGAINST CUT-OFFS
      WRITE(2,8000)
 8000 FORMAT(5X,25HEVALUATE AGAINST CUT-OFFS )
  700 DO 701 J=1,TW
      ALI(J)=OG(J)
      IF(EXP(J).GT.COP)     GO TO 703
```

Table A.8 (continued)

```
C                                COP=CUTOFF PRICE
      IF(EXD(J).GT.COD) GO TO 703
C                                COD=CUTOFF DELIVERY
      GO TO 701
  703 ALI(J)=0
  701 CONTINUE
COMMENT======== ALI AT THIS STAGE SHOWS WHATS LEFT AFTER CUT-OFFS
      WRITE(2,705)(ALI(J),J=1,10)
  705 FORMAT(10X,20HLEFT AFTER CUT-OFFS ,10(1H,,1X,I1,1X))
COMMENT======== COUNT SUPPLIERS ON LIST + BRANCH
      WRITE(2,8001)
 8001 FORMAT(5X,25HCOUNT REMAINING SUPPLIERS )
  800 JC=0
C                                J=COUNT OF CURRENT LIST
      DO 801 J=1,TW
  801 IF(ALI(J).EQ.1) JC=JC+1
      WRITE (2,851) JC
  851 FORMAT (10X,4HJC=  ,I2)
  802 IF(JC.EQ.0)GO TO 900
      IF(JC.EQ.1) GO TO 1503
COMMENT======== SELECT CUSTOMER'S FIRST PREFERENCE VARIABLE
      WRITE(2,8002)
 8002 FORMAT(5X,30HSELECT MOST IMPORTANT VARIABLE )
 1020 CONTINUE
      DO 1230 J=1,TW
 1230 ADEQ(J)=ALI(J)
 1000 MP=20
      DO 1001 J=1,5
      IF(CPL(J).GE.MP)GO TO 1001
      MP=CPL(J)
      FP=J
 1001 CONTINUE
      WRITE(2,1005)FP
 1005 FORMAT(10X,27HFIRST PREFERENCE VARIABLE = ,I2 )
C                                CPL(J)=CUSTOMER PREFERENCE LIST
C                                FP=CUSTOMER'S FIRST PREFERENCE VARIABLE
C                                MP=MIN PREF
COMMENT======== SELECT BEST SUPPLIER ON THIS VARIABLE + OTHER SATIS ONES
      WRITE(2,8006)
 8006 FORMAT(5X,30HSELECT SUPPLIERS WITHIN LIMITS )
 1200 IF(FP.GT.2.5)GO TO 1201
      MFP=10000000.
C     MFP=MIN(OR MAX) OF FST PREF
      DO 1202 J=1,TW
      IF(ADEQ(J).EQ.0) GO TO 1202
      IF(ATR(J,FP).LT.MFP) MFP=ATR(J,FP)
 1202 CONTINUE
C     ATR(J,FP)=ATTRIB(CUST J,1=PRCE,2=DELY,3=LOY,4=QUAL,5=CCP)
C  ADFP =ADEQ VAL OF FST PREF
      ADFP=MFP*(1+SEN(FP))
      DO 1203 J=1,TW
      IF(ADEQ(J).EQ.0)GO TO 1203
      IF(ATR(J,FP).GT.ADFP) GO TO 1220
      ADEQ(J)=1
      GO TO 1203
 1220 ADEQ(J)=0
 1203 CONTINUE
      WRITE(2,1658) ADFP
 1658 FORMAT(10X,6HADFP=  ,F8.3)
      GO TO 1600
 1201 MFP=-1.
      DO 1204 J=1,TW
      IF(ADEQ(J).EQ.0)GO TO 1204
      IF(ATR(J,FP).GT.MFP)MFP=ATR(J,FP)
 1204 CONTINUE
      ADFP=MFP*(1-SEN(FP))
      WRITE(2,1658) ADFP
      DO 1205 J=1,TW
      IF(ADEQ(J).EQ.0)GO TO 1205
      IF(ATR(J,FP).LT.ADFP) GO TO 1221
      ADEQ(J)=1
      GO TO 1205
 1221 ADEQ(J)=0
 1205 CONTINUE
      WRITE(2,1210)(ADEQ(J),J=1,10)
 1210 FORMAT(10X,26HAEFQUATE ON THIS VARIABLE ,10(1H,,1X,I1,1X))
 1600 JC=0
COMMENT======== COUNT CURRENT LIST + BRANCH
      WRITE(2,8002)
      DO 1601 J=1,TW
      IF(ADEQ(J).EQ.0)GO TO 1601
      JC=JC+1
      PRS=J
 1601 CONTINUE
      WRITE(2,1657)JC
 1657 FORMAT(10X,4HJC=  ,I2)
 1602 IF(JC.EQ.1)GO TO 1500
 1700 CONTINUE
COMMENT======== MOVE FIRST PREFERENCE TO BOTTOM OF LIST
 1800 CPL(FP)=CPL(FP)+5
      WRITE(2,8007)
 8007 FORMAT(5X,18HLIST CYCLING CHECK )
COMMENT======== CHECK FOR PREFERENCE LIST CYCLING ONCE
 1900 IF(CPL(FP).EQ.10)GO TO 2200
COMMENT======== CHECK FOR PREFERENCE LIST CYCLING TWICE
 2100 IF(CPL(FP).EQ.15)GO TO 2000
      GO TO 1000
COMMENT======== DOUBLE PREFERENCE SELECTION SENSITIVITIES
 2200 DO 2201 J=1,5
```

Table A.8 (continued)

```
 2001 SEN(J)=SEN(J)*0.5
      GO TO 1020
COMMENT======== NOTE PREFFERRED SUPPLIER
      WRITE(2,8008)
 8008 FORMAT(5X,25HSINGLE PREFERRED SUPPLIER )
 1500 DO 1501 J=1,TW
      IF(J.NE.PRS) GO TO 1502
      PRFS(PRS)=1.
      GO TO 1501
C                                      PRS=NO. OF PREFERRED SUPPLIER
 1502 PRFS(J)=0.
 1501 CONTINUE
C                                      PRFS(J) = PREF RATINGS  SUM TO 1
      GO TO 2300
 8989 WRITE(2,8899)
 8899 FORMAT(10X,25HNO SATISFACTORY SUPPLIER   )
      GO TO 8999
 1503 DO 1504 J=1,TW
 1504 PRFS(J)=ALI(J)
      GO TO 2300
COMMENT======== NOTE PREFERRED SUPPLIERS
      WRITE(2,8009)
 8009 FORMAT(5X,28HMULTIPLE PREFERRED SUPPLIERS )
 2000 CONTINUE
      KR=0
      DO 2001 J=1,TW
      IF(ADEQ(J).EQ.0) GO TO 2001
      KR=KR+1
 2001 CONTINUE
      DO 2002 J=1,TW
      AIND=ADEQ(J)
      BIND=KR
 2002 PRFS(J)=AIND/BIND
C                                      TP = RUNNING VARIABLE FOR TOT OF PRFS
      WRITE(2,2005)(PRFS(J),J=1,10)
 2005 FORMAT(10X,19HPREFERRED CUSTOMERS ,10(1H,,1X,F5.3,1X))
      GO TO 2300
COMMENT======== RELAX CUT-OFFS BY 10%
      WRITE(2,8003)
 8003 FORMAT(5X,20HRELAX CUT-OFFS A BIT )
  900 COP=COP*1.1
      COD=COD*1.1
COMMENT======== EVALUATE EACH SUPPLIER AGAINST CUT-OFFS AGAIN
      WRITE(2,8004)
 8004 FORMAT(5X,28HRE-EVALUATE AGAINST CUT-OFFS )
 1100 DO 1101 J=1,TW
      ALI(J)=OG(J)
      IF(EXP(J).GT.COP)GO TO 1103
      IF(EXD(J).GT.COD)GO TO 1103
      GO TO 1101
 1103 ALI(J)=0
 1101 CONTINUE
COMMENT======== COUNT SUPPLIERS ON LIST AND BRANCH
      WRITE(2,8005)
 8005 FORMAT(5X,24H(13)COUNT SUPPLIERS LEFT )
 1300 RT=0
      DO 1301 J=1,TW
      RT=RT+ALI(J)
 1301 PRS=J
      IF(RT.EQ.0)GO TO 900
      IF(RT.EQ.1)GO TO 1500
      GO TO 1020
COMMENT======== RELEASE DETAILS TO SELECTED SUPPLIERS
      WRITE(2,8010)
 8010 FORMAT(5X,15HINVITE RESPONSE )
 2300 IF(SPA.EQ.1) GO TO 3700
      DO 2301 J=1,TW
      IF(PRFS(J).LT.0.05) GO TO 2301
      CALL SUPBEH(J)
 2301 CONTINUE
COMMENT======== RECEIVE MARKET RESPONSE
 2400 CONTINUE
COMMENT======== CHECK WHETHER ANY PRESSURE ON CUT-OFFS
COMMENT========AGGREGATE CUT-OFF PRESSURE
      PCO=0.
      JPC=0
      DO 2501 J=1,TW
      PCO=PCO+PCOP(J)
 2501 JPC=JPC+1
      PCO=PCO/JPC
 2600 IF(PCO.LT.0.1)GO TO 2800
C                                      PCO= PRESSURE ON CUT-OFFS  0-1
COMMENT======== CHANGE CUT-OFF VALUES
      COP=COP*(1+PCO)
      COD=COD*(1+PCO)
COMMENT======== ALTER PREFERENCE ORDER
COMMENT========AGGREGATE PRESSURE ON PREF LISTS
 2800 DO 2904 JP=1,5
      PV(JP)=0.
      DO 2905 J=1,10
 2905 PV(JP)=PV(JP)+.5*PCPL(JP,J)
      IF(PV(JP).GT.1)PV(JP)=1.
      IF(PV(JP).LT.-1)PV(JP)=-1.
 2904 CONTINUE
 2900 DO 2901 J=1,5
 2901 NPL(J)=CPL(J)-2.*PV(J)
C                                      NPL(J) NEW PREF LIST
C                                      PV(J) PRESS TO CH LIST -1(REDUCEIMP)-+1(MI
      DO 2903 JP=1,5
```

Table A.8 (continued)

```
      LPS=100
      DO 2902 J=1,5
      IF(LPS.GE.NPL(J)) GO TO 2906
      GO TO 2902
 2906 NUM=J
      LPS=NPL(J)
 2902 CONTINUE
      CPL(NUM)=J2
 2903 NPL(NUM)=200.
      WRITE(2,2910)(NPL(J),J=1,5 )
 2910 FORMAT(10X,19HNEW PREFERENCE LIST ,5(1H,,1X,F7.3,1X))
      WRITE(2,61)(CPL(I),I=1,5)
   61 FORMAT(/,10X,26HCUSTOMER PRIORITIES: PRICE ,I1,10H  DELIVERY,I1,
     C10H  LOYALTY,,I1,10H  QUALITY,,I1,30H  BUYER'S CUSTOMER'S PRESSURE
     D,,I1)
C                                 NUM  LOOP
C                                 LPS  VARIABLES
COMMENT======== CALCULATE REVISED EXPECTATIONS
 3100 DO 3101 J=1,TW
      IF(CPX(J).LT.0.5)GO TO 3101
      EXP(J)=EXP(J)*0.9
      EXD(J)=EXD(J)*0.9
 3101 CONTINUE
      WRITE(2,3106)(EXP(J),J=1,10)
      WRITE(2,3305)(EXD(J),J=1,10)
 3106 FORMAT(10X,19HNEW EXPECTED PRICES ,10(1H,,1X,F7.2,1X))
 3102 CONTINUE
C                                 TSP  TOT PRESS ON SENSITIVITIES
COMMENT========AGGREGATE PRESSURE ON SENSITIVITIES
      SP(1)=0.
      DO 3302 J=1,TW
 3302 SP(1)=SP(1)+PSEN(J)
      IF(SP(1).LE.-2)SP(2)=.5
      IF(SP(1).GE.2) SP(2)=-.5
      IF(SP(1).GT.-2.AND.SP(1).LT.2)SP(2)=0.
      DO 3303 J=1,5
 3303 SP(J)=SP(2)
COMMENT======== CHANGE SENSITIVITIES
 3300 DO 3301 J=1,5
      IF(SP(J).LT.0.1)GO TO 3301
      SEN(J)=SEN(J)*(1+SP(J))
 3301 CONTINUE
C                                 SP(J) = SENSIT PRES
COMMENT======== ALTER INDIVIDUAL EXPECTATIONS
 3500 DO 3501 J=1,TW
      EXP(J)=EXP(J)*REQ(J)
      EXD(J)=EXD(J)*REQ(J)
      IF(PLOY(J).EQ.1)ATR(3,J)=ATR(3,J)*1.1
 3501 CONTINUE
      WRITE(2,3305)(EXD(J),J=1,10)
 3305 FORMAT(10X,23HNEW EXPECTED DELIVERIES ,10(1H,,1X,F7.2,1X))
      WRITE(2,3106)(EXP(J),J=1,10)
 3502 GO TO 3600
COMMENT======== CHECK WHETHER SALES PRESSURE HAS HAD EFFECT
 3600 SPA=1
      GO TO 300
COMMENT======== PLACE ORDER
 3700 DO 3701 J=1,TW
 3701 ORD(J)=PRFS(J)*Q
 3702 CONTINUE
COMMENT======== WRITE OUTPUT
      DO 9900 J=1,TW
 9900 WRITE(2,9906)J,ORD(J)
 9906 FORMAT(10X,I2,20X,F12.6)
 8999 CONTINUE
      GO TO 7
      STOP
      END
      SUBROUTINE ENQ     (I002,I003)
      DIMENSION A(1),A005(10),I006(10),A007(5,10),A008(10),A009(10),A010
     1(10),A011(10),I012(10),I013(5),I014(10),I016(10),I017(10,5),A018(1
     10),A019(10),A020(10,5),A021(5),A023(10),A024(10)
      COMMON A004,A005,I006,A007,A008,A009,A010,A011,I012,I013,I014,I015
     1,I016,I017,A018,A019,A020,A021,I022,A023,A024,A025,A026
      COMMON/C001/T1,K1
      COMMON/C005/I001
      T3=T1
      CALL MVT1(8HENQ      )
      I003=1
      A023(I002)=IDEV1(I027,1,11)
      A024(I002)=IDEV1(I028,2,12)
      T1=T3
      RETURN
25001 CALL EXIT1
      END
      SUBROUTINE SUPBEH(IS)
COMMENT========MEANING OF VARIABLES IN SUBROUTINE
C      ORDSZ = ORDER SIZE        =ORDQTY OR 0
C      COR(10)=CUT-OFF REJECT  ==ALI(10)
C      PCUP(10)=PRESSURE ON CUT-OFF POINTS   = PCOP
C      PRS(10) =SUPPLIER PREFERENCE MEASURE  =PRFS(10)
C      RANK(5) =PREFERENCE VARIABLE  =CPL(5)
C      IM=MIN RANK
C      PCPL(J,IS)=PRESSURE ON PREF VAR J FROM SUPP IM,+1 TO REDUCE CPL(J)
C                                -1 TO INC CPL(J) ,   =PCPL
C      PXV(IS)= PRESSURE TO TRANSFORM VARIABLES =1 TO GET BETTER =CPX
C      PSEN(IS)=PRESSURE TO CHANGE SENSITIVITIES 1-MORE SENS,-1LESS,=PSEN
C      PLOY(IS)=PRESSURE ON LOYALTY,1 TO INCREASE ,=PLOY
C      ORBK(IS)=ORDER BOOK LABEL,1=FULL , = OBDK
```

Table A.8 (continued)

```
C      REQ(IS) =REQUIRE FOR PRCE +DEL , =REQ
C      DOU(IS) =DRIG QUOTE
       INTEGER COR(10),RANK(5),ORBK(10)
      C,PCOP(10),TW,EX(10),AS(10,5)
       REAL ORDSZ,PRS(10),PCPL(5,10),PXV(10),PSEN(10),PLOY(10),REQ(10),
      DPR(10),TRD(10),ATR(10,5)            ,DOU(10)
        COMMON ORDSZ,PRS,PCOP,PCPL,PXV,PSEN,PLOY,REQ,COR,RANK,ORBK,TW,EX,
      CS,PB,TRD,ATR
       PSEN(IS)=0.
       PXV(IS)=0.
       DOU(IS)=1.
       PLOY(IS)=0.
       IF(ORDSZ.LT.0.5)GO TO 10
       IF(COR(IS).EQ.1)PCOP(IS)=1
       IF(PRS(IS).GT.0.6)GO TO 20
       IF(PRS(IS).GT.0.05)GO TO 21
       IM=200
       DO 22 J=1,5
       IF(RANK(J).GT.IM)GO TO 22
       IM=RANK(J)
    22 CONTINUE
       RV=5.5
       IF(IM.GT.5.5)RV=10.5
       DO 23 J=1,5
       IF(RANK(J).EQ.IM.OR.RANK(J).GT.RV)GO TO 24
       PCPL(J,IS)=1.
       GO TO 23
    24 PCPL(J,IS)=-1.
    23 CONTINUE
       GO TO 21
    20 IM=200
       DO 26 J=1,5
       IF(RANK(J).GT.IM)GO TO 26
       IN=J
    26 CONTINUE
       DO 27 J=1,5
       IF(J.EQ.IN)GO TO 28
       PCPL(J,IS)=-1.
       GO TO 27
    28 PCPL(J,IS)=1.
    27 CONTINUE
    21 IF(PRS(IS).GT.0.05)GO TO 29
       PXV(IS)=1.
    29 IF(PRS(IS).GT.0.6)GO TO 30
       IF(PRS(IS).LT.0.05)PSEN(IS)=-1.
       GO TO 31
    30 PSEN(IS)=1.
    31 IF(RANK(3).EQ.1.OR.RANK(3).EQ.2.OR.RANK(3).EQ.6.OR.RANK(3).EQ.7
      A.OR.RANK(3).EQ.11.OR.RANK(3).EQ.12) PLOY(IS)=1.
       IF(PRS(IS).GT.0.6)GO TO 32
       IF(ORBK(IS).EQ.1)GO TO 32
       REQ(IS)= 0.8
    32 CONTINUE
    10 CONTINUE
       RETURN,
       END
       SUBROUTINE GENINP
       REAL O,PB(10),EXP(10),OUP(10),EXD(10),OUD(10),TRD(10),COP    ,COD
      A    ,DM,PM,INTM,INT(3,10),BEST      ,SEN(5),PRFS(10),TP,SPI,PCO,PLP,
      BNPL(5),PV(5),LPS,SCPX,CPX(10),TSP,SP(5),TSF,SF(10),ORD(10)
      C,MFP,ATR(10,5),ADFP,            PSEN(10),PLOY(10),REQ(10),PCPL(5,10)
      D,TITLE(10)
       INTEGER X,J,TW,DA(10),EX(10),AS(10,5),CLI(10),OG(10),ALI(10),JC,MP
      C,CPL(5),FP,R(5),PRS,RT,NUM,SPA    ,ADEQ(10)
      D,PCOP(10),ORBK(10),ORDPROD
       COMMON O,PRFS,PCUP,PCPL,CPX,PSEN,PLOY,REQ,ALI,CPL,ORBK,TW,EX,AS,PB
      C,TRD,ATR,SEN  ,X,OUP,QUD,COP,COD
COMMENT THIS SUBROUTINE INPUTS BASIC DATA WHICH DOES NOT CHANGE WITH EAC
       WRITE(2,50)
 50    FORMAT(10X,5HTITLE)
       READ(1,93)      TITLE
   93 FORMAT(10A8)
       WRITE(2,95)
 95    FORMAT(1H1)
       WRITE(2,93)           TITLE
       WRITE(2,51)
 51    FORMAT(10X,'NO OF SUPS')
       READ(1,10)TW
       WRITE(2,52)
 52    FORMAT(10X,'EXP OF SUPS')
       READ(1,10)(EX(I),I=1,TW)
       WRITE(2,53)
  53    FORMAT(10X,'ORD BKS')
       READ(1,10)(ORBK(I),I=1,TW)
       DO 20 J=1,5
       WRITE(2,54)J
   20 READ(1,10)(AS(I,J),I=1,TW)
  54   FORMAT(10X,'AB SUP PROD ',I2)
   10 FORMAT(10I0)
       WRITE(2,55)
  55   FORMAT(10X,'PREP BUY IND')
       READ(1,30)(PB(I),I=1,TW)
       WRITE(2,56)
  56   FORMAT(10X,'DELY ADS')
       READ(1,30)(TRD(I),I=1,TW)
       DO 40 J=3,5
       WRITE(2,57)
  57   FORMAT(10X,'ATRS')
   40 READ(1,30)(ATR(I,J),I=1,TW)
```

Table A.8 (continued)

```
 30 FORMAT(10F0.0)
    RETURN
    END
    SUBROUTINE ORDINP
    REAL Q,PB(10),EXP(10),OUP(10),EXD(10),OUD(10),TRD(10),COP     ,COD
   A    ,DM,PM,INTM,INT(3,10),BEST       ,SEN(5),PRFS(10),TP,SPI,PCO,PLP,
   BNPL(5),PV(5),LPS,SCPX,CPX(10),TSP,SP(5),TSF,SF(10),ORD(10)
   C,MFP,ATR(10,5),ADFP,             PSEN(10),PLOY(10),REQ(10),PCPL(5,10)
    INTEGER X,J,TW,DA(10),EX(10),AS(10,5),CLI(10),OG(10),ALI(10),JC,MP
   C,CPL(5),FP,B(5),PRS,RT,NUM,SPA    ,ADEQ(10)
   D,PCOP(10),ORBK(10),ORDPROD
    COMMON Q,PRFS,PCOP,PCPL,CPX,PSEN,PLOY,REQ,ALI,CPL,ORBK,TW,EX,AS,PB
   C,TRD,ATR,SEN  ,X,OUP,CUD,COP,COD
COMMENT THIS SUBROUTINE INPUTS DATA FOR A PARTICULAR ORDER
    WRITE(2,60)
 60 FORMAT(10X,'PROD NO')
    READ(1,10)X
    WRITE(2,61)
 61 FORMAT(10X,'CUR PREF LIST')
    READ(1,10)(CPL(I),I=1,5)
 10 FORMAT(10I0)
    WRITE(2,62)
 62 FORMAT(10X,'QTY')
    READ(1,30)Q
    WRITE(2,63)
 63 FORMAT(10X,'CUT OFF DEL')
    READ(1,30)COD
    WRITE(2,64)
 64 FORMAT(10X,'CUT OFF PRICE')
    READ(1,30)COP
    WRITE(2,65)
 65 FORMAT(10X,'OT PRICES')
    READ(1,30)(OUP(I),I=1,TW)
    WRITE(2,66)
 66 FORMAT(10X,'OT DELS')
    READ(1,30)(OUD(I),I=1,TW)
    WRITE(2,67)
 67 FORMAT(10X,'SENS')
    READ(1,30)(SEN(I),I=1,5)
 30 FORMAT(10F0.0)
    RETURN
    END
    SUBROUTINE GENPRI
    REAL Q,PB(10),EXP(10),OUP(10),EXD(10),OUD(10),TRD(10),COP     ,COD
   A    ,DM,PM,INTM,INT(3,10),BEST       ,SEN(5),PRFS(10),TP,SPI,PCO,PLP,
   BNPL(5),PV(5),LPS,SCPX,CPX(10),TSP,SP(5),TSF,SF(10),ORD(10)
   C,MFP,ATR(10,5),ADFP,             PSEN(10),PLOY(10),REQ(10),PCPL(5,10)
    INTEGER X,J,TW,DA(10),EX(10),AS(10,5),CLI(10),OG(10),ALI(10),JC,MP
   C,CPL(5),FP,B(5),PRS,RT,NUM,SPA    ,ADEQ(10)
   D,PCOP(10),ORBK(10),ORDPROD
    COMMON Q,PRFS,PCOP,PCPL,CPX,PSEN,PLOY,REQ,ALI,CPL,ORBK,TW,EX,AS,PB
   C,TRD,ATR,SEN  ,X,OUP,OUD,COP,COD
C   THIS SUBROUTINE PRINTS THE INPUT OBTAINED BY GENINP
    WRITE(2,50)TW
 50 FORMAT(/,10X,19HNO. OF SUPPLIERS = ,I2)
    WRITE(2,51)(EX(I),I=1,10)
 51 FORMAT(/,10X,24HEXPERIENCE OF SUPPLIERS ,10(4X,I1))
    WRITE(2,52)(ORBK(I),I=1,10)
 52 FORMAT(/,10X,24HSTATE OF THEIR ORDER BKS,10(4X,I1))
    DO 53 J=1,5
 53 WRITE(2,54)J,(AS(I,J),I=1,10)
 54 FORMAT(/,10X,22HABILITY TO SUPPLY PROD,1X,I1,10(4X,I1))
    WRITE(2,55)(PB(I),I=1,10)
 55 FORMAT(/,10X,19HPREPARED TO BUY IND,10(1X,F7.4))
    WRITE(2,56)(TRD(I),I=1,10)
 56 FORMAT(/,10X,19HQUOTED TO EST DEL  ,10(1X,F7.4))
    WRITE(2,57)(ATR(I,3),I=1,10)
 57 FORMAT(/,10X,19HLOYALTY INDEX      ,10(1X,F7.4))
    WRITE(2,58)(ATR(I,4),I=1,10)
 58 FORMAT(/,10X,19HQUALITY INDEX      ,10(1X,F7.4))
    WRITE(2,59)(ATR(I,5),I=1,10)
 59 FORMAT(/,10X,19HPRESSURE FROM B'S C,10(1X,F7.4))
    RETURN
    END
    SUBROUTINE ORDIPR
    REAL Q,PB(10),EXP(10),OUP(10),EXD(10),OUD(10),TRD(10),COP     ,COD
   A    ,DM,PM,INTM,INT(3,10),BEST       ,SEN(5),PRFS(10),TP,SPI,PCO,PLP,
   BNPL(5),PV(5),LPS,SCPX,CPX(10),TSP,SP(5),TSF,SF(10),ORD(10)
   C,MFP,ATR(10,5),ADFP,             PSEN(10),PLOY(10),REQ(10),PCPL(5,10)
    INTEGER X,J,TW,DA(10),EX(10),AS(10,5),CLI(10),OG(10),ALI(10),JC,MP
   C,CPL(5),FP,B(5),PRS,RT,NUM,SPA    ,ADEQ(10)
   D,PCOP(10),ORBK(10),ORDPROD
    COMMON Q,PRFS,PCOP,PCPL,CPX,PSEN,PLOY,REQ,ALI,CPL,ORBK,TW,EX,AS,PB
   C,TRD,ATR,SEN  ,X,OUP,OUD,COP,COD
C   THIS SUBROUTINE PRINTS THE INPUT OBTAINED BY ORDINP
    WRITE(2,60)X
 60 FORMAT(/,10X,33HTHIS ORDER IS FOR PRODUCT NUMBER ,I1)
    WRITE(2,61)(CPL(I),I=1,5)
 61 FORMAT(/,10X,27HCUSTOMER PRIORITIES: PRICE,,I1,10H  DELIVERY,I1,
   C10H  LOYALTY,,I1,10H  QUALITY,,I1,30H  BUYER'S CUSTOMER'S PRESSURE
   D,,I1)
    WRITE(2,62)Q
 62 FORMAT(/,10X,19HQUANTITY ORDERED = ,F10.5,2HKG)
    WRITE(2,63)COD
 63 FORMAT(/,10X,28HMAXIMUM POSSIBLE DELIVERY = ,F10.5,6H WEEKS)
    WRITE(2,64)COP
 64 FORMAT(/,10X,32HHIGHEST PRICE BUYER WILL PAY = $,F13.5)
```

<u>Table A.8</u> (continued)

```
   WRITE(2,65)(QUP(I),I=1,10)
65 FORMAT(/,10X,19HQUOTED PRICES (£)  ,10(1X,F7.2))
   WRITE(2,66)(QUD(I),I=1,10)
66 FORMAT(/ ,10X,19HQUOTED DELIVERIES  ,10(1X,F7.2))
   WRITE(2,67)(SEN(I),I=1,5)
67 FORMAT(/,10X,25HDECISION SENSITIVITIES : ,5(3X,F9.4))
   RETURN
   END
   FINISH
```

APPENDIX B

SOME ASPECTS OF SUPPLIER BEHAVIOUR

B.1 Exploratory Review of IMI's Accounting System

This section briefly reviews the work carried out to gain familiarity with IMI's accountancy systems.

As part of a somewhat wide appraisal of the costs of technical constraints on production processes, the manufacture of titanium billet was investigated. This investigation was carried out jointly with a member of the Technical Department, and aimed to find the implications of reducing the surface quality of the billet by reducing the number of machining operations. The wide-ranging financial consequences of the possible changes were computed. These included changes in production cost, scrap production, working capital, machinery purchase and pricing policies.

Recommendations were made to the Divisional management as a result, and action was later taken. This in turn led to other work in the Division on a similar product. A somewhat similar investigation was commenced by the author into the machining of ingots. The approach was not, however, capable of generalisation into a financial model of the Division

for two reasons. The analyses depend on data which is not, in general, available for all products, and the cost data is based on accounting assumptions which would not be valid when large-scale production mix changes are considered (e.g. scrap production). If these two problems could be solved, then the approach would be capable of generalisation. However, it is felt that the approach adopted in Chapter 5 represents a more effective allocation of research effort.

A thorough review of the Divisional Financial system was carried out. This in turn led to a critique of the system's operation from the management control point of view. Proposals were formulated to model the system mathematically, as a set of equations. This would regard any intermediate or final product as being defineable by a vector of properties. At each production centre, this vector would be multiplied by a matrix representing the "transfer function" to give a vector representing the output product. While this approach seemed reasonable theoretically, its data requirements were so large as to preclude its use, even in a very simple situation.

Some work was carried out on the procedure for valuation of titanium machine swarf. It was concluded that the method in current use was misleading. An internal report was issued setting out the conclusions and reasons.

B.2 A Literature Review on the Determination of Cost Behaviour

Much work in accounting depends critically on a knowledge of cost behaviour (Sizer (1969)). It is surprising, therefore, that few practical studies appear in the literature to indicate how cost behaviour can be determined.

Sizer (1966), in a review of methods of determination of cost behaviour suggests six approaches which might be used: accounts classification, the knowledgable estimate method, the high-low points method, scatter charts, least squares regression, and the use of engineering estimates[1].

The accounts classification method involves the examination of each cost from a logical standpoint, and its classification into the fixed (i.e. negligible variable cost rate), variable (insignificant fixed cost) or semi-variable category. Further work is necessary to establish the elements of semi-variable costs. This approach seems to be the most widely accepted (Ray, Smith and Donaldson (1968)) in industry, but short cuts in the procedure are not unknown[2]. This method is open to criticism on the grounds

---

[1] In practice (Ray, Smith and Donaldson (1968)), it is usual for accountants to assume that costs tend to vary linearly with changes in output:

$$C = F + vW$$

Where C represents the total cost, F the fixed element of that cost, W the work output, and v the variable cost rate.

[2] These generally take the form of rigid cost classification systems often laid down in the head office of a company or group.

of its basis on opinion, and not fact.

The <u>knowledgable estimate</u> method is another practical approach to the problem. It involves seeking the opinions of appropriate staff as to the expected costs at high and low levels of activity. The linear cost behaviour assumption is then applied to interpolate between these activities. Sizer (1969) questions the accuracy of this method. It is however, very similar to the normal budget-setting process (Ray, Smith and Donaldson (1968)) in industry. It is open to similar criticism as the previous approach, since it relies on opinions, and not measurable data.

<u>Industrial engineering estimates</u> are produced usually for new items of equipment, or changed circumstances, and represent in cost terms the theoretical, or logically expected requirements of manpower and materials. As they are normally used where no experience exists, the only alternative method of cost determination is to use accounts classification, which is likely to be less detailed and more error-prone.

The <u>high-low points</u> method of estimating cost behaviour is one of three methods relying on historical data. Actual costs at two extremes of activity are noted, and the fixed/variable relationship determined using this information only. The <u>scatter chart</u> method relies on a plot of the cost against activity for a number of periods. A line of "best" fit is drawn in by eye for these points.

The <u>least squares regression</u> method involves the use of a statistical procedure to estimate the line of best fit through the data. The relationship can be assumed to be with just one measure of activity (simple regression) or with several (multiple regression) and of a linear form (linear regression) or a more complex form (polynominal regression). The statistical procedure used (Chatfield (1970)) in least squares regression is based on the assumption that the best fit is obtained when the sum of the squares of the deviations between actual and predicted costs is at a minimum.

A number of studies of cost behaviour using regression techniques have appeared in the literature, and a useful survey is made by Johnston (1960). The studies largely confine themselves to overall cost data which has been published, in an attempt to identify the production function of economics. At this aggregate level of cost behaviour the studies tended to show that the accounting assumption of a linear cost/output relationship is generally reasonable. Relatively few studies have been published concerning the costs of individual plants or production centres, but see for example Benston (1966), Chiu and De Coster (1966) and Lyle (1944).

There are a significant number of studies of the use of regression analysis in related fields (e.g. Coen, Gomme and Kendall (1969) and Johnson (1972)) which contain useful descriptions of the experimental procedures involved.

A comparison of the various methods for establishing cost behaviour is difficult as there are no proven techniques for measuring their accuracy. It seems to the present writer that, of the three methods, high-low, scatter chart, and least squares, which utilise historical data, least squares is by far the most useful. The high-low method loses much richness by discarding information from the data. Least squares regression is an objective, unbiassed technique for using all the data to obtain parameters for the proposed model.

Sizer (1969) shows how these approaches work in practice on a sample set of data. The data is shown in table B.1. He finds the high-low method gives a relationship of cost (£C) to activity (H, direct labour hours) of:

$$C = 287 + .00409H$$

Similarly, the scatter chart method gives:

$$C = 280 + .00414H,$$

and the least squares regression approach,

$$C = 415 + .00221H$$

The data here has low correlation ($r = 0.5$), and so the three lines are spread out. As the correlation increases (i.e. $r \rightarrow \pm 1$), the lines will tend to become closer together. It is only by using the least squares approach that different cases can be compared objectively.

It has been argued that the scatter diagram technique is useful in that extreme or spurious points can be ignored in drawing a line. One criticism levelled at the use of regression analysis is that "unrepresentative" data can

Table B.1 DATA USED BY SIZER (1969) FOR COMPARING THE THREE METHODS OF SUMMARIZING HISTORICAL COST BEHAVIOUR

Activity Direct Labour Hours	Cost £
68	640
60	620
68	620
78	590
84	500
64	530
52	500
52	500
62	530
70	550
86	580
96	680

significantly alter the regression coefficients. However, usually if adequate data is available to label a point as unrepresentative, then the point is as representative as any other single point, but such behaviour has low probability.

It is argued (in Sizer (1966) and the discussion on Coen, Gomme and Kendall (1969)) that before using the technique of regression analysis to estimate relationships, a strong expectation of causality should exist. Sizer (1969) makes a strong case for the use of a test of significance to determine whether, statistically, it is reasonable to fit the data by the relationship selected. Statistical methodology is available to compare the assumption that various degrees of polynominal fit the data (see for example Chatfield (1970)), and also for comparing co-efficients of regression for differing numbers of observations and complexities of cost functions (see Huang (1970)). Johnston (1960) in some empirical studies on various industries, shows their use in practice. The use of these techniques is also mentioned in Coen, Gomme and Kendall (1969).

The use of statistical t and F tests on cost data seems to be irrelevant in the comparison of regression to other ways of meausring cost behaviour. The use of simple regression analysis seems to the present author to play a useful part in the process, as any reasonable judgment used in one of the other methods, accounts classification, knowledgable estimate or engineering estimate, must surely be based on some measurement of reality. Even if the statistical tests show insignificant results, it can be argued that regression analysis offers the best estimate of cost behaviour under the given assumptions.

It has been argued by Sizer (1969) that since accountants will tend to use un-adjusted cost figures for regression analysis, this will reduce the use of such studies.

However, various authors including Johnston (1960), and Coen, Gomme and Kendall (1969), have suggested different methods of adjusting the figures, so this criticism can hardly be regarded as fundamental. The use of multiple regression techniques for cost behaviour measurement when the costs depend on various factors has not received a great deal of attention but see for instance Johnston (1960), and Benston (1966). This is an area where regression seems to have a clear advantage over the other ways of establishing cost behaviour, since the other techniques are less adequate with more than one explanatory variable. Chiu and De Coster (1966) suggest the use of multiple regression for the determination of joint product costs.

B.3 Prediction and Monitoring of Divisional Financial Results

B.3.1 Forecasting

The work on a cost model for use in the market simulation led to the development of a system for forecasting Divisional financial results. The system was developed for use by the Accountancy Department, who provided the necessary data.

Equations of the form:-

$$H = f + m_1W_1 + m_2W_2 + m_3W_3 + m_4W_4$$

were proposed to describe each of a number of cost and revenue headings[1]. In the equation, H represents the value

---

[1] These headings corresponded to those found on current Accountancy Department reports, and so were familiar to the accountants and managers.

(corrected for inflation) of the cost or revenue heading, and the Ws, the sales weights of each of the four product groups, during the quarter concerned. A series of historical values of the Hs and Ws were obtained, and used to estimate the values of f and the ms for each heading, by multiple least squares regression.

These equations are used to predict financial results. The forecast of sales weights in each product group is used to calculate the expected value of each cost or revenue heading.

A computer program has been written which operates from a remote access terminal. On input of the sales forecast, a tabulated financial results statement is produced.

B.3.2 Maintenance of System

It is important that all the equations used are kept up to date, and effectively characterise each cost or revenue heading. The maintenance routine described below uses newly available data to regularly monitor and control the relationships calculated. As a secondary use, the system acts as a means of highlighting costs which behave contrary to expectation.

When the regression calculations are carried out[1], a control limit is calculated for each cost or revenue heading.

---

1 These are performed on a computer regression program, which also calculates the control limit.

The limit is a single absolute value, for each heading. At the end of each quarter, a fresh set of data becomes available, of sales weights, costs and revenue. The actual sales weights are used with the equations, to estimate the value of each cost or revenue heading. The value obtained for each is compared with the true value. Where the difference between these two is less than the control limit, the equation is retained for further use. Otherwise, there is evidence that the regression relationship has ceased to characterise the cost or revenue heading adequately. The heading is investigated to determine the reason for the discrepancy, and the regression will usually be recomputed, using the latest available data. The investigation may, however, indicate a reason for retaining the previous equation (such as an exceptional cost item).

The control scheme uses all the available data to keep the relationships meaningful. It also performs an exception reporting function by indicating unexpected cost (or revenue) behaviour.

B.3.3. Discussion

Although the use of regression for cost prediction has been described in the literature, little has been written on its use in control situations. Comiskey (1966) puts forward a regression model of operating costs in consumer finance offices. He suggests that cost control can be achieved by using the model for exception reporting. Where actual costs are significantly different from those expected, action is taken. There is, however, no suggestion of what constitutes "significance" in this context. Jensen (1967) generalises from this work to a model for use in cost control. He equates significance with the concept of statistical confidence limits. However, he offers no practical help in applying tests of significance.

Mansfield and Wien (1958) describe a detailed study of costs in railway sidings. A model of cost behaviour is fitted using multiple regression. As each fresh set of data becomes available, the expected cost is compared with the actual cost. The differences between them are plotted on a control chart, which is used to detect changes in cost behaviour. The regression relationships are recomputed at regular intervals.

None of these studies takes account of the fact that an estimate from a regression relationship will, in general, not be precisely the true population value. Discrepancies of actual from expected costs will be attributable to two causes: the difference between the population mean cost (with the given values of the predictors), and the expected (using the regression equation) cost, and the difference between the population mean and the actual sample value.

Mansfield and Wien (1958) assume the regression relation is identical to the population behaviour. They therefore only deal with differences of the second kind. It is reasonable to characterise the population of these differences as being normally distributed, with constant variance, and zero mean. Thus a control chart with constant confidence limits is meaningful for monitoring costs in this restricted situation.

However, since the regression relation is most unusually identical to that describing the population, there will be a difference between expected and population mean values of cost, as noted above. The variance of this difference will vary according to the value of each predictor: it will be at a minimum at the mean of each predictor and increase as each predictor moves away.

When the effects of both of these differences are combined, the difference between expected and actual cost will depend on the value of the predictors: its minimum will be at their means and it will increase as each moves away. Thus confidence intervals on cost predictions will be narrowest at the predictor means, and slowly diverge. The precise calculation of the variance (and hence confidence limits) is a difficult and time consuming process.

The control scheme designed for the Accountancy Department is aimed at keeping the regression relationships under "control". In this approach it is different from the work described. The intention is to operate the control process with a reasonably small amount of effort and cost involved in recomputing regression relationships, and storing data on the computer.

The control limit is calculated for each cost heading as identical to half of the 95% confidence interval[1] when each sales weight is at its mean (of those values used in the regression calculations). The control limit will represent degrees of confidence successively less than 95% as each sales weight moves progressively away from its mean. This makes the process more sensitive[2] as one moves away from the central area of experience.

Although it has not yet been attempted it will at some stage be useful to examine in quantitative terms the sensitivity of the process. It may be possible to adapt a control

---

1 The 95% confidence interval is a band on either side of the estimated cost. A cost can fall outside the interval for two reasons: the regression no longer characterises the process, or it still holds, but unidentified influences cause the cost to lie outside. These influences will cause the cost to fall outside the 95% interval with a probability of .05. One is therefore confident that the equation no longer characterises the process when a cost falls outside this band.

2 i.e. the limit is more likely to be exceeded, both by chance and relatively smaller differences between expected and actual costs.

chart[1] to enable information to be obtained by sequential plotting of differences between actual and expected costs.

B.3.4 Conclusions

The approach had a number of useful practical features. It is simple to operate. The control limits are easily obtained when the computer program is carrying out the regression calculations and the test for significance only involves subtraction. The process becomes more sensitive as one moves away from ones area of experience - a valuable characteristic. Since the procedure is under manual control, exceptional cost items can be taken account of (and confidence in the system is enhanced). The system is most economical on computer storage and calculation. A useful facet of the system is its "exception reporting" of exceptional costs.

---

1 Statistical control charts normally have fixed limits for action, which are calculated from the (constant) variance of the controlled variable.

APPENDIX C

THE INTERACTIVE MODELS

C.1 A Survey of the Titanium Industry

C.1.1 Titanium's Physical Properties

Titanium is a reactive metal with a particularly strong affinity for oxygen. It is found naturally, mainly in the ores rutile and ilmenite. A complex, and expensive process is used to extract the metal from these two major ores.

On exposure to an environment containing oxygen, metallic titanium normally forms a tenacious surface layer of oxide.

This film affords the metal excellent corrosion resistance in many aggresive media.

Titanium alloys have good strength to weight ratios compared with many other metals (see table C.1 for some examples).

Table C.1 STRENGTH TO WEIGHT RATIOS OF SOME SELECTED MATERIALS

Material	$\frac{\text{Maximum yield strength}}{\text{Density}}$ $\frac{\text{ksi}}{\text{lb/in}^3}$
Boron reinforced epoxy plastics	4300
Titanium alloy A	1400
Titanium alloy B	1000
Maraging steel	1000
Aluminium alloy	900
Magnesium alloy	700
Nickel base alloy	580
Stainless steel	500

Source: von Matern and Weil (1967)

These two properties lead to the metals' main uses - in corrosive media and for structural applications where weight savings are valuable.

C.1.2 The Titanium Industry

An outline of the industry structure forms figure C.1. Estimates of the flow of titanium between the various areas are given[1], along with the prices for the titanium content.

Currently the only viable titanium-bearing ores are ilmenite (about 30% titanium) and rutile, which contains about 55% titanium. The larger part of the ores is used in the production of titanium dioxide, a chemical widely used for pigments. A smaller proportion of the ore is used in the manufacture of titanium sponge.

After extraction from the ore, the metal is quite pure, and in the form of granules. These are the principal raw materials for ingot production, along with process scrap from machining operations, and alloying constituents.

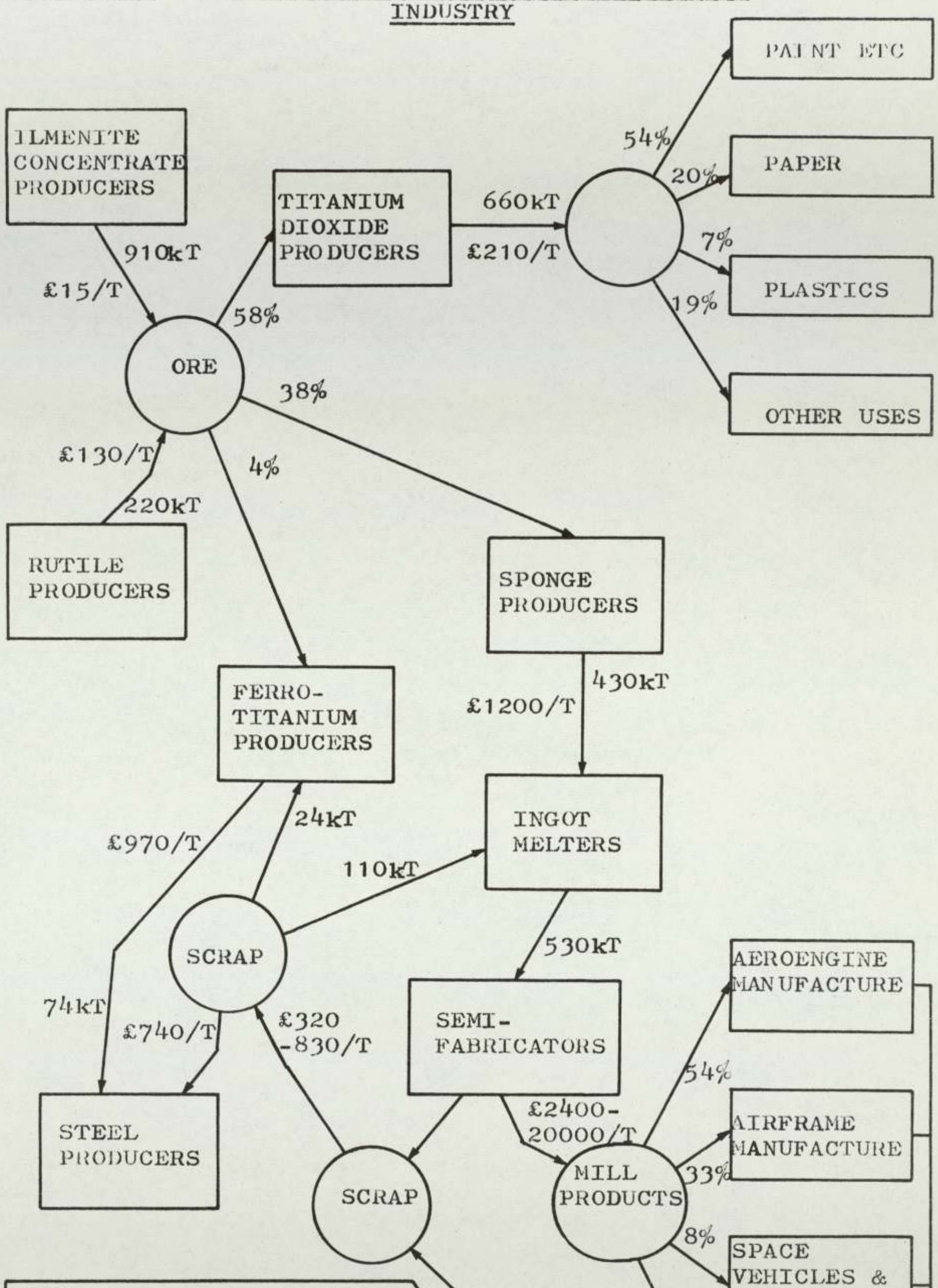
Ingot production is followed by a series of metal-working operations to produce the mill or final products, of the manufacturers. The products are sold largely into the aerospace industry, which uses titanium principally on account of its good strength to weight ratio.

The manufacture of ferrotitanium (alloys of iron and titanium with from 20% to 70% titanium) interacts with the titanium

---

[1] Obtained largely from von Matern and Weil (1967) and Roskill (1971).

Figure C.1 A SCHEMATIC DIAGRAM OF THE TITANIUM INDUSTRY



KEY:
£ Equivalent UK prices
T Tonnes
kT T x 1000

All data represents the TITANIUM CONTENT only of 1970 non-Communist world market metal production. Titanium is obtained both from ore and process scrap for the production of ferrotitanium. The major use for ferrotitanium is as an additive for special steels, and it competes with solid titanium scrap which can also be used.

Many of the companies operating in the industry are vertically integrated. Much of the ore production is contolled by pigment manufacturers, and other companies span the metal production part of the industry. Several of the large metal producers have extensive interests in steel, which gives a link with ferrotitanium, otherwise the most independent segment (vertically) of the industry.

C.1.3 Customers for Titanium

The aerospace industry is the largest customer for titanium. This industry is dominated by a small number of firms (prime contractors) who control a large number of sub-contractors for each project. The largest amounts of titanium are incorporated into the more recent airframe and aeroengine projects, which makes titanium manufacturers heavily dependent on the few large projects they supply.

Non-aerospace users of titanium come from various industries: process plant manufacturers, electricity generation, metal refining and some others. There are many independent firms in this area, in contrast to the aerospace industry.[1]

---

1. The various forecasting approaches tried in the different parts of titanium user industries are described in Appendix A.2

C.2 The Literature on Models which show the Production/ Marketing Interaction

C.2.1 Introduction

Various approaches have been used to examine the interaction between production and market behaviour. These may be classified in a variety of ways, but perhaps the most useful are between analytical and simulation, and between descriptive and optimising.

One major feature of the literature is that almost all of the models which consider market and production interaction, concentrate on one aspect, and treat the other with noticeably less detail. This is particularly so in Cyert, March, Cohen and Soelberg (1963), where output and pricing decisions are treated in much more detail than market behaviour, and Pifer (1969) who models the production unit in a fairly cursory fashion. In the following sections, important models are classified according to the schema indicated above.

C.2.2 Analytical Descriptive Models

In this category come models which treat the market/ production interaction in terms of mathematical equations, but do not attempt to optimise any performance measures. These models differ from simulations operationally in the fact that they are not designed to be stepped through time.

Harris (1966) considers the hypothetical case of a company making the decision whether to buy another company, to obtain its market share. The problem is formulated using statistical distributions for the expected market share and revenue. The solution gives the appropriate decision to take in the somewhat simplified circumstances modelled. In general, Harris regards an interdependent decision as one where the outcome probability distribution is not based solely on the outcome of the current decision. Clearly this is a very restrictive view of independence.

Allen (1966) uses a set of differential equations to model market behaviour over time. He models the market behaviour in terms of sales achieved, and makes no provision for production being "out of phase" with sales:

> "The results of this analysis are based upon selected situations which may not necessarily represent a real situation."

His cost model (the only aspect of production modelled) is merely that of a constant cost per time period plus a constant proportion of the market share.

Dutrow (1971) in an economic study of the Louisiana cotton-wood market presents equations which give predicted price levels in terms of previous price levels, stocks, wages and profits in the lumber industry. He extends the traditional price equation of economics to apply to the case of disequilibrium.

C.2.3 Simulation Models

Simulation models trace the path of the system being modelled through time, and let each state of the system be determined by the previous state. There are, however, various approaches to simulation.

Industrial Dynamics is one such approach. The models in this field are built up from a series of first order difference equations. Forrester (1961) gives an example of a generalised production/marketing system for a complete industry. This is a model which treats the production sector in some considerable detail, and uses a slightly less complex model for market behaviour. In another study, Forrester (1965) concentrates on communications between suppliers and customers in a hypothetical market. Ballmer (1960) shows an Industrial Dynamics model of the primary copper industry (from mine to customer). This treats customer and production sectors in similar detail. Although this model treats each sector in an aggregate form, it exhibits much of the behaviour of the real system. Swanson (1969) describes a simple production/market model in the gas transmission industry.

Walker (1967) has made a study of a hypothetical firm. He has developed a total firm simulation where the market is modelled in a fairly simple way. The study is particularly interesting in that it optimises the behaviour of the firm (using a hill-climbing technique) to find maximum profits. Cyert, March, Cohen and Soelberg (1963) offer a production/marketing system model which is largely normative, but relies on the system structure for much of its behaviour (the same is indicated for Industrial Dynamics models). Bonini (1967) presents a study which uses many of Cyert and March's (1963) propositions. This study treats decisions in a great deal of detail, but is similarly based on reasonable assumptions, rather than empirical observations. The marketing area receives less detailed treatment than do the other sectors. Pifer (1969) describes a study which differs in emphasis, i.e. the production sector of his model is less complex than his market. The same is true in a study by Kotler (1970), where cost is the only production variable modelled.

A simulation is presented by Schussel (1967) which is strongly based on empirical evidence. He modelled the behaviour of Polaroid film retailers by observing their actions and asking them questions on their rules for decision-making. The "production model" in this case - the ordering and stock line decisions - was modelled by Schussel's detailed heuristics. The market was treated in rather less detail - largely by using Polaroid executives' subjective forecasts.

There are thus many simulation models which show some interaction between production and marketing areas. Each has its own particular emphasis. Kotler's (1970) is unusual in that it describes the implementation as well as the model-building approach.

C.2.4 Optimising Models

This section examines those models which describe production/market systems with a view to optimising some variables within the system with respect to a given objective function.

Walker (1967) is the only study which was referred to with the simulation literature. The other models, to be mentioned here, consist largely of sets of analytical constraint formulations. The maximum of the objective function is obtained by a mathematical programming technique.

It is now almost "standard practice" to use a linear programming model with constraints to represent sales and capacity limitations. Such a model is described, as part of a paper by Tuckett (1969). This model is applied in a real situation. Questions of varying the constraints are treated by Godfrey, Spivey and Stillwagon (1968) who model the market in a more detailed fashion than production. This study relies on a hypothetical case for its exposition, however. A rather more complex market sector is defined by Thomas (1971) who includes the effect of advertising and pricing on demand. The production area is modelled in a similar degree of detail, to include effects of set-up costs and changing work force.

Belden (1971) has carried out a wide-ranging linear programming study, on a fairly self-contained system: the producing and marketing of turkeys. The project went into considerable detail with both the production and selling in that industry.

Linear programming is not the only optimisation technique which has been used to examine a market/production system. Thomas (1970) gives an algorithm for jointly selecting prices and production set up times. Baron (1972) examines the effect of centralisation on optimal decisions in a production/marketing system.

Tuite (1968) looks at the interaction of seasonal demand with production, concentrating on production-based factors such as production scheduling, inventory and labour costs.

C.2.5 Discussion

The published work in the area of combined market/production models suggests several conclusions. Most work is done from the viewpoint of either a market or a production model. A simple production model is added to the market model so that the study of the market model is more meaningful, or a market model appended to the production model for the same purpose. The major interest of the work cited has (with the exception of the Industrial Dynamics models) been in the behaviour of one or other sector of the model. Most of the studies are not heavily involved in examining the interaction between sectors.

Analytical models seem limited in their applicability to simple well structured situations. Even the complex mathematical programming models have basically a simple structure. Simulation methods appear the accepted approach to modelling areas with a complicated structure. However, the methods for understanding the behaviour of simulation models are as yet rather underdeveloped. Only one situation has been noted where a simulation model has been "optimised".

C.3 The Market Simulation Model

The model has been described in Chapter 7, in reasonably detailed terms. It has been written as a computer program, in FORTRAN IV. Since the program listing serves to define the model explicitly, the program is given, as table C.2. The following sections describe the structure and processing within the program.

Table C.2 THE MARKET SIMULATION PROGRAM

```
      LIBRARY(SUBGR )
      PROGRAM(TIFT)
      COMPRESS INTEGER AND LOGICAL
      COMPACT DATA
      MIXED SEGMENTS
      INPUT 1=CR0
      INPUT 3=TR0
      INPUT 5=CR1
      OUTPUT 2=LP0
      OUTPUT 6=LP1
      TRACE 0
      END


      MASTER TIMKT
C NEW LEAD TIME AND LOYALTY ROUTINES
C  TAKES SEVERAL SETS OF DATA
      INTEGER TMAX,J
      COMMON /Z/TMAX/TE/K
C     WRITE(6,7777)
 7777 FORMAT(15X ,'TIMKT')
   70 CALL INIT
      CALL INPUT
      K=1
   60 CALL TITLELO
      CALL ORDEF C
      CALL MANUF
      CALL UPDATE
      CALL OUTPUT
      CALL FINREP
      IF(K/12.EQ.K/12.)CALL CAPEX
      IF(K/12.EQ.K/12.)CALL PRUP
      IF(K/3.EQ.K/3.)CALL PRDOWN
      K=K+1
      IF(K.LT.TMAX+1) GO TO 60
      GO TO 70
      STOP
      END


      SUBROUTINE INIT
      REAL ORDERSZ(10,100),DEKGS(5,10),KPR(10,100)
      INTEGER J,L(10),ORDPR(10,100),ORDS(10),ORDCU(10,100),
     C ORDTA(10,100),OD(10,100),LT(10)
      COMMON /L/L/O/ORDERSZ,ORDPR,ORDS/AU/DEKGS/KP/KPR/R/ORDCU
     C /Q/ORDTA/BA/OD/LT/LT
C     WRITE(6,129)
  129 FORMAT(15X ,'INIT')
      DO 120 J=1,10
      ORDS(J)=0
      LT(J)=0
      DO 121 K=1,100
      ORDERSZ(J,K)=0.
      KPR(J,K)=0.
      ORDTA(J,K)=0
  121 OD(J,K)=0
      DO 122 K=1,5
  122 DEKGS(K,J)=0.
  120 L(J)=J
      RETURN
      END


      SUBROUTINE INPUT
      INTEGER TW,IT,AS(10,5),CPL(5)
     C ,JI,JK,REPFREQ,LL(10),PRN,MN
      REAL CTRD(5,10),CAP(10),ATR(10,5,5),SFN(5),PER(10),MP(5,5)
     C ,VC(10,5),WC1(10),WC2(10),FRM(3,10,7),EXPT(10),PRICE(10,5)
     C ,RSDO,RSDD,RSDP,P(5),RSDOP,FCI(10),MEAN(10,5,5),MIND(5,5)
     C,D(10)
      COMMON/F/TW/E/ATR,CPL,SFN/Z/IT/A/CTRD/B/MEAN,MIND,MP/U/AS
     C/P/CAP/FR/FRM,WC1,WC2/DR/D/RF/REPFREQ/VC/VC/EXT/EXPT

     C /SD/RSDO,RSDD,RSDP/PCP/P/SDP/RSDOP/CF/CAPFREQ
     C /PER/PER/L/LL/PRN/PRN,MN/PRI/PRICE/FCI/FCI/IW/SMF
C     WRITE(6,777)
  777 FORMAT(15X,'INPUT')
      READ(1,100)TW,IT,PRN,MN
  100 FORMAT(10I0)
      DO 202 J=1,MN
  202 READ(1,101)(CTRD(J,K),K=1,TW)
      DO 203 J=1,MN
  203 READ(1,101)(ATR(K,3,J),K=1,TW)
      WRITE(2,420)
  420 FORMAT(5X,'MARKET PERCEPTION OF SUPPLIER QUALITY')
      WRITE(2,302)(LL(J),J=1,TW)
      WRITE(2,309)
      DO 421 J=1,MN
      READ(1,101)(ATR(K,4,J),K=1,TW)
  421 WRITE(2,304)J,(ATR(K,4,J),K=1,TW)
      DO 204 J=1,MN
  204 READ(1,101)(ATR(K,5,J),K=1,TW)
      IY=(IT+11)/12
      DO 206 I=1,IY
      DO 206 J=1,PRN
  206 READ(1,101)(MEAN(I,J,K),K=1,MN)
      DO 422 K=1,PRN
  422 READ(1,101)(MIND(K,J),J=1,MN)
      DO 424 K=1,PRN
```

Table C.2 (continued)

```
424 READ(1,101)(MP(K,J),J=1,MN)
    READ(1,101)(CAP(J),J=1,TW)
    DO 207 J=1,TW
207 READ(1,100)(AS(J,K),K=1,PRN)
101 FORMAT(10F0.0)
    WRITE(2,300)TW,IT
300 FORMAT(5X,'NO OF SUPPLIERS = ',I3,/,5X,'TIME LIMIT ',I3,'MONTHS')
    WRITE(2,330)MN,PRN
330 FORMAT(/,5X,'NO OF MARKET SEGMENTS = ',I1,'NO OF PRODUCTS = ',I1)
    WRITE(2,301)
301 FORMAT(//,5X,'WEEKS ADDED TO DELY QUOTES')
    WRITE(2,302)(LL(J),J=1,MN)
    WRITE(2,309)
302 FORMAT(2X,'CUSTOMER',5X,5(I1,11X))
    DO 303 J=1,TW
303 WRITE(2,304)J,(CTRD(I,J),I=1,MN)
304 FORMAT(4X,I2,10(6X,F6.3))
    WRITE(2,305)
305 FORMAT(5X,'LOYALTY')
    WRITE(2,302)(LL(J),J=1,MN)
    WRITE(2,309)
    DO 306 J=1,TW
306 WRITE(2,304)J,(ATR(J,3,I),I=1,MN)
    WRITE(2,307)
307 FORMAT(5X,'CUSTOMER CUSTOMER PRESSURE')
    WRITE(2,302)(LL(J),J=1,MN)
    WRITE(2,309)
    DO 308 J=1,TW
308 WRITE(2,304)J,(ATR(J,5,I),I=1,MN)
309 FORMAT(2X,'SUPPLIER')
    WRITE(2,310)
    DO 312 JY=1,IY
    WRITE(2,322)JY
322 FORMAT(5X,'YEAR ',I2)
310 FORMAT(5X,'MEAN ORDER SIZES')
    WRITE(2,302)(LL(J),J=1,MN)
    WRITE(2,311)
311 FORMAT(2X,'PRODUCT')
    DO 312 J=1,PRN
312 WRITE(2,313)J,(MEAN(JY,J,I),I=1,MN)
313 FORMAT(4X,I2,5(6X,F6.1))
    WRITE(2,314)
314 FORMAT(5X,'MEAN MAX ACCTBL DEL')
    WRITE(2,302)(LL(J),J=1,MN)
    WRITE(2,320)
    DO 423 K=1,PRN
423 WRITE(2,304)K,(MIND(K,J),J=1,MN)
    WRITE(2,316)
316 FORMAT(5X,'MEAN MAX ACCTBL PRICE')
    WRITE(2,302)(LL(J),J=1,MN)
    WRITE(2,320)
    DO 425 K=1,PRN
425 WRITE(2,804)K,(MP(K,J),J=1,MN)
804 FORMAT(4X,I2,10(5X,F7.1))
    WRITE(2,317)
317 FORMAT(5X,'MONTHLY CAPACITIES')
    WRITE(2,309)
    DO 318 J=1,TW
318 WRITE(2,304)J,CAP(J)
    WRITE(2,319)
319 FORMAT(5X,'ABILITY TO SUPPLY')
    WRITE(2,320)(LL(J),J=1,PRN)
320 FORMAT(2X,'PRODUCT',6X,5(I1,11X))
    WRITE(2,309)
    DO 321 J=1,TW
413 FORMAT(4X,I2,5(6X,I1,5X))
321 WRITE(2,413)J,(AS(J,I),I=1,PRN)
    READ(1,101)(EXPT(J),J=1,TW)
    WRITE(2,600)(EXPT(J),J=1,TW)
600 FORMAT(2X,'MAX CAPACITY EXPANSION RATE',10(2X,F4.2))
    READ(1,101)(WC2(J),J=1,TW)
    WRITE(2,601)(WC2(J),J=1,TW)
601 FORMAT(2X,'£ OF WORKING CAPITAL PER TONNE PER MONTH',10(2X,F5.0))
    READ(1,101)(FRM(1,J,6),J=1,TW)
    WRITE(2,602)(FRM(1,J,6),J=1,TW)
602 FORMAT(2X,'INITIAL FIXED CAPITAL',10(2X,F8.0))
    READ(1,101)(D(J),J=1,TW)
    WRITE(2,603)(D(J),J=1,TW)
603 FORMAT(2X,'RATE OF ANNUAL DEPRECIATION = ',10(F3.2,2X))
    READ(1,100)RFPFREQ
    WRITE(2,604)
604 FORMAT(2X,34HFINANCIAL REPORTS PRODUCED YEARLY  )
    IF(RFPFREQ.EQ.3)GO TO 605
    WRITE(2,606)
606 FORMAT(1H+,36X,15H AND QUARTERLY  )
    IF(RFPFREQ.EQ.2)GO TO 605
    WRITE(2,607)
607 FORMAT(1H+,51X,' AND MONTHLY')
605 CONTINUE
    READ(1,101)RSDO,RSDD,RSDP,RSDOP
    WRITE(2,608)RSDO,RSDD,RSDP,RSDOP
608 FORMAT(2X,21HRATIO OF SD TO MEAN : ,'MONTHLY DEMAND ,',F4.2,/,23X,
   C'MAXIMUM DELIVERY ,',F4.2,/,23X,'MAXIMUM PRICE ,',F4.2,/,23X,
   C'QUOTED PRICES ,',F4.2)
    WRITE(2,370)
370 FORMAT(5X,'INITIAL PRICES')
    WRITE(2,320)(LL(J),J=1,PRN)
    WRITE(2,309)
    DO 371 I=1,TW
```

Table C.2 (continued)

```
      READ(1,101)(PRICE(L,J),J=1,PRN)
  371 WRITE(2,804)L,(PRICE(L,J),J=1,PRN)
      WRITE(2,372)
  372 FORMAT(5X,'VARIABLE COST RATES PER TONNE')
      WRITE(2,380)(LL(J),J=1,PRN)
      WRITE(2,309)
      DO 373 L=1,TW
      READ(1,101)(VC(L,J),J=1,PRN)
  373 WRITE(2,804)L,(VC(L,J),J=1,PRN)
      READ(1,101)(P(J),J=1,5)
      WRITE(2,610)
      WRITE(2,609)(P(J),J=1,5)
  610 FORMAT(2X,'RELATIVE FREQUENCIES FOR SUPPLIER SELECTION :')
  609 FORMAT(2X,
     C'PRICE,',F4.2,' DELIVERY,',F4.2,'LOYALTY,',F4.2,'QUALITY,',F4.2,
     C' CCP,',F4.2)
      READ(1,101)(SEN(J),J=1,5)
      WRITE(2,611)
  611 FORMAT(2X,'SELECTION SENSITIVITIES : ')
      WRITE(2,609)(SEN(J),J=1,5)
      WRITE(2,426)
  426 FORMAT(5X,'MONTHLY PERIOD COST/TONNE OF CAPACITY')
      WRITE(2,427)(LL(J),J=1,TW)
  427 FORMAT(2X,'SUPPLIER',5X,10(I2,10X))
      READ(1,101)(PER(J),J=1,TW)
      WRITE(2,428)(PER(J),J=1,TW)
  428 FORMAT(11X,10(F8.2,4X))
      WRITE(2,429)
  429 FORMAT(5X,'WORKING CAPITAL/TONNE OF CAPACITY')
      WRITE(2,427)(LL(J),J=1,TW)
      READ(1,101)(WC1(J),J=1,TW)
      WRITE(2,428)(WC1(J),J=1,TW)
      DO 613 J=1,TW
  613 FCI(J)=FRM(1,J,6)
      READ(1,101)SMF
      WRITE(2,492)SMF
  492 FORMAT(10X,'SMOOTHING FACTOR FOR LOYALTY = ',F5.3)
      RETURN
      END


      SUBROUTINE ORDEFC
      REAL O,COD,COP,M,DEV,D,RSDO,RSDD,RSDP,MEAN(10,5,5),MIND(5,5)
     C,MP(5,5)
      INTEGER J,K,SA,SB,SC,PRN,MN
      COMMON/D/J,K/B/MEAN,MIND,MP/G/O,COD,COP/TE/IT/PRN/PRN,MN
     C /SD/RSDO,RSDD,RSDP
C     WRITE(6,777)
  777 FORMAT(15X,'ORDEFC')
      I=(IT+11)/12
      DO 100 J=1,PRN
      DO 100 K=1,MN
      DEV=RSDO*MEAN(I,J,K)
      O=G05AEF(MEAN(I,J,K),DEV)
      IF(O.EQ.0.)GO TO 100
      M=MIND(J,K)*RSDD
      COD=G05AEF(MIND(J,K),M)
      D=MP(J,K)*RSDP
      COP=G05AEF(MP(J,K),D)
      CALL ORDEFF
  100 CONTINUE
      RETURN
      END


      SUBROUTINE MANUF
      REAL CAP(10),ORDERSZ(10,100),DEKGS(5,10),CAPLE
     C ,FRM(3,10,7),WC1(10),WC2(10),KPR(10,100),VC(10,5)
     C ,T3C(10),T3D(10)
      INTEGER TW,ORDPR(10,100),ORDS(10),ORDCU(10,100),ORDTA(10,
     C 100),OD(10,100),LT(10),PRN,MN
      COMMON/F/TW/P/CAP/O/ORDERSZ,ORDPR,ORDS/AU/DEKGS/R/ORDCU
     C /O/ORDTA/RA/OD/FR/FRM,WC1,WC2/KP/KPR/LT/LT/PRN/PRN,MN
     C/VC/VC/TCD/T3C,T3D
C     WRITE(6,7777)
 7777 FORMAT(15X,'MANUF')
      DO 100 J=1,TW
      CAPLE=CAP(J)
      IF(ORDS(J).EQ.0) GO TO 110
      DO 102 K=1,ORDS(J)
      IF(ORDERSZ(J,K).GT.CAPLE) GO TO 101
      FRM(1,J,1)=FRM(1,J,1)+ORDERSZ(J,K)
      FRM(1,J,2)=FRM(1,J,2)+ORDERSZ(J,K)*KPR(J,K)
      FRM(1,J,3)=FRM(1,J,3)+ORDERSZ(J,K)*VC(J,ORDPR(J,K))
      CAPLE=CAPLE-ORDERSZ(J,K)
      DEKGS(ORDCU(J,K),J)=DEKGS(ORDCU(J,K),J)+ORDERSZ(J,K)
      ORDERSZ(J,K)=0.
      GO TO 102
  101 ORDERSZ(J,K)=ORDERSZ(J,K)-CAPLE
      DEKGS(ORDCU(J,K),J)=DEKGS(ORDCU(J,K),J)+CAPLE
      FRM(1,J,1)=FRM(1,J,1)+CAPLE
      FRM(1,J,2)=FRM(1,J,2)+CAPLE*KPR(J,K)
      FRM(1,J,3)=FRM(1,J,3)+CAPLE*VC(J,ORDPR(J,K))
      GO TO 103
  765 LT(J)=ORDTA(J,K-1)
      GO TO 103
  102 CONTINUE
      GO TO 103
  110 DO 111 M=1,MN
```

Table C.2 (continued)

```
  111 DEKGS(M,J)=0.
  103 L=1
      IF(ORDS(J).EQ.0) GO TO 100
      DO 105 M=1,ORDS(J)
  108 IF(L.GT.ORDS(J))GO TO 107
      IF(ORDERSZ(J,L).EQ.0)GO TO 106
      GO TO 109
  106 L=L+1
      GO TO 108
 109  ORDERSZ(J,M)=ORDERSZ(J,L)
      ORDPR(J,M)=ORDPR(J,L)
      ORDTA(J,M)=ORDTA(J,L)
      ORDCU(J,M)=ORDCU(J,L)
      OD(J,M)=OD(J,L)
  105 L=L+1
  107 ORDS(J)=M-1
      TO=0
      DO 120 I=1,ORDS(J)
  120 TO=TO+ORDERSZ(J,I)
      LT(J)=TO/CAP(J)+.5
  100 CONTINUE
      RETURN
      END


      SUBROUTINE ORDEFF
      INTEGER TW,CPL(5),L,NO
      REAL SEN(5),ATR(10,5,5),P(5),CUMP(5),RN,PC(5)
      COMMON/F/TW/E/ATR,CPL,SEN/PCP/PC
C     WRITE(6,777)
  777 FORMAT(15X,'ORDEFF')
      DO 214 J=1,5
  214 P(J)=PC(J)
      DO 208 NO=1,5
      IF(P(1).EQ.-1.) GO TO 204
      CUMP(1)=P(1)
  205 DO 200 J=2,5
      IF(P(J).EQ.-1.) GO TO 206
      CUMP(J)=CUMP(J-1)+P(J)
  200 CONTINUE
      IF(CUMP(5).EQ.0.)GO TO 209
      GO TO 212
  209 CUMP(1)=P(1)+1.
      DO 210 J=2,5
  210 CUMP(J)=CUMP(J-1)+1.+P(J)
  212 RN=G05ABF(0.0,CUMP(5))
      DO 201 J=1,5
      IF(RN.LE.CUMP(J))GO TO 202
      GO TO 201
  202 CPL(J)=NO
      GO TO 203
  201 CONTINUE
  203 P(J)=-1.
      GO TO 208
  204 CUMP(1)=0.
      GO TO 205
  206 CUMP(J)=CUMP(J-1)
      GO TO 200
  208 CONTINUE
      CALL HEURISTIC
      RETURN
      END


      SUBROUTINE ORDPLA
      REAL ORDERSZ(10,100),QUP(10),QUD(10),ORD(10),ORKGS(5,10)
     C ,KPR(10,100)
      INTEGER TW,X,ORDS(10),ORDPR(10,100),T,CUST,K,ORDTA
     C (10,100),ORDCU(10,100),OD(10,100),II
      COMMON/F/TW/T/ORD/O/ORDERSZ,ORDPR,ORDS/S/T/TE/N/
     C D/K,CUST/I/QUP,QUD/Q/ORDTA/R/ORDCU/AT/ORKGS/BA/QD
     C /KP/KPR
C     WRITE(6,777)
  777 FORMAT(15X,'ORDPLA')
      DO 100 J=1,TW
      IF(ORD(J).EQ.0.0) GO TO 100
      ORDERSZ(J,ORDS(J)+1)=ORD(J)
      ORDPR(J,ORDS(J)+1)=K
      ORDS(J)=ORDS(J)+1
      ORDTA(J,ORDS(J))=N
      QD(J,ORDS(J))=QUD(J)
      KPR(J,ORDS(J))=QUP(J)
C     WRITE(6,780)ORDERSZ(J,ORDS(J)),KPR(J,ORDS(J))
  780 FORMAT(15X,'TONS ',F8.2,' £/T ',F8.2)
      ORDCU(J,ORDS(J))=CUST
      ORKGS(CUST,J)=ORKGS(CUST,J)+ORD(J)
  100 CONTINUE
      RETURN
      END


      SUBROUTINE TITLFLO
      REAL ORKGS(5,10),DEKGS(5,10)
      INTEGER T,TW,M,N(10),PRN,MN
      COMMON/S/T/F/TW/AT/ORKGS/AU/DEKGS/TE/L/PRN/PRN,MN
C     WRITE(6,777)
  777 FORMAT(15X,'TITLFLO')
      DO 900 I1=1,MN
      DO 900 I2=1,TW
```

Table C.2 (continued)

```
      ORKGS(I1,I2)=0.
  900 DEKGS(I1,I2)=0.
      WRITE(2,200)L
  200 FORMAT(10X,'TIME = ',I4)
      RETURN
      END


      SUBROUTINE SUPBEH(IS)
COMMENT========MEANING OF VARIABLES IN SUBROUTINE
C     ORDSZ = ORDER SIZE        =ORDOTY OR Q
C     COR(10)=CUT-OFF REJECT   ==ALI(10)
C     PCOP(10)=PRESSURE ON CUT-OFF POINTS   = PCOP
C     PRS(10) =SUPPLIER PREFERENCE MEASURE   =PRFS(10)
C     RANK(5) =PREFERENCE VARIABLE   =CPL(5)
C     IM=MIN RANK
C     PCPL(J,IS)=PRESSURE ON PREF VAR J FROM SUPP IM,+1 TO REDUCE CPL(J)
C                              -1 TO INC CPL(J) ,   =PCPL
C     PXV(IS)= PRESSURE TO TRANSFORM VARIABLES =1 TO GET BETTER =CPX
C     PSEN(IS)=PRESSURE TO CHANGE SENSITIVITIES 1-MORE SENS,-1LESS,=PSEN .
C     PLOY(IS)=PRESSURE ON LOYALTY,1 TO INCREASE ,=PLOY
C     ORBK(IS)=ORDER BOOK LABEL,1=FULL , = ORBK
C     REQ(IS) =REQUOTE FOR PRCE +DEL , =REQ
C     OOU(IS) =ORIG QUOTE
      INTEGER COR(10),RANK(5),X,II
     C,PCOP(10),TW,AS(10,5)
      REAL ORDSZ,PRS(10),PCPL(5,10),PXV(10),PSEN(10),PLOY(10),REQ(10),
     DATR(10,5,5),SEN(5)          ,OOU(10)
      COMMON/G/ORDSZ,COD,COP/J/COR,PCPL,PXV,PSEN,PLOY,REQ
     C /E/ATR,RANK,SEN/D/II,X
C     WRITE(6,777)
  777 FORMAT(15X,'SUPBEH')
      PSEN(IS)=0.
      PXV(IS)=0.
      OOU(IS)=1.
      PLOY(IS)=0.
      IF(ORDSZ.LT.0.5)GO TO 10
      IF(COR(IS).EQ.1)PCOP(IS)=1
      IF(PRS(IS).GT.0.6)GO TO 20
      IF(PRS(IS).GT.0.05)GO TO 21
      IM=200
      DO 22 J=1,5
      IF(RANK(J).GT.IM)GO TO 22
      IM=RANK(J)
   22 CONTINUE
      RV=5.5
      IF(IM.GT.5.5)RV=10.5
      DO 23 J=1,5
      IF(RANK(J).EQ.IM.OR.RANK(J).GT.RV)GO TO 24
      PCPL(J,IS)=1.
      GO TO 23
   24 PCPL(J,IS)=-1.
   23 CONTINUE
      GO TO 21
   20 IM=200  .
      DO 26 J=1,5
      IF(RANK(J).GT.IM)GO TO 26
      IN=J
   26 CONTINUE
      DO 27 J=1,5
      IF(J.EQ.IN)GO TO 28
      PCPL(J,IS)=-1.
      GO TO 27
   28 PCPL(J,IS)=1.
   27 CONTINUE
   21 IF(PRS(IS).GT.0.05)GO TO 29
      PXV(IS)=1.
   29 IF(PRS(IS).GT.0.6)GO TO 30
      IF(PRS(IS).LT.0.05)PSEN(IS)=-1.
      GO TO 31
   30 PSEN(IS)=1.
   31 IF(RANK(3).EQ.1.OR.RANK(3).EQ.2.OR.RANK(3).EQ.6.OR.RANK(3).EQ.7
     A.OR.RANK(3).EQ.11.OR.RANK(3).EQ.12) PLOY(IS)=1.
      IF(PRS(IS).GT.0.6)GO TO 32
      REQ(IS)=0.8
   32 CONTINUE
   10 CONTINUE
      RETURN
      END


      SUBROUTINE HEURISTIC
      INTEGER SPA,KJ,J,TW,PCOP(10),CLI(10),AS(10,5),JC,ALI(10)
     C,ADEQ(10),MP,CPL(5),FP,PRS,KR,IMPO,IMDQ,JPC,JP,J2,LPS,NUM
     C,PR,MC
      REAL REQ(10),ATR(10,5,5),CTRD(5,10),COP,COD,MFP,ADFP,SEN(5),PRFS(
     C10),ORD(10),AIND,BIND,MPQ,MDQ,PCQ,PV(5),NPL(5),CPX(10),SP(5)
     C,PSEN(10),Q,PCPL(5,10),PLOY(10),OUP(10),QUD(10)
      COMMON/G/Q,COD,COP/A/CTRD/PC/PCOP/U/AS/J/ALI,PCPL,CPX,PSEN,
     CPLOY,REQ/E/ATR,CPL,SEN/F/TW/I/OUP,QUD/D/PR,MC/T/ORD
C     WRITE(6,777)
  777 FORMAT(15X,'HEURISTIC')
      SPA=0
      KJ=0
  300 DO 73 J=1,TW
      PCOP(J)=0
      CLI(J)=1
      REQ(J)=1.
      IF(AS(J,FR).EQ.0) CLI(J)=0
```

Table C.2 (continued)

```
    73 KJ=KJ+CLI(J)
       IF(KJ.EQ.0) GO TO 8989
COMMENT======== CLI AT THIS STAGE SHOWS IF GOING TO ISSUE ENQUIRY
   303 JC=0
       DO 310 J=1,TW
       IF(CLI(J).EQ.1) CALL ENQ(J,KQ)
       IF(KQ.EQ.0) GO TO 310
       JC=JC+1
       ATR(J,1,MC)=QUP(J)
       ATR(J,2,MC)=QUD(J)+CTRD(MC,J)
   310 CONTINUE
       IF(JC.EQ.0) GO TO 392
  1100 JC=0
       DO 1103 J=1,TW
       ALI(J)=0
       IF(CLI(J).EQ.0) GO TO 1103
       IF(ATR(J,1,MC).GT.COP.OR.ATR(J,2,MC).GT.COD) GO TO 1103
       JC=JC+1
       ALI(J)=1
  1103 CONTINUE
   802 IF(JC.EQ.0)GO TO 900
       IF(JC.EQ.1) GO TO 1503
COMMENT======== SELECT CUSTOMER'S FIRST PREFERENCE VARIABLE
  1020 CONTINUE
       DO 1230 J=1,TW
  1230 ADEQ(J)=ALI(J)
  1000 MP=20
       DO 1001 J=1,5
       IF(CPL(J).GE.MP)GO TO 1001
       MP=CPL(J)
       FP=J
  1001 CONTINUE
C                                   CPL(J)=CUSTOMER PREFERENCE LIST
C                                   FP=CUSTOMER'S FIRST PREFERENCE VARIABLE
C                                   MP=MIN PREF
COMMENT======== SELECT BEST SUPPLIER ON THIS VARIABLE + OTHER SATIS ONES
  1200 IF(FP.GT.2.5)GO TO 1201
       MFP=10000000.
C      MFP=MIN(OR MAX) OF FST PREF
       DO 1202 J=1,TW
       IF(ADEQ(J).EQ.0) GO TO 1202
       IF(ATR(J,FP,MC).LT.MFP) MFP=ATR(J,FP,MC)
  1202 CONTINUE
C      ATR(J,FP)=ATTRIB(CUST J,1=PRCE,2=DELY,3=LOY,4=QUAL,5=CCP)
C   ADFP =ADEQ VAL OF FST PREF
       ADFP=MFP*(1+SEN(FP))
       DO 1203 J=1,TW
       IF(ADEQ(J).EQ.0)GO TO 1203
       IF(ATR(J,FP,MC).GT.ADFP) GO TO 1220
       ADEQ(J)=1
       GO TO 1203
  1220 ADEQ(J)=0
  1203 CONTINUE
       GO TO 1600
  1201 MFP=-1.
       DO 1204 J=1,TW
       IF(ADEQ(J).EQ.0)GO TO 1204
       IF(ATR(J,FP,MC).GT.MFP)MFP=ATR(J,FP,MC)
  1204 CONTINUE
       ADFP=MFP*(1-SEN(FP))
       DO 1205 J=1,TW
       IF(ADEQ(J).EQ.0)GO TO 1205
       IF(ATR(J,FP,MC).LT.ADFP) GO TO 1221
       ADEQ(J)=1
       GO TO 1205
  1221 ADEQ(J)=0
  1205 CONTINUE
  1600 JC=0
COMMENT======== COUNT CURRENT LIST + BRANCH
       DO 1601 J=1,TW
       IF(ADEQ(J).EQ.0)GO TO 1601
       JC=JC+1
       PRS=J
  1601 CONTINUE
  1602 IF(JC.EQ.1)GO TO 1500
  1700 CONTINUE
COMMENT======== MOVE FIRST PREFERENCE TO BOTTOM OF LIST
  1800 CPL(FP)=CPL(FP)+5
COMMENT======== CHECK FOR PREFERENCE LIST CYCLING ONCE
  1900 IF(CPL(FP).EQ.10)GO TO 2200
COMMENT======== CHECK FOR PREFERENCE LIST CYCLING TWICE
  2100 IF(CPL(FP).EQ.15)GO TO 2000
       GO TO 1000
COMMENT======== DOUBLE PREFERENCE SELECTION SENSITIVITIES
  2200 DO 2201 J=1,5
  2201 SEN(J)=SEN(J)*0.5
       GO TO 1020
COMMENT======== NOTE PREFERRED SUPPLIER
  1500 DO 1501 J=1,TW
       IF(J.NE.PRS) GO TO 1502
       PRFS(PRS)=1.
       GO TO 1501
C                                   PRS=NO. OF PREFERRED SUPPLIER
  1502 PRFS(J)=0.
  1501 CONTINUE
C                                   PRFS(J) = PREF RATINGS  SUM TO 1
       GO TO 2300
  8989 DO 12 J=1,TW
    12 CLI(J)=AS(J,PR)
```

Table C.2 (continued)

```
      GO TO 1100
 392  DO 301 J=1,TW
  301 ORD(J)=0.
      GO TO 8999
 1503 DO 1504 J=1,TW
 1504 PRFS(J)=ALI(J)
      GO TO 2300
COMMENT======== NOTE PREFERRED SUPPLIERS
 2000 CONTINUE
      KR=0
      DO 2001 J=1,TW
      IF(ADEQ(J).EQ.0) GO TO 2001
      KR=KR+1
 2001 CONTINUE
      DO 2002 J=1,TW
      AIND=ADEQ(J)
      BIND=KR
      IF(KR.EQ.0)GO TO 8721
      PRFS(J)=AIND/BIND
      GO TO 2002
 8721 PRFS(J)=0.
 2002 CONTINUE
C                                   TP = RUNNING VARIABLE FOR TOT OF PRFS
      GO TO 2300
  900 MPQ=99999.
      MDQ=99999.
      DO 901 J=1,TW
      IF(MPQ.LT.ATR(J,1,MC)) GO TO 902
      MPQ=ATR(J,1,MC)
      IMPQ=J
  902 IF(MDQ.LT.ATR(J,2,MC)) GO TO 901
      MDQ=ATR(J,2,MC)
      IMDQ=J
  901 CONTINUE
      COP=ATR(IMDQ,1,MC)
      COD=ATR(IMPQ,2,MC)
      GO TO 1100
COMMENT======== RELEASE DETAILS TO SELECTED SUPPLIERS
 2300 IF(SPA.EQ.1) GO TO 3700
      DO 2301 J=1,TW
      IF(PRFS(J).LT.0.05) GO TO 2301
      CALL SUPBEH(J)
 2301 CONTINUE
COMMENT======== RECEIVE MARKET RESPONSE
 2400 CONTINUE
COMMENT======== CHECK WHETHER ANY PRESSURE ON CUT-OFFS
COMMENT========AGGREGATE CUT-OFF PRESSURE
      PCO=0.
      JPC=0
      DO 2501 J=1,TW
      PCO=PCO+PCOP(J)
 2501 JPC=JPC+1
      PCO=PCO/JPC
 2600 IF(PCO.LT.0.1)GO TO 2800
C                                   PCO= PRESSURE ON CUT-OFFS  0-1
COMMENT======== CHANGE CUT-OFF VALUES
      COP=COP*(1+PCO)
      COD=COD*(1+PCO)
COMMENT======== ALTER PREFERENCE ORDER
COMMENT========AGGREGATE PRESSURE ON PREF LISTS
 2800 DO 2904 JP=1,5
      PV(JP)=0.
      DO 2905 J=1,10
 2905 PV(JP)=PV(JP)+.5*PCPL(JP,J)
      IF(PV(JP).GT.1)PV(JP)=1.
      IF(PV(JP).LT.-1)PV(JP)=-1.
 2904 CONTINUE
 2900 DO 2901 J=1,5
 2901 NPL(J)=CPL(J)-2.*PV(J)
C                                   NPL(J) NEW PREF LIST
C                                   PV(J) PRESS TO CH LIST -1(REDUCEIMP)-+1(MI
      DO 2903 J2=1,5
      LPS=100
      DO 2902 J=1,5
      IF(LPS.GE.NPL(J)) GO TO 2906
      GO TO 2902
 2906 NUM=J
      LPS=NPL(J)
 2902 CONTINUE
      CPL(NUM)=J2
 2903 NPL(NUM)=200.
C                                   NUM  LOOP
C                                   LPS  VARIABLES
COMMENT======== CALCULATE REVISED EXPECTATIONS
 3100 DO 3101 J=1,TW
      IF(CPX(J).LT.0.5)GO TO 3101
      ATR(J,1,MC)=ATR(J,1,MC)*0.9
      ATR(J,2,MC)=ATR(J,2,MC)*0.9
 3101 CONTINUE
 3102 CONTINUE
C                                   TSP  TOT PRESS ON SENSITIVITIES
COMMENT========AGGREGATE PRESSURE ON SENSITIVITIES
      SP(1)=0.
      DO 3302 J=1,TW
 3302 SP(1)=SP(1)+PSEN(J)
      IF(SP(1).LE.-2)SP(2)=.5
      IF(SP(1).GE.2) SP(2)=-.5
      IF(SP(1).GT.-2.AND.SP(1).LT.2)SP(2)=0.
      DO 3303 J=1,5
```

Table C.2 (continued)

```
 3303 SP(J)=SP(2)
COMMENT======== CHANGE SENSITIVITIES
 3300 DO 3301 J=1,5
      IF(SP(J).LT.0.1)GO TO 3301
      SEN(J)=SEN(J)*(1+SP(J))
 3301 CONTINUE
C                                SP(J) = SENSIT PRES
COMMENT======== ALTER INDIVIDUAL EXPECTATIONS
 3500 DO 3501 J=1,TW
      ATR(J,1,MC)=ATR(J,1,MC)*REO(J)
      ATR(J,2,MC)=ATR(J,2,MC)*REO(J)
      IF(PLOY(J).EQ.1)ATR(J,3,MC)=ATR(J,3,MC)*1.1
 3501 CONTINUE
 3502 GO TO 3600
COMMENT======== CHECK WHETHER SALES PRESSURE HAS HAD EFFECT
 3600 SPA=1
      GO TO 1100
COMMENT======== PLACE ORDER
 3700 DO 3701 J=1,TW
 3701 ORD(J)=PRFS(J)*Q
 3702 CONTINUE
COMMENT======== WRITE OUTPUT
 8999 CONTINUE
      DO 9899 J=1,TW
 9899 IF(PLOY(J).EQ.1)ATR(J,3,MC)=ATR(J,3,MC)/1.1
      CALL ORDPLA
      RETURN
      END


      SUBROUTINE ENQ(J,KQ)
      REAL M,OUP(10),OUD(10),ORDERSZ(10,100),ORDS(10),RSDOP,D
     C,PRICE(10,5),VC(10,5)
      INTEGER J,KQ,ORDPR(10,100),LT(10),IP,IC
      COMMON/I/OUP,OUD/O/ORDERSZ,ORDPR,ORDS
     C /LT/LT/SDP/RSDOP/PRI/PRICE/VC/VC/D/IP,IC
C     WRITE(6,777)
  777 FORMAT(15X,'ENQ')
      IF(ORDS(J).EQ.98)GO TO 100
      KQ=1
      GO TO 101
  100 KQ=0
      GO TO 102
  101 D=PRICE(J,IP)*RSDOP
      OUP(J)=G05AEF(PRICE(J,IP),D)
      IF(OUP(J).LT.VC(J,IP)) OUP(J)=VC(J,IP)
      OUD(J)=LT(J)
  102 CONTINUE
      RETURN
      END


      SUBROUTINE UPDATE
      REAL ORDERSZ(10,100),CTRD(5,10),
     C OUP(10),OUD(10),ATR(10,5,5),SEN(5)
      INTEGER ORDPR(10,100),ORDS(10),ORDTA(10,100),QD(10,100),
     C T,ORDCU(10,100),TW,CPL(5),L(10),PRN,MN
      COMMON/O/ORDERSZ,ORDPR,ORDS/A/CTRD/I/OUP,OUD/PRN/PRN,MN
     C /Q/ORDTA/BA/QD/TE/T/R/ORDCU/F/TW/E/ATR,CPL,SEN/L/L
C     WRITE(6,777)
  777 FORMAT(15X,'UPDATE')
      DO 101 J=1,TW
      DO 302 LL=1,MN
      DO 301 K=1,ORDS(J)
      ODC=0.
      N=0
      IF(ORDCU(J,K).NE.LL)GO TO 301
      OD=T-ORDTA(J,K)-QD(J,K)
      IF(OD.LE.0)GO TO 301
      N=N+1
      ODC=ODC+OD
  301 CONTINUE
      IF(N.EQ.0) GO TO 302
      CTRD(LL,J)=CTRD(LL,J)*.95+.05*ODC/N
  302 CONTINUE
  102 CONTINUE
  101 CONTINUE
      WRITE(2,200)
  200 FORMAT(///,2X,'LOYALTY FACTORS')
      WRITE(2,201)(L(J),J=1,MN)
  201 FORMAT(//,2X,'CUSTOMER',6X,5(I1,9X),/,2X,'SUPPLIER',//)
      DO 203 J=1,TW
      WRITE(2,204)J,(ATR(J,3,K),K=1,MN)
  203 CONTINUE
  204 FORMAT(4X,I2,7X,5(F7.4,3X))
      RETURN
      END


      SUBROUTINE OUTPUT
      REAL ORKGS(5,10),DEKGS(5,10),TTDELS(6),TTORDS(6),TOTORD(10),
     C TOTDEL(10),ATR(10,5,5),SEN(5)
      INTEGER TW,L(10),PRN,MN,CPL(5)
      COMMON/AT/ORKGS/AU/DEKGS/F/TW/PRN/PRN,MN/L/L/E/ATR/IW/SMF
     C ,CPL,SEN
C     WRITE(6,777)
  777 FORMAT(15X,'OUTPUT')
      DO 108 J=1,TW
      TOTDEL(J)=0.
```

Table C.2 (continued)

```
      TOTORD(J)=0.
      DO 108 K=1,MN
      TOTDEL(J)=TOTDEL(J)+DEKGS(K,J)
  108 TOTORD(J)=TOTORD(J)+ORKGS(K,J)
      DO 109 I=1,MN
      TTORDS(I)=0.
      TTDELS(I)=0.
      DO 109 J=1,TW
      TTORDS(I)=TTORDS(I)+ORKGS(I,J)
  109 TTDELS(I)=TTDELS(I)+DEKGS(I,J)
C  UPDATE LOYALTIES
      DO 200 J=1,TW
      DO 200 K=1,MN
  200 ATR(J,3,K)=SMF*ATR(J,3,K)+(1.-SMF)*ORKGS(K,J)/TTORDS(K)
      TTORDS(6)=0.
      TTDELS(6)=0.
      DO 110 J=1,TW
      TTORDS(6)=TTORDS(6)+TOTORD(J)
  110 TTDELS(6)=TTDELS(6)+TOTDEL(J)
      WRITE(2,102)
  102 FORMAT(///,2X,'ORDERS PLACED')
      WRITE(2,101)(L(J),J=1,MN)
  101 FORMAT(//,2X,'CUSTOMER',6X,4(I1,9X),I1)
      WRITE(2,150)
  150 FORMAT(1H+,64X,'TOTAL',/,2X,'SUPPLIER',//)
      DO 103 J=1,TW
      WRITE(2,104)J,(ORKGS(I,J),I=1,MN)
  104 FORMAT(4X,I2,7X,5(F7.2,3X))
      WRITE(2,151)TOTORD(J)
  103 CONTINUE
  151 FORMAT(1H+,63X,F7.2)
      WRITE(2,107)(TTORDS(J),J=1,MN)
  107 FORMAT(/,3X,'TOTAL',5X,6(F7.2,3X))
      WRITE(2,151)TTORDS(6)
      WRITE(2,105)
  105 FORMAT(///,2X,'DFLIVERY SUMMARY')
      WRITE(2,101)(L(J),J=1,MN)
      WRITE(2,150)
      DO 106 J=1,TW
      WRITE(2,104)J,(DEKGS(I,J),I=1,MN)
      WRITE(2,151)TOTDEL(J)
  106 CONTINUE
      WRITE(2,107)(TTDELS(J),J=1,MN)
      WRITE(2,151)TTDELS(6)
      RETURN
      END


      SUBROUTINE FINREP
      REAL FRM(3,10,7),WC2(10),VC(10,5),CAP(10),CAPUT(10)
     C,D(10),WC1(10),PER(10),T3C(10),T3D(10)
      INTEGER J,TW,K,T,REPFREQ,LT(10)
     C ,IND1(10),IND2(10)
      COMMON/FR/FRM,WC1,WC2/F/TW/TE/T/DR/D/RF/REPFREQ/LT/LT/VC/VC
     C /P/CAP/IN/IND1,IND2/PER/PER/CU/CAPUT/TCD/T3C,T3D
C     WRITE(6,100)
  100 FORMAT(15X,'FINREP')
      DO 101 J=1,TW
      FRM(1,J,4)=D(J)*FRM(1,J,6)/12.
      FRM(1,J,5)=CAP(J)*PER(J)
      FRM(1,J,7)=CAP(J)
  101 FRM(1,J,6)=FRM(1,J,6)*(1-D(J)/12.)
      IF(REPFREQ.EQ.1)CALL FIRPRI(1)
      DO 103 J=1,TW
      DO 103 K=1,5
      FRM(2,J,K)=FRM(2,J,K)+FRM(1,J,K)
  103 CONTINUE
      DO 110 J=1,TW
  110 FRM(2,J,7)=FRM(2,J,7)+CAP(J)
      IF(T/3.NE.T/3.)GO TO 102
      IF(REPFREQ.EQ.2.OR.REPFREQ.EQ.1)CALL FIRPRI(2)
      DO 104 J=1,TW
      CAPUT(J)=FRM(2,J,1)/FRM(2,J,7)
      FRM(3,J,7)=FRM(3,J,7)+FRM(2,J,7)
      FRM(2,J,7)=0.
      DO 104 K=1,5
      FRM(3,J,K)=FRM(3,J,K)+FRM(2,J,K)
  104 FRM(2,J,K)=0.
      IF(T/12.NE.T/12.)GO TO 102
      CALL FIRPRI(3)
      DO 165 J=1,TW
      T3C(J)=FRM(3,J,7)
      T3D(J)=FRM(3,J,1)
      DO 105 K=1,5
  105 FRM(3,J,K)=0.
  165 FRM(3,J,7)=0.
  102 CONTINUE
      DO 106 J=1,TW
      DO 106 K=1,4
  106 FRM(1,J,K)=0.
      WRITE(2,109)(LT(J),J=1,TW)
  109 FORMAT(5X,'LEAD TIMES',10(3X,I3))
      RETURN
      END


      SUBROUTINE FIRPRI(J)
      REAL FRM(3,10,7),CAP(10),WC1(10),WC2(10),ROI
```

Table C.2 (continued)

```
      INTEGER IFRM(10,13),K,J,IT(10),TW,T,IY,IQ,AR(10)
      COMMON/FR/FRM,WC1,WC2/F/TW/TE/T/P/CAP/L/IT
C     WRITE(6,400)
  400 FORMAT(15X,'FIRM1')
      WRITE(6,100)
  100 FORMAT(//,5X,34HCOMPARATIVE FINANCIAL RESULTS FOR  )
      IF(J.EQ.1)GO TO 101
      IF(J.EQ.2)GO TO 102
      IY=T/12
      WRITE(6,103)IY
  103 FORMAT(1H+,38X,'YEAR ',I2)
      GO TO 104
  101 WRITE(6,105)T
  105 FORMAT(1H+,38X,'MONTH ',I3)
      GO TO 104
  102 IQ=T/3
      WRITE(6,106)IQ
  106 FORMAT(1H+,38X,'QUARTER ',I3)
  104 DO 107 I=1,TW
      DO 108 K=2,5
  108 IFRM(I,K)=FRM(J,I,K)*.001+.5
      IFRM(I,6)=FRM(1,I,6)*.001+.5
      IFRM(I,8)=(FRM(J,I,2)-FRM(J,I,3))*.001+.5
      IFRM(I,9)=(FRM(J,I,4)+FRM(J,I,5))*.001+.5
      IFRM(I,10)=(FRM(J,I,2)-FRM(J,I,3)-FRM(J,I,4)-FRM(J,I,5))*.001+.5
      IFRM(I,11)=(WC1(I)*CAP(I)+WC2(I)*FRM(1,I,1))*.001+.5
      IFRM(I,12)=(FRM(1,I,6)+WC1(I)*CAP(I)+WC2(I)*FRM(1,I,1))*.001+.5
      ROI=(FRM(J,I,2)-FRM(J,I,3)-
     C FRM(J,I,4)-FRM(J,I,5))/(WC1(I)*CAP(I)+WC2(I)*FRM(1,I,1)+
     C FRM(1,I,6))
      IF(J.EQ.1)IFRM(I,13)=1200.*ROI+.5
      IF(J.EQ.2)IFRM(I,13)=400.*ROI+.5
      IF(J.EQ.3)IFRM(I,13)=(ROI*100.)+.5
      IFRM(I,1)=FRM(J,I,1)+.5
      IF(J.EQ.1)IFRM(I,7)=CAP(I)+.5
      IF(J.EQ.2)IFRM(I,7)=FRM(2,I,7)+.5
      IF(J.EQ.3)IFRM(I,7)=FRM(3,I,7)+.5
  107 CONTINUE
      WRITE(6,109)(IT(I),I=1,TW)
  109 FORMAT(1X,'SUPPLIER',9X,10(I2,4X))
      WRITE(6,110)(IFRM(I,7),I=1,TW)
  110 FORMAT(/,1X,'CAPACITY (T)     ',10(I5,1X))
      WRITE(6,111)(IFRM(I,1),I=1,TW)
  111 FORMAT(1X,'SALES WT (T)     ',10(I5,1X))
      WRITE(6,112)(IFRM(I,2),I=1,TW)
  112 FORMAT(/,' REALISN  (£K)    ',10(I5,1X))
      WRITE(6,113)(IFRM(I,3),I=1,TW)
  113 FORMAT(' VAR COST (£K)    ',10(I5,1X))
      WRITE(6,114)(IFRM(I,8),I=1,TW)
  114 FORMAT(17X,9('----- '),/,' CONTRIBN (£K)    ',10(I5,1X))
      WRITE(6,115)(IFRM(I,4),I=1,TW)
  115 FORMAT(17X,9('----- '),/,' DEPRECN  (£K)    ',10(I5,1X))
      WRITE(6,116)(IFRM(I,5),I=1,TW)
  116 FORMAT(' PER COST (£K)    ',10(I5,1X))
      WRITE(6,117)(IFRM(I,9),I=1,TW)
  117 FORMAT(17X,9('----- '),/,' TO FX CO (£K)    ',10(I5,1X))
      WRITE(6,118)(IFRM(I,10),I=1,TW)
  118 FORMAT(17X,9('----- '),/,' PROFIT    (£K)   ',10(I5,1X))
      WRITE(6,119)(IFRM(I,6),I=1,TW)
  119 FORMAT(17X,9('===== '),//,' FIXD CAP (£K)    ',10(I5,1X))
      WRITE(6,120)(IFRM(I,11),I=1,TW)
  120 FORMAT(' WORK CAP (£K)    ',10(I5,1X))
      WRITE(6,121)(IFRM(I,12),I=1,TW)
  121 FORMAT(17X,9('----- '),/,' CAP EMPL (£K)    ',10(I5,1X))
      WRITE(6,122)(IFRM(I,13),I=1,TW)
  122 FORMAT(17X,9('===== '),/,' PROF/CAP (%)     ',10(I5,1X))
      WRITE(6,123)
  123 FORMAT(17X,9('===== '))
      IF(J.NE.1)GO TO 500
      DO 401 IP=1,TW
      IF(FRM(1,IP,1).EQ.0) GO TO 403
      GO TO 404
  403 AR(IP)=-1
      GO TO 401
  404 CONTINUE
      AR(IP)=FRM(1,IP,2)*.01/FRM(1,IP,1)+.5
  401 CONTINUE
      WRITE(6,402)(AR(IP),IP=1,TW)
  402 FORMAT(' AV PRICE(£00/T)  ',10(I5,1X))
  500 CONTINUE
      RETURN
      END


      SUBROUTINE CAPEX
      REAL CAPUT(10),FRM(3,10,7),EXPT(10),FCI(10),WC1(10),
     C WC2(10),CAP(10),T3C(10),T3D(10)
      INTEGER J,TW,K
      COMMON /FR/FRM,WC1,WC2/F/TW/CU/CAPUT/EXT/EXPT/FCI/FCI/P/CAP
     C /TCP/T3C,T3D
C     WRITE(6,100)
  100 FORMAT(15X,'CAPEX')
      DO 101 J=1,TW
      CC=T3D(J)/T3C(J)
      IF(CC.LT..98)GO TO 102
      CAP(J)=CAP(J)*EXPT(J)
      FRM(1,J,6)=FRM(1,J,6)+(EXPT(J)-1)*FCI(J)
      FCI(J)=FCI(J)*EXPT(J)
  102 T3D(J)=0.
```

Table C.2 (continued)

```
      T3C(J)=0.
  101 CONTINUE
      RETURN
      END

      SUBROUTINE PRDOWN
      REAL CAPUT(10),PRICE(10,5),VC(10,5)
      INTEGER J,K,PRN,MN,TW
      COMMON /CU/CAPUT/VC/VC/PRI/PRICE/PRN/PRN,MN/F/TW
C     WRITE(6,100)
  100 FORMAT(15X,'PRDOWN')
      DO 101 J=1,TW
      IF(CAPUT(J).GE..8)GO TO 101
      DO 101 K=1,PRN
      PRICE(J,K)=PRICE(J,K)*.95
      IF(PRICE(J,K).LT.1.1*VC(J,K))PRICE(J,K)=1.1*VC(J,K)
  101 CONTINUE
      RETURN
      END

      SUBROUTINE PRUP
      REAL PRICE(10,5),CAPUT(10)
      INTEGER TW,J,PRN,MN
      COMMON/F/TW/PRN/PRN,MN/PRI/PRICE/CU/CAPUT
C     WRITE(6,100)
  100 FORMAT(15X,'PRUP')
      DO 101 J=1,TW
      IF(CAPUT(J).LT..98)GO TO 101
      DO 101 K=1,PRN
      PRICE(J,K)=PRICE(J,K)*1.05
  101 CONTINUE
      RETURN
      END

      FINISH
```

C.3.1 The Program Structure

The master segment, TIMKT, controls the calling of each other segment. It first calls segments INIT and INPUT. TIMKT then sets the "clock" to its starting value, and advances the month up to the required limit. In each month, it calls the segments required for each part of the simulation. The calling sequence of the program is shown as table C.3. Table C.4 indicates the use of all the variable names used in the program.

When a complete simulation has been carried out, TIMKT re-initialises the sequence by calling INIT, and inputs data using INPUT for a fresh run.

Go to 196

Table C.3

CALLING SEQUENCE OF SIMULATION PROGRAM

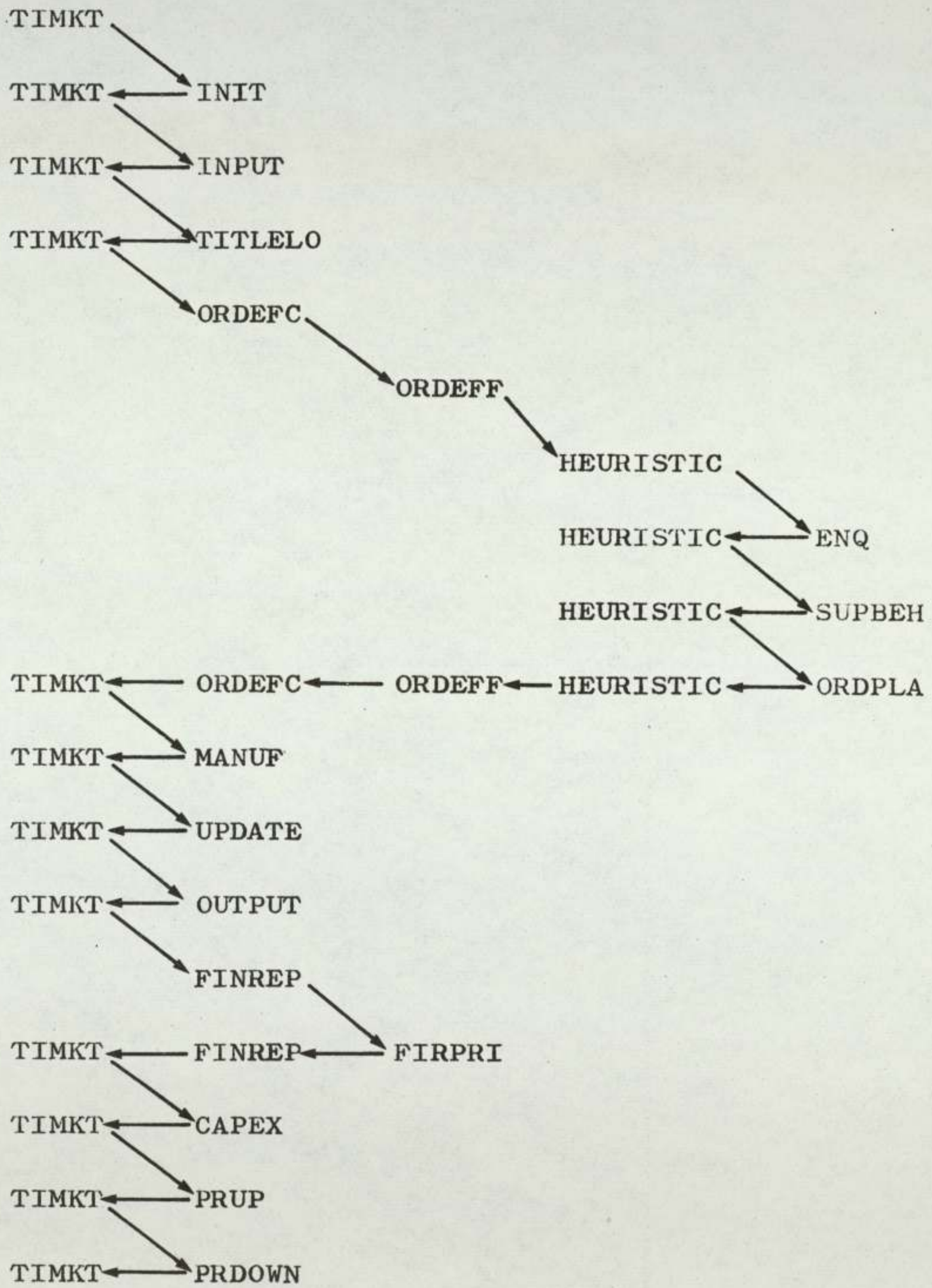


Table C.4 IDENTIFIERS USED IN THE SIMULATION PROGRAM

TIMKT

K	-	number representing the current month during the course of the simulation.
TMAX	-	limit to the number of months the simulation is desired to run.

INIT

J	-	running variable.
ORDS(J)	-	number of orders on supplier J's order book.
LT(J)	-	delivery lead time of supplier J.
K	-	running variable.
ORDERSZ(J,K)	-	size of K'th order on J's order book.
KPR(J,K)	-	unit price of K'th order on J's order book.
ORDTA(J,K)	-	month K'th order on J's order book was taken.
QD(J,K)	-	quotation of delivery lead time given for K'th order on supplier J's order book.
DEKGS(J,K)	-	total current monthly deliveries of product K by supplier J.
L(J)	-	dummy array used for printing titles.

Table C.4 (continued)

INPUT

TW	-	number of suppliers in the model.
IT	-	limit to the number of months the simulation is desired to run.
PRN	-	number of product groups in the model.
MN	-	number of market sectors in the model.
J	-	running variable.
CTRD(J,K)	-	months which sector J adds to supplier K's delivery quote to obtain his estimate of delivery month.
K	-	running variable.
ATR (I,J,K)	-	shared attributes between supplier I and market sector K.
ATR (I,3,K)	-	loyalty of sector K to supplier I.
ATR (I,4,K)	-	sector K's perception of supplier I's quality.
ATR (I,5,K)	-	pressure on sector K favouring supplier I.
LL(J)	-	array used for titles.
IY	-	number of years simulation will run.
I	-	running variable.
MEAN(I,J,K)	-	mean size of monthly order (in tonnes) which sector K will place in year I, for product J.
MIND (K,J)	-	mean of maximum acceptable delivery for product K, to sector J.
MP (K,J)	-	mean of maximum acceptable price for product K to sector J.

Table C.4 (continued)

CAP(J)	-	monthly capacity (in tonnes) of supplier J.
AS (J,K)	-	indicates (with a 1) whether supplier J is able to supply product K.
EXPT (J)	-	ratio of new to old monthly capacity, when supplier J increases capacity.
WC2	-	increase in supplier J's working capital caused by an increase in sales of 1 tonne per month
FRM (I,J,K)	-	matrix used for financial reports.
FRM (I,J,6)	-	fixed capital for supplier J.
D(J)	-	annual rate of depreciation of fixed assets of supplier J.
REPFREQ	-	denotes required frequency of financial reports output from the model. 1 - monthly and 2 - quarterly and 3 - annually
RSDQ	-	ratio of standard deviation to mean of sectors' monthly demand.
RSDD	-	ratio of standard deviation to mean for maximum acceptable deliveries.
RSDP	-	ratio of standard deviation to mean for maximum acceptable price.
RSDQP	-	ratio of standard deviation to mean of quoted prices.
L	-	running variable.

Table C.4 (continued)

PRICE (L,J)	-	supplier L's mean quoted price for product J (£/tonne).
VC (L,J)	-	supplier L's variable cost rate for product J (£/tonne).
P (J)	-	relative frequencies of choice of:- J = 1 - price J = 2 - delivery J = 3 - loyalty J = 4 - quality J = 5 - external pressure as most important variables in the supplier selection process.
SEN (J)	-	selection sensitivities for:- J = 1 - price J = 2 - delivery J = 3 - loyalty J = 4 - quality J = 5 - external pressure
PER (J)	-	supplier J's monthly period cost per tonne of monthly capacity.
WC1 (J)	-	working capital per tonne of monthly capacity, for supplier J.
SMF	-	smoothing factor for updating loyalty.
<u>ORDEFC</u>		
I	-	simulation current year.
IT	-	simulation current month.

Table C.4 (continued)

J	-	running variable.
PRN	-	number of product groups.
K	-	running variable.
MN	-	number of market sectors.
DEV	-	standard deviation of monthly demand.
RSDQ	-	ratio of standard deviation to mean of demand.
MEAN (I,J,K)	-	mean monthly demand in year I of sector K, for product J.
Q	-	size of current demand (tonnes).
G05AEF (I,J)	-	samples from a normal distribution with mean I, and standard deviation J. (Routine from NAG library).
M	-	standard deviation of maximum acceptable deliveries.
MIND (J,K)	-	mean of maximum acceptable delivery of product J, to sector K.
RSDD	-	ratio of standard deviation to mean maximum acceptable delivery.
COD	-	maximum acceptable delivery (months) for this demand.
D	-	standard deviation of maximum price.
MP (J,K)	-	mean of maximum price acceptable to sector K for product J.
RSDP	-	ratio of standard deviation to mean of maximum acceptable price.

Table C.4 (continued)

COP	-	maximum acceptable price (£/tonne) for this demand.
MANUF		
J	-	running variable.
TW	-	number of suppliers.
CAPLE	-	capacity left of the current supplier.
CAP (J)	-	monthly capacity (tonnes) of supplier J.
ORDS (J)	-	the number of current orders on supplier J's order book.
K	-	running variable.
ORDERSZ (J,K)	-	size (in tonnes) of the K'th order in supplier J's order book.
LT (J)	-	delivery lead time of supplier J.
ORDTA (J,K)	-	month in which the K'th order on supplier J's order book was placed.
FRM (I,J,K)	-	financial reporting matrix.
FRM (1,J,1)	-	total deliveries by supplier J in the current month (tonnes).
FRM (1,J,2)	-	total sales by supplier J in the current month (£).
FRM (1,J,3)	-	total variable costs incurred by supplier J in the current month.
KPR (J,K)	-	unit price of K'th order on supplier J's order book (£/tonne).
VC (J,K)	-	variable cost rate of supplier J for product K (£/tonne).

Table C.4 (continued)

DEKGS (K,J)	-	month's deliveries from supplier J to sector K.
ORDCU (J,K)	-	market sector which placed the K'th order on supplier J's order book.
M	-	running variable.
MN	-	number of market sectors.
L	-	running variable.
ORDPR (J,M)	-	product group of M'th order on supplier J's order book.
QD (J,M)	-	quoted delivery lead time of M'th order on supplier J's order book.
TO	-	total weight of orders on order book.
CAP (J)	-	monthly capacity of supplier J.
ORDEFF		
J	-	running variable.
P (J)	-	relative frquency of choosing attribute J in the selection process, at each stage, where:- J = 1 - price; J = 2 - delivery; J = 3 - loyalty; J = 4 - quality; J = 5 - external pressure
PC (J)	-	original value for P(J).
NO	-	running variable.
CUMP (J)	-	cumulative frequency, based on P(J).
RN	-	number selected at random.

Table C.4 (continued)

G05ABF (X,Y)	-	NAG routine which provides a number selected at random from the uniform distribution with range from X to Y.
CPL (J)	-	the order of consideration of suppliers' attributes in the selection process. J = 1 - price J = 2 - delivery J = 3 - loyalty J = 4 - quality J = 5 - external pressure.
ORDPLA		
J	-	running variable.
TW	-	number of suppliers.
ORD (J)	-	size (in tonnes) of order currently being placed on supplier J.
ORDS (J)	-	number of orders in supplier J's order book.
ORDERSZ (J,K)	-	size (in tonnes) of K'th order in supplier J's order book.
ORDPR (J,K)	-	product involved in the K'th order in supplier J's order book.
K	-	product group of current order.
ORDTA (J,K)	-	month in which the K'th order in supplier J's order book was taken.
N	-	current month of model.
QD (J,K)	-	delivery lead time quotation (months) given for order K on supplier J's order book.

Table C.4 (continued)

QUD (J)	-	current delivery quote given by supplier J.
KPR (J,K)	-	unit price quoted (£/tonne) for the K'th item on supplier J's order book.
QUP (J)	-	supplier J's current price quotation.
ORDCU (J,K)	-	market sector which placed the K'th order on supplier J's order book.
CUST	-	market sector placing current order.
ORKGS (CUST,J)	-	monthly total order weight placed by sector CUST on supplier J.
TITLELO		
I1	-	running variable.
MN	-	number of market sectors.
I2	-	running variable.
TW	-	number of suppliers.
ORKGS (J,K)	-	monthly total order weight placed by sector J on supplier K.
DEKGS (J,K)	-	monthly total weight of deliveries made by supplier K to sector J.
SUPBEH		
IS	-	supplier identification number.
PSEN (IS)	-	pressure applied by supplier IS to alter decision sensitivities.

Table C.4 (continued)

PXV (IS)	-	pressure from supplier IS for sector to reduce the time it adds to delivery quotations.
OQU (IS)	-	shows whether quote given by supplier IS. (1 - yes, 0 - no).
PLOY (IS)	-	pressure from supplier IS to change market sector's loyalty.
ORDSZ	-	size of current demand (tonnes).
COR (IS)	-	shows (=1) if supplier IS was rejected because price or delivery were quoted above the maximum. 0 if not.
PCOP (IS)	-	pressure from supplier IS to alter price and delivery maxima.
PRS (IS)	-	degree of preference of current sector for supplier IS. (A total of 1 is shared out among suppliers).
IM	-	running variable.
J	-	running variable.
RANK (J)	-	order of consideration of suppliers' attributes in the selection process. J = 1 - price J = 2 - delivery J = 3 - loyalty J = 4 - quality J = 5 - external pressure
RV	-	running variable.

Table C.4 (continued)

PCPL (J,IS)	-	pressure from supplier IS to alter order of consideration of attribute J, negative to increase RANK (J), positive to reduce it.
IN	-	running variable.
REQ (IS)	-	multiplier for supplier IS's price and delivery quotes.
HEURISTIC		
SPA	-	index which indicates whether sector is ready (= 1) to place its order.
KJ	-	index used to count suppliers considered at some stages in the selection routine.
J	-	running variable.
TW	-	number of suppliers.
PCOP (J)	-	pressure from supplier J to alter price and delivery maxima.
CLI (J)	-	indicates whether supplier J is present on the list of acceptable suppliers (1 - on, 0 - off).
REQ (J)	-	multiplier for supplier J's quotes.
AS (J, PR)	-	indicates supplier J's ability to supply product PR.
PR	-	number designating product group.
JC	-	running variable which counts acceptable suppliers.

Table C.4 (continued)

KQ	-	is set to 1 if a quotation is made or 0 if one is declined.
ATR (J,K,MC)	-	shared attributes between supplier J and market sector MC. K = 1, price expected K = 2, delivery lead time expected K = 3, loyalty of sector to supplier K = 4, sector's perception of suppliers' quality K = 5, pressure on sector to buy from supplier
MC	-	number designating market sector.
QUP (J)	-	price quoted by supplier J (£/tonne).
QUD (J)	-	delivery lead time quoted by supplier J (months).
CTRD (MC,J)	-	number of months which sector MC adds to supplier J's delivery quotation to arrive at expected lead time (months).
ALI (J)	-	indicates whether supplier J is present on the list of acceptable suppliers (1 = on, 0 = off).
COP	-	maximum acceptable price for this order (£/tonne).
COD	-	maximum acceptable delivery lead time for this order.
ADEQ (J)	-	indicates whether supplier J has performed adequately on each factor so far considered.

Table C.4 (continued)

CPL (J)	-	current value of preference for factor J.
MP	-	running variable used to find next most important variable in selection process.
FP	-	most important variable at this stage. 1 = price 2 = delivery 3 = loyalty 4 = quality 5 = external pressure
MFP	-	optimum available of variable FP.
ADFP	-	adequate value for variable FP.
SEN (FP)	-	sensitivity of selection of adequate suppliers, on variable FP.
PRS	-	number of preferred supplier.
PRFS (J)	-	degree of preference for supplier J.
ORD (J)	-	order size placed on supplier J (tonnes).
KR	-	running variable used to count suppliers left on acceptable list.
AIND	-	used to calculate PRFS (J)'s.
BIND	-	used to calculate PRFS (J)'s.
MPQ	-	minimum price quotation (£/tonne).
MDQ	-	minimum delivery quotation (months).
IMPQ	-	number of suppliers offering minimum price quote.
IMDQ	-	number of suppliers offering minimum delivery quote.

Table C.4 (continued)

PCO	-	aggregate pressure from suppliers to alter maximum price and delivery.
JPC	-	running variable used in counting active suppliers.
JP	-	running variable.
PV (JP)	-	pressure from suppliers to make variable JP more (positive) or less (negative) important.
PCPL (JP,J)	-	pressure from supplier J to make variable JP more (positive) or less (negative) important.
NPL (J)	-	used to change the order of importance of variables.
J2	-	running variable.
LPS	-	running variable used to find highest values of NPL.
NUM	-	running variable.
CPX (J)	-	pressure to alter expectation of price and delivery from supplier J.
SP (J)	-	pressure by suppliers to alter the sensitivity on factor J.
PSEN (J)	-	pressure by supplier J to alter sensitivity.
REQ (J)	-	requoting factor for supplier J.
PLOY (J)	-	pressure from supplier J to increase loyalty to him.
Q	-	total current demand.

Table C.4 (continued)

ENQ

J	-	supplier number.
KQ	-	indicates whetherthis supplier offers a quote (1 - he does, 0 - he doesn't).
ORDS (J)	-	number of live orders on supplier J's order book.
D	-	standard deviation of quoted price.
PRICE (J,IP)	-	mean price level of supplier J for product group IP.
IP	-	number of product group.
RSDQP	-	ratio of standard deviation to mean for quoted prices.
QUP (J)	-	price (£/tonne) quoted by supplier J.
G05AEF (I,J)	-	NAG routine which takes a random sample from a normal distribution with mean I and standard deviation J.
VC (J,IP)	-	variable cost (£/tonne) of production of product group IP, by supplier J.
QUD (J)	-	delivery lead time quoted by supplier J.
LT (J)	-	supplier J's estimate of his current lead time.

UPDATE

J	-	loop variable.
TW	-	number of suppliers in the market.
LL	-	loop variable.
MN	-	number of market sectors in the model.
K	-	loop variable.

Table C.4 (continued)

ORDS (J)	-	number of orders on supplier J's order book.
ODC	-	running variable used to calculate the cumulative number of months overdue of orders from a given sector to a supplier.
N	-	running variable used to calculate total number of overdue orders from each supplier to each sector.
ORDCU (J,K)	-	market sector of K'th order on supplier J's order book.
T	-	number of current month.
ORDTA (J,K)	-	month in which order K on supplier J's order book was taken.
QD (J,K)	-	delivery quoted for order K on supplier J's order book.
OD	-	months overdue for an order.
CTRD (LL,J)	-	months which sector LL adds to supplier J's delivery quotation.
L(J)	-	used only for writing a title.
ATR (J,3,K)	-	loyalty of sector K to supplier J.

OUTPUT

J	-	running variable.
TW	-	number of suppliers in the model.
TOTDEL (J)	-	total deliveries made by supplier J.
TOTORD (J)	-	total weight of orders booked by supplier J.
K	-	running variable.

Table C.4 (continued)

MN	-	number of market sectors in the model.
DEKGS (K,J)	-	weight (tonnes) delivered by supplier J to sector K.
ORKGS (K,J)	-	weight of orders placed by sector K with supplier J.
I	-	running variable.
TTORDS (I)	-	total orders placed by sector I.
TTDELS (I)	-	total deliveries to sector I.
ATR (J,3,K)	-	loyalty of sector K to supplier J.
SMF	-	smoothing factor for updating loyalty.
TTORDS (6)	-	total weight of orders placed.
TTDELS (6)	-	total weight of deliveries made.
CAP (J)	-	monthly production capacity of supplier J (tonnes).
PER (J)	-	monthly period cost per tonne of capacity for supplier J.
REPFREQ	-	desired frequency of financial reports 1 = monthly, 2 = quarterly, 3 = annually.
T	-	current month of simulation.
CAPUT (J)	-	quarterly capacity utilisation of supplier J.
K	-	running variable.
T3C (J)	-	annual capacity of supplier J.
T3D (J)	-	annual deliveries of supplier J.

Table C.4 (continued)

LT (J)	-	lead time of supplier J.
FIRPRI		
J	-	reported period, 1 - month, 2 - quarter, 3 - year.
IY	-	current year number of simulation.
T	-	current month number of simulation.
IQ	-	current quarter number of simulation.
I	-	running variable.
TW	-	number of suppliers in market.
K	-	running variable.
IFRM (I,K)	-	integer financial reporting matrix, for supplier I.
		K = 1 - sales weight (tonnes)
		K = 2 - sales realisation (£ x 1000)
		K = 3 - variable cost (£ x 1000)
		K = 4 - depreciation (£ x 1000)
		K = 5 - period cost (£ x 1000)
		K = 6 - fixed capital (£ x 1000)
		K = 7 - capacity (tonnes)
		K = 8 - contribution (£ x 1000)
		K = 9 - total fixed costs (£ x 1000)
		K = 10- profit (£ x 1000)
		K = 11- working capital (£ x 1000)
		K = 12- capital employed (£ x 1000)
		K = 13- profit to capital ratio (%)
FRM (J,I,K)	-	financial reporting matrix for period J, and supplier I.
		K = 1 - sales weight (tonnes)
		K = 2 - sales realisation (£)
		K = 3 - variable cost (£)

Table C.4 (continued)

FRM (J,I,K)	-	K = 4 - depreciation (£)
		K = 5 - period cost (£)
		K = 6 - fixed capital (£)
		K = 7 - production capacity (tonnes)
WC1 (I)	-	working capital per tonne of monthly capacity for supplier I (£)
CAP (I)	-	monthly capacity for supplier I (tonnes).
WC2 (I)	-	working capital per tonne of sales for supplier I (£).
ROI	-	rate of return on investment.
IT (I)	-	array used for titles.
IP	-	running variable
AR (IP)	-	average price obtained by supplier IP (£00/tonne).

<u>CAPEX</u>

J	-	running variable.
TW	-	number of suppliers.
CC	-	yearly capacity utilisation.
T3D (J)	-	total annual deliveries by supplier J.
T3C (J)	-	total annual capacity of supplier J.
CAP (J)	-	current monthly capacity of supplier J.
EXPT (J)	-	rate of capacity expansion of supplier J.
FRM (1,J,6)	-	current fixed capital of supplier J.
L (J)	-	array used for titles.

<u>FINREP</u>

J	-	running variable.
TW	-	number of suppliers in the model.

Table C.4 (continued)

FRM (I,J,K)	-	financial reporting matrix, for supplier J. I represents the period, and K the quantity. I = 1 - current month I = 2 - current quarter I = 3 - current year K = 1 - sales weight (tonnes) K = 2 - realisation (£) K = 3 - variable cost (£) K = 4 - depreciation (£) K = 5 - period cost (£) K = 6 - fixed capital (£) K = 7 - production capacity (tonnes)
D (J)	-	rate of annual depreciation used by supplier J.
FCI (J)	-	previous non-depreciated value of fixed capital of supplier J.
PRDOWN		
J	-	running variable.
TW	-	number of suppliers.
CAPUT (J)	-	capacity utilisation of supplier J, during the previous quarter,
K	-	running variable.
PRN	-	number of product groups in the model.
PRICE (J,K)	-	supplier J's average price for product K.
VC (J,K)	-	supplier J's variable cost of production of product K.

Table C.4 (continued)

PRUP

J	-	running variable.
TW	-	number of suppliers in the model
CAPUT (J)	-	capacity utilisation of supplier J during the previous quarter.
K	-	running variable.
PRN	-	number of product groups in the model.
PRICE (J,K)	-	mean price charged by supplier J for product K.

C.3.2 Processing in Each Segment

TIMKT

This, the master segment, controls the calling sequence, and cycles the clock. It starts a new simulation when enough months have been simulated. It stops the processing when all data is exhausted.

INIT

This subroutine initialises an array used in printing titles. All variables used in the program are initialised in this segment.

INPUT

This subroutine enters all input to the program, and also writes this out as identification of the output. Table C.5 shows the input required.

TITELO

This subroutine resets monthly two registers which accumulate orders and deliveries for each market sector/ supplier combination.

ORDEFC

This subroutine cycles through each product and each market sector. It selects for each combination the quantity required and initial maximum price and delivery times, using the NAG routine GO5AEF, which takes random samples from a normal distribution. The routine then calls, for each product/sector, ORDEFF.

ORDEFF

This subroutine selects the order of importance of price, loyalty, delivery, quality and customer pressure in the selection process. This is done using probabilities which are input, and a routine from the NAG library which samples from a uniform distribution : GO5ABF. ORDEFF then calls HEURISTIC.

HEURISTIC

Subroutine HEURISTIC is the supplier selection routine. It initially sends enquiries to each supplier, by calling ENQ for each one selected.

HEURISTIC then selects its preferred suppliers. It passes this information to the suppliers and invites their response, by calling SUPBEH for each supplier. After receiving the sales pressure, acting on it, and deciding on which supplier to patronise, HEURISTIC places its order or orders by calling ORDPLA for each supplier selected.

ENQ

This subroutine is called for each supplier invited to quote for an order. A quote is made providing there are not more than 98 orders currently on that suppliers order book. Price is quoted by impressing a sample from a normal distribution (using G05AEF) on the supplier's ruling price level for the product in question. Delivery is quoted by calculating how many months' orders are on hand.

SUPBEH

This routine describes the sales pressure exerted by each supplier after HEURISTIC has selected the preferred supplier.

ORDPLA

Subroutine ORDPLA is called for each supplier when an order is offered to it. Orders are always accepted. Data about the order is entered in the order book.

MANUF

This subroutine cycles through each supplier during each month. Orders are taken from the order book in order and delivered, up to each supplier's capacity limit.

UPDATE

Subroutine UPDATE causes each market sector's estimate of the accuracy of each supplier's delivery quote to be updated.

OUTPUT

This routine causes reports to be printed each month which show summaries of orders placed and deliveries made. All the loyalties are also updated.

FINREP

Subroutine FINREP organises the regular accumulation of the quantities required for all financial reports. Depending on the frequency of reports required, it calls FIRPRI, at appropriate intervals.

FIRPRI

This subroutine is called to print financial reports on each supplier.

CAPEX

Subroutine CAPEX is called once a year from TIMKT. It cycles through suppliers, and decides whether to increase their capacity.

PRUP

This routine decides whether to increase each supplier's price level. When such a decision is made it changes the level.

PRDOWN

This subroutine regularly makes the decision on whether to reduce each supplier's price.

Table C.5 INPUT REQUIRED BY SIMULATION PROGRAM

One set of data is required for each complete simulation. As many sets of data as desired may be submitted. All input is in free format. Real items must contain a decimal point, and integer items must not. Any number of spaces may separate each item from others on the same card.

1 card	TW, IT, PRN, MN	Integers
MN cards	CTRD (1,1) to CTRD (1,TW) to CTRD (MN,1) to CTRD (MN,TW)	Real
MN cards	ATR (1,3,1) to ATR (TW,3,1) to ATR (1,3,MN) to ATR (TW,3,MN)	Real
MN cards	ATR (1,4,1) to ATR (TW,4,MN) to ATR (1,4,MN) to ATR (TW,4,MN)	Real
MN cards	ATR (1,5,1) to ATR (TW,5,1) to ATR (1,5,MN) to ATR (TW,5,MN)	Real
IY sets of PRN cards	MEAN (I,1,1) to MEAN (I,1,MN) to MEAN (I,PRN,1) to MEAN (I,PRN,MN)	Real

for I = 1,2, ... IY

PRN cards	MIND (1,1) to MIND (1,MN) to MIND (PRN, 1) to MIND (PRN,MN)	Real

Table C.5 (continued)

PRN cards	MP (1,1) to MP (1,MN)	Real
	to	
	MP (PRN,1) to MP (PRN,MN)	
1 card	CAP (1) to CAP (TW)	Real
TW cards	AS (1,1) to AS (1,PRN)	Integer
	to	
	AS (TW,1) to AS (TW,PRN)	
1 card	EXPT (1) to EXPT (TW)	Real
1 card	WC2 (1) to WC2 (TW)	Real
1 card	FRM (1,1,6) to FRM (1,TW,6)	Real
1 card	D (1) to D (TW)	Real
1 card	REPFREQ	Integer
1 card	RSDQ, RSDD, RSDP, RSDQP	Real
TW cards	PRICE (1,1) to PRICE (1,PRN)	Real
	to	
	PRICE (TW,1) to PRICE (TW,PRN)	
TW cards	VC (1,1) to VC (1,PRN)	Real
	to	
	VC (TW,1) to VC (TW,PRN)	
1 card	P (1) to P (5)	Real
1 card	SEN (1) to SEN (5)	Real
1 card	PER (1) to PER (TW)	Real
1 card	WC1 (1) to WC1 (TW)	Real
1 card	SMF	Real

APPENDIX D

LOYALTY AS A COMPONENT OF THE INDUSTRIAL BUYING DECISION

by P L Bubb

and D J van Rest

An IHD Scheme Working Paper, May 1973

The University of Aston in Birmingham

LOYALTY AS A COMPONENT OF THE INDUSTRIAL BUYING DECISION

by P L Bubb and D J van Rest

SYNOPSIS

In industrial marketing, loyalty is more usefully regarded as a determinant of the buying decision than just a summary of decision outcomes.

Loyalty can be regarded as including those inertial influences on the buying decision not separately considered. In many cases it may be useful to isolate some variables which are often included within the concept of loyalty.

A study of a market is described, in which perceived product quality, pressure from the ultimate consumer and loyalty affect the buying decision outcome.

LOYALTY AS A COMPONENT OF THE INDUSTRIAL BUYING DECISION

What is Source Loyalty?

In consumer marketing, loyalty is regarded (Cunningham (1956)) as a statistic summarising the outcomes of a sequence of buying decisions. Loyalty is regarded as high, or present, when a high proportion of buys are with a given supplier. Wind (1970) has directly transposed this concept of loyalty to the industrial marketing area.

Such a concept of source loyalty seems to the present writers to lack managerial significance. A more useful summary of buying decision outcomes is given by the sales achievements. If, however, loyalty is also regarded as one of the factors which influence each buying decision, then the concept is very important from a management point of view. Loyalty becomes the means whereby past buying decisions affect the current one. We have found, from fieldwork, that at least some industrial marketing executives regard loyalty in this way. Recent press comment on the C & A chain of stores (Sunday Times (1972)) concurs with this view.

How is Loyalty Recognisable?

If loyalty is one of the factors which are considered in the buying decision, we can assess the behaviour due to loyalty by separating out the other influences. Loyalty will account for the residual tendency to buy from a previously favoured supplier, when each other factor has been isolated and accounted for. In many decisions, therefore, loyalty will not be able to influence the outcome, since it will be determined by the other factors.

The whole concept of loyalty is of a factor which will change relatively slowly in comparison with supplier decisions. In this way, since it links past decisions with the current one, loyalty is analogous to inertia. Clearly an operational definition of loyalty will entirely depend on the circumstances. It will generally be appropriate to treat price as a factor distinct from loyalty, but most other factors might in some circumstances be included in loyalty.

We can recognise loyal behaviour as a tendency (not explained otherwise) for a customer to repeatedly buy from a particular supplier. It will generally be responsible for a slowly fluctuating sales volume of a particular supplier.

Models which show Loyalty

There are a number of models which have been proposed and exhibit the behaviour expected from the concept of loyalty described above.

Industrial Dynamics (Forrester (1961)) uses closed-loop systems to model business interactions. Forrester (1961) used negative feedback to generate slowly fluctuating sales volumes in an industry study. Ballmer (1960) has made a study of the copper industry, in which he models the decision whether to buy copper or a competing material. He models the reluctance to change materials, which he calls "stickiness", using a similar type of feedback loop. Forrester (1965) offers a good example of intertial behaviour, in a model which shows the current sales rate as being entirely determined by various historical market influences. These models each show the type of behaviour expected of loyalty from either the supplier or customer view. Although the models were of industries rather than individual firms, the inference of loyalty seems valid.

The Behavioural Theory of the Firm (Cyert & March (1963)) postulates "problemistic search", where problems are solved by initially considering solutions which are similar to previous experience, and systematically widening the field of search until a solution is found. The search goals exhibit slow learning, or adaption. This approach to modelling can clearly give rise to loyal behaviour in a model of the customer. A model having a similar search hierarchy is put forward by Massy & Savvas (1964) to describe a department store buyer's behaviour. All lines stocked in the previous time period are re-stocked, providing they performed satisfactorily. Thus a current supplier has a better chance of being selected than any other, and so the buyer exhibits loyal, inertial or memory behaviour.

There are various models (e.g. Robinson & Faris (1967) and Moore (1969)) which use a list -processing scheme for source selection. A list of acceptable suppliers is first drawn up by the buyer, who selects one source from this list for the specific order. The list is changed infrequently compared to the buying decision. An elaboration of this concept by Webster & Wind (1972) prepares an acceptable list using slow-changing "non-task" variables, such as supplier reliability, and then selects the supplier from that list using "task" variables. These models will all tend to generate the behaviour described earlier as loyalty. A supplier will be more likely to be selected if he has recently been used and proved satisfactory.

Rational Factors Distinct from Loyalty

The concept of loyalty as outlined above is something of a catch-all. It includes everything which was not explained separately but affects the buying decision. The degree of detail to which it will be useful to explain the decision process will clearly vary with the circumstances, but we offer below a few of the factors which can sometimes be isolated.

1. Administrative Inertia

There are limitations in an organisation's capacity to react to and cope with changes. New sources of supply require administrative activity to make the necessary contacts and systems and technical capacity to cope with any complications arising as a result of the change.

Lack of change can of course, atrophy the capacity to deal with it. On the other hand too much change can overburden the internal organisation. Some limitation to the rate of search for new sources is necessary unless appropriate resources for this are made available and the cost of the activity recognised. This factor results in slow adaptation to a changing environment and repeat orders arising by default.

2. Familiarity

The use by an organisation of a special material means that the organisation will have adapted to it and learnt to cope with its special perculiarities. The history of product innovation is full of stories of surprising side-effects providing both unexpected new markets and unexpected limitations. Hence the use of a material from a source with which the organisation is familiar carries the assurance that unexpected difficulties are less likely to occur. Webster and Wind (1972) describe this as "risk reduction."

3. Persistence

There are advantages in building up long term business relationships with a supplier. A supplier is better able to be obliging, lay-down the necessary capacity, maintain standards, assist with problems and devote resources to the servicing aspect of supply if the investment in these aspects can be recovered over a number of supply contracts. At the other extreme quick profits can be made on single contracts if the purchaser over-estimates the value of the material supplied. Hence long-term commitment diminishes the value of a supplier allowing a purchaser to over-estimate the value of the supplies and promotes the liklihood of good service. This is, for example, reflected in the policies of Marks and Spencer Ltd. They regard their suppliers and the relationships built with them as an asset and invest money in their sources of supply (de Somogyi (1970)).

However, the C & A chain of stores operate policies at the opposite extreme. They operate a system which ensures that loyalty to their suppliers does not influence their buying decisions (Sunday Times (1972)).

4. Xenophobia

Organisations can recognise their inability to evaluate suppliers comprehensively in regard to their financial resources, business policies and technical expertise. A defensive device is the approved list, the specification of certain restrictive standards or membership of specific associations. This constitutes a preliminary screening of suppliers and as listing, meeting standards or membership of the associations has some value, the threat of exclusions or denouncement provides a weapon for retaliation by the purchaser in the event of the supplier falling down on his obligations.

5. Nationalism

National governments play an increasing role in the market-place for industrial goods. This is especially noted in high technology areas, where pressure is put on firms to buy indigenous products. This pressure becomes stronger where national security is involved. Communication problems are somewhat lessened within a country, by the relative proximity of buyer and seller, and the absence of language barriers.

6. Neighbourliness

Even more local deals are highlighted by this feature. The reasons are generally to improve communications, and interaction with the local community, which can have an impact on employee morale.

7. Company Relationships

Reciprocal trading is the most often noted of these. Elaborate procedures for ensuring "fairness" in reciprocity between the two firms can lead to a strong reluctance to change suppliers.
Often reciprocal training is managed at a point higher in the firm's organisation structures than "normal" buying. This can lead to reluctance to change in itself. In some countries (particularly the U.S.A.) reciprocity is regarded as somewhat immoral and in some cases it is illegal (Finney (1968)). This can easily lead to loyalty to other (i.e. non-reciprocal) suppliers.

Other types of special relationships between companies include the cases where one company holds part or all the equity of another. These cause different behaviour depending on the management policies.

8. Respect

Purchasers have varying estimates of the technical, managerial and financial resources available to suppliers. Fieldwork carried out by the authors located one case, in a highly technological industry, where an agreement was made to purchase a product whose specifications were only tentatively forecast, the decision being based on respect for the suppliers capability.

Where these factors can be identified and separately analysed a deeper insight can be given into the buying process. Where necessary information is not available they have to be grouped as the residual explanation of behaviour. However, understanding the multi-dimensional nature of loyalty explains the complications that it adds to the buying process.

A Market Model with Explicit Representation of Loyalty

The authors are engaged in a study of the European market for one of the newer metals. This is part of a project developing planning aids for a company which is one of a small number of suppliers to that market.

It was initially decided to build a model which described the where-to-buy decision in terms of a flow chart. The customers for this material were all industrial concerns, so it was not always clear which members of the customer organisation took the buying decision. The decision was therefore taken as the basic activity of interest. The initial investigation suggested that the decision to use this metal (rather than a competing material) could reasonably be treated separately from the decision on which supplier to buy it from.

The investigation started by studying a large number (some 70 or so) of separate decisions, with various customers, and various outcomes. Each of these situations was described as an individual flow chart.

It proved possible to combine most of these individual flow charts into a single model which described the majority of buying decisions studied.

The model was validated it by incorporating it into a simulation of the entire market, which was run to cover a period of five years, and compared to the actual market behaviour over that time. Agreement was good.

The model (shown in figure 1) is constructed from the point of view of the customer. It uses five factors to decide which supplier to use for each order. These factors are price, delivery time, loyalty, quality, and pressure from the customer's customer. The model is constructed as a list processing system: it starts off with a list of suppliers which might be acceptable, and eliminates suppliers from this list until only one is left, or the customer is indifferent among those suppliers left.

The customer initially sends enquiries to all the suppliers on his "acceptable list". He receives quotations from some of these suppliers. Others are eliminated from the list. After examination of the quotations, each supplier's delivery is compared to the customer's deadline. Those which don't meet it are eliminated. Each supplier left then has his price compared to the maximum which the customer is prepared to pay. Unacceptable suppliers are removed from the list. At this stage, the number of suppliers on the list is counted. If none are left, the price and delivery constraints are relaxed until at least one supplier is left. If more than one supplier is still on this list, further activity takes place to reduce the size of the list.

Each customer has a ranking order of the five market factors. He considers the most important factor separately first, and continues through each factor in descending order of importance to him. In general, each customer will have a different ranking for each buying decision. With each factor (taken in order), the best supplier left on the list is found. Any supplier significantly worse on this factor is removed from the list. The list is then counted, and only if more than one supplier remains is the next factor considered. After all the factors have been considered, if more than one supplier remains, the sensitivity of the process is increased, and this elimination procedure repeated. At any stage, if only one supplier is left on the list, the elimination process is halted, and the fact that that supplier is "preferred" is made known to the market. If, after completing the process, more than one supplier is left on the list, these are similarly regarded as preferred.

An opportunity is then given to all suppliers to respond, by improving their quote, or attempting to alter the customer's ranking order of factors. After receiving any such response, the entire elimination process is repeated, and the preferred supplier or suppliers selected. The order is shared equally among these suppliers this time, however.

In the market model, it was estimated that for about 30% of the decisions loyalty was the most important factor in the decision (i.e. it was considered first in the selcetion process).

With the market simulation used to validate the model, loyalty was allowed to vary over time. The rule used was to set loyalty between each customer/supplier pair, as a weighted average of the loyalty in the previous time-period, with the proportion of that customer's orders placed on that supplier in the current time period. Thus recent experience could be arranged to affect loyalty more than older buying behaviour.

Conclusion

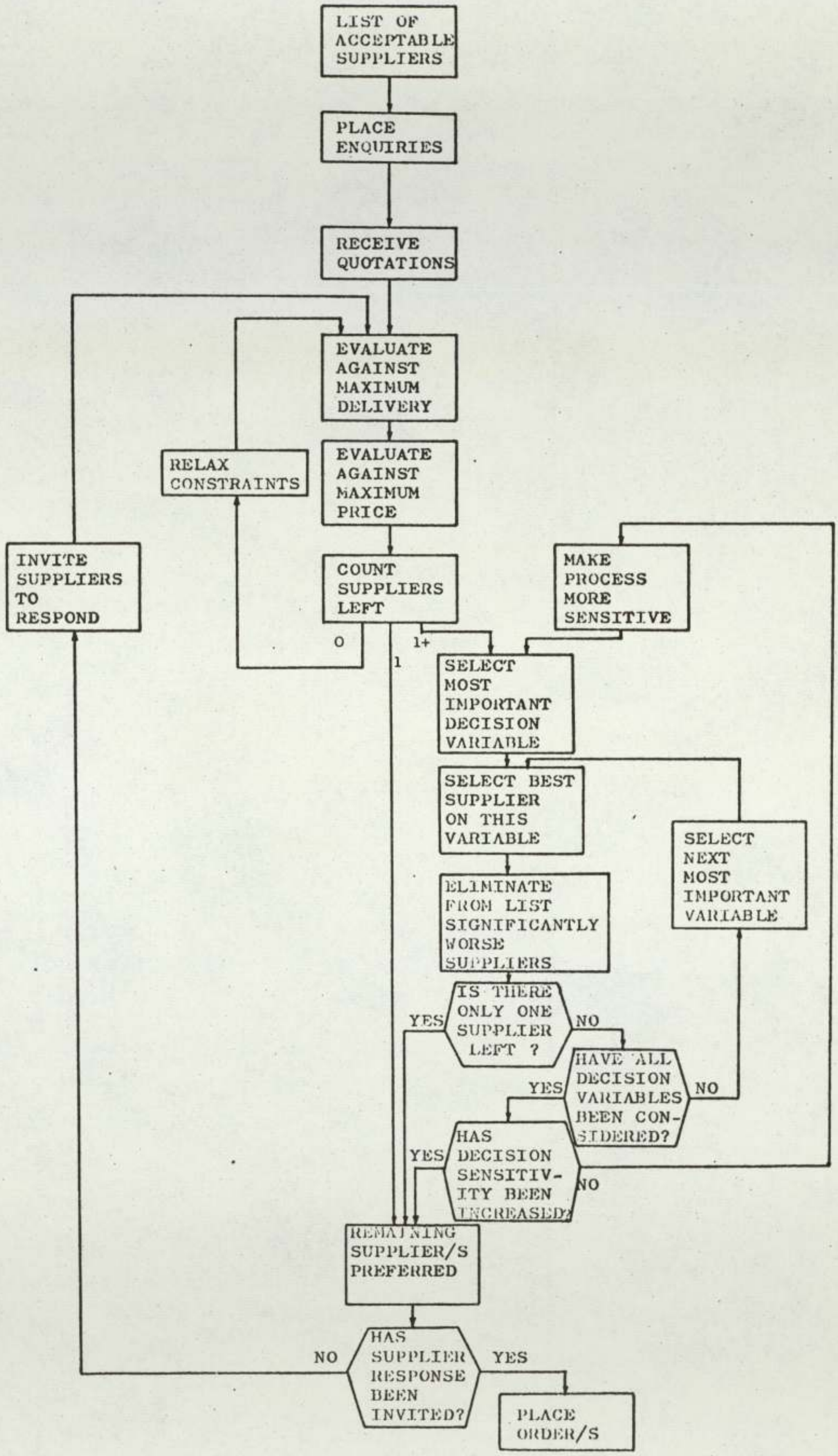
In industrial marketing, it is useful to regard source loyalty as one of the determinants of the buying decision, and not just a summary of decision outcomes. Operationally, loyalty can be regarded as including those influences on the decision not separately considered.

We have pointed out some factors which may be profitably treated separately in particular cases. These serve to indicate that source loyalty is not necessarily irrational.

Acknowledgements

The authors wish to acknowledge the support of the Science Research Council through a research studentship for training within the Inter-disciplinary Higher Degrees Scheme at the University of Aston in Birmingham. Helpful comments about this description were received from the other members of the team supervising the research, Mr M.K. Hussey, Mr J.E. Smith and Mr. I. Winterbottom, and also from Professors S.L. Cook and S.C. Littlechild.

FIGURE I THE BUYING DECISION MODEL



References

Ballmer, R.W. (1960) Copper Market Fluctuations: An Industrial Dynamics Study. S.M. Thesis, Massachusetts Institute of Technology, Cambridge (Mass.)

Cunningham, R.M. (1956) Brand Loyalty - What, Where, How Much. Harvard Business Review 34 116-128

Cyert, R.M. and March, J.G. (1963) A Behavioral Theory of the Firm, Englewood Cliffs: Prentice Hall.

de Somogyi, J. (1970) Supplier Developments Affecting Retailing, Wills, G. (ed), New Ideas in Retail Management, 44-45, London, Staples Press.

Finney, F.R. (1968), Reciprocal Buying and Public Policy. Ph.D Thesis, University of California, Berkeley.

Forrester, J.W. (1961) Industrial Dynamics. Cambridge, MIT Press.

Forrester, J.W. (1965) Modelling of Market and Company Interactions. p353-364 in P.D. Bennett (ed) Marketing and Economic Development, Proceedings of Fall Conference of the American Marketing Association.

Massy, W.F. and Savvas, J.D. (1964) Logical Flow Models for Marketing Analysis. Journal of Marketing, 28 30-37.

Moore, C.G. (1969) A descriptive Model of the Industrial Purchasing Process: The Supplier Selection Routine, in Weber, C.E. and Peters G., eds., Management Action: Models of Administrative Decisions, Scranton; International Textbook Company.

Robinson, P.J. and Faris, C.W. (1967) Industrial Buying and Creative Marketing, Boston; Allyn and Bacon.

Sunday Times Magazine (1972) The Richest Shopkeepers in the World, 17th December p 27.

Webster, F.E. and Wind, Y. (1972) Organisational Buying Behavior. Englewood Cliffs, Prentice Hall.

Wind, Y. (1970) Industrial Source Loyalty. Journal of Marketing Research 7 450-457

BIBLIOGRAPHY

ALLEN, R.W. 1966. Factors Influencing Market Penetration. Management Science, vol.13 no.1 September 1966. pp 22-41.

BALLMER, R.W. 1960. Copper Market Fluctuations: An Industrial Dynamics Study. M.S. Thesis, Massachusetts Institute of Technology.

BARON, B.D.P. 1972. Joint Decision Technologies with a Production-Marketing Example. Interorganisational Decision Making, 1972. pp 162-175.

BELDEN, S.A. 1971. An Analysis of Decisions and Performance in a Production and Marketing System for Turkeys. Ph.D. Thesis, Purdue University.

BENSTON, G.J. 1966. Multiple Regression Analysis of Cost Behaviour. The Accounting Review, vol.41, no.4 October 1966. pp 657-672.

BONINI, C.P. 1967. Simulation of Information and Decision Systems in the Firm. Chicago, Markham.

BUBB, P.L., M.K. Hussey and J.E. Smith. 1973. How Accurate are Your Figures? Management Accounting (U.K.), forthcoming.

BUBB, P.L. and J.E. Smith 1972a. A Rigorous Approach to Determining Cost Behaviour. Management Accounting (U.K.) vol.50, no.6 June 1972. pp 167-170.

BUBB, P.L. and J.E. Smith 1972b. Absorbing Overhead Cost with the Use of Computer. Management Accounting (U.K.) vol.50, no.12 December 1972. pp 402-404.

BUBB, P.L. and D.J. van Rest 1973. Loyalty as a Component of the Industrial Buying Decision. An IHD Working Paper, the University of Aston in Birmingham, May 1973. (please see Appendix D).

CHATFIELD, C. 1970 Statistics for Technology. Harmondsworth, Penguin.

CHIU, J.S. and D.T. De Coster 1966. Multiple Product Costing by Multiple Correlation Analysis. The Accounting Review, vol.41, no.4 October 1966 pp 673-680.

COEN, P.J., E.D. Gomme and M.G. Kendall. 1969. Lagged Relationships in Economic Forecasting. Journal of the Royal Statistical Society, series A, vol.132, part 2 1969. pp 133-152. Discussion on above paper, pp 152-163.

COHEN, K.J., R.M. Cyert, J.G. March and P.O. Soelberg 1963. A General Model of Price and Output Determination. R.M. Cyert and J.G. March. A Behavioral Theory of the Firm. Englewood Cliffs, Prentice-Hall pp 149-236.

COMISKEY, E.E. 1966. Cost Control by Regression Analysis. The Accounting Review, vol.41, no.2, April 1966 pp 235-238.

CYERT, R.M. and J.G. March 1963. A Behavioral Theory of the Firm. Englewood Cliffs, Prentice-Hall.

CYERT, R.M., J.G. March and C.G. Moore 1963. A Specific Price and Output Model. R.M. Cyert and J.G. March A Behavioral Theory of the Firm. Englewood Cliffs, Prentice-Hall. pp 128-148.

DUTROW, G.F. 1971. Disequilibrium Model for Stumpage Price Analysis. Forest Science. vol.17, part 2, June 1971. pp 246-251.

FORRESTER, J.W.. 1961. Industrial Dynamics. Cambridge, MIT Press.

FORRESTER, J.W. 1965. Modeling of Market and Company Interactions. American Marketing Association, Fall Conference 1965. pp 353-364.

GODFREY, J.T., W.A. Spivey and G.B. Stillwagon 1968. Production and Market Planning with Parametric Programming. Industrial Management Review, vol.10, Fall 1968. pp 61-75.

HARRIS, L 1966. Some Interdependent Decision Problems. Ph.D. Thesis, New York University.

HOWARD, J.A. and W.M. Morgenroth 1968. Information Processing Model of Executive Decision. Management Science, vol.14, no.7 March 1968 pp 416-428.

HUANG, D.S. 1970 Regression and Econometric Methods. New York, Wiley.

JENSEN, R.E. 1967. A Multiple Regression Model for Cost Control - Assumptions and Limitations. The Accounting Review vol.42, no.2, April 1967 pp 265-273.

JOHNSON, C.G. 1972. Dimensional Analysis and the Interpretation of Regression Coefficients. Journal of Financial and Quantitative Analysis. vol.6, no.1, January 1972. pp 1399-1406.

JOHNSTON, J. 1960. Statistical Cost Analysis. New York, McGraw Hill.

KOTLER, P. 1970. Corporate Models: Better Marketing Plans. Harvard Business Review. vol.48, July - August 1970. pp 135-172.

KUEHN, A.A. 1962. Heuristic Programming: A Useful Technique for Marketing. C.H. Hindersman (ed) Marketing Precision and Executive Action. Chicago, American Marketing Association. pp 162-170.

LYLE, P. 1944. Regression Analysis of Production Costs and Factory Operations. Edinburgh, Oliver and Boyd.

MANSFIELD, E. and H.H. Wein 1958. A Regression Control Chart for Costs. Applied Statistics. vol.7, no.1, March 1958. pp 48-57.

MASSY, W.F. and J.D. Savvas 1964. Logical Flow Models for Marketing Analysis. Journal of Marketing. vol. 28, part 1, January 1964. pp 30-37.

von MATERN, S. and F.E. Weil 1967. Long Range Planning Report: Titanium. Menlo Park, Stanford Research Institute.

MOORE, C.G. 1968. The Heuristic Programming of Marketing Decisions. American Marketing Association, Fall Conference, 1968. pp 41-49.

MOORE, C.G. 1969a. A Descriptive Model of the Industrial Purchasing Process: The Supplier Selection Routine. C.E. Weber and G. Peters (eds). Management Action: Models of Administrative Decisions. Scranton, International Textbook Co. pp 76-114.

MOORE, C.G. 1969b. Simulating Actual Decision Making in Organisations: A Progress Report. C.E. Weber and G. Peters. Management Action: Models of Administrative Decisions. Scranton, International Textbook Co. pp 285-315.

MORGENROTH, W.M. 1964. A Method for Understanding Price Determinants. Journal of Marketing Research, vol.1, no.3, August 1964. pp 17-27.

PIFER III, H.W. 1969. A Comparison of Alternative Decision-Making Strategies within a Simulated Oligopolistic Market. Ph.D. Thesis, Carnegie-Mellon University.

RAY, G., J.E. Smith and P. Donaldson 1968. Hardy Heating Co Ltd. London, BBC.

ROSKILL, O.W. and Company (Reports) Limited 1971. Titanium, Minerals, Chemicals, Metal and Alloys: World survey of production and consumption with special reference to future demand and prices. London, Roskill.

SCHUSSEL, G. 1967. Simulation and Sales Forecasting. Datamation, vol.13, no.6, June 1967. pp 40-45.

SIZER, J. 1966. The Determination of Fixed and Variable Costs. The Accountant. vol.155; no.4790, 8th October 1966, pp 441-445; no.4791, 15th October 1966, pp 472-476; no. 4792, 22nd October 1966, pp 507-510.

SIZER, J. 1969. An Insight into Management Accounting. Harmondsworth, Penguin.

SWANSON, C.V. 1969. Design of Resource Control and Marketing Policies Using Industrial Dynamics. Industrial Management Review. vol.10, Spring 1969. pp 61-76.

THOMAS, J. 1970. Price-Production Decisions with Deterministic Demand. Management Science, vol.16, no.11, July 1970. pp 747-750.

THOMAS, J. 1971. Linear Programming Models for Production - Advertising Decisions. Management Science. vol.17, no.8, April 1971. pp B474-B484.

TUCKETT, R.F. 1969. Combined Cost and Linear Programming Models of Industrial Complexes. Operational Research Quarterly. vol.20, no.2, June 1969. pp 223-236.

TUITE, M.F. 1968. Merging Marketing Strategy Selection and Production Scheduling: A Higher Order Optimum. Journal of Industrial Engineering. vol.19, no.2, February 1968. pp 76-84.

TURING, A.M. 1956. Can a Machine Think? J.R. Newman (ed). The World of Mathematics. New York, Simon and Schuster. pp 2099-2123.

WALKER, G.H. 1967. A Study on the Simulation and Optimization of a Hypothetical Total Firm. Ph.D. Thesis, University of Texas.

WEBSTER, F.E. and Y. Wind 1972. Organisational Buying Behaviour. Englewood Cliffs, Prentice-Hall.

WIND, Y. 1966. Industrial Buying Behaviour: Source Loyalty in the Purchase of Industrial Components. Ph.D. Thesis, Stanford University.

WIND, Y. 1970. Industrial Source Loyalty. Journal of Marketing Research. vol.7, part 4, November 1970. pp 450-457.

WIND, Y. 1971. A Reward-Balance Model of Buying Behavior in Organisations. G.Fisk (ed). New Essays in Marketing Theory. Boston, Allyn and Bacon. pp 206-217.

WIND, Y and P.J. Robinson 1968. Simulating the Industrial Buying Process. American Marketing Association, Fall Conference, 1968. pp 441-448.

Additional References

SHANNON, C. 1948 The Philosophy of Pulse Code Modulation. Proceedings of the Institute of Radio Engineers, vol. 36, no.11, November 1948, pp 1324-

HIRSCH, A.A. and M.C. Lovell 1969 Sales Anticipations and Inventory Behavior. New York, Wiley.

HAMPTON, J.M., P.G. Moore and H. Thomas 1973. Subjective Probability and its Measurement. Journal of the Royal Statistical Society, Series A, vol.136, part 1, pp 21-42

VAN HORN, R.L. 1971. Validation of Simulation Results. Management Science, vol.17, no.5, January 1971, pp 247-258.

RAO, A.G. 1970 Quantitative Theories in Advertising. New York, Wiley.

LIST OF TABLES

LIST OF FIGURES