JOINT PRODUCTS:
A STUDY IN COSTING AND THE MAXIMISATION OF RETURNS

by

DAVID RONALD DAY, B.Sc., M.B.A.

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PROMOTER: Prof. A.J.E. SORGDRAGER, D'Econ (A'dam)

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INTRODUCTION TO THE STUDY

INTRODUCTION TO THE STUDY

1 PURPOSE OF THE STUDY

The term "joint products" refers to those products which are produced simultaneously from the same set of raw materials by means of the same production facilities. Such products occur in the chemical, mining, food-processing, petroleum and other industries.

Extensive developments involving joint products and their manufacture have taken place in recent years. Most significant of these have been in the fields of petroleum refining and petrochemical manufacturing. Rapid growth and the application of advanced technology in these and other primarily joint product industries, have led to the establishment of large, capital-intensive manufacturing complexes; comprising numbers of interrelated process units. Management of the enterprises operating such complexes has consequently become a diverse and exacting function.

Common to all types of joint product manufacturing, is the factor of technical interdependence of the various products. This has the implication that certain of the systems and techniques which can effectively aid control and decision-making in other types of manufacturing, may be inadequate where joint products are involved.

The purpose of this study is:

(a) to examine and analyse particular managerial problems relating to costing and maximisation of returns in joint product manufacturing enterprises; and

(b) to review certain specialised systems and techniques which can assist in the optimal solution of these problems.

This thesis represents the results of research into the specific application to joint products of certain costing and optimisation principles and methods. Its findings in this respect constitute approaches to those managerial problems peculiar to joint product manufacturing.

2 SCOPE OF THE STUDY

In the light of its purpose, the scope of this study is restricted to certain aspects of management specifically relating to joint product manufacturing. It deals with a given enterprise operating in a market economy. Although some of the systems developed are designed to meet requirements for complex multiple-process production facilities, the principles involved are of general significance in all types of joint product manufacturing.

The scope does not include the technical aspects of manufacturing. Neither does it cover venture analysis with respect to grass-roots projects.

Within the scope as outlined, this study in no way pretends to be exhaustive on any aspect. Being objective-orientated in approach, it is essentially broad and empirical.

3 DEFINITION OF TERMS

In introducing this study, it is important to define precisely what constitutes a joint product, as well as what is meant by the term "returns" in this context.

3.1 JOINT PRODUCTS

As has been stated, joint products are produced simultaneously from the same set of raw materials by means of the same production facilities. This description is, however, incomplete. It is necessary to differentiate between the set of joint products and any by-products which may be produced in the same process.

J.C. LESSING ("Die kostevraagstuk van die mede- en neweprodukte in die chemiese bedryf, met spesiale verwysing na die kousale verband tussen kosprys en produksie," Unpublished thesis, P.U., 1965, p.214), distinguishes by-products ("neweprodukte") from joint products ("medeprodukte") on a relative market value basis as follows:

> "Indien die markwaarde van die produkte relatief min of meer dieselfde is, word van medeprodukte gepraat, maar as die markwaarde van een of meer van die produkte relatief minder is as die markwaarde van die ander produk of produkte, word daar van neweprodukte gepraat."

A. MATZ, O.J. CURRY and G.W. FRANK, ("Cost accounting," South-Western Publishing Co., New York, 1962, p.415) note that accepted accounting terminology refers to joint products as each possessing "... more than nominal value in the form in which it is produced."

While relative value should be used to differentiate between joint and by-products, little purpose is served by attempting to establish general rules as to where the distinction should be made. J.J.W. NEUNER and S. FRUMER, ("Cost accounting: principles and practice," Irwin Inc., Illinois, 1967, P.409) suggest that if the value of the jointly produced product is less than 10% of the total value of all products it can be considered as a by-product. That this does not hold where 11 products of equal value occur, is obvious. It may furthermore be difficult to assess the precise value of a product in the form in which it is produced if it requires further work-up after separation from its companion products before it can be sold. Ostensibly for this reason R.I. DICKEY, (Ed. "Accountants' cost handbook," Ronald Press Co., New York, 1967, p.13.19) states that by-products are normally differentiated from joint products "by degree of economic importance."

Differences in the methods by which they may be costed is the main reason for distinguishing between joint and by-products which occur together. It is consequently maintained that the decision as to the point at which the distinction is made on a relative value basis, should be left to the company cost accountant in each case.

In the light of the above, joint products are defined as:-

> different products possessing roughly similar realisable market value at separation which are necessarily produced simultaneously from the same set of raw materials, using the same production facilities.

It can be seen that changes in the relative demands for the products may warrant changes in classification with the passage of time.

Joint products are defined empirically in terms of the manner in which they are produced. The definition has the following implications with respect to joint product manufacturing:

(a) Joint products are technically interdependent in that the set of all joint products of a particular process is of necessity produced in order to produce any one of the components of the set.

(b) Where continuous, or repeated batchwise, production over an extended period is involved; the quantitative relationship between the outputs of the individual joint products of a particular process is variable only between certain limits.

(c) For a given process, a change in the yield of any joint product will inevitably result in a change in the yield of one or more of the remaining companion products. (For the purposes of this study, the yield of a joint product is expressed as weight-percentage of the set of raw materials.)

The term "jointly-produced" as used in this study refers to all products produced simultaneously from the same materials in the same process, regardless of the relative values at separation. Purely for identification purposes, products which are not jointly produced are referred to as "single-line products."

3.2 RETURNS

In general terms, manufacturing involves the utilisation of the resources of materials, labour and capital to produce saleable products. Managerial performance can be described as the effectiveness with which available resources are allocated to products and the efficiency with which they are used to generate revenue in the form of sales of these products.

The scope of this study is restricted to managerial activities specifically relating to joint product manufacturing in a given enterprise. In this context, managerial performance as described above, can be measured in terms of "returns" on joint products, which are defined as follows:-

> Revenue accruing from sales of a set of joint products manufactured in a given process; less selling and distribution expenses, less the cost price of the set of joint products.

Cost price ("kosprys") is defined by A.J.E. SORGDRAGER, ("Kosprys berekening en -tegniek," Nasau Bpk., Cape Town, 1967, p. 67) as follows:-

> "Kosprys is die som van die koste wat vir die totstandkoming van die produk gemaak is."

The maximisation of returns as defined represents the primary managerial objective with respect to joint product manufacturing activities in a given concern.

4 LAYOUT OF THE TEXT

This thesis is typewritten and consequently only one letter-type has been used. In order to distinguish them from the remainder of the text, definitions, direct quotations, important observations, and deductions of an original nature are type in close-spacing towards the centre of the page.

Each chapter is divided into sections and sub-sections, which have been numbered decimally. Where items are listed within a sub-section, they are numbered alphabetically. In the interests of clarity and ease of reading, each type of sub-division is positioned at a different distance from the left-hand side of the page.

5 LITERARY REFERENCES, FIGURES AND TABLES

On initial reference to any book, article or treatise, the following bibliographical details will be noted in the text:

(a) Initials and surname of the author (where known).

(b) Title of the work (where applicable).

(c) Title of the journal or collection in which the work is published (where applicable).

(d) Publisher (where applicable).

(e) Year in which the work appeared.

(f) Page number or numbers.

For example:

> P. F. DRUCKER, "Managing for results," Heinemann, London, 1964, p. 7.

If the same work is referred to subsequently, only the author's name and the page number are noted. Where more than one work by the same author is referred to, the year in which the work was published, is also noted. For example:

A.J.E. SORGDRAGER, (op. cit., p.62)
A.J.E. SORGDRAGER, (op. cit., 1967, p. 257).

A list of the authors and the works referred to in the text is given at the end of the study. Literary references consulted, but not directly referred to, are listed separately.

All tables and figures are collected in a single appendix. These are referred to in the text on the l e ft-hand side of the page as per the following example:

A.15, FIGURE II.3

A.15, above indicates the page number in the appendix, while II.3 denotes that the third figure in CHAPTER II applies.

Tables are referred to in the text in the same manner.

6 FRAMEWORK OF THE STUDY

This study is divided into four parts:

PART ONE deals with the nature, development and management of joint product manufacturing.

In CHAPTER I the basic nature of the processes whereby joint products are manufactured is empirically examined. The concept of the joint process is defined and its implications are discussed. Mention is made of the industries in which joint processes occur.

In CHAPTER II developments in joint product manufacturing and the factors affecting them are outlined. Attention is focused in particular on the growth and status of the petroleum refining and petrochemical manufacturing industries. Special reference is made to the importance of joint products and their manufacturing in certain South African industries.

CHAPTER III deals with the management of the joint product manufacturing enterprise. The nature and relevant aspects of modern manufacturing management in general are discussed prior to an examination of the particular problems associated with the maximisation of returns in respect of joint product manufacturing.

In PART TWO aspects of the principles and practice of joint product costing are considered.

In CHAPTER IV the particularization of joint product costs is discussed in the light of the technical-economic concept of cost.

CHAPTER V comprises a critical examination of various documented methods whereby joint costs can be allocated to individual products.

CHAPTER VI deals with the development of a costing system for joint product manufacturing. Attention is focused on the use of certain material standards which are significant with respect to efficiency control of the joint process.

PART THREE deals with managerial planning and decision-making for joint product manufacturing. Procedures and systems which can be used to provide meaningful information in these respects are detailed.

Pricing procedures for joint products are discussed in CHAPTER VII.

Some advanced demand forecasting systems are considered in CHAPTER VIII.

CHAPTER IX is devoted to the use of simulation models as planning and decision-making tools in large-scale multi-process joint product manufacturing systems. Procedures for compiling an optimisation model for such a system, which is based on sound cost particularization principles, are developed.

In CHAPTER X an optimisation model for a multi-process system is used to simulate the results of case study decisions.

The conclusion to and summaries of the study are contained in PART FOUR.

UNLESS OTHERWISE STATED, ALL FACTS, FINDINGS AND OBSERVATIONS CONTAINED IN THIS STUDY ARE THE RESULTS OF OWN RESEARCH.

PART ONE

THE NATURE, DEVELOPMENT AND MANAGEMENT OF JOINT PRODUCT MANUFACTURING

FOREWORD TO PART ONE

In PART ONE the particular managerial problems associated with joint product manufacturing are examined with respect to their underlying causes and the importance of their solution.

CHAPTER I is devoted to the nature of the joint product manufacturing system. The concept of the joint process is empirically defined and its relevant implications examined. In CHAPTER II developments in joint product manufacturing industries are discussed. Particular reference is made to the growth and status of industries operating joint processes in South Africa. In CHAPTER III the problems confronting management with respect to the maximisation of returns on joint products are examined and analysed.

CHAPTER I

THE NATURE OF JOINT PRODUCT MANUFACTURING

1 INTRODUCTION

Joint products are defined in terms of the manner in which they are produced. A.J.E. SORGDRAGER, (op. cit., p.257) states that:

> "Gemeenskaplike produksie is van die tegniese aard van die produksie-proses afhanklik."

Consequently, comprehensive definition of the basic nature of the processes whereby joint products are produced is essential, if the precise significance of the terms "joint products" and "joint costs" is to be understood.

In this chapter the various manufacturing activities which make up joint product manufacturing systems are defined and discussed. Attention is focused on the concept and basic nature of the joint process which forms an integral part of every such system.

The term "manufacturing" is used in its widest sense in this study, and is taken to include the recovery of minerals from mined raw materials.

2 THE JOINT PRODUCT MANUFACTURING SYSTEM

A joint product manufacturing system is the ordered arrangement of the production facilities necessary to convert a set of raw materials into joint products. The system consists of one or more processes, each comprising a series of what are generally termed "unit operations" which are necessarily performed sequentially on the materials being processed.

Within a given enterprise, the initial stage of the system is the acquisition, by purchase or transfer, of the set of basic raw materials involved. Thereafter it includes all unit operations required to convert this set into products; each of which is in the final state in which it will eventually be sold or used as one of the raw materials in another manufacturing system.

3 THE JOINT PROCESS

At least one of the processes in a joint product manufacturing system is a "joint process." The concept and basic nature of such processes are examined.

3.1 THE JOINT PROCESS DEFINED

In defining joint products, the term "production facilities" was used. These facilities consist of equipment, labour, utilities and process materials. The manner in which they are used constitutes a process or series of processes.

3.1.1 THE BASIC DEFINITION

A joint process is defined as:

> a manufacturing operation or series of operations, each of which is of necessity performed simultaneously on a set of raw materials in order to produce two or more distinct products; both or all of which comply with the previously-stated definition of joint products

3.1.2 COROLLARIES TO THE BASIC DEFINITION

Based on the above definition, the following can be said of joint processes:

3.1.2.1 EVERY JOINT PROCESS INCLUDES A SEPARATION OPERATION:

Regardless of the manner in which the products as such are created, the fact that they occur simultaneously in the same unit operations, implies that their separation is an integral part of the joint process. In the simplest case, the joint process consists only of a separation operation, with the set of raw materials receiving no treatment prior thereto.

3.1.2.2 ANY MANUFACTURING OPERATIONS PERFORMED ON THE SET OF RAW MATERIALS PRIOR TO THE SEPARATION OF ANY JOINT PRODUCT ARE PART OF THE JOINT PROCESS:

If, for example, the set of raw materials consists of two substances which are mixed together and then filtered, both the mixing and the filtering operations are part of the joint process.

See A.1, FIGURE 1.1

If, however, the substances are filtered individually prior to mixing, neither filtering operations is performed on the set of all raw materials, and neither is part of the joint process.

See A.2, FIGURE 1.2

3.1.2.3 ANY OPERATIONS PERFORMED ON ANY JOINT PRODUCT OR PRODUCTS SUBSEQUENT TO THE ISOLATION OF ANY MEMBER OF A PARTICULAR SET, ARE NOT PART OF THE JOINT PROCESS BY WHICH THIS SET WAS PRODUCED:

This factor has important implications with respect to multi-process manufacturing complexes. The case is considered where the set of joint products consists of products A, B and C.

See A.3, FIGURE I.3

If product A is isolated from B and C in one operation, and B and C are separated from each other in a subsequent operation, two joint processes (I and II), are involved. Process I comprises operations prior to and including the isolation of A. The joint products of this process are A and a mixture of B and C. This mixture forms the raw material for joint process II which involves all operations performed on B and C subsequent to the isolation of A, and prior to and including the separation of B from C.

Where more than one joint process occurs in a manufacturing system, the final products of the system are strictly speaking not all joint with respect to each other. They are all produced from the same original raw materials, but, in their final form, all have not been produced using the same production facilities. In the above case, product A, for example, was not produced using the facilities comprising joint process II.

The same principle holds for the work-up of separated individual products. By definition the processes involved in the further treatment of individual products subsequent to separation are in no way joint.

The final products of a joint product manufacturing system have each been produced by means of joint processes. They can each be legitimately termed a joint product. The term "set of joint products" can be seen to be ambiguous unless qualified. For the purposes of this study, the final products of a specific joint manufacturing system will be termed "the set of joint products" unless otherwise stated.

3.2 SPLIT-OFF POINTS

3.2.1 DEFINITION

> The unit operation by means of which the joint products of a joint process are separated from each other, is termed a split-off point.

Each joint process has one, and only one, split-off point; regardless of the number of products isolated in the unit operation concerned. A joint product manufacturing system will therefore have as many split-off points as joint processes. It may be that every product is isolated in a single separation operation, in which case only one split-off point is involved. On the other hand each product may be isolated individually in a separate unit process. In this limiting case, the number of split-off points is equal to the number of joint products involved, less one.

3.2.2 SPLIT-OFF OPERATIONS

Some unit operations which constitute split-off points in various types of joint product manufacturing systems are listed below. Combinations of chemical and physical processes, such as precipitation and filtration, are encountered; and are regarded as constituting a single unit operation.

3.2.2.1 CHEMICAL SEPARATION OPERATIONS

(a) Ion exchange

(b) Molecular sieving.

(c) Fractional distillation.

(d) Osmosis.

(e) Electrolysis.

(f) Solvent extraction.

(g) Precipitation.

(h) Adsorbtion.

(j) Chemical absorbtion.

3.2.2.2 PHYSICAL SEPARATION OPERATIONS

(a) Diffusion.

(b) Gravitation.

(c) Filtration.

(d) Centrifuging.

(e) Liquifaction.

(f) Freezing.

(g) Mechanical cutting.

(h) Sorting.

3.3 JOINT PROCESS OPERATIONS PRIOR TO THE SPLIT-OFF POINT

Joint processes can be broadly grouped into two categories: extractive processes and synthesis processes.

3.3.1 EXTRACTIVE OPERATIONS

Where the raw material consists of a conglomerate or mixture of the joint products, the joint process operations involved in their manufacture are essentially associated with the separation of the products from each other, and/or from accompanying by-products and/or waste.

Examples of this type of joint extraction processes are found in industries such as food processing, mining and petroleum refining. The raising of agricultural products, the actual mining of ore, and drilling for petroleum cannot be classed as manufacturing operations and do not form part of the manufacturing system.

A type of extractive operation which occurs mainly in the petrochemical industry is known as "cracking." This involves catalytically or thermally induced decomposition of a substance composed of long-chain molecules into two or more substances of shorter-chain molecular composition. Manufacturing systems incorporating this type of extractive operation involve more than the straightforward isolation of the useful ingredients of a conglomerate as described earlier.

3.3.2 SYNTHESIS OPERATIONS

Certain manufacturing systems involve joint processes in which the products are synthesised, as opposed to extracted, from the raw materials. As these processes involve chemical reactions, they occur for the most part in the chemical and petroleum industries. Although synthesis and separation may be effected in the same unit operation, the synthesis process is frequently succeeded by extractive operations in the manufacturing system.

An example of the latter type of system is found in the South African Coal, Oil and Gas Corporation, Limited, (Sasol) oil-from-coal plant. So-called synthesis gas is converted into a range of organic compounds which are subsequently separated in extractive processes similar to those employed in petroleum refineries.

4 THE EXTENT OF THE TECHNICAL INTERDEPENDENCE OF THE PRODUCTS OF A JOINT PROCESS

4.1 THE QUANTITATIVE RELATIONSHIP

In the introduction to this study, one of the implications of the definition of joint products was the following. Where continuous, or repeated batchwise, production over an extended period is involved; the quantitative relationship between the outputs of the individual joint products of a particular process is variable only between certain limits.

The extent to which the ratio of product-outputs may be varied depends on the nature of the joint process. In some cases it is a function, over a defined range, of some or other interdependent variable. The list of such variables includes the following:

(a) Raw material composition;

(b) Operating conditions such as temperature, pressure, retention time, etc.,;

(c) Catalyst selectivity;

(d) Type of process material; etc.

An example of the dependency of the ratio of product outputs on operating conditions is the effect of temperature in the naphtha-cracking process. This process is employed in the petrochemical industry to produce a range of products including ethylene, propylene, C_4 hydrocarbons, gasoline and fuel gas. The feedstock, petroleum naphtha, is vapourised and rapidly heated in the presence of steam. At the so-called cracking temperature, the higher molecular weight hydrocarbons in the feedstock are broken down into lower molecular weight products.

Within limits, the ethylene yield is a function of the cracking temperature. The higher the temperature the higher the yield of ethylene, and the lower the yield of gasoline and C_4 hydrocarbons. (Vide A.L. WADDAMS, "Chemicals from petroleum," Butler and Tanner, Ltd., London, 1968, p.30).

It can be seen that by adjusting operating conditions for this process, the ratio of product yields can be varied to a limited extent. The range over which this is possible is bounded by practical considerations. If the temperature is too low, insufficient cracking takes place, and if it is too high excessive coking of the furnace tubes results.

Technically, however, a plant may have an unbounded range with respect to the relative output of one or more joint products. By, for example, varying the feedstock composition, it may be possible to reduce the output of one product to zero. In such a case conceptual limits would apply. At some stage a point would be reached where this product could no longer be considered to be a joint product on a relative value basis. At this point it would cease to be a member of the set of joint products.

If, in the case described, only two products were involved, the process would cease to be joint for as long as one of these was classed as a by-product or was not produced at all. If more than two products remained under such circumstances, it would still be a joint process. From a conceptual point of view, however, in the light of the fact that a new set of joint products was now being produced, it would not be the same process as before.

In practice the type of situation described above is rarely encountered where continuous production is involved. In most cases, the ratio of outputs is fixed to within relatively narrow limits for all products by either technical or economic considerations. The latter apply when any deliberate change in the ratio of outputs results in a decrease in returns. It is important to note that economic considerations only apply within the technical or conceptual limits, and are not a basic consideration in this respect.

4.2 QUALITATIVE RELATIONSHIP

Depending on the nature of the joint process, the products may bear a limited qualitative relationship to each other. This type of product interdependence is common to those extractive joint processes where the products are not pure substances or identifiable compounds, but mixtures required to meet certain physical specifications.

The example is taken of a fractionation process where a mixture of hydrocarbons is separated into two fractions. One is the so-called "light fraction" having a low boiling range, while the other is termed the "heavy fraction" and has a higher boiling range. If conditions are altered so as to raise the upper limit of the light fraction boiling range, the lower limit of the heavy fraction boiling range will automatically increase to a corresponding extent.

In this case a change in physical properties of one joint product resulted in a simultaneous change in the properties of the other. Here there was an accompanying change in the ratio of the product yields, but qualitative changes are not necessarily accompanied by quantitative changes. The extent of the range over which the qualitative relationship is variable will, in virtually all cases, be bounded by limits of the specifications under which the products are sold.

5 WORK-UP PROCESSES

For the purposes of this study, the term "work-up processes" refers to those operations incorporated in the joint product manufacturing system which are performed on individual products subsequent to their isolation. The work-up of a separated product may be a relatively simple purification process, or it may involve a complex series of unit operations; depending on the state in which the final product is required.

If, at some stage subsequent to separation, a joint product becomes in effect one of the raw materials for another manufacturing system within the enterprise; the operations constituting this system are not part of a work-up process. Some of the chlorine produced jointly with sodium hydroxide at the Chloorkop works of Klipfontein Organic Products, Limited,(S.A.) is used in the manufacture of insecticides. These insecticides are by no means products of the joint process in which the chlorine is produced, and their manufacture is not part of the work-up of this product.

Where some, but not all, of the products occurring in a joint process are blended with each other subsequent to isolation and possibly purification, the blending operation is part of the work-up processes of the products involved. It is not, however, part of the joint process in which they were synthesised or extracted, as it does not involve the complete set of raw materials. Blending of separated joint products is an integral part of gasoline manufacture in the petroleum industry.

6 CONFLICTING TERMINOLOGY AND THE NEED FOR PRECISE DEFINITION OF JOINT PRODUCT MANUFACTURING CONCEPTS

The term "joint products" appears for the most part in the literature dealing with cost accounting. Even in this specific context, a number of conflicting definitions of the term "joint cost" are to be found. (Vide Chapter IV; op.cit.). Some examples of conflicting manufacturing terminology are discussed below.

6.1 COMMON PROCESSES

The situation is frequently encountered in manufacturing industries where different products are processed by means of the same facilities. The following are examples of this type of process:

(a) A furnace is used to produce various types of alloy.

(b) Chairs and tables are made from oak boards using the same joinery equipment.

(c) Standard parts which are later assembled in different combinations are made using the same machinery.

(d) Steam from a boiler is used to drive several machines making various products.

None of the above processes complies with the stated definition of a joint process. Although two or more products are produced in each case using the same facilities, the condition that the set of all raw materials is necessarily operated on simultaneously is not met. The processes and products are "common" with respect to facilities, but are in no way "joint" as defined.

J.C. LESSING (op.cit., p.214), states correctly that "saamgevoegde produksie (common production) ontstaan slegs as gevolg van 'n doelbewuste bestuursbesluit."

It can not be agreed with A.A. WALTERS ("The allocation of joint costs," in American Economic Review, June, 1960), who regards goods subject to different transport tariffs aboard the same carrier as joint goods. J.M. CLARK ("Studies in the economics of overhead costs," University of Chicago Press, Chicago, 1923, p.100), adopts much the same approach with respect to joint costs.

6.2 DIVERGENT MANUFACTURING SYSTEMS

If after a point in the manufacturing system, a single-line product or a separated joint product can be processed in alternative ways to give two or more different end products, the system is termed "divergent" at that point.

L.L. BETHEL, F.S. ATWATER, G.H.E. SMITH and H.A. STACKMAN, ("Industrial organisation and management," Kogakusha Co. Tokyo, 1962, p. 15) refer to joint processes as "divergent functions," making the following statement:

> "In the joint-product group, the manufacture of any one of the different products might be discontinued without affecting the others produced, as, for example, when butter and cheese are produced from milk."

These authors are in fact referring to alternative work-up processes which are in no way joint and may not even be common.

6.3 COPRODUCTS

J.W. NEUNER and S. FRUMER (op.cit., p. 408 et. seq.) refer to "joint and/or coproducts," stating of the difference between the two that:

> "Coproducts, if and when a distinction must be made, refer to the production of two or more products at the same time but not necessarily from the same processing operations or the same raw material."

They give as an example the processing of oak, pine and walnut boards at the same time, but from different trees.

If, in the above example, the same process is involved, it is a common process, which perhaps gives rise to the term coproducts (common products) as used. If different processes are employed to make the various boards, each is a single-line process which is neither joint nor common.

R.B. STOBAUGH ("Petrochemical manufacturing and marketing guide," Gulf Publishing Company, Houston, 1968) refers repeatedly to "coproducts" (e.g. on p.10,Vol.2) which are produced in joint processes as defined. He distinguishes between "coproducts" (companion products) and by-products on the basis of realisable value at separation. His use of the term "coproducts" thus differs entirely from that of NEUNER and FRUMER.

NEUNER and FRUMER's "coproducts" may be technically independent. The term as used by STOBAUGH conforms to the definition of joint products as stated and refers to technically interdependent products. It will be shown subsequently in this study that the factor of technical interdependence of joint products has an important bearing on costing and decision-making.

The above serves to demonstrate the need for precise and uniform definition of joint product manufacturing concepts.

7 INDUSTRIES IN WHICH JOINT PRODUCT MANUFACTURING SYSTEMS ARE OPERATED

A product is classified as a joint product according to the method by which it is manufactured, and its market value relative to that of other products produced in the same process. Depending on these factors, the same type of product may be produced singly; as a joint product, or as a by-product. Refined gold, for example, is a single-line product of ore reduction, where the raw material does not contain economically recoverable amounts of other substances. It is a joint product in some gold/uranium reduction works, and a by-product of certain copper and silver refining activities.

With some notable exceptions, few products are invariably produced as joint products and never as main products or by-products.

Similarly, within the same industry, some manufacturers may operate joint processes while others produce single-line products. With some exceptions, which will be discussed in the succeeding chapter, joint product manufacturing cannot be universally categorised according to product or type of industry. Joint processes are, however, more prevalent in some industries than in others. (Vide L.L. VANCE, "Theory and technique of cost accounting," Henry Holt and Company, New York, 1959, p.325).

See A.12, TABLE I.1

The above table lists examples of such industries, their basic raw materials and commonly occurring products. Taking into account that under certain circumstances, some of these products may be classified as by-products, they are listed as jointly-produced products.

Certain other industries which are not listed in table 1.1 may be classed as joint product producers by virtue of the form in which the raw materials are acquired. Tobacco processing enterprises, for example, sometimes purchase bulk lots of leaf which are sorted into various grades and then used to produce a range of end products. The sorting operation in these cases is part of the manufacturing system, and is, strictly speaking, a joint process. This type of joint process is termed "grading." The recovery of industrial and gem quality diamonds; and the sorting, prior to preserving, of fruit purchased in bulk, fall into this category of joint process. Grading is regarded as an extractive process as it involves the separation of the various products from each other and/or accompanying material.

8 SUMMARY

Every joint product manufacturing system includes at least one joint process in which members of the set of joint products or groups thereof, are synthesised and/or extracted. By stipulating that the set of all raw materials is operated on in every unit operation comprising the joint process, it becomes possible to define the precise extent of such processes.

The ratio of the product outputs for some continuous joint processes is a function, over a defined range, of an independent variable such as catalyst selectivity, raw material composition, or operating conditions. The range is generally limited by technical considerations. In certain cases joint products bear a limited qualitative relationship to each other.

Joint product manufacturing systems are found in a variety of industries. Although in most cases it is impossible to categorise joint products according to type of product or industry, they are more prevalent in certain industries than in others. The most important of these are the petroleum refining, petrochemical, chemical and food-processing industries.

Examples of conflicting terminology appear frequently in the literature on the subject of joint products and joint costs. The fact that joint products can only be defined in terms of the manner in which they are produced emphasises the need for precise and comprehensive definition of the nature and extent of the processes in which they are produced.

Having defined its basic nature, the following chapter deals with facts and statistics concerning joint product manufacturing.

CHAPTER II

DEVELOPMENTS IN JOINT PRODUCT MANUFACTURING

1 INTRODUCTION

In recent years, joint product manufacture has undergone extensive development in many types of industry. Most prominent in this respect has been the unprecedented development of certain basic petroleum and chemical products.

In this chapter factors influencing the development of joint product manufacturing in general are discussed, while the growth and characteristics of the petroleum and petrochemical industries are considered in some detail. Attention is focused on the rapid development of South African industries of this nature.

The facts and statistics contained in this chapter illustrate the increasing importance of joint product manufacturing both in South Africa and overseas. Many of the manufacturing sequences involved are complex, capital-intensive and have a high capacity. This emphasises the need for specialised approaches to the problems associated with the management of the joint product manufacturing enterprise. These problems are discussed in the succeeding chapter.

2 FACTORS INFLUENCING THE DEVELOPMENT OF JOINT PRODUCTS AND THEIR MANUFACTURE

2.1 TECHNOLOGICAL PROGRESS

As is well known, the commercial application of scientific discoveries since the turn of the century has "revolutionised" virtually every aspect of industrial manufacturing. New industries have been created and some old ones rendered obsolete. Not only new manufacturing methods and processes, but also new products have made their appearance in recent years.

It has been estimated that 40% of all manufactured goods sold in 1967 were products different from anything produced in 1952; and that 60% of the goods sold in 1985 will be products unknown in 1970. (Vide R.J. KENARD, "Creating and exploiting the new technology," Chemical Engineering, January, 1970, p.85).

The list of "new" products which have come into commercial use in the past 20 years includes many joint products and their derivatives. Examples of these are: high octane gasoline, jet fuel, plastics such as high-density polythene, polyurethane and epoxy resins; synthetic fibres, nuclear fuels, aerosol propellants and numerous types of industrial, household, agricultural and pharmaceutical chemicals.

Technology has influenced joint product manufacturing in a number of ways. In numerous instances technological innovation has provided industry with the method or means by which certain joint products can be synthesised and/or extracted. Furthermore, new and improved processes and equipment have resulted in greater efficiency and lower unit production costs; thus rendering the manufacture or recovery of many joint products economically feasible.

A less direct influence of technological progress has been its effect on the demand for various products. In a large number of cases, demand for a previously unimportant by-product of a particular manufacturing process has been created or greatly increased as a result of innovations in other industries. The rapid growth in demand for gasoline, formerly a by-product of kerosene refining, is a direct result of the development of the internal combustion engine. The rise in demand for uranium, a previously neglected joint product of some gold mining activities, is similarly linked to advances in nuclear technology.

In some instances the by-product has been the starting point, and a demand created by the development of its applications.

The influence of technology on joint product manufacturing has been not only to render it possible in many cases, but economically feasible as well.

2.2 THE PROFIT INCENTIVE IN A MARKET ECONOMY

The profit motive has, in many instances, prompted fruitful research into joint product development. In the market economies of the "free world," the profit incentive under competitive conditions results in a drive for efficiency and productivity. (Vide G.N. HALM, "Economic systems," Holt, Rinehart and Watson Inc., New York, 1964, pp. 64, 65).

Where jointly produced products are involved, productivity and efficiency are associated with the economic exploitation of each and every product resulting from a set of raw materials. Profit-motivated research has led to the development of waste and by-products to the stage where they are classed as joint products by virtue of their contribution to total revenue.

In secondary industries, the drive for profitability has resulted in a search for cheaper substitute materials. The effect of this may be an increase in the demand for the by-products of a primary industry. The classic example of this effect is the phenomenal increase in the use of plastics and polymers in recent years. This has resulted in the large-scale development of petroleum products such as ethylene and propylene. (Vide R.B. STOBAUGH, op. cit., Vol. II, pp. 49, 110).

2.3 THE AVAILABILITY OF CAPITAL

Mechanisation and sophisticated production processes have greatly increased the fixed portion of the total cost of manufacturing many important joint products. Manufacture of these products is only economically feasible on a very large scale. In these cases the availability of capital has a controlling influence on the rate of development of the industry.

The rapid development of the Japanese petrochemical industry over the last 15 years has been influenced by boom conditions and readily available capital in that country. Japan's first petrochemical venture was launched in 1955, and since then the industry has developed at an annual growth rate of 25%. Government policy has done much to boost the industry's rapid growth by means of tax incentives and special financing arrangements. It has encouraged the use of foreign technology (mainly American) and restricted chemical imports. (Vide "Japan's chemical industry," in Petroleum Press Service, Vol. 37, no. 7, July, 1970, pp.253, 254).

In other countries, including South Africa, governments have assisted both directly and indirectly in the financing of large-scale joint product industries. An example is the financial sponsorship via the South African Industrial Development Corporation of Sasol. Government policy in this respect was described by MR. J.J. KITSHOFF (in J.A. LOMBARD, ed., "Die ekonomiese politiek van Suid-Afrika," Haum, Cape Town, 1967, p.30) in his capacity as chairman of the Board of Trade and Industry, as follows:

> "Die (Nywerheid-ontwikkelings-) Korporasie is in die lewe geroep hoofsaaklik met die doel om die nywerheidsontwikkeling van die land te bevorder deur, onder andere, die finansiering van nywerheidsondernemings te vergemaklik."

The availability of capital, whether privately or state-owned, has influenced the development of joint product manufacturing to a considerable extent in many instances.

3 THE GROWTH AND STATUS OF JOINT PRODUCT MANUFACTURING IN THE OIL-REFINING AND PETROCHEMICAL INDUSTRIES

In most cases joint products cannot be categorised according to type of product or industry. Even in the chemical industry, where a significant percentage of basic products are produced in joint processes, (vide B.E. GOETZ, "Management planning and control," McGraw-Hill Co., New York, 1949, p.123) products may be singly or jointly produced depending on the nature of the enterprise and the raw material.

There are however two major classes of products, the large scale manufacture of which virtually always involves joint processes. They are the refined products of natural petroleum or oil from coal; and those chemical products from raw materials of petroleum origin known as petrochemicals.

The importance of these joint product industries can not be overemphasised. P.H. FRANKEL, ("Mattei: oil and power politics," Faber and Faber, London, 1966, p.76) makes the following statement:

> "The oil industry is more international than any other: petroleum is the biggest item in world trade, both by volume and by value, a distinction which it has now enjoyed for more than thirty years."

In view of the economic, industrial and strategic importance of the petroleum refining and petrochemical manufacturing, the development and characteristics of these joint product industries are discussed in some detail below.

3.1 PETROLEUM REFINING

3.1.1 BACKGROUND

Naturally occurring petroleum was first utilised as a fuel in 1870, when H. St. CLAIRE DEVILLE invented what is thought to be the first petroleum-fired furnace. (Vide Scientific American, January, 1970, p. 10). Subsequently a cleaner-burning fuel, kerosene, was obtained from crude oil by distillation. It was only when the internal combustion engine came into relatively widespread use that the large-scale derivation of various grades of fuel by means of fractional distillation came into practice.

Crude petroleum consists essentially of a mixture of hydrocarbons. The purpose of its refining is to separate this mixture into fractions having like properties, and to obtain products complying with certain specifications. As the constituency of crude petroleum varies from deposit to deposit, modern refineries are "tailored" to suit the available raw material.

The various fractions obtained in the initial distillation operation may be further processed in a number of ways. The majority of post-fractionation processes are designed to produce the maximum of high octane components for subsequent blending into various grades of gasoline. Higher molecular weight fractions are thermally or catalytically cracked, while those of lower molecular weight are polymerised or alkylated.

In most cases, not only the initial fractionation process, but also the subsequent cracking and polymerisation, as well as the associated separation stages, are joint processes.

3.1.2 THE WORLDWIDE GROWTH IN REFINING CAPACITY

In January, 1969, there were 833 petroleum refineries in operation throughout the world, with a total refining capacity of 2,041 million metric tons per annum. (Vide "International petroleum encyclopedia," The Petroleum Publishing Company, Tulsa, 1968, pp.260,261).

See A.13, TABLE II.1

The above table reflects the increase in total free world refining capacity from 1940 to 1968. The increase of nearly sixfold over this period represents an average growth rate of 20.8% per annum.

The increase in refining capacity of the Republic of South Africa is no less spectacular.

See A.14, TABLE II.2

The above table reflects the increase in refining capacity in South Africa since 1940, projected to mid-1971 when an inland refinery at Sasolburg is expected to be in operation.

3.1.3 JOINT PRODUCTS OF PETROLEUM REFINING

See A.15, TABLE II.3

Disregarding petrochemicals which are sometimes produced jointly by the same enterprise, table II.3 reflects the range of final products produced in a typical refinery, situated at the coast. The majority of these products are blends, the components of which are produced jointly in the various process units.

See A.4, FIGURE II.1

The above figure is a simplified flow diagram of the Tidewater Oil Company's Delaware refinery, showing the joint products of the main processing units.

In the case of refineries which are situated inland, there is often a limited market for heavy fuel oil, which is sold as ships' bunker oil by coastal refineries. In such cases this oil is cracked to produce greater percentages of the remaining products. The inland refinery at Sasolburg now under construction for National Petroleum Refiners of S.A. (Pty). Ltd. (Natref), will produce a minimum of heavy fuel oils. In order to achieve this, highly sophisticated process units will be installed to convert these fractions to gasoline components.

3.1.4 CHARACTERISTICS OF PRODUCTION FACILITIES

3.1.4.1 LARGE SCALE

The economics of petroleum refining favour large scale integrated production processes. The majority of modern refineries are thus big, both in terms of output and capital investment. By world standards, a medium sized refinery has a throughput of around 5 million metric tons of crude oil per annum. (Vide A.L. WADDAMS, op. cit., p.6).

The largest refinery in the world in 1970 is the Shell Netherlands refinery at Pernis, Rotterdam, which has a production capacity of 25 million metric tons per annum. The investment in equipment per metric ton of crude oil processed per annum for a medium sized refinery varies between R20 and R50 depending on the nature of the raw materials and products.

In view of the high capital investment involved, it is not surprising to find the world petroleum refining scene dominated by a relatively small number of very large companies.

See A.16, TABLE II.4

The above table reflects details of the nine petroleum companies listed among the twenty largest industrial corporations in the free world.

3.1.4.2 CAPITAL INTENSITY

Another characteristic of the petroleum refining industry is that it is capital-intensive. The industry has high sales per employee and low sales per Rand invested.

See A.17, TABLE II.5

Total investment in the Shell Netherlands refinery at Pernis is R500 million. It employs 7,200 persons, so that the investment per employee is approximately R70,000. (Vide Petroleum Times, February, 1970, p.iv).

Of the total running costs of a refinery, a relatively low proportion varies with throughput of raw materials. Defining "variable costs" as those costs " ... not affected by an increase in turnover percentagewise," T.P. VAN DEN BERG (Petroleum Times, op. cit., p. iv) states that only one third of the total working costs of the Shell, Pernis, refinery falls into this category. During the last ten years technological know-how and developments have brought down variable costs at this refinery by 20% , about half of which has been effected in the last five years. The variable percentage of running costs is expected to decrease further in future years.

As signposted by the high investment in equipment per employee, refineries are characterised by a high degree of automation. The nature of the operation of a modern refinery is such that total labour costs for a plant of a given size are generally regarded as being fixed costs, i.e. costs which remain constant in total as output increases. (Vide C.T. DEVINE, "Cost accounting and analysis," The Macmillan Company, New York, 1950, p.13).

It is noteworthy that, in practice, a decrease in output is frequently accompanied by an increase in total labour costs for that period, particularly when decreased output is due to a breakdown. This phenomenon is caused by the necessity to work overtime on repairs and maintenance during periods of decreased or interrupted throughput.

Characterised by a high degree of capital intensity; relative to other types of manufacturing, the petroleum refining industry has

(a) high sales per employee;

(b) low sales per Rand invested;

(c) a high proportion of fixed running costs.

3.1.4.3 COMPLEX OPERATION

A modern integrated petroleum refinery generally consists of five or more main processing plants, each of which involves a large number of unit operations. The processing plants are frequently single-train, i.e. major process units are not duplicated and the product of one unit operation becomes the feed for the next in the train.

Continuous operation of such a manufacturing system is extremely complex. Coupled with the fact that a number of products of different unit prices are produced jointly, specialised managerial information systems are required if returns are to be maximised.

3.2 PETROCHEMICAL MANUFACTURING

3.2.1 BACKGROUND

Historically the most important raw materials for the chemical industry have been coal, molasses, animal and vegetable oils, various ores, water and air. The widespread use of petroleum as a source of basic chemicals is a relatively recent development, which, until 1939, was restricted to the United States of America. (Vide A.L. WADDAMS, op. cit., p.3). However, since 1950 the development of petrochemical manufacturing in Europe and elsewhere has been an outstanding feature even in a picture of widespread industrial activity.

The importance of petroleum as a chemical raw material is underlined by the fact that 93% of the total organic chemical production in the

U.S.A. in 1968 was derived from petroleum. (Vide A.L. WADDAMS, op. cit., p.226). Furthermore, the range of products which may be derived from petroleum includes virtually every organic chemical as well as some important inorganic compounds.

The factors influencing the rapid development of the petrochemical industry are precisely those listed earlier in this chapter. Technological innovations in the fields of plastics, rubber and synthetic fibres led to significant increases in the demand for a range of basic petrochemicals. The processes developed to meet the demand for high octane fuels, led to the increased availability of olefin-rich gas streams at refinery locations. The profit motive in turn stimulated the economic exploitation of these streams, converting them from by-products, or waste, into valuable revenue sources.

The same applies to natural gas which, depending on circumstances, may bring in greater returns as petrochemical feedstock than as a heating fuel. Certain liquid refinery streams, termed naphtha or gas oil, can be cracked to produce gasoline. However, where low-cost crude oil is available, it is less profitable to crack these streams than to refine fresh crude. This is evidenced by the fact that naphtha is frequently priced well below crude oil. With the increase in demand for petrochemicals, it has become profitable to crack naphtha under special conditions to produce a maximum of olefin-rich gas and a minimum of gasoline.

The main raw materials for basic petrochemical products are thus refinery gas streams, natural gas and naphtha. For the purposes of this study the special case of gases produced in the manufacture of oil from coal is included under refinery gas streams. Petrochemical plants using refinery and natural gases are frequently situated near the source of these materials, while those using naphtha are more common in areas remote from such sources.

3.2.2 THE GROWTH IN PETROCHEMICAL OUTPUT

Before 1939 petrochemical production on a large scale was virtually restricted to the U.S.A. This was owing to the fact that this country was alone in possessing the necessary raw materials and refining capacity, together with a substantial market for the products.

See A.18, TABLE II.6

The above table reflects the production of petrochemicals in the U.S.A. from 1935 to 1966, as well as the percentage of the total chemical production derived from petroleum. It is estimated that in 1975 petrochemical production in that country will be 145 million metric tons representing 50% of the total chemical production. (Vide A.L. WADDAMS, op. cit., p.225 et seq.).

See A.19, TABLE II.7

The above table shows the increase in ethylene consumption in the U.S.A. Ethylene is one of the main basic petrochemicals, and the growth in its output from 14,000 metric tons in 1930 to 4.25 million metric tons in 1965 signposts the extensive development of petrochemical production over this period.

Petrochemical manufacturing in Europe and Japan began with the siting of refineries there after the Second World War. After 1950, Western European production expanded rapidly.

See A.20, TABLE II.8

By 1969 Japan's ethylene capacity was 2.3 million metric tons per annum and is expected to reach 4.2 million by 1972. (Vide "Petrochemical report - 1969," supplement, Oil and Gas Journal, September, 1969, p.10).

3.2.3 JOINT PRODUCTS OF PETROCHEMICAL MANUFACTURING

Classified as raw materials in the production of basic petrochemicals, are refinery gases, natural gas, refinery reformate, gas oil and naphtha, and, to a lesser extent, wax. With the exception of natural gas, these materials are generally produced jointly in petroleum refineries. They may themselves be classified as either joint or by-products depending on the relative value. The following basic petrochemicals are derived from these raw materials:

(a) Acetylene

(b) Ethylene

(c) Propylene

(d) Butadiene

(e) Higher Olefins

(f) Aromatics.

These compounds are sometimes referred to as secondary petrochemical raw materials. (Vide A.L. WADDAMS, op. cit., p.18). Their joint derivation from the various raw materials listed above is discussed.

3.2.3.1 PRODUCTS FROM REFINERY GASES

The use of refinery gases as raw material for petrochemical manufacturing is largely restricted to the U.S.A. In 1965 approximately 10% of that country's ethylene requirements were met from this source. Elsewhere in the world, where supplies of this material are less plentiful, there is greater dependence on the other raw materials. The main sources of refinery gases are catalytic cracking and reforming processes used in the manufacture of high octane gasoline. The feedstock for these processes is usually gas oil or naphtha.

See A.21, TABLE II.9

The above table lists the typical yields of basic petrochemicals in refinery gases from these sources. The joint processes used in the manufacture of these chemicals involve their isolation and/or conversion processes such as selective cracking and polymerisation.

3.2.3.2 PRODUCTS FROM NATURAL GAS

The joint production of petrochemicals from natural gas is again virtually restricted to the U.S.A. This is largely because the gas available in other industrialised countries consists mainly of methane, whereas American natural gas frequently contains quantities of higher paraffins and some basic petrochemicals as well. These include C_4 hydrocarbons, ethane and propane, as well as traces of condensate containing higher olefins.

It is noteworthy that the natural gas deposit discovered off the South African coast at Plettenberg Bay is of a similar constituency.

As for refinery gases, the joint manufacture of basic petrochemicals from natural gas, involves extractive and/or synthesis processes. Two joint processes using natural gas as feedstock are of particular importance.

(a) Pyrolysis of propane, or a mixture of propane and ethane, results in a set of joint products ranging from acetylene to butadiene.

See A.22, TABLE II.10

The above table shows the typical yield of propane pyrolysis. This process is an important source of ethylene in America and accounted for 62% of the total ethylene production in that country in 1965. (Vide R.B. STOBAUGH, op. cit., Vol. II, p.43).

(b) Chemische Werke Huls AG have developed a plasma process which converts gaseous hydrocarbon feedstock into a range of petrochemical products. A gas-whirl stabilised DC electric arc with a capacity of 8,200 kw, burns between two hollow electrodes. The gases flow through an anode tube parallel to the arc and are brought to cracking temperature. Immediately after the arc the cracked products are quenched with fresh feedstock, which is pyrolised in the process.

A variety of feedstock can be used with this process, including refinery gases or even vapourised naphtha. Using natural gas the most important joint products are acetylene and ethylene.

3.2.3.3 PRODUCTS FROM GAS-OIL AND NAPHTHA

The joint production of basic petrochemicals as well as gasoline from these raw materials involves thermal cracking in the presence of steam. Large quantities of ethylene are produced by this process in many parts of the world, notably Western Europe and Japan. South Africa's entire ethylene demand is met by a naphtha cracking plant operated by the South African Coal, Oil and Gas Corporation.

See A. 23, TABLE II. 11

The above table lists the typical yield of joint products obtained by cracking naphtha. The various percentages are subject to the so-called "crack severity" which is a function of the temperature at which the operation is performed.

3.2.3.4 PRODUCTS FROM REFINERY REFORMATE

The naphthenes in heart-cut refinery hydrocarbons can be reformed into aromatic compounds using a platinum catalyst at high temperature and pressure. These aromatics can be separated from the paraffins and residual naphthenes using aqueous diethylene glycol as a solvent. The aromatic stream is then fractionally distilled to yield benzene, toluene and mixed xylenes as joint products. (Vide R.B. STOBAUGH, op. cit., Vol. I, p.2).

Although in America some 60% of all the benzene consumed is produced from refinery reformate, the majority of the benzene produced in South Africa is distilled from coking coal. The South African Iron and

and Steel Corporation (Iscor) is the major producer in this country.

3.2.3.5 PRODUCTS FROM WAXES

Less important than the other raw materials discussed, wax may be cracked to yield a range of higher olefins, refinery gases and fuel oil. This process is known as a paraforming process.

3.2.4 CHARACTERISTICS OF PETROCHEMICAL MANUFACTURING PLANTS

Being closely associated with petroleum refining, it is not surprising to find that most petrochemical manufacturing plants display the same characteristics as refineries. As such they are large, complex and capital-intensive. A striking feature of the petrochemical industry is the increase in the size of individual processing plants over the last decade.

See A. 5, FIGURE II.3

The above figure reflects the increase in ethylene-producing capacity of the largest petrochemical plants constructed both in the U.S.A. and the rest of the free world each year from 1962 to 1969. The graph shows that if, during any year in this period, a company decided to erect an ethylene-producing plant as large as the biggest then in existence, by the time it came into production, a plant nearly 1.5 times its size would have been under construction somewhere in the world. (This assumes an erection period of two years.)

In general, the capital cost of a modern automated petrochemical plant varies in proportion to the capacity to the power o.6. This factor has had the effect of limiting the minimum economic size, while the maximum increases as technological problems are overcome.

3.2.5 FUTURE PETROCHEMICAL PRODUCTION

It is not anticipated that the increase in the world demand for petrochemicals will reach its peak for several decades to come.

See A. 6 , FIGURE II.4

The above figure reflects the forecasted increase in world-wide petrochemical production up to and including the year 2000. It can be seen that the petrochemical industry, the basic products of which are primarily joint products, is and is likely to remain one of the most rapidly developing industries.

4 THE IMPORTANCE OF JOINT PRODUCT MANUFACTURING IN SOUTH AFRICA

The list of joint products produced in South Africa includes a wide variety of organic and inorganic chemicals, fuels, metals and agricultural products. A major proportion of the chemical industry in this country has been built up around a joint process for the conversion of coal to fuels and chemicals which is unique in the world. Other joint process operations which are still in the planning stage are likely to be of considerable economic importance.

4.1 OIL FROM COAL

Of the South African joint product manufacturing industries, that of oil-from-coal is of particular significance. In the absence of economically recoverable deposits of natural petroleum there has been a lively interest in the Fischer-Tropsch process for the manufacture of liquid fuels from coal since the announcement of its feasibility in 1935.

The rights to this process were acquired by the Anglovaal company and in 1949 a licence was issued to cover such manufacturing. Owing to devaluation and demands on its capital resources, Anglovaal approached the Government for financial assistance. At that stage it was agreed that all rights be taken over by the Government.

In 1950 the South African Coal, Oil and Gas Corporation (Sasol) was formed with the purpose of erecting an oil-from-coal plant in the Northern Orange Free State. Erection was started in 1952 and in 1955 the first products were sold. In 1965 a naphtha cracking plant was completed to supplement the production of olefins. Raw material for this plant is imported from the Middle East.

In addition to various grades of liquid and gaseous fuels, Sasol produces a wide variety of chemical products in a complex series of joint processes. The oil-from-coal process consumes approximately 8% of the Republic's total coal production and accounts for a significant percentage of its fuel requirements. Sales by its wholly-owned subsidiary, Sasol Marketing Company, amounted to R72 million during its 1969-70 financial year. Of this R24 million accrued from the sale of chemicals. The company produces approximately one-third of the country's nitrogenous fertilizer requirements.

A number of secondary industries based on oil-from-coal and naphtha products have been established in Sasolburg. These include plants for the manufacture of fertilizers, plastics, synthetic rubber, cyanide and raw materials for bio-degradable detergents. When the Natref petroleum refinery in the area comes into production in 1971, the gasoline and diesel fuel production capacity in Sasolburg will total approximately 40% of the country's requirements.

Together with the coastal petroleum refineries, the growth rate between 1957 and 1965 in volume of output of petroleum and coal products was the highest for all major industries. (Vide G. MARAIS, in "South African Statistical Yearbook," Bureau of Statistics, Pretoria, 1966, p.17).

The total contribution to the gross national product of industries in the Sasolburg complex, which are based on joint products and their derivatives, was in excess of R80 million in 1969. The average contribution per worker to the gross national product was above R7,500. (Vide D.P. DE VILLIERS, "The development of the Sasolburg petrochemical complex," Paper delivered at the National Development and Management Foundation Conference, Vereeniging, February, 1970).

4.2 THE EXTRACTION OF COKING COAL

A recent development of considerable economic importance is the perfection of a process for the extraction of coking coal from medium grade deposits in the Eastern Transvaal.

The process consists of the "floatation" of lighter, high carbon-content coal from the conglomerate of grades comprising the coal seam as mined. A series of operations is involved, using water as the floatation medium. The yield of high carbon-content constituents is approximately 30% by weight, but varies according to the characteristics of the seam being mined.

The primary use of coking coal is in the manufacture of carbon steels. There is a world shortage of coking coal at present and the supply position is likely to deteriorate in future years. Initially the entire South African production by this process will be exported to Japan. The ex-works price obtainable is roughly twice the price obtainable for the coal in the form in which it is mined.

The remainder of the raw material will be purchased by the Electricity Supply Commission (Escom) for use in thermal power stations in the vicinity.

The economic significance of the development of this joint process is that a substantial amount of foreign exchange will be earned. In terms of value, it enables greater utilisation of the country's natural resources.

4.3 THE PARTIAL REFINING OF CRUDE PETROLEUM TO PRODUCE NAPHTHA AND FUELS

A feasible development concerning joint product manufacturing would be the partial refining of crude petroleum to produce cracking feedstock for the South African petrochemical industry, and various types of heating and motor fuel.

The Republic is the closest industrialised country in the Western world by sea from the Middle East oilfields to the East of the Suez Canal. Consequently the landed price of petroleum in South Africa can be expected to compare favourably with corresponding prices in America and Japan. Under these circumstances it may be economically feasible to produce naphtha from crude petroleum instead of importing it as such.

This can be achieved by partial refining to produce a set of joint products comprising naphtha, heavy fuel oil, diesel fuel and petroleum gases.

See A. 24 TABLE II.12

The above table reflects the yields of the various products and estimated realisable prices where a market exists.

Where the price is competitive with that of coal on a calorific value basis, thermal power stations are a potential outlet for the heavy fuel oil fraction. In the case where the coal price exceeds R5 per ton the estimated discounted cash flow on the partial refining process is in the order of 15% per annum before taxes.

Such a system has potential and represents a possible development in the field of joint product manufacturing in South Africa.

5 SUMMARY

Influenced extensively by technological progress as well as the availability of capital and the profit incentive, joint product manufacture has developed at a rapid rate in recent years. In the major fields of petroleum and chemicals, joint product manufacturing is characterised by large, complex and capital-intensive production facilities. A number of enterprises engaged primarily in joint product manufacturing, rank high on the list of the largest industrial corporations in the free world.

In the Republic of South Africa, joint products account for a significant percentage of the gross national product and their manufacture is of major strategic, economic and industrial importance. Consequently the optimal solution of the managerial problems associated with joint product manufacturing is of considerable importance.

CHAPTER III

MANAGEMENT OF THE JOINT PRODUCT MANUFACTURING ENTERPRISE

1 INTRODUCTION

Having examined its nature and development, this chapter deals with the managerial aspects of joint product manufacturing. The factors of large scale production and technological intricacy tend to complicate the functions of management in any capital-intensive industry. Where joint processes are involved, however, these functions are further complicated by virtue of the technical interdependence of the products.

The scope of this study is restricted to the given concern operating in a given, dynamic environment. In this context the primary objective of manufacturing management may be stated as being the maximisation of returns, as defined. In this chapter the nature and functions of modern manufacturing management are outlined, and the particular managerial problems associated with joint product manufacturing are examined and analysed.

The approach adopted is to contrast single-line with joint product manufacturing with respect to decision-making and control. Specialised managerial information is shown to be necessary if returns in respect of joint product manufacturing enterprises are to be maximised.

2 THE NATURE OF MANUFACTURING MANAGEMENT

2.1 DEFINING MANAGEMENT

J. BATTY, ("Industrial administration and management," McDonald and Evans, London, 1966, p.123) maintains that there is no generally accepted definition of management. Much depends on the point of view of the person who is attempting to define the term. This is borne out by the fact that various definitions of the term are almost as numerous as the writers on the subject. The widely-used functional approach and the more recently developed co-ordinative concept are discussed below.

2.1.1 THE FUNCTIONAL APPROACH

The functional or anatomical approach to the concept of management is largely an extension of the "management is getting things done through other people" definition, by elaborating on how this can be effectively achieved. E. DALE, ("Management theory and practice," McGraw-Hill Co., New York, 1965, p.1) states that:

> "Management is best defined ... in terms of the functions that all true managers perform, to a greater or lesser degree, whether they are business managers or managers of other types of organisations."

These functions have been variously described by a wide range of authors on the subject. One of the first of these was L. GULICK, ("Papers on the science of public administration," Institute of Public Administration, New York, 1937, p.13) who coined the word POSDCORB from the initial letters of the functions of planning, organising, staffing, directing, co-ordinating, reporting and budgeting. L.A. ALLEN, ("The management profession," McGraw-Hill Co., New York, 1964, p.263) includes "motivating," while W.H. NEWMAN, C.E. SUMMER and E.K. WARREN, ("The process of management," 2nd Ed., Prentice-Hall Inc., New Jersey, 1967, p.11) refer to "leading" as an intrinsic managerial function.

P.F. DRUCKER ("The practice of management," Harper and Row Inc., New York, 1954, p.47) states correctly that managing a business "cannot be a bureaucratic, an administrative or even a policy-making job." Maintaining that managing is a creative rather than an adaptive task, he emphasises the innovative aspect thereof.

A primary objection to the multiple function approach is the fact that in practice, the various functions overlap and can not be realistically isolated. The longer the list of functions, sub-functions and activities, the less meaningful the functional definition becomes. By restricting the list to planning, organising and controlling, and stipulating that all three are invariably basic to and inherent in all managerial activity, it becomes more significant. (Vide W.M. FOX, "The management process," Irwin Inc., Illinois, 1963, p.3). These three are termed basic functions, relevant aspects of which are discussed later in this chapter.

2.1.2 THE CO-ORDINATIVE CONCEPT

Similar to the approach adopted by FOX; in terms of the co-ordinative concept, management is regarded as an integrated activity. "Co-ordinative" in the sense used, holds "allocation of resources" connotations, and the concept centres around the manager as a decision-maker in this respect. M.H. SPENCER and L. SIEGELMAN, ("Managerial economics," Irwin Inc , Illinois, 1965, p.16) maintain that the co-ordinative activity is the process of selecting an action from alternative courses of action, stating that:

> "It is management in the co-ordination sense which is now recognised by many modern scholars as a central concept of management theory."

When selecting a course of action, the manager is in effect taking a decision at the present time in order to obtain results in the future. As such, an element of risk is always present and a decision can at best be "probably correct" at the time it is taken. In terms of the co-ordinative concept, managerial decision-making is regarded as being the selection of the course of action which has the greatest probability (or least uncertainty) of fulfilling the objectives of the enterprise. Thereafter the results of the decision are controlled by measuring the effects of the course of action selected; comparing them with the relevant objectives, and taking corrective action where necessary.

Although more abstract than the functional approach, this concept has merit. It incorporates the innovative or creative aspect of setting up alternatives and embodies the principles of management by objectives.

2.2 THE BASIC FUNCTIONS OF MANUFACTURING MANAGEMENT

Using the functional approach, manufacturing management can be broadly described as planning, organising and controlling the activities involved in converting raw materials into finished products. As a prelude to the examination of the particular problems associated with the execution of these functions in the joint product manufacturing enterprise, their nature and scope are discussed in general terms below.

2.2.1 PLANNING

The function of planning in the given manufacturing concern involves the setting of performance objectives for each segment of the organisation, which, when co-ordinated, represent a plan by which the primary objective of the enterprise can be attained. This normally involves three phases, namely:

(a) forecasting the demand for each product for the period involved;

(b) allocating available resources in such a way as to maximise returns;

(c) compiling functional operating plans for each segment of the organisation.

Relevant aspects of each of these phases are outlined below.

2.2.1.1 DEMAND FORECASTS

In most manufacturing concerns the anticipated volume of sales for each product forms the framework within which operating plans are formulated. In a market economy, demand for a particular product tends to vary, to a greater or lesser extent, according to its price. Where this factor is significant, it is necessary to compile a demand schedule for each product which reflects the anticipated volume of sales at various prices. The revenue which it is anticipated will accrue from sales at each volume level is obtained by multiplying the number of units by the corresponding unit price in the demand schedule. This information can be used to compile revenue/volume schedules for each product.

The revenue/volume schedule for a product reflects the sales revenue for each feasible volume of sales. Taken together with cost/volume schedules, they provide valuable information on which resource allocation decisions may be based.

Demand forecasts and resource allocation plans are termed short-run or short-term if they cover periods of up to one year, and long-term if they cover periods in excess of two years.

Depending on the nature of the product and the manufacturing sequence employed, the degree to which returns can be maximised is a function of the accuracy and reliability of the demand forecast. In general the less flexible the production facilities are with respect to type and quality, the greater is the need for accurate forecasting. Furthermore, the higher the proportion of fixed manufacturing costs, the greater the need for reliable long term demand forecasts if returns are to be maximised.

2.2.1.2 RESOURCE ALLOCATION

Manufacturing resources are alliteratively referred to by H. SPEIGHT, ("Economics and industrial efficiency," 2nd Ed., Macmillan, London, 1967, p.9) as being manpower, money, machines, materials and management. The optimisation of manufacturing activity involves the allocation of available resources to products in such a manner as to maximise returns on the investment which this allocation represents.

Some of the decisions involved in resource allocation planning are as follows:

(a) which products should be produced;

(b) how much of each product should be produced;

(c) whether a product should be sold or worked up further;

(d) whether intermediates should be manufactured or purchased;

(e) which grade of raw materials should be used;

(f) which process should be employed, etc.

Resource allocation planning is of course subject to the constraints imposed by technical considerations, and a sound knowledge of the manufacturing process is essential if the activity is to be optimised.

Short-term allocation generally involves a relatively fixed set of resources and range of products. Long-term resource allocation plans may involve different products and/or manufacturing facilities. Under these conditions the relative quantities of the various resources may change. For example, equipment resources may be increased at the expense of capital or labour resources.

Depending on circumstances, resource allocation may involve a large number of alternatives. Selection of the optimal course of action is subject to the availability of reliable revenue/volume and cost/volume information.

2.2.1.3 OPERATING PLANS

Once the optimum manner in which resources should be allocated for a forthcoming period has been determined, it remains to compile functional operating plans for each sector of the organisation based on this information. These plans are based on forecasted data and can be regarded as being forecasts in themselves. In allocating resources, predicted costs and prices were used. If they are to be effectively employed for control purposes, the operating plans should incorporate cost elements and prices. As such they are combination forecasts and budgets. (Vide J. BATTY, "Management accountancy," MacDonald and Evans Ltd., London, 1966, pp.77-89).

2.2.2 ORGANISING

In the sense in which it is used in this study, the term "organising" refers to the managerial function of ensuring that efforts within the business enterprise are directed toward the primary set of objectives. As such the function includes such activities as staffing, motivating, leading, co-ordinating, communicating and directing. It is in effect the link between the plan and the results. Relevant aspects of this function are discussed below.

2.2.2.1 ORGANISATIONAL STRUCTURES

Organisation invariably involves people. For this reason it is the sphere of management in which strict scientific principles cannot be adhered to with consistent results. A scientifically based personnel framework is however essential to the effective co-ordination of activity in any manufacturing enterprise. E.F.L. BRECH ("Organisation:

the framework of management," Longmans, London, 1965, p.16), refers to the nature of the organic structure as follows:

> "... a 'known arrangement' between the persons concerned in sharing of the responsibility is essential, if conflict, confusion or chaos are to be avoided."

The "known arrangement" is alternatively described as an "organisational structure," a "pattern of defined responsibilities," or a "framework for the management process of delegation."

Decentralisation and technological progress have had a significant effect on manufacturing organisational structures, particularly in multi-process and multi-product industries. In these areas the products of one division may be worked up in others, requiring close co-operation between them in a number of spheres.

Departmentalisation based on cost-incurring considerations has resulted in a trend away from the strictly vertical organic structure and toward parallelisation, with horizontal and diagonal relationships.

A logical extension of the departmentalisation of manufacturing operations is the centralisation of service activities such as production planning, maintenance, inspection, technical and laboratory services, etc. Specialist service departments are a prominent feature of modern manufacturing organisational structures.

Despite the scientific basis of organisational structures, there is no set formula for their formation. Structures in different companies may often be similar, but are rarely exactly the same.

2.2.2.2 MOTIVATION AND THE DECENTRALISATION OF AUTHORITY AND RESPONSIBILITY

Whatever the enterprise, management involves the continuous task of accomplishing objectives via the efforts of others. Motivating is thus an integral part of managerial organising, and involves the blending of the personal needs and goals of the individual employee with the objectives of the enterprise as a whole. The size of the modern manufacturing corporation, coupled with a high degree of automation, has resulted, to a certain extent, in a loss of individuality among industrial employees. This can lead to serious motivation problems in a large concern. E.C. SCHLEH, ("Management by results," McGraw-Hill, New York, 1961, p.3), points out that greater productivity per manhour and increased mechanisation has resulted in the fact that "larger losses than formerly are possible at any individual work place along the line." This is particularly true in process manufacturing.

Motivation of lower level employees is further complicated in this type of industry by the fact that, in a number of cases, no suitable basis exists for monetary incentives in the form of production bonuses. Motivation of employees at every level has thus become an important aspect of the co-ordinating function.

Decentralisation can have a favourable motivating effect in a manufacturing organisation. With respect to lower level employees, the size of the enterprise is in effect reduced. Instead of being one of several hundred (or thousand) company workers, he becomes a member of the ABC Department production team. In this way he preserves a degree of individuality.

On the other hand, unless guarded against, decentralisation can have negative results with respect to motivation of the lower ranks. L.A. ALLEN (op. cit., p.206) states that:

> "To be most effective, there should be a consistent and systematic effort to delegate authority to the operating levels."

It is maintained that although in many other respects delegation is insufficiently practised, the least-transferable managerial skill of leadership is frequently the first to be passed down the line. If the pyramid organisational structure is considered, it is seen that the men most skilled in the managerial functions are furthest removed from the men who actually perform the revenue-generating operations.

Motivation of these men is often and for the most part, left to their immediate superiors. These superiors are theoretically inferior in managerial skills and experience to all but the lowest rank in the organisation.

It is proposed that this syndrome is one of the determinants underlying the findings of F.J. ROETHLISBERGER (In H. KOONTZ, Ed. "Toward a unified theory of management," McGraw-Hill Co., New York, 1964, pp.41 et seq.), who investigated organisation behaviour with respect to morale, motivation, leadership and productivity. One of these findings was that the motivational assumptions underlying the principles of management were inadequate.

The effect of decentralisation and delegation on departmental managers is generally favourable. If each department is regarded as an individual enterprise, the incentive for its managers to strive more actively to meet the objectives set, is significantly increased.

Where departmentalisation is warranted by the size and nature of the enterprise, it is important that sub-division be based on cost-incurring considerations. The motivating effect of decentralisation can be increased if profit margins can be attributed directly to manufacturing departments.

2.2.3 CONTROLLING

Regardless of how carefully its activities are planned and organised, the primary objectives of a business enterprise can not be achieved except by accident unless the system is in a state of control. D.S. SHERWIN ("The meaning of control," in Dun's Review and Modern Industry, January, 1956, p. 46), describes the underlying concept of the control function as follows:

> "The essence of control is action
> which adjusts operations to pre-
> determined standards, and its
> basis is information in the
> hands of managers."

Managerial control based on the detailed objectives discussed earlier under the planning function, involves three phases:

(a) measurement of actual performance;

(b) comparison with plans and evaluation of deviations;

(c) corrective action.

For the most part responsibility for the day-to-day control of manufacturing operations rests with line supervisors. In this respect feedback of control information from the various sectors of the organisation takes the form of periodic reports. These enable management to measure and evaluate performance in general terms on a weekly or monthly basis.

Longer-term evaluation, however, is usually concerned with cost and revenue measurement. Here budgetary control, standard costing systems and sales schedules play an important role in providing management with information on which assessments and decisions can be based.

2.2.3.1 ASPECTS OF COST CONTROL

Costing is an essential aspect of the first phase of the controlling function in a manufacturing enterprise; namely, measurement of actual performance. J.H. ELS ("The application of standard costs in certain South African industries," Unpublished thesis, P.U., 1964, pp. 6, 7), makes the following statement:

> "A cost system, properly adapted to the the production process, will also assist management in the control of the cost and cost items resulting in savings and increased efficiency by pointing out those performances which are out of line with those planned, thus enabling management to make use of the principle of exception, that is, attention being focused only on those results which are not in accordance with those predetermined."

ELS maintains correctly that the future of any business undertaking is closely related to its cost structure and the effectiveness of its cost control system.

Costing systems should be designed to meet the particular requirements of the enterprise concerned. For control purposes it is desirable to relate the costing system to the organisational structure of the enterprise. In this way the line managers concerned can utilise the information directly, and be held accountable for variances from predetermined performance. (Vide H. KOONTZ and C. O'DONNELL, "Principles of management," McGraw-Hill Co., New York, 1955, p.190).

A.J.E. SORGDRAGER ("The particularization of indirect cost in modern costing administration," Ajax, Potchefstroom, 1964, p.168), points out that "the cost centre structure is identified as the centre of responsibility." SORGDRAGER attributes the development of this system of responsibility to A. MEY. E.W. NETTEN ("Responsibility accounting for better management," in The Canadian Chartered Accountant, Vol.83, No. 3, September, 1963, pp.164-168), emphasises the importance of such a system in the exercise of effective managerial control.

In many concerns, so-called "direct costing" is favoured for control purposes. Direct costing is a concept under which only variable costs of manufacturing are treated as product costs. (Vide J.R.E. PARKER, "Perspectives on direct costing," in The Canadian Chartered Accountant, Vol.78, No. 3, March, 1961, p.225).

H.R. ANTON and P.A. FIRMIN, ("Contemporary issues in cost accounting," Houghton Mifflin Co., Boston, 1966, p.139) maintain that direct costing has the advantage of focusing on more controllable costs, and so facilitates control of responsibility centres.

Direct costing is criticised by J.H. ELS (op. cit., p.163) on the grounds that no differentiation is made between the "rational or irrational sacrifices" of any excess capacity; which is almost always charged as part of the "cost" of the products manufactured.

2.2.3.2 EFFECTIVE BUDGET CONTROL

The value of any control information system lies in the extent to which it reveals the real cause of both favourable and adverse deviations from planned performance. It is important therefore that the budget control system be designed to facilitate the isolation of variance causes.

Unless budget control information is sufficiently detailed, the danger exists that adverse and favourable variances which are not reflected separately will cancel each other. The result may be a low nett variance indicating all-round efficiency which is not the case. It may be necessary to reflect each cost element separately for each cost centre if production costs, for example, are to be effectively controlled.

The incorporation of standard costs in the budget control system has become generally accepted in a large number of industries (Vide D. SOLOMONS, "Flexible budgets and the analysis of overhead variances," in Management International, Vol. 1, 1961, p.84). By incorporating standard variable costs in the production budget, efficiency and price variances can be determined, thus facilitating the isolation of variance causes. (Vide J. BATTY, op. cit., 1966, "Management accountancy," p. 268).

In a departmentalised manufacturing concern, responsibility for cost control in each department is delegated to the manager thereof. In such concerns it is advantageous to distinguish between "controllable" and "uncontrollable" variances in each department. Variances due to such causes as changes in raw material quality may be uncontrollable with respect to the production department manager in whose budget the variance is reflected. In general, efforts should be made to isolate those variances which reflect performance in a particular area from those which result from changes in non- or semi-controllable factors. (Vide J.A. BECKETT, "A study of the principles of allocating costs," in Accounting Review, Vol. 26, No. 3, July, 1951, p.328).

The use of electronic data processing can greatly facilitate cost accumulation and analysis for budget control purposes. By means of correlation analysis and other statistical methods, variance trends can be signposted during the budget period, permitting corrective action to be taken promptly. The cost of the system should, however, be weighed up against the economic advantages of its results.

2.3 THE INNOVATIVE ASPECT OF MANAGEMENT

If returns are to be maximised, the business enterprise has to have leadership in something of real value to the customer or market. It may be leadership in cost, service, quality or the ability to convert ideas into saleable products speedily and at low cost. Maintaining that any leadership position is transitory, P. DRUCKER, ("Managing for results," Heinemann, London, 1964, p.7) states the following of innovative management:

> "It is, then, the executive's job to reverse the normal drift. It is his job to focus the business on opportunity and away from problems, to re-create leadership and counteract the trend toward mediocrity, to replace inertia and its momentum by new energy and new direction."

Having examined the basic nature of management and dealt with relevant aspects of its basic functions, the remainder of this chapter is devoted to managerial problems peculiar to joint product manufacturing.

3 PARTICULAR MANAGERIAL PROBLEMS ASSOCIATED WITH JOINT PRODUCT MANUFACTURING

Joint product manufacturing management is faced with the objective of maximising operating profit, over the long term, on two or more products. These products are interrelated with respect to quantity, costs, and in some cases, quality. They may, however, be entirely independent with respect to demand and market value. Furthermore, as will be established subsequently in this study, manufacturing costs can not be allocated to individual joint products other than on a semi-arbitrary basis.

The factors of product interdependency and the unsuitability, in several respects, of allocated joint costs as decision-making information, complicate the functions of joint product manufacturing management. In this section the effect of these factors on aspects of the basic managerial functions is examined.

3.1 PLANNING ASPECTS

3.1.1 DEMAND FORECASTS FOR JOINT PRODUCTS

Demand forecasting for joint products involves the prediction of the simultaneous demand, over a certain period, for two or more products. The reliability of the composite demand forecast depends on the accuracy with which the demand for each individual product can be predicted. Taken separately, the forecast for each product carries a certain probability of being correct. If the products are sold in different markets, the respective probabilities may differ appreciably.

The accuracy probability of the composite forecast for resource allocation purposes is governed by the accuracy probability of the least predictable individual product demand. As a result the degree of uncertainty associated with production plans based on composite demand forecast for a set of joint products tends to be appreciably greater than that for a set of single-line products.

Resource allocation and the resultant operating plans are based on forecasted revenue/volume and cost/volume data. Manufacturing activities will only remain optimised for as long as a satisfactory correlation exists between forecasted and actual conditions. As every demand forecast carries some degree of uncertainty, plans must be regularly updated in the light of additional market information if returns are to be maximised. (Vide R.A. KNAPP, "Forecasting and measuring with correlation analysis," in Financial Executive, Vol. 31, No. 5, May, 1963, pp.13-19). This holds for both single-line and joint product manufacturing. However, the inherent inflexibility of the joint product mix tends to seriously impede short-run optimisation in the event of unpredicted variations in the demand for one or more products.

> In general, any deviation from forecasted demand on which optimum resource allocation has been based, tends to result in a greater deviation from maximum returns than otherwise if the products are technically interdependent.

3.1.2 RESOURCE ALLOCATION TO JOINT PRODUCTS

The primary objective of the planning function in a manufacturing enterprise is to establish the manner in which resources should be allocated to products in order to maximise returns. Of the resource allocation decisions listed under 2.2.1.2 in this chapter, the first two, namely, which products should be produced, and how much of each, are fundamental decisions.

For a large multi-process manufacturing complex a considerable number of courses of action may be associated with each resource allocation decision. A system which can provide reliable and comprehensive information on which these decisions can be based is essential if the optimum course of action is to be selected.

With respect of single-line products, break-even analysis techniques can be usefully employed for this purpose. S.A. TUCKER, ("The break-even system: a tool for profit planning," Prentice-Hall Inc., New Jersey, 1963, p.xi) describes the system as follows:

> "Practically every action or planned decision in a business enterprise will affect costs, prices, volume and profits. The break-even system discloses the interplay of all these factors in a way which aids management in selecting the best possible course of action now and in the future."

(Break-even analysis is comprehensively covered both in theory and in practical application by J.C.M. VAN NIEKERK, "Die wins- en verlieskruispunt in teorie en praktyk," Unpublished thesis, P.U., 1968).

While break-even analysis has certain limitations, it provides useful information on which resource allocations to single-line products can be based. The limitations are examined by A.J.E. SORGDRAGER, (op. cit., 1967, pp.239, 240). The system and variations thereof have found widespread use in many types of industry (Vide R.I. DICKEY, op. cit., p.18.19).

Where more than one product is produced, unless the cost/volume relationship for each individual product is known, break-even analysis serves little purpose with respect to resource allocation decision-making. As has been stated, joint manufacturing costs can not be allocated to individual products except on a semi-arbitrary basis. The value of allocated joint costs for the important purpose of optimising resource allocation is therefore questionable.

Although they make no reference to allocated variable costs, several authors on break-even analysis are critical of the use of allocated fixed joint costs. R.I. DICKEY (op. cit., p.18.13) quotes the National Association of Accountants (U.S.A.) on the allocation of fixed costs as follows:

> "Where a significant portion of the facilities represented by the fixed costs is shared in common by the various products, difficulties which are inherent and cannot be readily overcome cause the resulting break-even figures to have only limited reliability in many cases."

S.A. TUCKER (op. cit., p.46) states that:

> "In an arbitrary allocation of joint fixed costs, the only significant piece of information obtained from this (break-even) chart is the PV."

PV is defined as (1 - variable cost percentage of sales.) He maintains that in using only the variable product cost - "we would be comparing known values without compounding it with the presence of an arbitrary fixed cost." It is evident that despite this author's use of the word "joint" he is not referring to joint products as defined in this study. For these products, allocated joint variable costs would be as arbitrary as the joint fixed costs he avoids using. (Both the concept of joint cost and various allocation methods are discussed in PART TWO of this study.) Provided that the ratio of product yields remained constant for every joint process in the manufacturing sequence, it would be possible to compute a single break-even volume expressed as aggregate sales revenue. It is, however, doubtful whether the trouble taken to do this could be justified. Furthermore, to plan for a fixed product mix except over short periods will more often than not lead to sub-optimum resource allocation.

It is maintained that allocated joint costs and cost/volume/profit relationships for individual joint products tend to be unsuitable and may be misleading as far as resource allocation decision-making is concerned. The usefulness of break-even analysis and related techniques for planning purposes is thereby limited. If resource allocation to joint products is to be optimised, alternative decision-making information systems are required.

A further consideration with respect to resource allocation planning for joint products is that the entire joint product manufacturing sequence must be considered as a whole. This is necessitated by the technical interdependence of the products. Where a multiplicity of products and processes are involved the use of sophisticated optimisation techniques may be essential if returns are to be maximised.

3.1.3 JOINT PRODUCT PRICING

The role of pricing in the maximisation of returns is particularly significant in the joint product manufacturing enterprise. By means of pricing, management is able to regulate the demand for the various joint products to a limited extent. Pricing, therefore, represents a partial solution to the ever-present problems arising from the independent demands for jointly-produced products.

The establishment of a sound long-term pricing policy and structure is essential if returns are to be maximised. Although rigid cost-plus-profit pricing is a detrimental practice, manufacturing cost data is of basic importance in this respect. A.J.E. SORGDRAGER (op. cit., 1967, p.59) makes the following point:

> "Alleen wanneer die kosprys van die produk bekend is, is dit moontlik om te oordeel of die ruil van die goedere by 'n gegewe pryestand op die mark, voordelig is."

A detailed knowledge of cost-volume relationships for individual products extensively facilitates optimisation of pricing decisions. In this respect break-even analysis can provide management with valuable information. (Vide J.C.M. VAN NIEKERK, op. cit., p.228 et seq.).

While the break-even system can be effectively employed for single-line product pricing, the lack of rational cost-volume data for individual products precludes its direct application for joint products in all but isolated cases.

Pricing is a key managerial function and its optimisation is essential to the maximisation of returns. In the case of joint products, specialised procedures, which do not depend on allocated joint costs, are necessary.

3.2 ORGANISATION ASPECTS

Not all joint product manufacturing concerns operate large integrated production complexes. Such facilities are, however, common - and in fact the rule - in the petroleum-refining, petrochemical and ore-refining industries. The way in which the technical interdependence of the products affects the organising function in these plants is discussed below.

3.2.1 CO-ORDINATING JOINT PRODUCT MANUFACTURING ACTIVITIES

Joint product manufacturing systems may consist of a large number of processes. With respect to many of these, the end products of one process become the raw materials for others. The presence of recycle streams, common utility facilities and post separation blending, further increases the extent of the interrelationship between these processes. At the same time, each process may be operated and controlled by a different team of operators.

It can be seen that under these conditions effective co-ordination of manufacturing activities is an exacting and vitally important function. This applies particularly in the petroleum refining and petrochemical industries where large-scale continuous processes and limited intermediate storage capacity are common features.

3.2.2 DECENTRALISATION OF AUTHORITY AND RESPONSIBILITY WITHIN THE JOINT PRODUCT ENTERPRISE

Departmentalisation in manufacturing industries should be based on product lines or related process activities. This is in accordance with the principle of combining responsibility for production efficiency with control thereof. The greater the degree of decentralisation the more authority and responsibility is delegated to line managers.

In the extreme case, each production department is regarded as a separate manufacturing enterprise within the organisation. These are called "quasi-firms," each of which is considered to incur its own profit or loss. (Vide R.B. HORNBLOWER, "Observations on decentralisation in large enterprises," in Industrial Economics, November, 1960, pp. 7,8). For this degree of decentralisation to be feasible, each department must be relatively independent of the others with respect to throughput, quality, raw materials, etc.

Although decentralisation to this extent is rarely encountered in process industries, many large multiple product concerns compromise by instituting some form of divisional profit responsibility. (Vide M.J. GORDON and G. SHILLINGLAW, "Accounting: a management approach," Irwin Inc., Illinois, 1964, pp.753-755). Decentralisation along these lines can be effective in single-line product industries, but is rarely practicable where joint processes are involved. (Vide H.C. GREER, "Divisional profit calculation," in NAA Bulletin, Vol. 43, No. 11, July, 1962, pp.6-7).

Regardless of the manner in which the processes comprising a joint product manufacturing sequence are departmentalised, all are interrelated by virtue of the technical interdependence of the products. This factor necessitates consideration of the sequence as a whole for optimisation purposes. Consequently, decision-making with respect to practically every aspect of production quantities or qualities is of necessity a centralised activity.

Joint product manufacturing management is thus faced with an unavoidably high degree of centralisation of authority and responsibility, with accompanying problems in the areas of motivation, communication and control.

3.3 CONTROL ASPECTS

As has been stated, the allocation of joint manufacturing costs to individual products is at best a semi-arbitrary process. The consequences thereof and other aspects concerning managerial control of joint product manufacturing activities are examined.

3.3.1 COST CONTROL IN THE JOINT PRODUCT ENTERPRISE

Cost control can be broadly described as the determination and analysis of cost data with a view to cost reduction. The importance of this function in the maximisation of returns cannot be over-emphasised. The need to accumulate and analyse the costs involved in joint product manufacturing is undisputed. The arbitrary nature of allocated joint costs for individual products poses a real problem with respect to their use for control purposes.

Unit product costs and cost/volume relationships are used extensively for control purposes in single-line manufacturing concerns, particularly where more than one product is manufactured. Individual product costs play an important role in budgeting and standard costing for multiple product manufacturing, both of which systems provide valuable control information.

It is on these grounds that a case can be made for the use of allocated joint costs for control purposes. R.I. DICKEY (op. cit., p. 13.37) makes the following statement in this connection:

> "Care must be taken, however, in the use of allocated joint costs, since the allocations may introduce fluctuations not related to managerial performance and may focus attention on the method of allocation rather than the amount of cost to be controlled."

In view of the absence of any generally recognised basis on which joint costs may be allocated to individual products, management is faced with the important decisions of whether and how to allocate these costs for control information purposes.

3.3.3 EFFICIENCY CONTROL FOR JOINT PROCESSES

Modern mechanised and capital-intensive joint processes are characterised by a low proportion of variable costs. This is particularly so in the petroleum-refining and petrochemical industries. In CHAPTER II of this study a figure of 25% was quoted for the Shell, Pernis refinery. Of this variable cost the major portion is made up of raw material costs. For such processes, therefore, the efficiency with which raw materials are converted to saleable products is a useful guide to the efficiency with which the joint process is operated. Figures which reflect deviations from standard material efficiency constitute useful control information.

The material efficiency of a single-line process can be measured by comparing actual and standard performance. By incorporating standard raw material costs, variances can be determined which reflect the cost of deviation from standard performance. A useful single yardstick in this respect is the material quantity variance (or usage variance) which is derived from the following formula:

(Actual quantity - standard quantity)
x standard cost.

Another variance which facilitates material efficiency control is the so-called "mix variance." (Vide C.B. NICKERSON, "Managerial cost accounting and analysis," McGraw-Hill Co., New York, 1962, pp.311-312). This variance may be used where various combinations of differently priced raw materials may be required to meet product specifications under different (uncontrollable) conditions. It is important to note that the "mix" variance alludes to the raw material and not the product mix.

For single-line processes the usage and, where applicable, the "mix" variances are sufficient to reflect material efficiency adequately. This does not apply in the case of joint processes. The case is taken of a joint process which involves the extraction of products A and B from a given raw material. All else being equal, the usage variance as described may be zero at sub-optimum efficiency. This can occur if product A has a higher market value at separation than B, and is lost to B due to inefficient separation.

Additional performance indicators are seen to be essential if joint product manufacturing is to be effectively controlled.

4 CONCLUSIONS

The factors of technical interdependence of joint products and the absence of any non-arbitrary basis on which joint costs may be allocated to individual products, tend to complicate the management of a joint product manufacturing enterprise. The conclusions arrived at in this respect are summarised below.

(a) The degree of uncertainty associated with manufacturing plans based on the composite demand forecast for a set of joint products is inherently greater than that for a set of single-line products.

(b) Any deviation from forecasted demand on which optimum resource allocation has been based tends to result in a greater deviation from maximum returns than otherwise if the products are technically interdependent.

(c) The joint product manufacturing sequence must be considered as a whole for optimisation purposes. Where a multiplicity of products and processes are involved, resource allocation decision-making can become an extremely complex function.

(d) Allocated joint costs and cost/volume/profit relationships for individual joint products tend to be unsuitable for certain planning purposes. Alternative decision-making information systems are necessary if resource allocation to products is to be optimised.

(e) Joint product pricing is a particularly important and complex function. Specialised procedures which do not depend on the allocation of joint costs to individual products may be necessary.

(f) In the absence of any generally recognised basis on which joint costs may be allocated to individual products, management is confronted with the important decisions of whether and how to allocate these costs for control purposes.

(g) Documented cost-variance analysis procedures for single-line products provide insufficient control information regarding the efficiency with which a joint process is operated.

The above are special managerial problems associated with joint product manufacturing. In the course of the remainder of this study, various systems and techniques are reviewed which can assist in the optimal solution of these problems. PART TWO is devoted to an analysis of the theory and practice of joint product costing.

PART TWO

JOINT PRODUCT COSTING:

PRINCIPLES AND PRACTICE

FOREWORD TO PART TWO

In CHAPTER IV the principles of joint product costing are examined. The particularization of direct and indirect costs incurred in the joint process is discussed in the light of the technical-economic concept of cost. In CHAPTER V various documented methods by which joint costs can be allocated to products are critically examined. CHAPTER VI deals with the development of a costing system for joint product manufacturing with special reference to joint process efficiency control.

CHAPTER IV

PRINCIPLES OF JOINT PRODUCT COSTING

1 INTRODUCTION

Broadly stated, returns constitute the difference between revenue and costs. Of these two variables, management has control over only one: costs. Revenue is not directly under the control of anyone within the business enterprise, but, in a market economy, depends solely on the customer and what he is prepared to pay for the goods produced. In this respect, P.F. DRUCKER (op. cit., 1964, p.4) states that there are no profit centres within the business, but only cost centres.

> "The only thing one can say with certainty about a business enterprise ... is that it consumes efforts and thereby incurs costs. Whether it contributes to results remains to be seen."

It would, however, be a gross misconception to believe that the maximisation of returns simply involved the minimisation of costs. Despite the exogenous nature of the revenue variable, one of the primary entreprenerial functions involves the exploitation of opportunities within the source of revenue; namely, the market.

As the endogenous profit variable, costs are manufacturing managements' key concern. Their determination, particularization and control are vital to its objective of maximising returns. In this chapter the principles involved in the particularization of manufacturing costs to joint products are examined in the light of the basic technical-economic concept of cost.

2 THE CONCEPT OF COST

The basic concept on which the costing aspect of this study is based originated in the Netherlands. Business administration has long been regarded as an applied economic science in that country, and the development of cost accounting into a normative science is attributed to the Amsterdam school. The cost concept of this school is founded on the work of Th. LIMPERG Jnr., whose theories were later developed by his pupils, H.J. VAN DER SCHROEFF, A. MEY and S. KLEEREKOPER. (Vide A.J.E. SORGDRAGER, op. cit., 1964, p.7). A valuable contribution, particularly with respect to the practical application of this concept has been made by SORGDRAGER who is a pupil of Prof. VAN DER SCHROEFF.

Relevant aspects of this concept are examined.

2.1 COST AND VALUE

The incurrence of cost is generally understood to involve the sacrifice of something of value. Technically speaking, cost is the recorded measurement of a sacrifice which can ultimately be expressed in terms of monetary units. With respect to manufacturing costs, A.J.E. SORGDRAGER (op. cit., 1964, p.25) states that:

> "The valuation of this sacrifice is intrinsically the valuation of the services of the factors of production which have gone into the product."

The extent to which a sacrifice is economically justified depends on the difference between the value of the sacrifice made and the realisable value of the goods or services received in exchange. Costs thus involve sacrifices which, in order to be meaningful in an economic sense, must be related to value.

A.J.E. SORGDRAGER (op. cit., 1964, p.7) states correctly that value and cost are closely linked, in that cost is not possible without value and no unit can possess value if the sacrifices involved are not coupled with cost. He defines the concept of cost as follows:

> "Costs are those value units which must be sacrificed for the production in order to obtain new values."

Th. LIMPERG ("De gevolgen van de depreciatie van de gulden voor de berekening van waarde en winst voor het bedrijf," Vijf en Twintig Jaren Maandblad Voor Accountancy en Bedrijfshuishoudkunde, Deel I, 1936, p.336) describes the economic value unit as:

> "de kwantitatiewe voorstelling van de betekenis van een goed voor de behoeftebevrediging van de bezitter of gegadigde."

2.1.1 THE REPLACEMENT VALUE CONCEPT

Technical costs, once incurred or imputed, are definite measured quantities. Value, in a dynamic environment, may fluctuate widely in sympathy with a large number of complex variables. A direct relationship between cost and value can consequently only exist at the moment of transaction.

J.H. ELS (op. cit., p.25) attributes the most important development in cost-value relationship to the Amsterdam school, with the development of the replacement value concept. The replacement value is the valuation on the basis of the price on the buyer's market at the moment of economic exchange. (Vide A.J.E. SORGDRAGER, op. cit., 1964, p.33).

In terms of the concept, replacement must be based on an economically efficacious decision. Inopportune replacement or arbitrary replacement does not comply with this requirement and in such cases replacement price, as opposed to value, is involved. A.J.E. SORGDRAGER (op. cit., 1964, Chapter II) shows clearly how replacement price is not necessarily related to cost, in the technical-economic sense.

If the replacement value as defined is incorporated in the basic concept of cost, the measurement of the sacrifice in exchange becomes economically meaningful.

2.1.2 COST AND EXPENSE

It is clear that although "costs" and "expenses" are related, the terms are by no means interchangeable. The difference lies in the economic justification of the sacrifice involved in the exchange. J.H. ELS (op. cit., p.34) sums this up as follows:

> "Costs should not be seen as the expenditure incurred, but as the expenditure necessarily incurred in the manufacture of the product and only that expenditure efficiently incurred."

P.F. DRUCKER (op. cit., 1964, p.64) refers to expenditure which does not produce economic results as waste, stressing that the ratio between efforts and results is more important than the absolute (technical) cost level.

> "Cost, after all, does not exist by itself. It is always incurred - in intent at least - for the sake of results. No matter how cheap or efficient an effort, it is waste rather than cost if it is devoid of results."

(It is interesting to note that DRUCKER is in fact stating one of the basic principles of the normative approach to costing.)

Only those sacrifices which are necessarily incurred in order to produce economic results can be classified as costs, the remainder are waste. Waste does not include technically or economically unavoidable plus-usage, the sacrifices associated with which are, by definition, costs. Standard costs provide a means by which waste and plus-usage may be differentiated. As such, standard costing can be regarded as an extension of the replacement value concept.

Only by incorporating the replacement value concept in the concept of cost can any distinction be made between cost and waste. The technical-economic concept of cost is consequently of fundamental importance to the practice of effective managerial control and decision-making.

2.2 COMMENTS ON THE NORMATIVE COST CONCEPT

The technical-economic concept of cost as outlined above is by no means universally accepted or applied. Although the importance of the relationship between cost and value is generally recognised, this aspect is circumvented rather than placed on a sound theoretical basis.

The traditional American approach in this connection is aptly illustrated by N.M. BEDFORD (in Accounting Review, Vol. 32, No. 1, Jan., 1957, p.9). Quoting the findings of the American accounting association committee on cost concepts and standards, he states that cost represents a release of value for the creation or acquisition of economic resources. He notes that:

> "... this view is broad because of the indefinite nature of the term 'value release.' But this breadth is also the advantage of the term for it allows a variety of methods for measuring cost so that preciseness of a concept of cost may be provided by the method by which cost is measured."

This approach can be traced back to J.M. CLARK (op. cit., p. 281) and his concept of "different costs for different purposes." This approach to the basic cost concept is justifiably termed "not only pragmatic, but opportunistic" by A.J.E. SORGDRAGER (op. cit., 1964, p.14).

The idea of different costs for different purposes is widely advocated in the Anglo-Saxon literature on the subject of costing. R.I. DICKEY (op. cit., p.1.11) states that it is advisable to use the word "cost" with a qualifying adjective or phrase which will convey the shade of meaning intended. He lists 22 "types of cost."

It is to be regretted that this approach is also prevalent in South Africa. (Vide J.H. ELS, op. cit., pp.29-33, and J.C.M. VAN NIEKERK, op. cit., p.18). The findings of ELS and VAN NIEKERK in this connection were confirmed by the writer in the course of the study of costing procedures in certain joint product manufacturing enterprises.

Non-acceptance of the normative approach to the concept of cost is not restricted to the Anglo-Saxon literature. J.A. GEERTMAN ("De leer van de marginale kostprijs," Elsevier, Amsterdam, 1948, p.19) criticises the approach as being in conflict with realities encountered in practice. Referring to the LIMPERG (Amsterdam) school of thought, he states that:

> "Dese school houdt zich te ver van de realiteid verwijderd ... De idealistishe en normatieve instelling ... kan tot conflict met de werklijkheid leiden."

This statement will be shown to be erroneous.

With respect to joint product costing, unless sound technical-economic principles are applied in the particularization of joint costs, the resultant product costs have no economic significance and may be meaningless and misleading. If purely technical cost concepts are applied, provided that the sum of the allocated individual product costs is equal to the cost of joint manufacturing and separation; any allocation basis, no matter how arbitrary, must be considered as being valid. That this is not the case is obvious.

Far from being in conflict with reality, the technical-economic concept of cost provides a basis on which costs may be particularized to joint products in a manner which is meaningful for control and

and decision-making purposes.

The remainder of this chapter is concerned with these precepts and the development of the concept of joint product costing as a problem in partial particularization.

3 THE NATURE OF JOINT MANUFACTURING COSTS

Having defined the basic concept of cost, the cost of manufacturing a set of joint products of a given joint process is examined.

3.1 CATEGORIES OF MANUFACTURING COST

The sacrifices involved in a manufacturing system may be classified as follows:

(a) application of raw materials and auxiliary materials;

(b) application of human labour;

(c) wear and tear of durable means of production;

(d) use of the land;

(e) services of those outside the system;

(f) taxes, royalties, etc.

(Vide A.J.E. SORGDRAGER, op. cit., 1964, p.55).

The cost price of a product or set of products is the sum of the costs associated with its manufacture. With respect to the set of joint products, some of these costs can be classed as direct in that they can be traced directly to the set. The remainder are indirect. Both direct and indirect costs can be broadly grouped into labour costs, material costs and overhead costs.

It must be noted that a direct cost of the set of joint products is not necessarily a direct cost of an individual joint product.

3.2 JOINT MANUFACTURING COSTS DEFINED

A number of conflicting definitions appear in the Anglo-Saxon literature with respect to joint manufacturing costs. This is largely the result of the use of the "different costs for different purposes" principle, and the prevailing lack of any precise definition of what constitutes a joint process. A notable exception in the latter respect is the valuable contribution to the Anglo-Saxon literature on this subject by T.J. KREPS, ("Joint costs in the chemical industry," Quarterly Journal of Economics, Vol. 44, 1930, pp.416-461).

3.2.1 A TECHNICAL-ECONOMIC DEFINITION

Having examined the nature of the joint process and the technical-economic concept of cost, the cost of manufacturing the set of joint products of a particular joint process can now be defined as follows:

> The sum of the direct and indirect costs associated with the sacrifices which are required technically, essential for the joint process, and economically unavoidable.

In this study the term "joint cost" refers to the above definition. Where used, joint cost thus applies to the cost of manufacturing the set of joint products of a particular joint process. It should not be confused with the "joint costs" used by some Anglo-Saxon authors in connection with the cost of transporting mixed loads; real estate costs, etc. Furthermore, it should not be taken to refer to the cost of manufacturing the set of products of the joint manufacturing system. (Vide Chapter I, 3.1.2.3, op. cit.)

3.2.2 JOINT COSTS AND COMMON COSTS

It is necessary to distinguish clearly between the concepts of joint costs and common costs. Some documented definitions are critically examined.

(a) E.L. KOHLER ("A dictionary for accountants," Prentice-Hall, New York, 1957) regards joint costs as a special type of common costs, defining them as follows:

> "The common cost of facilities or services employed in the output of two or more simultaneously produced, or otherwise related operations, commodities or services."

(b) I.W. KELLER and W.L. FERRARA ("Management accounting for profit control," McGraw-Hill Co., New York, 1966, p.608) adopt a similar line, with joint costs being described as:

> "Those costs of a basic raw material and processing from which inevitably arise two or more distinct products;"

and common costs as:

> "Those costs of any kind which cannot be nonarbitrarily assigned to any segment of a firm. The products (if any) involved need not be distinct products nor products which inevitably arise together."

The view that joint costs are a form of common costs with no distinction being made on a cost concept basis, is held by a number of authors. (Vide R.I. DICKEY, op. cit., p.133). These include H. BIERMAN Jr. ("Topics in cost accounting and decisions," McGraw-Hill Co., New York, 1963, p.59). He cites the classic example of joint products, namely the slaughtering of a pig with resultant joint products in the form of various cuts, meats and processed products such as ham and bacon. By referring to the purchase price of the pig as "common" and the cost of processing it as "joint," the two concepts are sadly confused.

(c) In contrast to the above, L.L. VANCE (op. cit., p.324) regards the two concepts as being mutually exclusive. He maintains that common costs can be traced to the separate products on a cause and effect basis or by tracing the use of facilities, and do not include direct materials and labour. Joint costs can not be so traced and do include direct material and labour costs. G. SHILLINGLAW, ("Cost accounting, analysis and control," Irwin, Illinois, 1962, p.102) holds much the same view.

(d) A.J.E. SORGDRAGER, (op. cit., 1967, p.257) using the normative approach, distinguishes clearly between the two concepts on a sound technical-economic basis. What follows is a summary of his reasoning.

> Common costs ("saamgevoegde koste") occur when common facilities are used for reasons of economy. Joint costs ("gemeenskaplike koste") occur when two or more products are produced simultaneously in a joint process from the same materials owing to technical unavoidability.

It must be noted, however, that in his book, "The particularization of indirect costs," the terminology is reversed. (Op. cit., p.62). One of the primary differences between the two types of cost is that the costs associated with each operation in a joint process are always incurred simultaneously with respect to all products. This is not the case with common costs. By virtue of the fact that the word "joint" holds time connotations of concurrency (vide P.M. ROGET, "Roget's

Thesaurus," Penguin, London, 1953, p.60), whereas "common" does not necessarily denote concurrency; the reversed terminology is not favoured.

3.2.3 WORK-UP COSTS

R.I. DICKEY (op. cit., p.13.7) quotes LORIG as follows:

> "In effect, the costs incurred up to and including the split-off point and the separate processing costs incurred afterward up to the point where sales values are determined are all joint costs."

This statement must of course be rejected as costs incurred in the work-up of individual products may be common costs but are in no way joint costs.

Where two or more joint processes are incorporated in the joint product manufacturing system, a case may be made on practical (although not conceptual) grounds for regarding these as constituting a single process. This only holds for certain cases. The example is taken of a set of joint products which are actually formed in a single synthesis process, but are separated in a series of separation processes. If the costs of separation make up a minor percentage of the total cost, it may be feasible to group the joint processes for practical purposes. If, in such an event, costs are to be allocated to individual products for control purposes, care must be taken to ensure that the objective thereof is not defeated.

4 THE CAUSAL RELATIONSHIP BETWEEN JOINT COSTS AND JOINT PRODUCTS

The question arises as to whether any of the costs associated with a joint process bear determinable causal relationships to the values imparted to the individual products by virtue of their incurrence. The direct costs of the joint process can be traced on a causal basis to the set of jointly-produced products. Whether any of the cost categories bear a determinable relationship to the individual separated products is examined.

4.1 JOINT MATERIAL COSTS

4.1.1 RAW MATERIALS

In most cases the raw materials consumed in a joint process or combinations of the components thereof, can be directly identified in the products. In extractive processes the raw material actually consists of a conglomerate containing the eventual products. Gold/uranium ore thus contains the products, elemental gold and uranium oxide. In synthesis processes the identification is not as straight forward. The basic chemical elements constituting the final products are, however, identifiable in the raw material.

An exception occurs in the case of jointly produced radioactive isotopes, manufactured by the bombardment process. Here, the resultant products as such cannot be identified in the raw material.

The cost of the raw material can rarely be associated with the value of the joint products. In order to relate the sacrifice involved in the acquisition of the raw materials directly with the materials constituting each joint product, the purchase price of the raw material must be based directly on its individual components going to make up the separated products. An example of this occurs in the case of platinum/nickel ore, where the price is based directly on the assay of both components. Such cases occur mostly where the prices are artificially fixed and bear no relation to the actual cost of producing the raw materials in the first place.

Unless the raw material price is based on the product components as described, no relationship can be established between the purchase price or cost of the raw material, and the replacement value of the product. Consequently, in the majority of cases, raw material costs cannot be directly traced to individual joint products on a cause and effect basis.

4.1.2 PROCESS MATERIALS

The set of all joint products is operated on simultaneously in the joint process. The cost of any process materials consumed can not be said to be incurred for the sake of producing any one, but not the other, joint products. Consequently, the cost of materials such as catalysts, fuel, coolants, etc., consumed in the joint process, bear no determinable relationship to any individual joint products, but only to the set thereof.

Furthermore, the fact that a change in the yield of any one joint product inevitably results in a change in the yield of one or more of the companion products, precludes the quantitative establishment of any causal relationship between process materials used and individual products.

4.2 JOINT LABOUR COSTS

Any human effort expended in the course of the joint process is of necessity applied simultaneously to the set of all raw materials. No part thereof can therefore be directly identified with any single unit of product produced in a joint process. No causal relationship between labour costs and individual joint products can therefore be determined.

4.3 JOINT OVERHEAD COSTS

With respect to joint product manufacturing equipment, overhead costs such as capital costs, maintenance etc. bear no direct relationship to individual products. All joint products are processed simultaneously by means of the same equipment and in order to produce any one, all must be operated on together.

4.4 CONCLUSIONS

The following can be said concerning the causal relationship between joint costs and the replacement value imparted to joint products by virtue of their incurrence:

(a) the technological nature of the joint process is such that no causal relationship is determinable between any individual joint product and the incurrence of any definable proportion of the total joint costs involved;

(b) although direct costs of the joint process may be traced to the set of jointly produced products, it is in effect impossible for any single product of a joint process to incur cost individually prior to its split-off point.

The conclusions arrived at with regard to the causal relationship between the joint cost and the individual products of the joint process are concurrent with those of J.C. LESSING (op. cit., p.244), and serve to corroborate his findings in this respect.

The remainder of this chapter is devoted to the principles involved in the allocation of joint costs to products in the light of the above.

5 COST PARTICULARIZATION PRINCIPLES AND JOINT COST ALLOCATION

In the following chapter various methods by which joint costs may be allocated to individual products, are discussed. These methods can be broadly grouped into two categories:

(a) methods based on some physical unit common to all products;

(b) methods based on the relative realisable value of the products at separation.

The principles of cost particularization with respect to joint processes and the merits of the above methods are examined.

5.1 THE THEORY OF COST PARTICULARIZATION

C.W. SARGENT, ("Handbook of cost accounting," D. van Nostrand Co., New York, 1951, p.61) lists product cost allocation as a major business problem. He maintains that there is no such thing as an "actual product cost" in the sense of absolute authenticity and verifiability. This argument is based on the degree of arbitrarity involved in the allocation of indirect costs and the average nature of direct costs accumulated on a period basis.

The allocation of manufacturing costs to products is seen to present a major problem, the optimal solution of which is relevant to the maximisation of returns. In this respect the particularization theory developed by A.J.E. SORGDRAGER is of considerable significance.

> The basic principles and their application are contained in his thesis: "Die verbesondering van indirekte koste," (A.A.A.-Rotex, unpublished thesis for D'Econ, Amsterdam, 1961) to which the reader is referred.

The concept of the particularization process incorporates the tracing of all costs to cost centres, which may be regarded as separate enterprises. From these cost centres, costs may be further apportioned to products by tracing the causal relationship between the incurring of the cost and the product. If this relationship can only be traced as far as the cost centre, then the particularization process should not be carried further, but the cost should rather be prorated to the products of the activity involved.

A pupil of A.J.E. SORGDRAGER, J. BATTY ("Application of standard costing as a tool of management in certain British industries," Unpublished thesis for D.Com., P.U., 1967, p.139) describes the particularization theory as follows:

> "There is no question of all fixed costs being put into a pool and not being traced to products as in marginal (direct) costing, nor all costs being allocated or apportioned as in total or conventional costing. Instead each type of cost is treated on its own merits and action taken accordingly."

The above constitutes a brief outline of this concept, which is considered to represent a major breakthrough in costing theory. It forms the basis of the approach to the principles of joint product costing adopted in this study.

5.2 THE PARTICULARIZATION PROCESS

G. SHILLINGLAW (op. cit., p.103) states correctly that all costs may be classified as being either direct or indirect. As far as the enterprise as a whole is concerned, all costs are direct. Within the cost structure of the enterprise, however, indirect costs occur with respect to cost centres and products which must be particularized if costing is to be placed on a sound basis. A.J.E. SORGDRAGER, (op. cit., 1964, p.72) describes this process as follows:

Total costs are divided into costs directly traceable to the product, and indirect costs. By tracing a causal relationship between the indirect costs and the cost centres involved, these costs are classified as particular costs of the cost centre, or as general costs. General costs and indirect costs have in common that each must still be particularized to cost centres or products. Indirect costs are made particular costs of the product via the partial particularization.

What are indirect costs of the product may be particular costs of the cost or sub-cost centre. The particularization always takes place from a bigger to a smaller unit with cost centres being regarded as interim steps in the process of arriving at the cost per product.

See A.7, FIGURE IV.1

The above figure depicts the classification scheme of the direct, indirect, general and particular costs.

5.3 THE PARTICULARIZATION OF JOINT PROCESS COSTS

The joint process, as described in chapter I of this study, comprises a series of unit operations which are performed sequentially on a set of raw materials. These operations or related groups thereof constitute cost centres. The final cost centre in the process sequence will constitute or contain the separation operation which is the split-off point.

The proration of direct costs to the cost centres involved can be effected in the normal manner. Indirect costs must then be particularized to the cost centres via the causal relationship, thereafter becoming particular costs of the various cost centres. The sum of the particular costs of the final cost centre will include all the particular costs of all cost centres in the joint process.

> The sum of the costs particularized to the final cost centre is the particular cost of producing the set of joint products of the joint process. It is thus the joint cost as defined.

The question now arises as to whether the joint cost can be particularized to individual products. A.J.E. SORGDRAGER (op. cit., 1964, p.98) states specifically that:

> "... it is essential to trace an organic or causal relationship to arrive at a particularization basis."

As has been shown, no causal relationships can be traced between joint cost and individual products. It is therefore not feasible to carry the particularization further than the last cost centre in the joint process.

Particularized in this way and up to this point, the cost of producing the set of joint products of the joint process is controllable. In respect of the joint cost as defined, the split-off point is the control point. In view of the absence of traceable causal relationships beyond this point, further particularization serves no purpose from a cost accumulation point of view, with respect to the joint process.

Immediately after it has been separated, any further work-up costs incurred by an individual product can be particularized to that product as if it were a single-line product.

5.4 THE ALLOCATION OF PARTICULARIZED JOINT COSTS TO SEPARATED PRODUCTS

Hypothetically, a knowledge of the cost price of each individual joint product is just as desirable as that of any other type of product. However, in the absence of determinable causal relationships, no non-arbitrary basis exists on which the joint cost can be prorated to individual products. It is consequently impossible to determine the cost price of any individual joint product on a normative basis.

Despite their arbitrary nature, a number of well-documented methods exist for the allocation of joint costs to separated products. These are discussed in the following chapter. What follows is an examination, in principle, of the usefulness and significance of allocated joint costs.

5.4.1 THE USES OF ALLOCATED JOINT COSTS

5.4.1.1 STATUTORY REQUIREMENTS IN SOUTH AFRICA

Under certain circumstances a South African manufacturer may be legally required to keep records pertaining to the cost of manufacturing one or more members of a set of joint products. The price controller may, from time to time, by notice in the Gazette, or, with the authority of the Minister of Economic Affairs, in the case of a particular person, require any person purchasing any goods for use in the manufacture of any class of goods for sale, to keep records relating to the cost of "processing, manufacture or production of such goods." (Vide Price Control Act, No. 25 of 1964, section 11, as amended in section 6 of Act No. 80 of 1967).

The controller may alternatively require such records as will permit "the ready and accurate ascertainment" of the cost of manufacturing any goods.

Where such goods are jointly produced, allocation of joint costs to products by some or other means is necessary.

5.4.1.2 THE USEFULNESS OF ALLOCATED JOINT COSTS AS MANAGERIAL INFORMATION

As has been stated, with respect to the joint process joint cost allocation to individual products serves little purpose. However, if a non-arbitrary basis on which this could be effected, existed, such costs could be used for the following purposes:

(a) as a basis for pricing policy;

(b) cost/volume analysis for decision-making purposes. (This would apply particularly where the ratio of product yields was a function of some or other joint cost);

(c) cost control; including budgeting, process costing with respect to work in process and lost units in work-up departments, and efficiency variance analysis.

(These factors were discussed in chapter III of this study).

The absence of a normative basis on which allocation can be made seriously limits the usefulness of allocated joint costs for decision-making purposes. As will be shown in the subsequent chapter, most of the documented methods will result in product "costs" which are either entirely unsuitable or may be misleading if generally used for pricing or cost/volume analysis purposes.

However, as discussed in chapter III, (op. cit)., a case can be made for apportioning the joint cost to products for control purposes. Manufacturing management may consequently be faced with the decision as to which type of allocation method to employ. This question is discussed in principle below.

5.4.2 JOINT COST ALLOCATION FOR CONTROL PURPOSES: RELATIVE MARKET VALUE VERSUS PHYSICAL UNITS AS A BASIS

Recognising that the problem of allocating joint costs to products is extremely difficult and "perhaps impossible," I.W. KELLER and W.L. FERRARA (op. cit., p.601) state that the least arbitrary method seems to be the sales value method since it yields an equality of gross margin percentages.

> "The only way to eliminate the arbitrariness of joint cost allocation is to eliminate the allocation, and this can only be done if joint products are valued ... at their net realisable value."

M.J. GORDON and G. SHILLINGLAW (op. cit., p.715) are adamant in their condemnation of methods based on average or weighted physical units.

> "Allocation on some physical basis such as weight or volume is an obvious but unacceptable course of action. The resultant cost figures need bear no relation to the value of each product, and fluctuations in periodic income would bear little relation to the firm's performance."

They regard relative market value as being the least arbitrary basis.

R.I. DICKEY, (op. cit., p.13.11) maintains that many, if not most, cost accountants believe that joint costs should be allocated to individual products according to their ability to absorb joint costs. Underlying this is the theory that costs would not be incurred unless the jointly produced products would yield enough revenue to cover all costs plus a reasonable return.

While this idea has merit, DICKEY, in common with a number of Anglo-Saxon authors, makes no attempt to justify use of the realisable value basis on conceptual grounds.

In principle, the use of relative realisable market value as a basis for joint cost allocation, is partially justified in terms of the technical-economic concept of cost. In order to conform to this concept, cost must be related to the replacement value imparted to the product by virtue of its incurrence. Where the realisable market value is congruent with replacement value, the costs obtained are conceptually correct.

In practice, however, market prices may be determined by factors which are unrelated to the cost of manufacturing the set of joint products. In such cases, the prices actually obtained for the various joint products may bear little relation to the replacement value as defined. In effect management may not be able to take economically efficacious decisions with respect to the moment of selling for every product in a fluctuating price situation. Limited storage capacity, the credit supply and other factors may prevent this.

The use of standard market values tends to nullify the above effects which represent a serious objection to the use of the method. By standards in this sense are meant predetermined values based on the optimised resource allocation plan and marketing strategy. Standard realisable market value thus represents the revenue accruing from the sale of the optimum quantity at the optimum price, and at the most opportune moment. Provided that the forecasted data on which the plans, strategies and standards were based, prove to be acceptably accurate, joint cost allocation on this basis for cost control purposes is conceptually superior.

It will be seen in the next chapter that other methods of cost allocation can result in certain joint products showing an excess of cost over selling price, while other products reflect a substantial profit margin. As the products are technically interdependent, the "losses" shown for certain products in this case need not reflect managerial or operating inefficiency. Proportions thereof are in fact costs incurred in the production of the other "more profitable" products.

Use of the realisable market value method is not advocated for any purpose other than cost control. Its use for pricing purposes is obviously unfeasible and in view of the fact that it results in the same gross profit margin for each product, it can definitely not be generally used for decision-making purposes.

It must be emphasised that the joint cost of the set of joint products is the primary consideration as regards decision-making. The split-off point remains the control point in this respect, as any production decision affecting any one product must affect one or more others produced in the joint process.

6 SUMMARY

Using the normative approach, the joint cost is defined as the sum of the costs associated with the sacrifices which are required technically, essential for the joint process, and economically unavoidable. While the direct and indirect costs can be particularized to the set of joint products at the split-off point; the indeterminable causal relationships between the joint cost thus obtained and the separated products precludes the determination of individual cost prices on a normative basis.

The absence of a normative basis on which joint cost can be allocated seriously limits the usefulness and significance of individual joint product costs comprising artificially apportioned segments of the joint cost. Costs allocated on the basis of standard realisable market value (as described) may be economically meaningful but can only be used for cost control purposes.

In the following chapter aspects of the various documented joint cost allocation methods used in practice are critically examined.

CHAPTER V

A SURVEY OF JOINT COST ALLOCATION METHODS

1 INTRODUCTION

A.J.E. SORGDRAGER (op. cit., 1964, p.64) makes the following statement in connection with joint cost allocation:

> "From the point of view of a causal relation there is in this instance an insoluble problem and theoretically the matter can be taken no further. In practice no management can accept such a position and artificial solutions will have to be found in order to come to an approximate cost by certain allocation methods ..."

There is no generally accepted method by which joint cost may be allocated to individual products. In practice a wide variety of systems are employed. In this chapter various bases and procedures in common use are examined, and illustrated by means of case studies.

Although some of the methods reviewed are highly arbitrary, they have been developed in response to particular managerial information requirements. As such each merits examination, albeit critical.

As defined, the term joint cost refers only to the sum of the costs incurred up to the split-off point and excludes work-up costs. However, several of the methods outlined in this chapter make no distinction between joint and work-up costs, and all product costs are regarded as being joint.

Although a statistical survey of the methods used in South African industries has not been attempted, certain systems encountered in the course of research are mentioned in this chapter. Details of these systems have been omitted at the express request of the companies concerned.

2 THE AVERAGE UNIT COST METHOD

2.1 DISCUSSION

Perhaps the simplest method of joint cost allocation is the average unit cost system. Under this system each product is valued at the average cost in proportion to the quantities produced. R.I. DICKEY (op. cit., p.138) states that total costs only are figured, yielding an average cost per unit and one nett profit. An average cost is obtained for the set of joint products and then prorated according to the number of units of each produced.

The system has limited application and the following conditions should apply for the method to be usable:

(a) The products must all be expressed in the same units, e.g. litres, tons, cubic meters, etc.

(b) The sales values per unit for all products should be roughly equal with no product being priced significantly higher or lower than its companions.

(c) The method can only be used without modification if no product or group of products incurs appreciably more cost after separation than the remainder.

2.2 CASE ILLUSTRATION

To illustrate the application of this method, the case of a sawmill and timber-treating concern is considered.

The enterprise is a family-owned sawmill and creosoting concern, centrally situated among pine and bluegum timber estates. Timber is purchased on a forest-acre basis as it matures, whereupon the trees are felled, stripped and transported to the sawmill. The timber is cut into poles, the aim being to obtain straight lengths of as many multiples of one meter as possible. The poles are then sorted into similar lengths and stacked for seasoning, the offcuts being burned to produce charcoal. When seasoned, the poles are weighed and pressure impregnated with creosote under controlled conditions. Thereafter they are allowed to dry and stacked for despatch.

The units in which the raw material and the products are measured are cubic meters. The selling price per cubic meter varies according to the length and thickness of the pole; which two factors determine the grade of the product. The different products are graded joint products, two or more being obtained from the same raw material and being processed simultaneously prior to separation. In this case the sawing operation represents the split-off point.

See A.25, TABLE V.1
See A.26, TABLE V.2

Table V.1 reflects the calculation of the average unit cost, while table V.2 shows how the unit cost is used to cost the various grades according to the quantities produced. The off-cuts are treated as a by-product and costed by subtraction.

2.3 ADVANTAGES AND DISADVANTAGES

From table V.11 it can be seen that grades A and B show an excess of costs over selling prices according to this method of allocation. The case is taken of a 12 m straight length which is cut into two 5 m lengths and one 2 m length. In order to produce two "high profit" 5 m lengths it is technically unavoidable to produce either one 2 m or two 1 m lengths in addition thereto. The apparent "losses" on grades A and B obtained by this method are in effect costs of producing the other "high profit" products.

The method has serious limitations with respect to pricing and should not be used for this purpose.

The system is based on a certain amount of logic from a technical cost point of view. It can not be stated with conviction that prior to the split-off point, any grade is more or less expensive to produce.

A practical advantage is that the method provides an incentive to produce the maximum proportion of high market value products. However, unless post separation costs are accumulated separately, this factor may lead to sub-optimum resource allocation. Where graded joint products are concerned, none of which receive appreciably different unit work-up costs, the system is aptly suited for incorporation in a standard costing system.

2.4 APPLICATIONS

Subject to the conditions stated under 2.1 above, the average unit cost method or variations thereof can be used wherever graded joint products occur. Examples of the industries employing joint processes of this type are as follows;

- Trawler fishing;
- Leather tanning;
- Flour milling;
- Tobacco curing and processing;
- Fruit packing;
- Stone crushing, etc.

3 THE WEIGHTED AVERAGE METHOD

3.1 DISCUSSION

The weighted average method of joint cost allocation is a logical extension of the average unit costing method described above. It finds application in joint processes where the various products may not all be expressed in the same units, or where it is desirable that certain products should carry a greater percentage of the joint cost.

The procedure involves the expression of units produced in terms of "equivalent units" obtained by weighting the number of actual units produced by application of a suitable coefficient. A. MATZ, O.J. CURRY and G.W. FRANK, (op. cit., p.420) give the weighting factor in "points" by which actual units are multiplied to obtain equivalent units. Cost allocation is then made on the basis of the relative quantities of equivalent units.

The average unit cost is based on the total joint cost divided by the number of equivalent units and not the actual quantities as in the case of the method described under 2.1 of this chapter.

The weighting coefficient or weighting factor may be based on one or more of the following considerations:

(a) Costs incurred after split-off.

(b) Quantitative considerations with respect to the units involved (size, weight, volume, etc.)

(c) Time consumed in processing.

(d) Ease of manufacture.

(e) Labour.

(f) Process materials,

etc.

If the factor is based on more than one consideration, it is termed a "composite factor." Factors are usually set for each size, grade, etc., of product.

3.2 CASE ILLUSTRATIONS

To illustrate the weighted average method a talcum powder and a fruit canning process are discussed.

3.2.1 A TALCUM POWDER PROCESS

The process involves the pulverisation of refined talc chips in a single tituration process. The nature of the milling equipment is such that a range of particle sizes is inevitably obtained, although a degree of flexibility exists with respect to the ratio of product yields.

The powder mixture resulting from the primary tituration process is sifted into various grades according to particle size. The coarse grade is marketed in 200 kg barrels as commercial french chalk for use in the rubber, plastics and allied industries. The medium grades are scented and marketed in 50 kg plastic containers for use as cosmetic body or baby talcum powder. The fines are marketed in 10 kg tins for eventual use as face powder.

As mentioned, the relative quantities of the various grades can be varied to a limited extent by adjustment of the titurating equipment, but for technical and economic reasons, all grades are produced simultaneously in roughly fixed relative quantities. Altogether four grades are produced and marketed as Technical, Cosmetic A, Cosmetic B and Super-fine. The following table reflects the quantities produced as well as the costs incurred after separation and the total cost of production.

See A.27, TABLE V.3

For the purposes of costing the various grades, a composite weighting factor for each grade is applied. These factors comprise three elements:

(a) Quantity of units produced;

(b) Packaging cost;

(c) Cost of materials added.

See A.28, TABLE V.4

The above table shows the composite factor for each grade and its use in determining equivalent units; and the allocated cost per unit.

3.2.2 A FRUIT-CANNING PROCESS

See A,29, TABLE V.5

The above table depicts K.E. JANKOWSKI's now classical approach to the joint cost allocation problem in the fruit-canning industry. (Vide R.I. DICKEY, op. cit., p.13.10). Cases containing various grades and quantities of fruit are packed from mixed batches of fruit purchased in bulk.

The quantitative cases are used to allocate direct-preparation labour and other costs directly relating to the quantity of unprepared fruit. The qualitative cases are used to allocate the purchase price of the raw materials. The totals applicable in each instance are divided by the total basic case to obtain the cost per basic case. This unit cost is then multiplied by the relative factors to obtain the cost per actual case.

3.2.3 FURTHER EXAMPLES OF WEIGHTING FACTORS

In the case where a highly automated capital-intensive process using cheap raw materials is involved, separating and post-separation periods traceable to each product may be incorporated in the composite factor. Jointly produced isotopes for example may be separated by a diffusion process. Some of the products diffuse rapidly while others only separate from each other over a longer period.

Other examples of processing time as a cost-related factor occur in the chemical industry. (Vide BETRIEBSWIRTSCHAFTLICHEN AUSSCHUB DES VERBANDES DER CHEMISCHEN INDUSTRIE, e.V., "Kostenrechnung in der chemischen industrie," Gabler, Wiesbaden, 1962, p.107).
Further examples of composite factors based on various prior and post split-off considerations are quoted by P. RIEBEL, ("Die kuppelproduktion," Köln und Opladen, 1955) which reflect the versatility of this approach.

3.3 ADVANTAGES AND DISADVANTAGES

As can be deduced from the above illustrations, the method involves allocating the joint costs (as defined) involved on an average unit basis, with the factors applying for the most part to work-up costs and, in some cases, raw materials costs. The method has the prime advantage of simplicity. Once the number of units and the total cost is known, predetermined factors can be applied. The fact that the composite factors can be predetermined enables them to be incorporated in flexible budgets and standard costing systems without prior knowledge of the sales prices.

One of the disadvantages of the method is that not all cost factors can be conveniently incorporated in a composite factor. However, statistical methods may be used to establish the significance of cost and cause relationships in this respect. Furthermore, the method is only as appropriate as the factors used. These may be inappropriate either in the first place, or become so with the passage of time.

The weighted average system represents an attempt to establish a relationship between products and costs. In most cases, however, weighting factor merely converts the product volumes to common units and/or makes provision for work-up costs. In general, the use of carefully compiled and realistically based composite factors enables the adaptation of this method to a variety of joint processes.

Joint product costs obtained by this method can, under certain circumstances, be used as a rough guide to pricing. The method is certainly less arbitrary in this respect than the average unit cost system. Direct use of the resultant costs for pricing purposes is unsound, however, for the same reasons as those given for the average unit cost method on which this method is based.

The weighting factor is in effect a standard cost coefficient. Comparison with other standard costs for control purposes may be meaningless as the standard itself and not the cost will be compared. Where composite factors are employed, the resultant costs can rarely be used directly for variance analysis purposes. Their usefulness as control information is thereby limited.

3.4 APPLICATIONS

The weighted average method is best suited to graded products which have a roughly similar market value at separation. It can theoretically be employed in any type of industry. The South African Iron and Steel Corp. Ltd. uses a variation of this method for allocating certain by-product mixture work-up costs.

4 BASE UNIT SYSTEMS

4.1 DISCUSSION

In some joint processes a single constituent or physical unit is common to the primary raw material and all resulting joint products, and is used as a denominator for the allocation of costs. For example, in the natural gas industry, all constituent gases and mixtures thereof may be expressed in terms of the heat they produce on combustion, i.e. in joules or British thermal units (BTUs). In the liquor industry various quantities such as tons, gallons, litres, cases, etc., can be reduced to a common denominator - proof gallons, which is related to the alcohol content. Another example of a base unit involving a material component occurs in the nitrogen fertilizer industry, where nitrogen units form a useful common denominator for cost allocation.

The base unit systems as described apply only to the proration of the joint cost to products at separation. It is essential that post separation work-up costs be accumulated separately where this type of system is used.

A variation of the system is the so-called "theoretical" or "formula" basis for joint cost allocation. J.W. NEUNER and S. FRUMER (op. cit., p.414) describe this method as follows. During a given period, for every 5,000 lbs. of a certain material processed, 3,000 lbs. of product A and 1,800 lbs. of product B are obtained, with 200 lbs. being lost. This would establish a ratio of 18:48 for product B and 30:48 for product A, to be used in prorating the material costs, and, if required, the labour and overhead costs of all joint production. In this case the base unit is the physical unit of weight, namely lbs.

R.I. DICKEY (op. cit., p.13.10) quotes the example of the system whereby molecular weight is used as a base unit. In the electrolysis of sodium chloride solution, sodium hydroxide, chlorine and hydrogen are obtained as joint products by means of the following reaction:

$$2NaCl + 2H_2O = 2NaOH + Cl_2 + H_2$$
$$(116) + (36) = (80) + (70) + (2)$$

The figures in parenthesis represent the molecular weights of the compounds involved. Neglecting inefficiency and impurities, it can be assumed that 116 lbs. of sodium chloride in solution will produce 80 lbs. of sodium hydroxide, 70 lbs. of chlorine and 2 lbs. of hydrogen. Joint costs may be allocated to these products in the ratio 40:35:1, based on their molecular weights.

The important difference between the base unit system and the average unit cost method is that in terms of the latter, the total cost is divided by the total number of units of the final products. In the base unit system, joint costs only are allocated to products at separation according to the predetermined ratio of the quantities of base units associated with them. It can be seen that the method can only be incorporated in a process costing system if the relative quantities of base units remain practically constant for the accounting period.

4.2 CASE ILLUSTRATION

To illustrate the application of this method using weight as a base unit, the case of a lubricating oil plant is considered.

The solvent extraction department produces four different grades of base lubricant from hydrofinished long residue feedstock. The process involves dewaxing of the feedstock by means of solvent extraction and separation of the various grades by means of fractional distillation. The solvent used is methyl-ethyl-ketone (M.E.K.) which is recycled through a purifying distillation process in which the wax removed from the feedstock is obtained as residue.

This wax is known in the industry as "slack-wax" and is sold as a heavy fuel oil constituent or as cracker feedstock. The slack wax is treated as a by-product for costing purposes and revenue resulting from the sale thereof is subtracted from the total joint cost.

The joint products are known as:

(a) Light/medium, medium viscosity index (paraffinic) oils (L/med. MVIP);

(b) Light/medium, high viscosity index oils (L/med. HVI);

(c) Heavy, medium viscosity index (paraffinic) oils (Heavy MVIP);

(d) Heavy, high viscosity index oils (Heavy HVI).

Raw material costs amount to R3,000 under design load conditions of 100,000 l. throughput per accounting period.

See A.30, TABLE V.6

In this process the realisable value of the four joint products at separation is roughly proportional to weight. Differences in price of the final products being related to the value of various inhibitors added at a later stage.

4.3 ADVANTAGES

(a) The procedure whereby joint costs are allocated to each product according to the number of associated base units may be useful where product prices tend to be based on the same unit.

In the case of certain natural gas constituents, 97% of the various joint products (on average) is used as fuel in some or other application. (Vide C.A. SMITH and H.R. BROOK, "Accounting for oil and gas producers," Prentice-Hall, New York, 1959, p.435). The large majority of consumers in this case are in fact purchasing energy. For this reason prices will tend to be related to the calorific value, i.e. joules/mg or BTU/lb.

If, in the above case, joint cost is allocated according to thermal units, the resultant product costs are indirectly related to market value. In the fertilizer industry, prices are sometimes related to nitrogen content. If this proportion is used as a basis for joint cost allocation the product costs will be related to market value.

In cases where the quantity of base units associated with the units of production are related to market value, the costs allocated by this method take on an economic significance. They conform somewhat more closely to the technical-economic concept of cost. Where the relationship is more or less direct at separation, such costs may be used effectively for pricing considerations.

Where a direct relationship exists between base unit and market value, a semi-causal relationship between joint material costs and products may possibly be traceable. For example, the manufacturer who sells constituents and combinations of natural gas for use as fuel can theoretically be regarded as a producer of a single product, energy, in different packages. The semi-causal relationship will only be applicable in the case of raw material costs; as labour, wear and tear, etc., are not traceable to the base units.

Furthermore, in the case where raw material prices are based directly on the assay of all constituents of the raw material, a semi-causal material cost relationship can be traced if joint material costs are allocated in terms of the units used to measure the relative quantities of constituents. As in the above case, the same can not be said for labour and overhead costs.

(b) An advantage of the base unit system in practice is that the unit serves as a useful basis for the determination of the material efficiency of the joint process. Lost units in work-up departments may also be costed according to the base units involved.

(c) The ratio of the base units associated with the various products are predetermined for an accounting period. This may enable the system to be incorporated in a standard costing or flexible budget control system.

(d) The base unit system can sometimes be applied satisfactorily for control purposes where more logical, but more complicated systems are not worth the additional effort involved.

4.4 DISADVANTAGES

(a) Unless the number of base units is closely related to market value, costs allocated on this basis are unsuitable for pricing purposes, and can be misleading in this respect. The same applies to the use of the costs so obtained for cost/volume analysis.

(b) In order for a unit to be suitable as a cost allocation base, a decrease in the quantity of base units associated with one product must be accompanied by a corresponding increase in the units associated with the other joint products for the same throughput and overall efficiency. Unless this is the case, fluctuating costs will result. In many processes a suitable unit conforming to this tenet does not exist; thus limiting the universitility of the system.

(c) From a conceptual point of view, not all costs are by any means directly related to physical units or constituent quantities.

4.5 APPLICATIONS

The method can be applied to any process where the raw materials and all joint products bear a semi-constant relationship to each other in terms of some physical unit or constituent material common to all.

The resultant costs are only meaningful for decison-making purposes where the base unit bears a semi-direct relationship to raw material prices and realisable product value at separation.

Thus, although not universally applicable, the method is particularly suited to joint material cost allocation in certain industries. The formula basis is used effectively for control purposes at the Chloorkop works of Klipfontein Organic Products, Ltd. (S.A.). This company operates a chlorine/caustic soda joint process with brine as the basic raw material. A comprehensive computerised process costing system provides detailed budget and standard variance analyses on costs which have been allocated in this way. African Explosives and Chemical Industries (S.A.) operate a similar system.

Joint processes which lend themselves to the base unit allocation system are found in the mining, chemical, heating fuel and dairy industries.

5 THE REALISABLE MARKET VALUE METHOD

5.1 DISCUSSION

In terms of the documented "sales realisation" or "market value" method, joint costs are allocated on the basis of the market or sales value of the individual joint products. In describing the procedure involved for costing of petroleum products by this method, C.H. GRIFFIN, ("Multiple products costing in petroleum refining," Journal of Accountancy, Vol. 105, No. 3, 1958, p.47) makes the following statement:

> "In the application of this method, data must be accumulated on yields of the various grades of refined products, total crude and processing costs for the period under study, and the expected market realisations from the sale of each product. The relative market values of refined products provide the basis for assigning costs to various product classes."

It is thus seen that basically the procedure is similar to that for the weighted average method, with the relative market value of the various products forming the weighting factor. In this connection, J.J.W. NEUNER and S. FRUMER, (op. cit., p.413) state that:

> "The quantity of production is weighted (multiplied) by the average sales price or assumed market price before computing the proportion of the total cost for material and/or labor applicable to each product."

In order to conform somewhat with the technical-economic concept of cost, joint costs allocated by this method should in the first place be accumulated separately from any work-up costs. The latter costs must be particularized to individual products separately according to the causal relationship.

The above implies that a knowledge of the relative realisable value of each joint product at separation is a prerequisite. This condition is not always met in practice. The various alternatives encountered are discussed.

5.1.1 DETERMINATION OF THE REALISABLE MARKET VALUES WHERE ALL PRODUCTS OF THE JOINT PROCESS ARE SOLD IN THE FORM IN WHICH THEY ARE SEPARATED

In this case the realisable market value is the so-called "nett-back" value. This is defined as follows:

> The realisable selling price of the product in the established market; less those costs associated with it which cannot be considered to contribute directly to its replacement value, but are necessarily incurred in order to be able to market it via existing channels.

Costs such as selling costs, distribution and transport, storage, loading, packaging, final inspection, etc., are not included in the nett-back value. Although selling and distribution costs are not classified as manufacturing costs many cost accountants include storage, loading and even packaging costs under this heading. (Vide J.J.W. NEUNER and S. FRUMER, op. cit., p.158). In view of the fact that there is no causal relationship between these costs and the joint process, these should be excluded from the basis on which joint costs are allocated.

For this reason, realisable nett-back value is considered to be a superior basis to realisable price as such.

5.1.2 THE CASE WHERE ESTABLISHED MARKETS EXIST FOR ALL PRODUCTS AS SEPARATED, BUT ONE OR MORE INCUR WORK-UP COSTS

This case is relatively straight forward. Where products are not sold in the form in which they are separated an estimated or theoretical nett-back value may be derived from average market prices for these products as separated.

5.1.3 DETERMINATION OF THE REALISABLE MARKET VALUES WHERE NO MARKET EXISTS FOR ONE OR MORE PRODUCTS IN THE FORM IN WHICH THEY ARE SEPARATED

In the case where no established market exists for one or more joint products at separation, it is impossible to determine the relative realisable value of any of the joint products directly.

For example, in the saponification of fats and oils in the soap-making process the glycerine separated in the spray chambers can be valued immediately according to the ruling market prices for various grades of the product. On the other hand, the remaining joint products, crude soaps, require further expenditure before standard marketable products, which can be identified and valued, are obtained. In cases such as this, it is necessary to derive artificial market values for the joint products unvalued at separation in order to establish the relative market value factors for the various products.

One method of arriving at an artificial realisable value at separation would be to assume that post-separation processing costs do not contribute to the products' replacement value and subtract such costs from the respective nett-back values. This assumption has little justification under most circumstances, however, as post-separation processing which alters the form of a product in such a way as to render it marketable, must be considered to contribute to its profitability.

A more logical approach is to assume that the post-separation processes and the joint process earn the same gross profit margin. Based on this assumption, a theoretical realisable value at separation may be obtained by subtracting the post-separation processing cost plus its gross profit margin from the nett-back value. The gross profit margin in this case is the difference between the total nett-back for all products and the joint cost plus all post-separation processing costs expressed as a percentage of these costs.

Although this procedure must be classed as artificial in view of the assumption that joint and post-separation processes contribute equally to the profit margin, it has merit in certain respects. If no market exists for the joint product at separation, it may perhaps be argued that the post-separation process is in effect an extension of the joint process and the costs incurred are technically and economically necessary if the set of joint products is to be rendered marketable.

5.1.4 COMPLICATING FACTORS ENCOUNTERED IN PRACTICE

In cases where no established market exists at separation and extensive post-separation processing is involved, the establishment of an artificial realisable value by either of the above methods may be unfeasible.

Practical considerations may render the particularization of post-separation costs to individual products highly complicated or economically unjustified. If, for example, some of a joint product of one process is blended with some of a companion product to form the raw material for another joint process, the tracing of causal relationships becomes involved to say the least. Other factors such as the use of common work-up facilities may complicate post-separation costing to an extent where it becomes impractical.

Under these conditions the best alternative may be to ignore post-separation costs and to allocate joint costs according to completed nett-back value. The case for this approach is even stronger if common work-up costs are allocated on a sales value basis.

5.2 CASE ILLUSTRATION

In order to illustrate the procedures involved in this method the case is taken of a platforming process in a petroleum refinery. The quantities and prices used are those on which the design for the Ohio Oil Company's Detroit refinery was based in 1960. (Vide S.S. MILLER and D.C.D. ROGERS, "Manufacturing policy," Irwin, Illinois, 1964, p.791, etc. seq.).

To arrive at the relative realisable value at separation, any post split-off processing costs plus margin are subtracted from the nett-back value as described.

Post-separation costs such as anti-knock compounds, oxidation inhibiting additives, colouring, storage, loading, etc., are not included. The hydrogen and fuel gas also produced in the process are treated as by-products and as such do not feature in the joint cost allocation schedule.

The process involves the catalytic reforming of a C_6-C_7-C_8 heart-cut naphtha stream to produce a mixture of aromatic-rich gasolines, benzene, toluene, liquified petroleum gases, fuel gas and hydrogen.

The hydrogen and fuel-gas are separated in a separator and depentaniser respectively whereupon the depentaniser bottoms are fed to a splitter column. This column is regarded as the split-off point with the bottoms (high octane gasoline) being valued at nett-back, while the overheads (medium octane gasoline and aromatics) receive further processing before being separated into completed products in an aromatic extraction unit.

See A.31, TABLE V.7

The above table reflects the allocation of joint costs to products on a relative realisable value basis.

5.3 ADVANTAGES

(a) Where the standard realisable nett-back for each product at separation can be directly established, joint costs allocated by this method tend to conform more closely to the technical-economic concept of cost. In such cases, the costs derived are economically meaningful and the system must be considered to be conceptually superior to physical unit methods.

(b) The method reflects the same gross profit for all products, thus providing equal motivation to sell them. This is an undesirable feature where the ratio of product yields is at all variable. However, the method does not result in the unrealistic situation where some products appear unprofitable while others are reflected as being consistently profitable.

Costs are sacrifices incurred in the creation of value. Costs allocated on a technical basis may lack economic significance. Allocation on a technical basis only may result in the case where the hindquarters of a pig are sold at a high "profit" while the forequarters of the same pig are sold at a "loss."

(c) Being economically significant the product costs obtained by this method are particularly useful as control information. They also enable realistic inventory costing.

(d) The method is entirely independent of any physical units or constituents and can be used for allocating labour and overhead as well as material costs.

(e) In a number of cases occurring particularly in the chemical and ore-refining industries, raw material tender prices are related to the probable market value of the products. In such cases there is a semi-causal relationship between raw material cost and the value of the prodcts at separation. C.B. NICKERSON (op. cit., pp.209, 210) makes the following statement:

> "In effect he (the purchaser of a joint process raw material) is buying a package containing a variety of items, and he tries to determine their value in arriving at a price to be paid for the lot. Having bought material on this basis, it is then logical for him to allocate its cost in proportion to the market values of the segments actually realised."

5.4 DISADVANTAGES

Despite its conceptual superiority, the sales realisation method suffers from practical application difficulties, and the costs obtained have serious limitations as decision-making information.

(a) Costs allocated on a market value basis cannot be used as such for pricing purposes for obvious reasons. No price floor can be set for any individual product, and if any one product is underpriced due to faulty marketing policy, it will not be reflected as a decrease in profit margin on that product only, but as a general reduction in profitability for all joint products.

(b) In a market economy, prices fluctuate as a result of changes in the relationship between supply and demand. In addition to externally caused price variations, such internal policies as cash discounts, reduced unit prices on large orders, and introductory offers, result in fluctuations of the price received for joint products. If based on actual prices, the relative costs of the joint products may fluctuate although no change has taken place in either the total cost or the manufacturing process.

On the other hand, if prices are fixed artificially as in the case of certain precious metals, these may bear no relation to the actual cost of manufacturing. This effect is generally short term, but gold prices are an exception.

(c) The method is only as rational as the means by which the realisable value at separation is deduced. It may be argued that in cases where post-separation work-up is involved, if the product were sold at separation, it would alter the balance between supply and demand, and deflate prices. By this reasoning where post-separation processing is involved, it is impossible to value the product absolutely at separation.

(d) Product blending and the use of common work-up facilities may render the particularization of post-separation costs impractical. In such instances it is necessary to base cost allocations on final sales values or estimated values. This introduces further arbitrarity.

(e) J.C. LESSING (op. cit., p.225) objects to the method on the following grounds:

> "Daar bestaan geen prinsipiële regverdiging vir die bewering dat die gemeenskaplike koste volgens die opbrengs van medeprodukte verdeel moet word nie."

This statement is based on the lack of direct causal relationship between changes in the product price and joint cost. It may be argued that under this method if the price of one product drops for some or other reason, the relative cost will be disturbed in favour of this product. Moreover, if the same quantity and quality of raw material components are identifiable with the product, it is illogical to alter the cost thereof because of changes in product price.

(f) The fact that the method reflects the same gross profit margin for all products renders the resultant product costs invalid for decision-making purposes with respect to the joint process.

5.5 CONCLUSIONS

(a) Despite its conceptual superiority, the realisable market value method cannot always be realistically applied.

(b) The costs obtained are entirely unsuitable for pricing and joint process decision-making purposes.

(c) If standard realisable nett-back values are employed, the costs obtained may be economically significant and can provide valuable control information. (Vide chapter IV, 5.4.2, op. cit.).

5.6 APPLICATIONS

The realisable market value method can be used to allocate joint costs to products for control and inventory costing purposes, irrespective of the nature of the joint products. It can be more realistically applied where the market value at separation can be readily determined.

A variation on this method is used for inventory valuation at Sasol.

6 OTHER METHODS OF JOINT COST ALLOCATION

Although the majority of joint cost allocation procedures are based on the four methods described above, several variations which have particular application in certain industries are worthy of mention.

6.1 THE BY-PRODUCTS METHOD

Under this method the assumption is made that all production activity is directed toward the manufacture of a single principal product. All other joint products thus become supplementary, or incidental to, the principal product and its manufacture. Thus, regardless of sales value or quantity, all joint products excepting the principal product, are considered as "by-products," and costed as such.

If the subtraction method is employed for the costing of these products, the joint cost assigned to the principal product is the sum of raw materials and processing costs for all joint products, less the anticipated revenue from the sale of the "by-products."

The accounts and accounting procedures subcommittee of the financial and accounting committee of the American petroleum institute ("Outline of petroleum-industry accounting," Amercian petroleum institute, New York, 1954, p.144) states the following in respect of the use of this method in the petroleum refining industry:

> "The market value of all by-products is deducted from total refinery expense, and the remainder is considered to be the cost of gasoline produced."

In the costing of coal distillation products, coke may be considered as the principal product, and the oils, tars, aromatics, ammonia and gas are regarded as by-products. The accepted definition of by-products as being of considerably less market value does not hold for the purposes of this method. The combined sales value of these products may conceivably well exceed that of the principal product, although the method is unlikely to find acceptance in such cases.

The method assumes that the by-products do not contribute to the profitability of the joint process and all profit is attributed to the principal product. Thus, although the method is related to the sales realisation method, the cost of the principal product so obtained is generally less than that derived by the latter method. In view of the above assumption, the method must be classed as totally arbitrary.

In practice it has the serious disadvantage that it provides no information on the cost of the so-called "by-products." In addition changes in market conditions may substantially alter the relative economic importance of the various products; resulting in the displacement of the principal product, and rendering the allocation method ineffective.

In effect the by-product allocation method assumes that with the exception of the "principal" product, the joint products earn no profit, while the sales realisation method assumes that all products earn an equal profit margin. In view of the characteristics of the joint process, the latter assumption is considered to be more logical.

6.2 THE BARREL-GRAVITY METHOD IN PETROLEUM REFINING

This method is described by C.H. GRIFFIN (op. cit. p.50) as an attempt to reflect the emphasis given in some refineries to the properties of the crude oil processed. The specific gravities of the various refined products are used as weighting factors in the apportionment of raw stock costs in much the same manner as physical units are used in the weighted average method. The technique seeks to recognise an alleged correlation between the specific gravity of the petroleum products and their commercial value, but as C.H. GRIFFIN (op. cit., p.51) points out:

> "Formerly, this correlation may have been significant, but presently it is regarded as slight."

It is true to a certain extent that the cost of refining is influenced by the chemical composition of the crude feedstock, but to assume that these costs are directly proportional to the specific gravity of the products is highly arbitrary to say the least.

Incorporation of the calorific value as a weighting component gives rise to a method known as the "gravity-heat unit method" which is considered to be no less arbitrary. R.I. DICKEY (op. cit. p.13.17) mentions that neither the barrel-gravity nor the gravity-heat unit method is widely used.

6.3 THE REPLACEMENT VALUE METHOD IN PETROLEUM REFINING

Under this method, gasoline is assumed to be the principle petroleum refining product and its cost should be determined as independently as possible. Joint products of the refining process are valued as potential gasoline, less the expenditure required to convert them into this product.

The American petroleum institute (op. cit., p.144) describes this method as being fundamentally an adaptation of the by-product method, although "the departure therefrom is of such significance and so widely recognised" that it is given prominence. C.H. GRIFFIN (op. cit., p.49) describes the method as follows:

> "Replacement value costing provides for the establishment of a hypothetical processing plan by which crude and unfinished stocks are processed in existing facilities to maximise the yields of the three aforementioned products (namely gasoline, fuel-oil and fuel gas), assuming no imposition of limitations on equipment capacity."

Based on this theoretical plan, the basic cost of gasoline is deduced, assuming that the plan results in costs which are comparable to those incurred in actual operations. In effect the method is an extension of the by-products method, as the anticipated sales value of the joint products are deducted from the estimated cost of producing maximum gasoline yield.

R.I. DICKEY (op. cit., p.13.17) quotes the committee on price determination (Cost behavior and price policy, National bureau of economic research, U.S.) as stating that:

> "There can be no doubt that costing of gasoline by the replacement value method provides the closest approximation to the correct economic allocation of joint cost

> under varying proportions of any of the accounting methods in common use."

The validity of this statement is disputed on the following grounds:

(a) The tremendous growth of such industries as plastics, fertilizers, bio-degradible detergents, synthetic rubber and aromatic chemicals over recent years; coupled with the threat of over-supply on the world gasoline market, has encouraged the production of high return speciality products at the expense of gasoline.

(b) Formerly the assumption that refineries operated primarily to produce gasoline may have been valid. However, it has been estimated that nearly a third of a million products are obtainable from the refining and processing of natural petroleum. (Vide C.H. GRIFFIN, op. cit., p.48 and A.L. WADDAMS, op. cit., p.4). Greater returns than on gasoline are possible on a number of these.

(c) To cost all such products as potential gasoline on a hypothetical basis can today hardly be described as "correct economic allocation." The method is deemed to have considerable value in the determination of profitability of existing or proposed post-separation processing costs, but is considered to have little to recommend it as a standard procedure in joint costing.

A more appropriate system for decision-making in modern refineries would be to compare alternative nett-back on a product with all alternative (replacement) products and thus evaluate its profitability. Such a system is used for product proposal evaluation at Sasol on an ad hoc basis.

7 IMPLICATIONS WITH RESPECT TO THE ALLOCATION OF COMMON COSTS

In multi-product manufacturing industries, use is frequently made of common -

as opposed to joint - production facilities, for reasons of economy. J.C. LESSING (op. cit., p.213) states that:

> "Die gesamentlike produksie vind plaas weens die ekonomiese voordeel wat daardeur verkry kan word omdat dit in sekere gevalle goedkoper is om die produke saam te produseer as om elk afsonderlik te vervaardig."

While the causal relationship between joint costs and products is indeterminable, this is not the case in respect of common costs. As A. MATZ, O.J. CURRY and G.W. FRANK (op. cit., p.140) point out: "... each of the products could have been obtained separately ..." L.L. VANCE (op. cit., p.325) states expressly that:

> "... common costs can be traced to the separate products on a cause-and-effect basis or by tracing the use of facilities ..."

If the cost prices of commonly-produced products are to be determined, it is necessary to allocate the common costs involved to the products on some or other basis. A number of the so-called "joint cost allocation methods" described in this chapter can be effectively used for this purpose.

These documented methods have in most cases been developed to meet the requirements of Anglo-Saxon "full" or "direct" costing systems. Applied to common processes as defined in the previous chapter, the bases described may well be congruent with the causal relationships between the common cost and the various products involved. Where such congruency exists, allocation of the common cost by the relevant method conforms to the principles of cost particularization in this respect.

The choice of method depends on the particular manufacturing circumstances involved. Common costs allocated on an appropriate physical unit basis as described can be incorporated in a process costing system with meaningful results. The resultant cost prices can be effectively employed for pricing, control and decision-making purposes. The use of allocation systems based on physical units in the case of joint products, however, may provide invalid and misleading unit costs.

In effect, the physical unit allocation methods described in the Anglo-Saxon literature erroneously equate joint and common costs. To advocate the use of the "cost prices" of jointly-produced products determined by these methods for pricing and decision-making purposes, represents a failure to appreciate the basic nature of the joint process and the technical-economic cost concept.

8 SUMMARY

The decision to allocate joint costs to individual products as well as the choice of method is entirely dependent on the use to which the resultant product costs are to be put. The arbitrarity present to a greater or lesser extent in each of the methods renders them unsuitable for control or decision-making in some or other respect.

In this chapter each allocation basis has been examined and none was shown to be generally acceptable in all aspects or universally applicable with significant results.

A number of the methods can, however, be effectively applied for the allocation of common costs, in which cases causal relationships can be traced. It is maintained that the use of methods based on physical units represents an ill-advised attempt to treat joint costs as common costs.

In respect of value to management as control information, costs obtained by the realisable market value method were shown to be superior on most counts. Product costs allocated by this method are, however, invalid for decision-making purposes.

CHAPTER VI

COSTING SYSTEMS FOR JOINT PRODUCT MANUFACTURING

1 INTRODUCTION

So far in PART TWO of this study, the principles of joint product costing and various methods by means of which joint costs may be allocated to products have been discussed. It remains to examine the somewhat specialised procedures comprising an effective overall system for costing joint products.

[illegible] g systems are examined in the light [illegible] ss costing procedures for joint pro- [illegible] considerations in cases where a [illegible] r in the same manufacturing system.

[illegible] important part played by standards in [illegible] lised standards are shown to be of [illegible] to control of the material efficiency [illegible]

[illegible] developed in this chapter are incor- [illegible] joint product manufacturing discussed [illegible]

L.L. VANCE (op. cit., p.1) states that a truly comprehensive cost accounting system for a business enterprise will in the first instance provide the unit manufacturing costs of products or services. However, each of the various joint cost allocation methods described in the previous chapter will result in different cost prices for the same individual products. The validity of some or all of these methods with respect to cost price determination is thus questionable.

J.C. LESSING, (op. cit., 1967, p.225) points out that:

> "Die hele doel van die kosprysberekening is immers om realistiese verkoopspryse te bepaal."

With few exceptions, allocated joint costs are unsuitable for pricing purposes. It is consequently necessary to examine the objectives of costing before developing procedures for a joint product costing system.

2.1 WHY A BUSINESS NEEDS A COSTING SYSTEM

Any costing system is in effect a source of managerial information. The effectiveness of such a system lies in the extent to which it facilitates the maximisation of returns. J.C.M. VAN NIEKERK (op. cit., p.12) lists the following reasons why a business needs a costing system:

> "Bepaling van die koste van produksie;
>
> toepassing van kostebeheer;
>
> bepaling van die verkoopprys, waar konkurrensie dit toelaat;
>
> 'n doeltreffende stelsel van kosteberekening vergemaklik die voorbereiding van rapporte vir bestuursbesluite."

J.J.W. NEUNER and S. FRUMER (op. cit., p.7) list virtually the same reasons, these being:

(a) determination of various costs for accounting and record purposes;

(b) analysis and classification of total and unit costs with a view to reducing them;

(c) determination of unit costs as a guide to testing the adequacy of selling prices;

(d) the provision of reports for managerial decisions.

These reasons can be summarised as being the provision of information for the purposes of record keeping, cost control, pricing, and decision-making.

2.2 CONSIDERATIONS WITH RESPECT TO JOINT PRODUCT MANUFACTURING

The effect of the absence of any non-arbitrary method for allocating joint costs on the purposes served by a costing system is examined.

2.2.1 RECORD KEEPING

The total cost of producing and working up a set of joint products is independent of the manner in which joint costs are allocated. The evaluation of total inventories, work in process and cost of sales, can be effected by means of any recognised costing system. Record keeping with respect to the set of joint products requires no specialised costing procedures outside of the incorporation of an appropriate joint cost allocation basis.

2.2.2 COST CONTROL

The effectiveness of a cost control system is a function of the extent to which it reveals the underlying causes of deviations from the optimum. In this respect the particularization of costs via the causal relationship to cost centres - and (if feasible) - products, can be seen to play an important part.

It is maintained that in order to be effective as a source of control information, the joint product costing system should be based on sound particularization principles. Where one or more products incur work-up costs, from the point of view of these products the determinable causal relationship is interrupted at the split-off point.

This effect must be considered in the development of a costing system for joint products. Specialised procedures are consequently required if the system is to be effectively used as a source of control information, or incorporated in a decision-making model.

2.1.3 PRICING

Cost prices for individual products incorporating allocated joint costs are for the most part unsuitable for pricing purposes. Consequently, the information provided by a joint product costing system can rarely be used directly for decision-making with respect to individual product prices. The system should, however, be tailored to suit the requirements of any specialised pricing procedures employed.

2.1.4 DECISION-MAKING

Up to and including the split-off point, the set of products of a joint process are technically and cost-wise interdependent. Consequently any decision taken with respect to the production of any joint product will in some or other way affect one or more members of the remainder of the set. Subsequent to separation, however, this does not necessarily hold.

The split-off point represents the control point with respect to the particularization of joint costs. The costing system must be so designed as to facilitate cost accumulation at the control point of every joint process in the joint product manufacturing system.

2.3 CONCLUSIONS

In view of the arbitrary nature thereof, the determination of the "cost prices" of individual products for record-keeping and pricing purposes can not be considered among the primary objectives of the joint product costing system. This leaves the provision of control and production decision-making information as the main objectives in the majority of cases.

> The most effective overall joint product costing system is that which provides the best information for control and production decision-making purposes, under the particular circumstances involved.

The remainder of this chapter is devoted to the principles and procedures involved in the development of such a system.

3 THE ESSENTIALS OF PROCESS COSTING

3.1 COMPATIBLE PRODUCTION STRUCTURE

Proper classification of the technological structure of the enterprise is essential to the meaningful particularization of costs in a costing system. A.J.E. SORGDRAGER (op. cit., 1964, p.71) lists the following manufacturing characteristics compatible with process costing procedures:

(a) large volume of business and standardisation of products. (Norm and standard costing can easily be introduced);

(b) special purpose equipment;

(c) production for stock.

Process costing is best suited to this type of production structure, particularly where continuous processes are involved. (Vide

G.R. CROWNINGSHIELD, "Cost accounting principles and managerial application," Houghton Mifflin Co., Boston, 1962, p.53).

3.2 DOCUMENTED PROCESS COSTING PROCEDURES

Process costing involves the accumulation of costs for all units of production operated on in the various departments of the manufacturing system over a given period of time. The methods and procedures for single-line products are well documented in the Anglo-Saxon literature. (Vide R.I. DICKEY, op. cit., Section 12). The majority of these conform to the procedures described. (Vide J.G. BLOCKER and W.K. WELTMER, "Cost accounting," McGraw-Hill Co., New York, 1954, p.227 et seq.).

(a) Costs, both direct and indirect, are accumulated in cost accounts during the period and are reclassified by departments or processes at the end of the period.

(b) Production, in terms of quantities such as units, tons, gallons, etc., is recorded by processes daily or weekly, and is summarised in departmental reports at the end of the period.

(c) The total cost of each process is divided by the total production for the process to obtain an average cost per unit for the period.

(d) When products remain in process at the end of the period, production and inventories are computed in terms of completed products, the stage of completion usually being estimated and the indentity of each lot or batch being ignored.

(e) If units are lost or spoiled in a department, the loss is borne by the units completed and remaining within the department, thus increasing the average cost per unit.

(f) In cases where products are processed in two or more departments, costs incurred in one department are transferred to the next, the total cost and unit cost of products being accumulated when completed.

A detailed study of the American approach to process costing has been made by D.B. VAN DER SCHYF ("Enkele beskouings oor die teorie van proseskoste na aanleiding van Amerikaanse praktykgebruik," Unpublished thesis, P.U., 1964) to which the reader is referred.

3.3 PROCESS COSTING REPORTS

Although the form of process costing reports for single-line products is not standardised, two main types listed by J.J.W. NEUNER and S. FRUMER (op. cit., pp.294, 295) are described.

3.3.1 THE SUMMARY COST OF PRODUCTION REPORT

The principal characteristics of the summarised cost of production report are as follows:

(a) For each department the costs are shown separately for each element, namely material, labour and manufacturing overhead. These costs are total and on a per unit basis.

(b) An analysis is made of the total costs of production in each department. This analysis shows; the cost of production transferred to the next department, the cost of work completed and not transferred, and the unfinished work or work-in-process in the department. Lost units are treated separately, either as a separate element of cost or as additional manufacturing overhead in the department in which the losses occur.

3.3.2 THE QUANTITY OF PRODUCTION REPORT

The quantity of production report is necessary for the calculation of lost units. This report shows, for each department, the quantity received and how accounted for, and the yield percentages.

4 PROCESS COSTING FOR JOINT PRODUCT MANUFACTURING

The majority of joint products are manufactured for stock rather than for specific orders. This is principally due to the nature of the joint process where products are unavoidably produced in roughly fixed relative quantities, regardless of firm orders or demand for individual products. Furthermore, many joint processes, especially in capital-intensive industries, are operated on a continuous basis.

Process costing is consequently compatible with the production structures encountered in a high percentage of joint product manufacturing systems. The essential features of a process costing system for joint product manufacturing are examined.

4.1 DISCUSSION

The single-line process costing procedures described earlier in this chapter are based on the assumption that all units produced incur exactly the same amount of cost in every stage of the production process. This enables the classification of all cost elements by products and by sequential operating departments. All costs can be shown in a single cost-of-production report. This report reflects both the total unit cost of manufacturing and the unit cost incurred in each successive department.

Where joint processes are involved, the above system can only be applied directly where joint costs are allocated on an average unit cost basis, and no distinction is made between joint costs and common work-up costs. Where the latter distinction is made the units of the various isolated products incur different proportions of the joint cost, depending on the allocation method employed.

Furthermore, regardless of whether and how joint costs are allocated, it is essential to differentiate clearly between joint costs and work-up costs if meaningful control and decision-making information is to be provided.

The primary feature of an effective process costing system for joint products can be summed up as follows:

> Joint costs (as defined) are particularized to the set of joint products at the control point of the joint process; work-up costs are particularized to individual products.

4.2 PROCEDURES FOR THE PROCESS COSTING OF JOINT PRODUCTS

In the light of the above discussion process costs for joint products should be accumulated separately according to whether they are joint or work-up costs.

4.2.1 COSTS INCURRED PRIOR TO THE SPLIT-OFF POINT

There is no reason why costs incurred up to and including the split-off point of a joint process may not be accumulated and classified by the documented process costing procedures described. Lost units, work in process and the effect of materials added may be computed for all departments in the normal way.

The set of raw materials is in effect regarded as going to make up a single product (the set of joint products at split-off), the cost of which is thereby obtained. In the particularization process, direct costs are particularized to the set of products, while indirect costs are first particularized to cost centres (departments). Particularization of direct costs to the set should only be directly effected for cost centres within the joint process as defined in chapter I. Direct costs incurred prior to, but outside the joint process, should be particularized via that portion of the set of raw materials operated on, to joint cost centres.

The sum of the particular costs of the set of products at the control point of the joint process represents the joint cost of the set. This cost may be allocated to individual products by one or other of the methods described in the previous chapter. Alternatively, it may be retained as a sub-total for subsequent particularization to the set of products of the joint manufacturing sequence as a whole.

4.2.2 COSTS INCURRED SUBSEQUENT TO SEPARATION

4.2.2.1 THE CASE WHERE JOINT COSTS ARE ALLOCATED

For the purposes of this procedure, the joint cost of the set obtained above is allocated to individual products by means of a method which will suit the purposes of the system. The allocated cost for each product is then treated as the raw material cost of the first post-separation department in which each product is worked up. The individual products may now be costed in these and succeeding work-up departments by means of normal process costing procedures.

Once the joint cost has been allocated, lost units and equivalent work in process may be readily evaluated. This procedure results in a "total" unit cost by elements and departments for each individual product. An artificial "cost price" is thereby obtained.

Although this "cost price" is generally unsuitable for pricing and cost/volume analysis, it may provide useful control information. It may be possible to incorporate these costs in standard/budget control systems, but this depends on the allocation method used. As pointed out previously, the formula, weighted average and some variations on the base unit system can result in the comparison of standard against standard instead of actual against standard.

Only if the joint cost is allocated can process costing techniques be used with respect to the evaluation of lost units and work in process in the work-up departments.

4.2.2.2 WHERE JOINT COSTS ARE NOT ALLOCATED

Whereas a case can be made for the allocation of joint costs for control purposes; for decision-making and the evaluation in terms of returns of alternative courses of action, allocation serves little purpose. Many joint product manufacturing systems do not lend themselves to an allocation method which provides meaningful control information.

> In such cases there is no point in attempting to prorate joint costs to products on a contrived basis simply in order to be able to apply documented process costing procedures.

It is none the less essential to particularize work-up costs to separated products if effective decision-making and control information are to be provided.

Where joint costs are not allocated, post-separation costs may be particularized on a "value added" basis. Costs incurred prior to separation are ignored for the purposes of this procedure and the value added to each product in each cost centre is divided by the number of units processed to arrive at a unit work-up cost. Under this method the total material-in-process cost and lost unit expenses can not be evaluated directly.

Post-separation costs can be traced to products on a causal relationship basis. The unit work-up costs can be effectively used in standard costing systems. The marginal work-up costs can be used for decision-making with respect to post-separation activities. Product decisions which are based on work-up costs without reference to allocated joint costs are as follows:

(a) sell or process further;

(b) tender prices for post-separation materials added;

(c) blend formulation decisions, where two or more joint products are sold as a blend;

(d) product mix decisions where the ratio of joint product yields are variable;

(e) determination of the price below which a joint product should be dumped rather than worked up; etc.

The unit work-up cost can be obtained from the cost of production report in cases where joint costs have been allocated, by means of subtraction. To whatever purpose the costs are put, the user must be made fully aware of the basis on which the costs were determined.

4.3 PROCESS COSTING REPORTS FOR JOINT PRODUCT MANUFACTURING

According to the procedures described above, joint costs are regarded as having been incurred by a single product which is completed at the split-off point. After split-off, each product is costed separately by elements and cost centres. If joint costs are allocated, an "artificial cost price" is obtained. Where joint costs are not allocated, the joint cost of the set of products of the joint process, and the unit work-up costs of each product are obtained separately. The costing reports involved are as follows:

(a) summary cost of production prior to split-off. (Joint cost report);

(b) quantity of production prior to split-off (Joint process quantity report);

(c) yield ratio report;

(d) joint cost allocation schedule (where costs are allocated);

(e) summary cost/work-up cost reports for each separated product;

(f) quantity of production reports for individual products in work-up cost centres.

Regarding the case where joint costs are not allocated, if a product has a known market value at separation, a gross work-up "profit" figure can be calculated. This is obtained by subtracting work-up cost from the difference between sales value on completion and sales value at separation. This figure has limited usefulness, but can conceivably be used for return on investment comparisons.

4.4 DRAWBACKS OF PROCESS COSTING

The system described suffers from the same drawbacks as any process costing system. These are outlined by A.J.E. SORGDRAGER (op. cit., 1967, p.356) as follows:

> "Die metode is gebaseer op die delingskalkulasie waarteen verskeie besware ... geopper is. .... 'n Ander beswaar teen die delingskalkulasie is die retrospektiewe inslag. Daar word van die offers van 'n bepaalde periode uitgegaan wat op die offers van die verlede of historiese kosprys gebaseer is."

(See also R.I. DICKEY, op. cit., pp. 12.2, 12.3)

The incorporation of standard costs in the system is desirable for the above reasons. The costs remain "average costs" however and the system suffers from lack of flexibility from a particularization point of view.

4.5 CONCLUSIONS

In principle, the process costing procedures described whereby joint and work-up costs are accumulated separately, are sound. A traceable causal relationship exists between the joint cost and the set of products of a joint process. Furthermore, work-up costs may be particularized to separated products. As the causal relationship between the joint cost and individual products is indeterminable, it is logical to reflect joint and work-up costs separately.

From a practical point of view, the cost reports resulting from the system described are in line with the objectives of a joint product costing system. Meaningful, although not comprehensive, control and decision-making information is provided. The reports reflect a breakdown of costs by elements and cost centres both before and after separation. Whether or not joint costs are allocated, this information is valuable from a control point of view.

5 COSTING FOR BATCHWISE-PRODUCED JOINT PRODUCTS

In certain manufacturing processes where joint products occur, the raw materials are purchased in relatively small lots or batches. Examples of industries in which such processes occur include lumber milling, food processing, leather treating, etc. In most of the above processes the completed units consist of various grades of the same product.

The purchase price paid for each lot of raw material may vary widely according to the quantity and quality of the anticipated final product yield. In such cases it is in the interests of the concern to distinguish between the processing costs of each batch, where practicable. A.J.E. SORGDRAGER (op. cit., 1964, p.71) lists the following characteristics of a production structure to which job order (batch production) costing methods are suited.

(a) Production of a variety of products (multiple cost system, overhead application and rates).

(b) All-purpose machines.

(c) Production based directly on sales.

Job order costing procedures for single-line products are well documented, (vide R.I. DICKEY, op. cit., Chapter II) and will not be discussed here. Suffice to state that as for process costing for joint products, job order joint and work-up costs should be reflected separately.

6 THE IMPORTANCE OF THE COST CENTRE STRUCTURE IN A JOINT PRODUCT MANUFACTURING ENTERPRISE

Whatever costing system is used, where joint processes are involved it is desirable to reflect joint and work-up costs separately. It is consequently necessary to design the cost centre structure in such a way as to enable costs to be accumulated accordingly.

In general the cost centre structure should be based on the causal relationship.

See A.7, FIGURE IV.1

A.J.E. SORGDRAGER (op. cit., 1964, p.74) states that cost centres must be considered as interim steps to arrive at the cost per product.

In view of the interruption in determinable causal relationship between costs and products at the split-off point, the cost centre structure for a joint product system should be similarly divisionalised. The cost centres themselves should be classified as follows:

(a) centres in which the costs incurred are traceable only to the set of joint products; and

(b) centres in which the costs incurred are traceable to individual products.

Where only one joint process is involved a structure based on the above classification principle can be readily developed. A complication arises where more than one split-off point occurs, as is often the case in practice.

An example of multiple joint processing is found in the petroleum industry. Crude oil may be separated into gasoline- and naphtha-fractions in a preflash column at the outset of the process. Both fractions then undergo further processing before being separated into petroleum gases, avgas, (aviation gasoline) straight run gasoline, jet fuel and other products, in secondary separation processes.

As stated in chapter I of this study, it is not inconceivable for a joint product manufacturing sequence to consist of as many joint processes, less one, as the number of products. Where a large number of products are involved it must be recognised that if traceable causal relationships are to be strictly adhered to, an extremely complex and unwieldy structure may result.

In such cases it is recommendable to group certain joint processes in the joint product manufacturing system under a single cost centre. This is a deviation from the principle that the cost centre structure should be based on the causal relationship. For example: if product A is separated from a conglomerate consisting of A, B and C in joint process I; and B is separated from C in joint process II; there is no causal relationship between A and the costs of process II. If both joint processes are grouped in the same cost centre, A will in effect carry a portion of the costs incurred only by B and C. This will affect allocated joint costs.

A way of circumventing this problem would be to regard the split-off point of process I as the only split-off point and class joint process II as a common work-up facility. This would result in more realistic allocated costs but is no less arbitrary.

In practice virtually every situation is different and no hard and fast rules can be laid down regarding the cost centre structure of a joint product manufacturing system. The following are proposed as guidelines:

(a) where a multiplicity of joint processes occur they should be grouped in cost centres so as to enable the establishment of a practical cost structure;

(b) this grouping should be done in such a way as to coincide as closely as is feasible to causal relationships;

(c) work-up activities, the cost of which is directly traceable to individual products should not be included in the same cost centre with joint process activities.

In effect, the grouping of joint processes in the same cost centre alienates the control point from the split-off points of all but one process. The effectiveness of the new control point should be the primary consideration when grouping joint processes.

In view of the interruption in determinable causal relationship between joint cost and individual products at the split-off point, the cost centre structure deserves special attention where joint processes are involved.

7 THE USE OF STANDARDS IN JOINT PROCESS COSTING

A.J.E. SORGDRAGER (op. cit., 1964, p.135) makes the following statement:

> "The cost information of the cost centres, measured against a specific norm, is management's tool to control costs in the cost centres before the cost of the final product becomes available."

Waste and inefficiency can then be reported promptly to management enabling timely corrective action.

The use of predetermined norms in the joint product costing system can extensively facilitate cost allocation procedures as well as the provision of important control information. Aspects thereof are examined.

7.1 STANDARD COSTING DEFINED

The nature and uses of standard costing is described as follows by J. BATTY (op. cit., 1967, p.101):

Standard costing is a system of cost accounting which is designed to show in detail how much each product should cost to produce and sell when a business is operating at a stated level of efficiency and for a given volume of output.

Through carefully planned and organised accounting procedures the differences between actual and standard costs (the cost variances) are analysed and then promptly reported upon to managers. The latter, in turn, take corrective and preventative action, as well as employing the data for planning, co-ordination and control.

An important feature of the system should be the measurement and attainment of a high level of efficiency and a constant review of methods employed in production. When necessary the standard costs should be amended so that they reflect current realistic conditions and practices. A further essential characteristic of a standard costing system is that it should be forward-looking and, since it is intended to be a tool of management, the system should be part of a fully co-ordinated management accountancy system.

Conceptual aspects of standard costs are comprehensively covered by J.H. ELS in his thesis "The application of standard costs in certain South African industries" (op. cit.) to which the reader is referred.

7.2 SPECIFIC STANDARDS OF IMPORTANCE IN JOINT PRODUCT COSTING SYSTEMS

The main application of standards in joint product costing is associated with material costing. As I.W. KELLER and W.L. FERRARA (op. cit., p.603) point out, standard labour costs are developed by time studies, and standard factory overhead rates from the overhead budgets at normal production volumes:

> "Thus, for direct labour and factory overhead, the cost and budget procedures follow those of any other industry."

A material and a value standard of importance in joint product costing and control of the joint process efficiency are discussed below.

7.2.1 STANDARD YIELD AT SPLIT-OFF

The quantitative relationship between the outputs of the individual products of a joint process is variable only between certain limits. The yield of a joint product was defined as its weight expressed as a percentage of the set of raw materials.

In many joint processes, scientifically predetermined standards may be set for product yields under varying conditions. The actual yield for a particular volume of input is dependent on the constituency of the raw material and the nature of and manner in which the joint process is operated. If standard yields are based on optimised production plans under expected conditions for the period, the ratio of standard yields at separation will reflect that product spectrum on which maximum returns are anticipated.

Under these circumstances, variances between actual and standard yields for each joint product at split-off, provide a measurement of raw material quality and conversion performance. If multiplied by a suitably derived standard joint cost, these variances can be expressed in monetary terms, thus providing useful control information.

In the interests of pin-pointing reasons underlying yield variances, it serves a purpose to attempt to eliminate the effects of variations in raw material quality. Testing of raw material inventories may enable the standard yield to be corrected for changes in the average composition of the raw material. Such standard yields will be termed "corrected standard yields" for the purposes of this study.

As distinct from the control aspects, standard yields may be directly incorporated in certain joint cost allocation methods for process costing purposes. Standard yields may be expressed in terms of base units in certain cases, enabling yield ratios or percentages to be predetermined. Using the base unit allocation system, joint costs are allocated by multiplying the total joint material cost by the standard yield percentage for each product.

Where predetermined values are used, both the "formula" and the weighted average allocation methods are in effect based on either standard yields or standard cost-incurring factors.

7.2.2 STANDARD REALISABLE MARKET VALUE

Predetermined unit product realisable market values at separation are particularly useful in the allocation of joint costs by the realisable market value method. If standard values are based on the optimised resource allocation plan and marketing strategy, they represent the revenue accruing from the sale of the optimum quantity at the optimum price.

Such standard values approximate to the replacement value. Their use in joint cost allocation lends economic significance to the resultant joint product costs.

From a practical point of view, where process costing systems are employed, the use of actual market values is more often than not unfeasible. The actual price paid for a product may only become known months after the product has been produced. In addition, fluctuations in price caused by any number of factors will cause the cost relationship of the various products to fluctuate irrationally if actual values are used.

Using standard realisable values, the market value allocation method has distinct advantages with respect to variance analysis. If allocated product costs have economic significance, variances from standard can be expressed in realistic terms.

Certain of the cost allocation systems described can result in some joint products showing a "loss" while others show a "profit." The same percentage deviation from standard will be reflected as a disproportionately low nett variance on the "profitable" products; and a disproportionately high nett variance on the "loss" products. This can not occur if product costs are related to market value.

A further application of predetermined market values is in the establishment of the price payable for raw materials. The sum of the products of the standard unit values and the standard yield for each joint product, provides a useful guide to the prices which may be tendered for raw materials.

7.3 THE USE OF STANDARDS FOR MATERIAL EFFICIENCY MEASUREMENT FOR JOINT PROCESSES

In single-line product manufacturing two material variances are of importance. These are listed by J. BATTY (op. cit., 1966, "Management accountancy," p.349):

(a) material price variance:
(actual price - standard price) x actual quantity;

(b) material usage variance:
(actual quantity - standard quantity) x standard price.

The quantities in the above formulae refer to the amounts of raw material required to manufacture a given quantity of finished products.

The latter variance can be said to provide adequate information concerning the material efficiency of a single-line process.

This variance does not, however, tell the full story with respect to a joint process. To illustrate its shortcomings the case is taken where joint products A and B are separated in a distillation process. It is assumed that A is a high value product made to stringent specifications. B is a lower value product with wider specification limits.

At zero usage variance indicating optimum efficiency, A may be lost to B due to poor operation of the process. The sum of the quantities of A and B are not affected by the loss and as B has wide specification limits, the loss may go unnoticed with respect to quality. Revenue will be adversely affected.

Thus, although the total usage variance will reflect deviations from standard efficiency with respect to scrap, waste, spoilage, etc., it provides no information on revenue losses due to sub-optimum product mix. Addition variances are thus necessary if effective material efficiency control in the joint process is to be exercised.

7.3.1 YIELD-VALUE VARIANCES

In the illustration quoted in the previous paragraph, the deviation from optimum yield could have been deduced from a comparison of actual and standard yields. Such a comparison will only reveal quantity variations, and in order to determine the extent to which revenue is affected, product values at separation must be taken into consideration. It is thus proposed that a third variance be computed in order to provide the more detailed information necessary if returns on joint products are to be maximised.

This variance is termed the yield-value variance and is computed by means of the following formula for a given input:

(corrected standard yield - actual yield) x standard unit realisable value x actual input.

The sum of the yield-value variances for each product provides the total yield-value variance for the set of joint products at split-off. The total variance which may be computed on a regular basis, provides a prompt means of measuring the all-round efficiency of the joint process.

Although the relative quantities produced in the joint conversion process are at best only semi-controllable within certain limits, in virtually every case the actual yield is dependent on the proficiency with which the products are separated. Factors such as the down-grading of spoiled units, failure to separate high value products sharply or separation of "over-specification" products, can have a highly adverse effect on profitability. Unless some means of detection is available, this may go unnoticed.

7.3.2 COST OF MATERIAL EFFICIENCY VARIANCE

It will be noted that the yield-value variance reflects the loss of potential revenue. It is in effect a value and not a cost variance. To obtain the corresponding cost of material variance for each product the relative standard realisable value must be computed and multiplied by the joint raw material cost. The resultant cost is then substituted as the multiplier in the variance formula.

This variance will then reflect the "cost" of deviation from standard yield as opposed to the loss of revenue.

It must be noted that yields only are being compared in this process. The actual cost for the set of products at split-off requires separate analysis in the normal way, since for this purpose the set is regarded as a single product.

7.4 THE IMPORTANCE OF THE YIELD-VALUE VARIANCE IN THE OPTIMISATION OF THE JOINT PROCESS

The maximisation of returns on joint products manufactured in a given enterprise involves the quantitative optimisation of the joint product spectum at split-off in favour of those products with the highest realisable value. The optimisation process is subject to the constraints imposed by the following factors:

(a) raw material constituency;

(b) market considerations;

(c) technological limits inherent in the process with respect to the extent to which the relative yield of any separated product is variable.

Albeit to a minor extent, in most cases the ratio of product outputs for a given set of raw materials, or the constituency of these materials, are variable.

> It is consequently possible that returns on a set of joint products may fluctuate over a relatively wide range, while the total material cost as well as unit prices and the total quantitative sales remain constant.

Controls based on the standard cost of manufacturing the set of products of a joint process become ineffective under these conditions.

> It is maintained that supplementary information regarding the joint product mix, and the effect on revenue of deviations from the optimum, is vital to the maximisation of returns.

This information is provided by the type of yield and value variance analysis described in the previous sections.

8 SUMMARY

The objectives of a joint product costing system are to provide control and decision-making information that will facilitate the maximisation of returns. In order for the system to be effective in this respect, joint and work-up costs should be accumulated and reflected separately.

Where a multiplicity of joint processes occur in the same joint product manufacturing system it may be necessary to group them in cost centres for practical reasons.

Standards, and in particular material and realisable market value standards, play an important part in an effective joint product costing system. Supplementary to the documented standards for single-line products, two specialised norms are of particular significance with respect to the efficiency of the joint process.

These are:

(a) the standard yield of a joint product for a given input of raw material;

(b) the standard realisable value of a joint product at separation.

The former is useful for control and joint cost allocation purposes; while the latter renders use of the realisable value allocation method more feasible from a practical as well as conceptual point of view. (Use of the standard realisable value does not alter the limitations as decision-making information of costs allocated on this basis).

Together the above standards can be used to compute what is termed the yield-value variance. This provides information regarding the joint product mix which can extensively facilitate the optimisation of the joint process.

In part three aspects of decision-making for joint product manufacturing systems are discussed. The incorporation of the costing principles and standards described in this chapter in planning and decision-making simulation models are examined.

PART THREE

MANAGERIAL PLANNING AND DECISION-MAKING FOR JOINT PRODUCT MANUFACTURING SYSTEMS

FOREWORD TO PART THREE

The factors of technical interdependence of joint products and the absence of any non-arbitrary basis on which joint costs may be allocated, tend to complicate managerial planning and decision-making in a joint product manufacturing enterprise. In PART THREE managerial information systems which can facilitate planning and decision-making for maximum returns are examined.

CHAPTER VII deals with price-setting and pricing policy determination for joint products. In view of the importance thereof, particularly where capital-intensive joint processes are involved, CHAPTER VIII is devoted to environmental forecasting. CHAPTER IX deals with simulation models as planning and decision-making tools for the maximisation of returns on joint products. In CHAPTER X a model for a multi-process joint product manufacturing system is used to simulate the results of case study decisions.

CHAPTER VII

PRICING JOINT PRODUCTS

1 INTRODUCTION

Decision-making with regard to prices and pricing policy for joint products differs in many respects from that for single-line products. Joint production involves a range of different products produced simultaneously in roughly fixed proportions. Each of these products may be subject to different demand elasticity, pricing legislation, competition and other market factors.

The pricing decision for each individual product is subject to considerations involving the entire product spectrum, and specialised procedures are necessary if pricing decisions are to be optimised.

In this chapter various aspects of joint product pricing are discussed and a procedure based on demand analysis is examined.

2 CONSIDERATIONS WITH RESPECT TO JOINT PRODUCT PRICING

2.1 THE USE OF PRICING TO REGULATE DEMAND

Ever present in the field of joint product manufacturing is the problem of independent demand fluctuations of the various products. Within limits, pricing can provide a useful means whereby demand may be regulated. Restrictions on the use of pricing for this purpose include the following:

(a) inelastic demand characteristics for one or more joint products;

(b) the impracticality and adverse effect on customer relations of frequent price variation;

(c) the time lag between price adjustment and the resultant change in sales volume;

(d) the practice can only be optimised if the price/volume relationship is known to a reasonable degree of accuracy. This is not always the case.

Largely as a result of these restrictions, long term sales contracts are frequently sought, particularly with respect to large volume, low priced products. Although this has the advantage of guaranteeing certain sales levels over the contract period, it may be necessary to sacrifice income by lowering the price in order to secure the contract.

In a situation where prices are rising as a result of inflation or rising demand, fixed price long-term contracts are detrimental to revenue maximisation. Furthermore, the danger exists that the contract will not be renewed on expiry, resulting in a sudden (and possibly unexpected) drop in sales.

2.2 COMPETITION ASPECTS

The consideration of competition with respect to joint products is a very important one. Two aspects are discussed; inter-joint product competition, and competition from products produced outside of the enterprise.

2.2.1 INTER-JOINT PRODUCT COMPETITION

Depending on the nature of the joint products, a change in the price of a product or a change in consumer preference may bring the product into competition with another in the same set. Under these circumstances sound pricing is a very relevant consideration.

The case is taken of a concern manufacturing a range of heating fuels, including bottled gas and light fuel oil. The products are marketed through various agencies and the concern has never attempted to determine the end-use pattern. The ratio of product yield is variable over a small range.

Gas stocks show signs of a build-up, and management decides to lower the price on a temporary basis to avoid having to cut back on total production. This induces certain fuel oil customers to switch to gas and they install the necessary equipment. Gas sales go up, but within a few months fuel oil stocks are at danger level.

Management can now drop the fuel oil price or raise the gas price and risk the probable customer loss. Either way revenue is forfeited.

The technical interdependency of the products renders the joint product concern vulnerable to the see-saw effect described above where products may compete with each other. Sound pricing and marketing strategy is necessary if revenue is to be optimised.

2.2.2 EXTERNAL COMPETITION

Where a joint product is in competition with a single-line product, more often than not the latter has the advantage of production flexibility. In the simplest case of a single-line product sharing the market with a joint product, production of the former could conceivably be doubled. If a percentage of the resultant cost saving is passed on to the customer, the entire market could be captured. The joint product manufacturer, on the other hand, cannot vary output of any one product to any great extent without a corresponding change in the output of the remaining products.

The intensity of competition between joint product producers operating similar processes can be expected to vary inversely as the capital investment required. In view of the capital intensity and giant size of many of today's multi-product manufacturing processes, entrepreneurs are unlikely to enter the market unless a reasonable share thereof for the majority of the products is assured. Depending on the number of products produced in the joint process, however, the chances of capturing a proportional share of the market for all products is remote. A certain amount of "cut-throat" competition between particular joint products can thus be expected.

2.3 THE QUALITATIVE PRODUCT MIX

A further consideration with respect to the optimisation of price decision-making is the large amount of detailed market information required in cases where the quantitative product mix is flexible. It may be that further work-up, or lack thereof, places the product in an entirely different market. Ruling prices and the elasticity of demand in both markets must therefore be considered before an optimum price decision can be taken. Where a large number of products and alternative final forms in which they may be sold are involved, a considerable quantity of information is required.

The not uncommon belief that "all the market can bear"-pricing is synonymous with income optimisation under given circumstances can be faulted on various grounds as a long term policy. Where joint production is involved it does not even hold over the short term unless the demand characteristics for alternative derivatives, intermediates, and product blends are taken into account.

3 PRICING PROCEDURES FOR JOINT PRODUCTS

In the case of single-line products; where sound cost particularization principles are put into practice, the resultant cost price is of considerable importance to effective product pricing. Replacement value considerations and clear distinction between cost and waste, tend to relate all product costs to the value at the moment of economic exchange. Cost price thus serves an important purpose as the underlying basis on which the pricing policy and presentation-prices should be established. (Vide A.J.E. SORGDRAGER, op. cit., 1964, pp.128-131; and 1967, p.59).

In the light of the indeterminable causal relationship between joint cost and individual products, artificial "cost prices" for joint products do not serve the purpose described above. The joint cost as such is the primary consideration. The split-off point remains the control point with respect to pricing; as with cost control and other managerial decision-making.

Viewed from the normative approach adopted with respect to costing and the maximisation of returns, the following can be said of joint product costs and prices:

> Returns (as defined) may be negative unless pricing is based on a sound knowledge of the behaviour of the cost price of the set of joint products under the relevant conditions.

Procedures for the setting of presentation prices under various circumstances are discussed.

3.1 PROCEDURES BASED ON A FIXED RELATIONSHIP TO ALLOCATED JOINT COSTS

Very few joint product costs apportioned by the methods discussed in chapter V (op. cit.) provide reliable decision-making information for pricing purposes. The following are the conditions under which it may be possible or necessary to base prices on allocated joint costs:

(a) Where a single customer purchases virtually the entire set of joint products on a "packaged deal" basis.

(b) Where the base unit or weighted average allocation method results in costs which are relatively meaningful from a marketing point of view.

(c) Where one or more of the products is sold on a "cost-plus margin" tender basis. (This type of purchasing is rarely encountered in South Africa and is listed as a theoretical possibility.)

Conditions vary according to process, product and market environment and no rules can be laid down with respect to precise allocation methods in the above circumstances.

3.1.1 JOINT PRODUCT COST/PRICE RELATIONSHIPS

In the event of allocated costs being used for pricing purposes on a direct basis, the following procedures can be applied. (Vide J. DEAN, "Management economics," Prentice-Hall Inc., New Jersey, 1951, pp.473, et. seq.)

(a) Prices proportional to full cost; that is, prices that produce the same profit margin in terms of the average unit cost for all products.

(b) Prices proportional to incremental costs; that is, that produce the same percentage contribution-margin over incremental costs for all products. This method is used by several South African joint product concerns to adjust prices in the event of an increase in raw material costs.

(c) Prices with profit margins that are proportional to average conversion cost and take no account of purchased material cost. Presumably time studies are used as a basis for labour cost apportionment.

The above relationships may be used under particular circumstances. Further discussion is unwarranted.

3.1.2 OBJECTIONS TO THE USE OF ARTIFICIAL COST PRICE AS A DIRECT PRICING BASIS

Unless costs can be particularized to products on a causal relationship basis, they may be unsuitable for pricing purposes. A.J.E. SORGDRAGER (op. cit., 1964, p.128) emphasises the danger that factors which are related to the demand problem may otherwise be confused with factors relating to the cost price. Profit is the difference between price and cost. Prices realised are functions of exogenous variables, while costs are incurred with managerial intent and are endogenous with respect to the enterprise. If cost and demand factors are confused, returns can not be maximised.

3.2 PROCEDURES BASED ON DEMAND ANALYSIS AND THE JOINT COST OF THE SET OF PRODUCTS

The demand for a product refers to the number of units that will be absorbed by the market at a particular price. Demand analysis is the result of market studies concerning the relationship between demand and price. In the simple case where external factors are ignored, the relationships between sales volume and price for a particular product can be represented by an equation and depicted graphically as a "demand curve." More sophisticated analysis incorporating the effect of exogenous market variables, can be represented by a system of parameters.

If the demand curve for each joint product is known, a relatively simple model incorporating the marginal joint cost may be set up. From this model individual product prices at optimum joint output can be determined. J. DEAN (op. cit., pp.475) proposes a system whereby products which are interrelated on the cost side can be priced according to contribution margins that depend on the elasticity of demand of different market segments. In evaluating the above system, J.A. HOWARD ("Marketing management: analysis and planning," Irwin Inc., Illinois, 1963, p. 375) states that:

> "... if it is interpreted to include adequate consideration of product interrelationships; it is simply an application of the short-run optimising model to the more complex problem of interrelated products."

The following is an example of the procedure involved.

3.2.1 A GRAPHIC METHOD FOR THE SHORT-RUN OPTIMISATION OF JOINT PRODUCT PRICING

The following procedure is advocated by H. BIERMAN (op. cit., p.65):

The following are assumed:

(a) Joint products A and B are manufactured from 10 lbs. of raw material.

(b) The yield ratio is 4 lbs. of A to 6 lbs. of B.

(c) Both products have known demand curves which are either horizontal or slope to the right; i.e. the number of units sold is independent of price over the range considered, or it varies inversely as the price.

See A.8, FIGURE VII.1
A.9, FIGURE VII.2

Considering the two products together, the average revenue is obtained and plotted against the number of units sold of the theoretical product (AB), consisting of four lbs. of A and six lbs. of B. The average revenue for one unit would be the sum of the prices necessary to sell four lbs. of A and 6 lbs. of B, both of which may be read off on FIGURE VII.1. The marginal cost curve is assumed to be a horizontal line so as to serve as an average variable cost curve. The marginal revenue of the theoretical product (AB) is then computed and plotted on the same axes.

See A.10, FIGURE VII.3

OQ is seen to be the optimum output of the theoretical product (AB) expressed in terms of units representing four lbs. of A and six lbs. of B. OR represents the total revenue.

To find the prices at which the units must be sold, FIGURE VII.1 is consulted. This graph shows the prices for A and B that will clear the market of the number of units produced. The price of A multiplied by the number of units of A, plus the price of B multiplied by the number of units of B, will be equal to OR.

3.2.2 DISCUSSION

As a short-run optimisation procedure the validity of the method can not be refuted. In practice its application is hampered by the following factors:

(a) The graphical method becomes unwieldy where a large number of products are concerned.

(b) The method as described makes no provision for unequal unit work-up costs or a multiplicity of joint processes.

(c) It is in fact based on cost/volume analysis, and is subject to the limitations of the break-even system. (Vide J.C.M. VAN NIEKERK, op. cit., chapter XII). The method can not, however, be seriously objected to on this score.

(d) The primary objection must be that the effectiveness of the method as an optimisation procedure is a function of the accuracy with which the demand curves for each product. An unrealistic curve for one product will adversely affect all the other prices computed by this method.

Factors (a) and (b) above can be overcome by using a mathematical model which takes the cost centre structure of the system into consideration. With respect to the primary objection, namely the probable inaccuracy of the demand forecast, it is proposed that this problem should be approached objectively.

Both as a short-run optimisation procedure as well as a guide to long-term pricing policy, the method represents a theoretically sound way of analysing cost-volume-sales relationships, which does not depend on artificial cost prices. If returns are to be optimised, the problem of demand forecasting must be satisfactorily solved within the constraints of diminishing returns.

4 CONCLUSIONS

Pricing of joint products is at once a highly important yet complex managerial function. The conclusions drawn in this chapter in this respect are summarised.

(a) Pricing represents a partial solution to the ever-present problem of the independence of demands for jointly produced products. The use of pricing for this purpose is subject to limitations and can only be optimised if the price/sales-volume is known to a reasonable degree of accuracy.

(b) Returns on joint products can not be optimised unless pricing is based on demand characteristics and costs particularized on a causative basis.

(c) Provided that the demand characteristics for each joint product are known to a realistic extent pricing for optimum revenue can be effected without allocating joint costs to these products.

The importance of the demand forecasting function in a joint product enterprise has been emphasised with respect to pricing. Aspects of demand analysis for joint products and some advanced forecasting systems are examined in the following chapter.

CHAPTER VIII

ENVIRONMENTAL FORECASTING FOR THE JOINT PRODUCT ENTERPRISE

1 INTRODUCTION

The environment of an enterprise may be described as the set of exogenous factors constituting the bounds or limits within which the enterprise operates. For a manufacturing concern, the basic exogenous factors are the demand for the resultant products and the availability of the manufacturing resources of capital, labour and materials. Within limits these factors may be functions of the "price" attached to them by management.

In order to be able to optimise manufacturing activities, it is important to know where these limits lie, and the relationship between factor and "price." In a dynamic environment the prediction of future conditions is involved, and this function is termed environmental forecasting. The desired end-result of environmental forecasting for a manufacturing concern is the predicted supply of each resource (related to its cost) and the demand for each product (related to its price).

In this chapter demand forecasting for joint products is discussed and certain advanced environmental forecasting systems are examined in the light of the decision-making information requirements in a joint product manufacturing concern. Reference is made to the importance of technological forecasting in capital-intensive industries.

2 DEMAND FORECASTING AND JOINT PRODUCT DECISON-MAKING

2.1 THE NEED FOR RELIABLE DEMAND FORECASTS

A complicating factor in joint product decision-making is that each product may be subject to different demand characteristics. Each product may therefore be regarded as having a different "market environment." This market environment is in effect a set of influencing factors, some or all of which may change with the passage of time. Many of these factors may be common to all the "market environments," i.e. a change therein will affect the demand for each product to a greater or lesser extent. On the other hand, changes in a factor may have a pronounced effect on the demand for one product in the spectrum leaving the demands for the others unaffected.

Rainfall, for example, can extensively influence the demand for fertilizer during a particular season. The raw materials for this fertilizer may be produced jointly with industrial fuel gas, as is the case with ammonium sulphate at Sasol. Rainfall has no effect on the demand for industrial gas.

Many important joint product industries are capital-intensive. This fact has two important implications with respect to the need for reliable demand forecasts. Firstly, with a high percentage of fixed costs, down-time or reduced throughput as a result of sales of one or more joint products falling below forecast, can seriously affect profits. The second implication involves new plants or expansions to existing ones. If demand forecasts turn out to have been optimistic, the facilities are run below capacity and possibly at a loss. If forecasts were pessimistic or too far on the "safe" side, the new plant may turn out to be uneconomically small within a few years.

T.E. CORRIGAN and M.J. DEAN ("Determining optimum plant size," Chemical Engineering, August, 1967, pp.152-156) emphasise the importance of thorough market research with respect to plant sizing. Examples based on discounted cash flow over ten years quoted by the above authors show how price-decreases over this period drastically reduce the profitability of an undersized plant.

Conclusions drawn earlier in this study were that the degree of uncertainty associated with the composite demand forecast for a set of joint products was inherently greater than that for a singly-produced product. Furthermore, any deviation from forecasted demand on which optimum resource allocation has been based tended to result in a greater deviation from maximum returns than otherwise if the products are technically interdependent.

2.2 JOINT PRODUCT FORECASTING REQUIREMENTS

The extent of the demand for a product is a function of its "price," as is the supply of a resource. In the former instance "price" is the price (in real terms) which the supplier will accept in exchange for his product, while in the latter instance it is the replacement price of the resource.

For decision-making purposes it is necessary to know the relationship between demand and "price" and supply and "price," for each realistic level of production of each product. In a dynamic environment, these relationships may change with the passage of time. In order to optimise decision-making, forecasted changes in these relationships are required.

The above relationships and changes in them with the passage of time are termed the demand/supply characteristics for the product/resource.

3 MODELS FOR ENVIRONMENTAL FORECASTING

Demand forecasting and analysis traditionally falls under the heading of Market Research. Responsibility for this function normally lies within the scope of the marketing division in the company's organisational structure. Sales forecasts may be based on the results of executive or salesmen polls, where existing customers are questioned as to their estimated purchases; or from projections of existing demand trends.

The limitations of these methods and the development of operations research techniques have led to a more scientific approach to forecasting. Of the less sophisticated techniques in this respect is correlation analysis, which enables appraisal and updating of forecasts in the light of actual developments. This technique is described by H.R. ANTON and P.A. FERMIN (op. cit., p.331) as being the derivation of a mathematical equation which best discloses the nature of the relationship that exists between a business element to be predicted and one or more causal factors.

The increasing availability and scope of computers has led to considerable research into the construction of more comprehensive models. In view of the importance of reliable forecasts in large-scale joint product manufacturing it is not surprising to find petroleum and chemical corporations among the pioneers in this field.

Notable in this respect are the following:

(a) Esso Petroleum Co., Ltd., (U.K.) (Vide G. OWEN, "How Esso studies the far horizon," Financial Times, London, March 30, 1967, p.15).

(b) Shell Oil Co., (U.S.A.). (Vide R.C. McCURDY, "Application of operations research to chemical technology," Industrial and Engineering Chemistry, Vol. 60, No. 2, Feb. 1968, p.21).

(c) Imperial Chemical Industries Ltd., (U.K.). (Vide P.V. YOULE, "Optimisation of a petrochemical complex; a case history," European Chemical News, Nov. 1969, pp.76 et. seq.).

Of the advanced models; two types, the statistical and the econometric, are of importance.

3.1 STATISTICAL MODELS

This type of model is the logical result of the application of electronic data processing techniques to marketing analysis involving statistical methods. Depending on the number of products, sales outlets, etc., companies accumulate large masses of statistical data concerning sales. The use of electronic data processing techniques enables the assimilation of this information in a form which will reveal significant trends.

This function is more important than it may seem on first examination. For example: the overall sales of a jointly produced product may show a downward trend indicating redundancy. A breakdown of the sales may, however, reveal that the sales to customers in an industry with a positive growth potential are increasing, while those to customers in industries with negative growth potential are declining. A model programmed to interpret the statistical breakdown of these sales will forecast an upward swing which might otherwise have gone unpredicted.

The statistical model can be programmed to discriminate between seasonal and random fluctuations, apply exponential smoothing, compute price-demand relationships, relate sales to promotion expenditure, and test the statistical significance of each result. A further application of the statistical model is that short-term or tactical forecasts can be easily correlated with actual results. By means of the so-called "Box Jenkins" method, subsequent predictions can be modified in the light of the errors in previous forecasts.

A limitation of the statistical model is that it cannot be used to simulate the effect of new influences for which historical data is not available. Such influences include competition from a new entrepeneur or product, changes in economic climate, relaxation of import control, etc.

On the practical side the statistical model requires little specialised maintenance. The company using such a model will be likely to process its accounts, opinion surveys and customer polls on a computer in any event. It is a relatively simple matter to arrange for the model data file to be simultaneously updated.

This type of model thus improves with age. Where existing trends are maintained, it can be effectively used to predict the type of detailed demand-price relationships required for pricing, blending and overall optimisation models.

3.2 ECONOMETRIC MODELS

Econometrics is the science of explaining past economic activity and predicting future economic activity by means of the derivation of mathematical functions that express the most probable interrelationships between the set of relevant variables. The econometric forecasting model is thus built up of relationships between economic variables derived from historical data and economic theorems. Econometric models based on these relationships have been used to simulate complete national economies.

W.W. LEONTIEF, ("The structure of the American economy, 1919-1939," Oxford University Press, New York, 1951; and "Input-output economics," Oxford University Press, London, 1966) develops a method by which the flow of resources between various sectors of an economy is studied by means of input-output models.

The econometric model of use to the management of a particular enterprise for environmental forecasting purposes is of a far more specific nature. It incorporates only those economic variables which are more or less directly related to its activities. Such variables may include disposable income, government spending, balance of trade, construction plans passed, interest rates, etc.

Setting up this type of model involves the derivation of empirical relationships between these economic variables and the relevant resource supplies and/or product demands. In most cases the relationship as well as the choice of variable will be the result of statistical analysis. In some instances relationships may be based on "theorems" applicable to certain market situations. For example, the two-person, zero-sum games theory is applicable to a duopolistic market where one competitor's gain is equal to the other's loss. By incorporating games theory postulates, the nett effect of the adoption of alternative marketing strategies by the competitors can be predicted. D. BUTLER, ("High potential for marketing," in Annual Review of Management Techniques, 1969, London, Haymarket Press, 1969, p.51) notes that models of competitive situations have been successfully tested.

The econometric model obviously becomes extremely complex as more causative variables and effect relationships are built in. Moreover, the accuracy of the resultant forecasts is by no means directly proportional to its size, the laws of diminishing returns holding strictly in this respect. The principle which renders this type of model feasible is that the pattern of the results is not necessarily as complex as the interacting mechanisms causing it.

This point is emphasised by B. WAGLE ("The use of models for environmental forecasting and corporate planning," Operational Research Quarterly, Vol. 20, No. 2, September, 1969, pp.327-336) in describing the construction of an econometric forecasting model for the Esso Petroleum Company in England. This model has ten economic sectors represented in it. These are:

(a) Exports.

(b) Imports.

(c) Balance of Payments.

(d) Fixed Investment.

(e) Consumers' Expenditure.

(f) Nett Direct Taxes.

(g) Final Demand.

(h) Stocks.

(i) Gross National Product.

(j) Prices.

In each of these sectors a basic set of variables is related to a second set and the functional relationships are estimated using statistical methods. The results given by the model were compared with actual results for the period from 1958 to 1967 and the correlation is reported to have been "satisfactory for all practical purposes".

Basically, the econometric model relates, or attempts to relate, cause to effect with respect to forecasting. It is therefore less dependent on internal company historical data and can be used to simulate conditions under alternative assumptions. As such it has distinct advantages over other types of forecasting techniques in the field of venture analysis.

On the other hand the model is likely to be expensive to set up and maintain. Changing economic conditions must be continuously analysed and interpreted, which may require the services of a full-time research team. M.H. SPENCER and L. SIEGELMAN (op. cit., p.69) note that the construction and updating of this type of model is usually carried out by professional econometricians working in universities or research organisations.

4 MEETING JOINT PRODUCT FORECASTING REQUIREMENTS

Having underlined the importance of environmental forecasting in the optimisation of multi-product manufacturing, it remains to examine how these requirements can best be met. For the purposes of the following discussion it is assumed that the enterprise is large, capital-intensive and sells in a number of markets.

4.1 STATISTICAL VERSUS ECONOMETRIC MODELS FOR JOINT PRODUCT PRICING AND PLANNING

Provided that recent trends are maintained, statistical models based on sufficient historical data are capable of predicting both demand levels and price relationships with a desirable degree of accuracy. This does not hold for periods immediately after a change in trend direction. Once the "turning point" has been reached, however, the model can project the new trend as accurately as before. Economic time series do, for the most part, show a persistent tendency to move in the same direction for a period of time because of their inherent cumulative characteristics. As a result the statistical model will be accurate for a high percentage of the time.

In the above respects, the econometric model has a greater capacity for predicting the effect of previously unexperienced influences. Forecasts using this type of model are thus likely to be more accurate for periods in which the trend changes direction. For the remainder and greater part of the time, its predictions can be expected to be less precise. This statement is based on the fact that in order to take account of the factors causing changes in the trend, the model is more susceptible to random fluctuations during steady trend periods.

An important consideration in joint product demand forecasting is that the shape of the demand curve may be relatively independent of the actual demand level. Changes in the type of causative economic variables incorporated in econometric models are likely to have a roughly equal effect on the demand levels of all the joint products. Provided that the shapes of the curves remain constant during a change in economic conditions, the joint process will remain optimised under the resultant increased or decreased output levels. The inherent inflexibility of the capital-intensive joint manufacturing process leaves little scope for managerial action in such an event.

In practice the situation where all demand levels vary to exactly the same extent while all curves remain fixed, may rarely be encountered. The above reasoning does, however, serve to demonstrate that for optimisation purposes it may not be as important to predict changes in demand level trends as it is to forecast levels and curves accurately under prevailing trend conditions.

In general it is maintained that the use of sophisticated econometric forecasting models in joint product manufacturing concerns is rarely justified. This type of model is, however, better suited to simulating the feasibility of new ventures, products or markets.

In the above appraisals econometric and statistical models were assumed to be two distinct and different types. This is not strictly the case. Economic factors can be effectively used to "weight" statistical projections, and should in fact be taken into consideration to some extent in any forecasting model.

4.2 SOURCES OF FORECASTING DATA

The accuracy and reliability of any forecast is dependent on the adequacy and statistical significance of the information on which it is based. Data sources within and outside the enterprise are listed.

4.2.1 INTERNAL SOURCES

Internal forecasting data consist of facts and figures compiled by and exclusive to the company concerned. Sources of such information include:

(a) Records of sales and prices.

(b) Records of purchases and costs.

(c) Records of tenders and contracts lost.

(d) Market surveys conducted by or on behalf of the company.

(e) Sales staff reports.

(f) Customer polls.

4.2.2 EXTERNAL SOURCES

External data sources are publications which list information relevant to company environmental forecasts. Such publications may obviously include anything from daily newspapers to opposition companies' annual reports. With respect to South African external data sources, however, the following general publications are considered to be the most important:

(a) "The Republic of South Africa statistical yearbook."

(Issued by the Department of Statistics, Pretoria). This publication lists statistics relating to a number of industrial, economic and demographic factors which may be related to joint product demands and resource supplies. Certain statistics, such as those on total population, are projected for periods of up to 10 years ahead. The Department of Statistics also issues a quarterly bulletin of statistics as well as a monthly news release entitled "Short-term economic indicators."

(b) "Monthly abstract of trade statistics," issued by the Department of Customs and Excise, Pretoria.

This publication is of particular importance to the manufacturer who produces products which compete with, or replace, imports. It is also relevant in cases where raw materials are imported. The publication is criticised on the grounds that certain import figures are lumped together under a common heading. The fault probably lies outside the Department, however, and with the importer or agent who does not specify the consignment sufficiently accurately.

(c) BER Publications.

The Bureau for Economic Research attached to the University of Stellenbosch compiles and publishes a quarterly "Opinion survey" and annual "One-year and medium-term forecasts." The opinion surveys are conducted by means of mailed questionnaires to some 2,000 collaborators in various commercial and industrial sectors. The forecasts are mainly compiled in a national accounts framework. The forecasting methods used include an adapted form of the opinion survey and econometric relationships. Qualitative information is obtained by way of interviews with representatives of government departments and other bodies.

One of the aims of this research bureau is to make a continuous study of economic conditions in South Africa with special reference to the following:

- diagnosis and prognosis of the business cycle;
- structural changes in the South African economy;
- the analysis of various economic sectors.

As such the bureau publications provide valuable forecasting data.

5 TECHNOLOGICAL FORECASTING

So far in this chapter two basic methods of forecasting have been discussed. One, based essentially on the projection of recent trends, was seen to be inaccurate for periods following changes in trend direction. The other goes some of the way in overcoming this disadvantage by taking changes in the economic environment into consideration on a cause and effect relationship. With respect to manufacturing industries, changes in product demand and resource supply due to economic factors tend to be cyclic, in that they are temporary and average out over the long term. More permanent are the effects of changes in the technological environment. In addition, although more difficult to predict, the relationship between technological changes and product demand or resource supply is more direct.

> The rate of technological advance has accelerated to such an extent over recent years that it has become a very relevant factor in long range forecasting and venture analysis.

Although specific technological applications may be generated from within the enterprise, technological progress in the broad sense is a continuous exogenous process. It is thus classified as an environmental factor.

5.1 TECHNOLOGICAL CHANGE AND THE JOINT PRODUCT MANUFACTURING ENTERPRISE

The various ways in which the joint product manufacturing concern may be affected by technological innovations and the possible effects thereof are discussed.

5.1.1 COMPETITION EFFECTS

The profitability of a multi-product concern depends on the continued demand, at reasonable prices, for all of the jointly produced products. Furthermore, if the process is capital-intensive (as is frequently the case) the minimum demand for every product must be above a certain level if large-scale losses are to be avoided. T.E. CORRIGAN and M.J. DEAN (op. cit., p.152) maintain that most chemical processes operating at below 60% of design capacity do so at a loss. As a result a single joint process is vulnerable on as many fronts as the number of products, to product obsolescence.

Product obsolescence can be described as a relatively rapid decline in demand for a product owing to the availability of a cheaper or superior product made possible by technological innovation. Competition to a joint product may come from the same product produced more efficiently by means of an improved process. Alternatively it may come from an entirely different product with similar or superior properties which can be marketed at a more competitive price.

Competition from the latter type of "replacement" product may not be as serious as that from the same but cheaper product. This is owing to the fact that it may replace the existing product in certain but not all applications. Moreover, the possibility exists that by adjusting the price of the existing product it can compete in other markets where it is not threatened by the replacement product.

Although forewarned is forearmed, even if technological advances resulting in increasing competition are predicted, there are not many courses of action open to the joint product manufacturer. If a new process is involved, he has little option but to reduce price or to replace equipment. If a new product is involved, he can immediately launch a research and development programme aimed at being the first in the field. Alternatively he can watch the situation and hope to get in ahead of any rivals when the product form and its manufacturing process become available.

Where a single-line product manufacturer can replace equipment or adapt it for production of another product in the face of the type of competition resulting from technological innovation, the joint product manufacturer can not. In his case the product challenged is one of a series produced by the same equipment. Competition of this nature can, of course, come from an improved joint process which results in a similar product spectrum. If this is predicted, the existing manufacturer can consider replacing equipment as and when it becomes available, to meet any competition on an equal footing.

It can be seen that technological innovations in the field of single-line products and processes which can render one or more existing joint products obsolete, are an ever-present threat to multi-product profitability. This fact serves to emphasise the importance of technological forecasting with respect to venture analysis on plant expansions and additions.

5.1.2 APPLICATION REDUNDANCY DUE TO TECHNOLOGICAL INNOVATION

A factor which can affect the demand for a jointly produced product is the redundancy, owing to technological advance, of its major application. If forecast, however, the joint manufacturer can research alternative markets and applications for the product concerned.

The petroleum refining companies are doubtless keeping a watchful eye on developments in the field of electrically driven vehicles, especially in the light of the outcry against air pollution. Polyvinyl chloride (PVC) is produced from two primarily jointly produced products: ethylene and chlorine. This material will sooner or later face redundancy owing to its biological undegradability and the fact that when burned on municipal rubbish dumps it gives off poisonous fumes.

The implications of application redundancy considerations are that technological forecasting is required in a large number of fields. Predictions covering not only the challenge of new products and processes to those of the enterprise itself, but also those of its major customers, are required.

5.1.3 NEW APPLICATIONS FOR JOINT PRODUCTS

The inverse of joint product redundancy, namely the creation of new applications for joint products, is of equal importance to the multi-product manufacturer. New uses open up new markets, which, even if they are not more profitable, increase the marketing alternatives and decrease product vulnerability with respect to obsolescence and application redundancy. In many cases the increased demand will result in an increase in product price, improving the profitability of the joint process. Although it may not be possible to increase the output of the product concerned to exploit greater demand without producing more of the remaining joint products, the overall programme may be optimised at a higher profit level.

Forecasted additional uses for one or more jointly produced products is an important consideration in the planning of plant expansion. New applications may call for products of a different purity or blend composition to those being currently produced. These factors have a bearing on decision-making in connection with the planning and design of work-up facilities.

Long-term contracts are sometimes negotiated to secure a steady market for a lower priced joint product. Technological forecasts concerning new applications for these products should be taken into account when deciding on the terms of such contracts.

5.1.4 TECHNOLOGICAL ADVANCE AND THE JOINT PROCESS

Whether it be a synthesis/separation or purely extractive operation, the joint process itself may be affected in a number of ways by technological advances and innovations. The maximisation of returns with respect to a joint process concerns the maximisation of the higher value products at the expense of those having a lower value at separation.

In a synthesis process, such as those encountered in the chemical industry, new unit processes with yield ratios favouring higher value products may become available. In such cases new plants may be installed to supplement or replace existing joint process units, with a consequent increase in revenue.

The technological advance may be in the field of process materials or operating techniques which do not involve entirely new plants or extensive capital outlay. Such innovations may come in the form of improved catalysts which increase conversion efficiency or have increased selectivity with respect to higher value products. New materials may enable operating pressures and temperatures to be optimised with respect to yield ratio or conversion efficiency.

Improved separation techniques can have applications in both synthesis/separation and purely separation joint processes. In the case where imperfect separation results in higher value products being lost to lower value products, improved techniques or equipment will favourably influence the yield ratio. In other cases usage or throughput will be improved.

The instances cited above are examples of how improved technology may be applied to increase joint process profitability. In some cases the profit-limiting constraint common to all joint processes, namely restricted product mix at separation, may be relaxed to an extent.

5.2 THE IMPORTANCE OF TECHNOLOGICAL FORECASTING IN JOINT PRODUCT INDUSTRIES

Many of the industries most influenced by recent technological advances are based on joint processes. They therefore operate in fields where the rate of technological change has been the greatest to date. These fields include transport (petroleum refining), synthetic polymers (petrochemical), energy generation (uranium/gold mining, petroleum), processed foods (meat packaging) and medicine (chemical). There is little to indicate that the progress in these fields will slow down.

By taking predicted technological innovations into consideration in long range plans, the manufacturing management is in a better position to exploit new opportunities or to hedge against obsolescence. Its capital intensity and inflexibility with respect to product mix renders this type of forecasting even more important in planning and decision-making in large joint-product industries.

Preparing technological forecasts, particularly by the delphi method where a number of expert predictions are programmed, stimulates creative thinking. (Vide H.W. NORTH and D.L. PYKE, "Probes of the technological future," Harvard Business Review, May-June, 1969, pp.69 et. seq). The resultant predictions give direction to research and development programmes.

6 SUMMARY

The optimisation of managerial decision-making in a joint product manufacturing enterprise is dependent on the availability of accurate and reliable environmental forecasts. In general the joint product concern is more vulnerable profit-wise with respect to environmental changes than its single-line manufacturing equivalent.

Where large-scale capital-intensive joint processes are involved, the use of advanced forecasting procedures may be justified. Statistical models were shown to be superior to, as well as more feasible than econometric models for the purposes of joint product demand forecasting.

Technological forecasting is an important aspect of long-term planning and demand forecasting. A number of the industries in which the rate of technological advance has been the most rapid in recent years, are primarily joint product producers or consumers. The factors of large-scale, capital intensity, and inflexible product mix render this type of environmental forecasting a necessity in many joint product concerns.

CHAPTER IX

COMPUTER MODELS AND JOINT PRODUCT DECISION-MAKING

1 INTRODUCTION

Multi-process joint product manufacturing systems consist of chains of interrelated unit processes. As such the end products of one process become the raw materials for others. In many cases, however, the processes are related on more than an "upstream-downstream" basis, with recycle and blended product streams being commonly encountered features. A number of processes in the system may be joint and intermediate products may be sold or bought-in.

Planning and decision-making for maximum returns for a system of this nature becomes highly complex. As a result interest in mathematical programming techniques as aids to optimisation in the industries where such systems occur has been growing over a number of years.

In this chapter managerial optimisation techniques are discussed and certain models which can assist in the maximisation of returns on joint products are examined.

2 MANAGERIAL OPTIMISATION SYSTEMS

The primary objective of manufacturing management was defined for the purposes of this study as the maximisation of returns. Managerial optimisation involves the maximisation of revenue less costs under various conditions. The break-even system is a good example of a managerial optimisation system. Cost-volume-profit graphs reflect profit under various cost and volume conditions. (Vide J.C.M. VAN NIEKERK, op. cit., p.157-165). If the product mix of a joint product system is permanently fixed, the break-even system can be applied by regarding the set of products as a single product. The information provided thereby was, however, shown to be of very limited value.

Where the final product mix is variable even to a small degree, the break-even system as described becomes invalid for optimisation purposes, and alternative systems are necessary. J.M. HENDERSON and R.E. QUANDT,("Microeconomic theory: a mathematical approach," McGraw-Hill Co., New York, 1958, pp.67-75) have developed a procedure whereby the optimum inputs and outputs for a joint product manufacturing system may be calculated. Although this system is theoretically valid and is generally applicable in principle; where more than five constraints are involved, it becomes extremely complex and unwieldy. Computer optimisation techniques are the alternative, and aspects thereof are discussed.

2.1 LINEAR PROGRAMMING: THE SIMPLEX METHOD

Within recent years there has been a remarkable increase in the use of operational research techniques as aids to managerial decision-making. Linear programming is perhaps the best known of these techniques and has found widespread commercial, industrial and military application. It may be defined as a method of maximising or minimising a linear function subject to a number of restraints stated in the form of linear inequalities. (Vide D. WHITE, W. DONALDSON and N. LAWRIE, "Operational research techniques," Vol. I, Business Books Ltd., London, 1969, p.14).

The simplex method, attributed to G. DANZIG (vide A. CHARNES, W.W. COOPER and A. HENDERSON, "An introduction to linear programming," Chapman and Hall, London, 1954, p.2) is an extension of this optimisation technique in which the inequalities are transformed into equalities by the introduction of non-negative "slack" variables. It is essentially a "short-cut" method of solving linear programming problems; the mathematical routines for equalities being simpler than those for inequalities. In essence it involves the optimisation of an objective function subject to certain constraints. The optimisation of joint product blending is discussed as an illustration of how the technique may be employed.

2.2 THE OPTIMISATION OF JOINT PRODUCT BLENDING USING THE SIMPLEX METHOD

A wide variety of joint products is sold in the form of blends. Some examples are as follows:

(a) Gasoline. (Frequently a grade of gasoline is a blend of six or more jointly produced components).

(b) Liquified petroleum gases.

(c) Solvents.

(d) Creosotes and bitumen.

(e) Processed meats such as polony, etc.

Such blends are usually formulated to meet predetermined specifications, conforming either to customer, legal or general industrial requirements. Components may comprise products from more than one joint process and may include single-line or purchased materials.

Depending on the circumstances, the specifications may permit a number of alternative product combinations. As the sales values of the various blends may differ substantially, the optimisation of blend formulations and quantities is vital to revenue maximisation.

The routines involved in the optimisation of blending where the component availability is fixed, but a range of formulations can be used, are discussed.

2.2.1 THE OBJECTIVE FUNCTION

If variable costs could be directly associated with each blending component, and the quantity of each component produced was controllable; the objective function would be total revenue less total variable cost.

If the components are jointly produced, the relative component quantities are fixed within certain limits. The actual quantities available for blending will be determined by considerations with respect to the non-blended as well as blended products of all the joint processes involved. Total allocated variable costs for the blending components can not be used for optimisation purposes. The objective function for single-line products stated above can therefore not be used where one or more of the components is jointly produced.

In practice it can frequently be assumed that all joint product blending component costs can be regarded as being fixed. This can be defended on the grounds that at the blending stage the products have already been produced and would have incurred the same cost whether sold as such or in blended form.

In the light of the above, one of the following two objective functions should be used, depending on circumstances:

(a) Total revenue for all blends;

(b) Total revenue for all blends less the sum of all variable costs which can be directly particularized to the blending processes.

(a) is used when all components are jointly produced and none incurs variable cost specifically in order for it to be able to be blended; and the variable cost of blending is nominal.

(b) is used where one or more single-line or purchased components are used; or where one or more jointly produced components incur variable cost in order to be able to be blended; or where the variable cost of the blending process itself (exclusive of direct material costs) is more than nominal.

Revenue for each blend in both of the above cases is the number of units produced multiplied by the standard unit realisable market value.

2.2.2 CONSTRAINTS

The operating constraints subject to which the objective function is maximised include the following:

(a) The unit realisable value of each blend.

(b) The minimum and maximum quantity of each component in each blend which will result in an on-specification product.

(c) Quantities of components available for blending; and unit variable costs where applicable.

(d) Minimum or maximum limits applying to the sale of any blend. (These may apply in cases where fixed contracts have been entered into.)

The above are the constraints usually applying to joint product blending. Others such as variable cost of blending, selling price/volume functions and inventory situation constraints may be included, provided that they can be expressed as linear functions.

2.2.3 SOLUTION BY THE SIMPLEX METHOD

The solution to the blending problem is derived from the simplex tableau reflecting the value of the object function; slack variables used, etc., for each permutation possible within the constraints set. The optimal solution is the quantity and formulation of each blend, which together will earn maximum returns.

Owing to the nature of the constraints, the optimal solution to a joint product blending problem may include unused quantities of one or more components. The income from these products, which require to be sold as such, is not included in the blend revenue.

Master simplex linear programmes are readily available as standard data processing software. Additional decision-making information which can be obtained from a simplex programme includes so-called "shadow prices" and "critical costs." Both are misnomers to a degree, but are nonetheless useful. The shadow price in a maximisation routine is the extent to which the optimum revenue would be reduced if one unit of the component to which it applies is unavailable. It is therefore a useful guide to pricing of purchased materials. The critical cost is the shadow price plus marginal cost per unit of the component. This provides valuable information on which selling prices of components as such may be based.

2.2.4 LIMITATIONS OF THE METHOD FOR THE SOLUTION OF BLENDING PROBLEMS

One of the obvious limitations of linear programming as an optimisation technique is that either the objective function or one or more of the constraints may be non-linear. With respect to the revenue variable, unless all the demand curves are linear, the price/volume relationship cannot be taken into consideration directly.

Specification constraints may also be non-linear. In the optimisation of gasoline blending, the constraints include specified octane ratings. The octane number can be effectively increased by means of the addition of purchased compounds such as tetra-methyl and tetra-ethyl lead. These are expensive and their optimum use for this purpose is a relevant consideration. However, the relationship between octane increase and the quantity of lead added is closer to logarithmic than linear, and varies from blend to blend.

It may be possible to overcome the problem of isolated non-linear constraints without excessive loss of flexibility by means of suitable programming techniques. One such technique which can be used to effect when the demand curve is non-linear, is described by A. CHARNES, W.W. COOPER and A. HENDERSON (op. cit., pp.19, 20). It consists of subdividing a blend constraint into several segments, the demand for each of which is assumed to be linear within defined limits. These segment blends are in effect alternatives depending on the sales volume. Should the optimal solution involve less than maximum demand for the blend in question, the relevant segmental blend with its corresponding linear price relationship will become effective. (Vide "Linear programming mark 3:

1900 series," Monograph, International Computers Limited, Technical Publications Service, London, 1969, p.43).

In this way a series of linear functions approximating to the demand curve enables non-linear price/volume relationships to be incorporated into the solution tableau. It is possible to optimise gasoline blending with respect to lead addition in a similar manner (Vide "Linear programming gasoline blending," Monograph, International Business Machines Inc., New York, 1965, pp.19-23).

Another limitation of the simplex programme for blending and product mix optimisation, is the sheer size of the matrix when a number of constraints are involved. (Vide A. BATTERSBY, "Mathematics in management," Penguin Books Ltd., London, 1966, pp.127, 128). Work done by A.R. CATCHPOLE (Operational Research Quarterly, Vol. 13, No. 2, 1962, pp.163 et. seq.) in connection with the optimisation of product scheduling and blending in a petroleum refining complex, showed matrix size to be a problem.

This problem is a function of the processing equipment available and as a result of developments in the field of computer hardware and software, this limitation is practical rather than theoretical.

2.2.5 THE LIMITED VALUE OF THE OPTIMAL SOLUTION

The constraints usually applicable in blending optimisation listed above include quantities of components available for blending. These were assumed to be fixed for jointly produced components. This assumption limits the value of the optimal solution.

These quantities are in fact dependent on planning and scheduling managerial decisions. The blending solution will be sub-optimal unless the remainder of the system is considered. This aspect will be discussed in more detail later in this study.

Use of optimisation techniques for isolated blending problems within the joint product manufacturing system is only relevant where the revenue accruing from the blends is a small proportion of the total revenue. A model which can be used to simulate the system as a whole is discussed.

3 MODELS AND SIMULATION

D. GLASSER and P.L. SILVERSTON, ("Process simulation and optimisation for middle management and senior technical staff," Unpublished notes for a short course and workshop; University of Witwatersrand, Johannesburg, 1969, p.52) define simulation broadly as follows:

> "... the representation of the full behaviour of a prototype system such as a chemical plant, by some model."

The mathematical model is a series of relationships expressed as mathematical statements which represent an operating system. This type of model can therefore be used to duplicate, or simulate, the behaviour under varying conditions of the system it represents.

M.H. SPENCER and L. SIEGLEMAN, (op. cit., p.531) state that:

> "If one can segregate a given system into a set of definable elements for which operating rules are available, then the system can be simulated on a computer."

Although the validity of this statement can not be refuted, the availability of satisfactory "operating rules" imposes a restraint in the case of many systems and limits the application of simulation and modelling techniques.

The parameters incorporated in most models used in simulation are determined from experimental and historical measurements. The accuracy and validity over the full range of conditions of such measurements are therefore important and often restrictive considerations.

See A.32, TABLE IX.1

The above table reflects the prerequisites for system simulation.

3.1 MANUFACTURING SYSTEM MODELS

Although computer models have found widespread application in the solution of aspects of multi-process manufacturing industries, their use in the overall optimisation of the production system appears to have met with more limited success. (Vide R.F. TUCKETT, "Combined cost and linear programming models," Operational Research Quarterly, Vol. 20, No. 2, June, 1969, p.224). This is probably due to the complexity of compiling the overall model. Furthermore, the overall model is specifically tailored for one particular application. On the other hand, transport, blending or inventory models have widespread applications and have therefore merited proportionately greater attention from both computer and software vendors.

It must be noted that joint products are technically interdependent and the joint product manufacturing system must be considered as a whole for optimisation purposes.

Manufacturing system models can be divided into two main categories which R.C. McCURDY (op. cit., p.20) terms planning models and control models.

3.2 PLANNING MODELS

Planning models cover a time span of at least one month and possibly up to several years. The model represents "average" or, more appropriately, standard operation of the system for the planning period. As such it ignores day-to-day upsets which may occur. It provides strategic guidelines for production planning and can be used for simulating the results of decisions concerning production variables, debottlenecking, raw material quality, etc. It is in effect a basic managerial decision-making model, the setting up of which for a joint product manufacturing system is discussed later in this chapter.

It is theoretically possible to extend the planning model to incorporate inventory and distribution variables, and, conceivably, demand forecasting.

3.3 CONTROL MODELS

Control models are used to optimise the day-to-day operation of the process. They make use of dynamic modelling techniques and as such, can scan a number of measurements and convert them into signals relating to changes in key plant variables.

Combinations of planning and control models designed to cover all major aspects of manufacturing have been developed and are in use in various parts of the world. International Computers Limited (UK) (ICL) has designed the so-called PROMPT system - Production, Reviewing, Organisation and Monitoring of Performance Techniques. It has four main parts; order analysis, stock management, factory planning and control and purchase control. Together these make up an integrated production control system, while it is possible to operate each independently or in conjunction with one or two others.

The development of the PROMPT series of models is reported to have cost ICL some R1 million. (Vide D. CAMINER, "Controlling the factory," in Annual Review of Management Techniques, op. cit., p.45). It is being used by several large manufacturing concerns and could prove to be the forerunner of total computer control.

4 A MANAGERIAL PLANNING AND DECISION-MAKING OPTIMISATION MODEL FOR A MULTI-PROCESS JOINT PRODUCT MANUFACTURING SYSTEM

The following is a description in general, non-mathematicl terms, of how a model for the maximisation of returns for a given joint product manufacturing system can be compiled. The method is applicable to the modelling of systems comprising a number of joint and work-up processes. The model caters for situations where some of the jointly produced products are sold in blend form or as by-products. Buying in or selling of intermediates are taken into consideration.

4.1 ASSUMPTIONS

The following assumptions are made concerning the nature of the system:

(a) The enterprise is capital-intensive.

(b) An established market exists for each product in either its final or "intermediate" form.

(c) The product ranges of the joint processes are fixed in that there is no choice as to which products are produced at separation.

(d) All labour and overhead costs are fixed.

(e) Returns are positive.

(f) The demand curve for each product is horizontal in the feasible output range; and constant over the period under consideration.

It can be seen that the above assumptions coincide to a large extent with actual conditions prevalent in joint product manufacturing industries.

4.2 THE OBJECTIVE FUNCTION

Optimisation of manufacturing activities involves the maximisation of returns. The objective function to be maximised is the difference between revenue and cost. If returns are positive, fixed costs do not affect the optimisation routine, and can be ignored for the purposes of this exercise.

Total revenue is the number of units of each product sold multiplied by its selling price. In terms of the assumptions made, production is equivalent to sales. Once demand characteristics have been forecast, standard realisable values can be established. Accordingly, revenue is equivalent to production of each product multiplied by standard realisable value in each case.

Total variable cost is equivalent to the sum of raw and process material costs which vary directly with the volumes of the product streams concerned.

In terms of the above the objective function is stated as:

> Total manufacturing revenue less total variable material cost.

4.3 THE MASS BALANCE

If fixed costs are ignored, for optimisation purposes the direct cost flow pattern for the joint product system will coincide with the mass balance. This is the case if material costs only are considered. Plus-usage is apportioned among remaining units. It is important to note that only the cost flow pattern and not the quantitative cost flows coincide with the mass balance. Inability to trace the causal relationship at split-off prevents the particularization of joint cost quantities to individual post-separation streams, but does not have any bearing on the cost flow pattern.

The mass balance can consequently be used as the basis for the input-output constraints. To be effective in this respect the mass balance should reflect each material stream in the system with all quantity relationships expressed in mass units or mass-mass ratios.

4.4 CONSTRAINTS

The constraints subject to which the objective function is maximised can be classed as either material or cost/value constraints. They may be equalities or inequalities. Not all the constraints listed below may be applicable, and/or others may be necessary. The set of constraints represents the framework of the model and will be different for different systems. The following are considered to be applicable in most cases.

4.4.1 MATERIAL INPUT-OUTPUT CONSTRAINTS

The material input-output constraints are derived from the mass balance. All units are mass units and ratios are expressed as mass to mass.

(a) The usage ratio for each process; i.e., the quantitative relationships between the sum of the product outputs and the sum of direct material inputs.

(b) The quantitative relationship between the usage ratio and the sum of the direct material inputs. (It may be that usage is lower at very high and/or very low throughput.)

(c) The yield of every product for each process; i.e., the quantitative relationship between the output of each product and the sum of the inputs for each process.

(d) If (c) above is a limited function of an operating parameter; the limits between which it is variable.

(e) The relationship between (c) and the input composition for each process.

(f) Maximum and minimum throughput limits for each process.

(g) Maximum and minimum sales limits for each saleable product.

(h) Permissible blending permutations.

(i) Maximum and minimum limits on raw material and bought-in intermediate material availability.

(j) The quantity of process materials (catalysts, utilities, etc.,) consumed per unit of throughput for each process.

4.4.2 COST AND REALISABLE VALUE CONSTRAINTS

The constraints listed below are obtained by means of the particularization process in the case of costs. Standard realisable values are used. All costs and values are expressed per mass unit of the material or product concerned. Process material costs such as those of catalysts and utilities are expressed per mass unit of throughput of the process concerned, in accordance with partial particularization via the causal relationship. Electricity is classed as a process material where the cost thereof varies with throughput.

(a) The cost of each raw material per unit of input of that material to the relevant process(es).

(b) The cost of each purchased intermediate per unit of input of that intermediate to the relevant process(es).

(c) The cost of each process material per unit of throughput for the relevant process(es).

(d) The realisable value of each saleable product.

(e) The "negative cost" accruing from sales of by-products of any process.

4.4.3 THE CONSTRAINTS DISCUSSED

Although the above lists of constraints are not claimed to be comprehensive, each is valid in that a change in any one of them will result in a change in returns. The model is designed to reflect the quantitative effect, in terms of returns, of any change. The accuracy of the reflected effect will depend on the correlation between the values and relationships making up the constraints; and what happens in reality.

> Maximisation of returns can be seen as an exercise involving the causal relationships between revenue and sacrifice factors.

The constraints can obviously be criticised on the grounds that demand curves are not horizontal and unit material purchase prices vary with volume. While this is true, sight should not be lost of practical considerations in this respect. By expanding the model these relationships could be taken into consideration. However, these relationships will be no more accurate than the forecasted average unit purchase prices or demands over the period.

The cost and realisable value constraints can be readily updated in the light of actual circumstances. For the given system, optimisation subject to prevailing circumstances is a main objective. In practice, industrial unit costs and realisable prices do not vary overnight. They more often move in stepwise jumps and usually with fair warning. Management requires to optimise under new conditions by substituting new values into fixed relationships. Incorporation of unit cost/volume and forecasted demand/price relationships may tend to defeat the objective in this respect.

Perhaps the most important aspect with regard to the cost constraints is that they must incorporate variable costs which are meaningful in a technical-economic sense.

> Unless sound particularization of variable costs is practised, the joint product manu-

> facturing system cannot be optimised. If costs which do not conform to the normative concept are included in any constraints, the optimal solution will be fictitious; regardless of the fact that the sum of the apportioned "costs" is technically correct.

Two aspects of the constraints listed must be clarified. The first concerns the use of standard realisable values. This was defined earlier in this study as the revenue accruing from the sale of the optimum quantity using optimum marketing strategy. As the quantity of at least some of the joint products in the optimal solution will be a function of the value constraint, the reasoning is circular. Where justifiable, a regressional analysis routine can be built into the model if this factor is relevant.

The second aspect concerns the "negative cost" of by-products as a constraint. Although critical of the method, some Anglo-Saxon authors state that income from by-products can be accumulated as "other income" and credited to a separate profit and loss account. (Vide R. I. DICKEY, op. cit., pp.13.20, 13.21). That this practice is unsound is obvious. Failure to consider the realisable value of a by-product of a process as a "negative cost" variable for that process will result in sub-optimisation.

4.5 THE USE OF STANDARDS IN THE OPTIMISATION MODEL

The objective of the model is to provide planning, decision-making and control information. The constraints should therefore reflect future conditions, be it the long-term or immediate future. Predetermined standards should be used in this respect.

The fact that the model will provide an optimal solution in no way infers that optimum or theoretically possible standards should be incorporated. The solution will only be as realistic as the standards used in the constraints. Prevailing and anticipated performance, usages, yields, costs and realisable values; based on experience and careful judgement must be incorporated.

The standards used in the constraints can and should be regularly reviewed and updated in the light of actual circumstances.

A major advantage associated with the incorporation of standards as constraints in the optimisation model is that it extensively facilitates material efficiency control. If standard yields and realisable values are used, the yield/value variances for each product can be readily determined. These variances reflect deviations from optimum performance with respect to conversion and recovery efficiency and product mix, with the system as a whole taken into consideration. Their value as managerial control information cannot be overestimated, particularly where a degree of flexibility exists as regards the final product mix.

4.6 PROCESSING THE MODEL

If all the constraints are linear the optimisation model can be compiled as a standard simplex matrix. However, a review of the constraints listed above will reveal several of them to involve non-linear relationships.

Where only minor variations between narrow limits are involved, a non-linear relationship may be regarded as being fixed with little or no effect on the final solution. This applies particularly where uncontrollable factors are involved. The relationship between the usage ratio and the sum of the inputs can, for example, be regarded as being fixed in many instances without it affecting the solution.

Other non-linear constraints may be "linearised" using programming techniques such as those described for the demand curves in the blending optimisation problem. These techniques could well be applied in cases of progressive or digressive costs (sacrifices). (Vide A.J.E. SORGDRAGER, op. cit., 1964, p.90).

In the case of some constraints, the relationship may not be a continuous function but a series of steps. For example, catalyst P might produce two joint products, A and B, in a ratio of 3A:2B while catalyst Q results in a yield of 2A:3B. This type of constraint may be included in a linear programme by regarding the input stream as being composed of two components, A and B. The joint process itself is then treated as a blending operation with permissible permutations being 3A,2B and 2A,3B. In the optimisation process one or other of the "blends" will be selected depending on the profitability consideration. In this way the yield ratio can be related to catalyst cost. Relationships between alternative raw materials and yield ratios may be treated in the same way.

In theory most non-linear functions may be broken down into a series of steps or points and built into the linear programme as "alternatives" in the way described. In practice, however, this can complicate the programme to an unacceptable degree. In cases where linearisation is impracticable, it may be feasible to employ non-linear programming techniques, such as hill-climbing with penalty functions or geometric programming. Both of these are described by D. GLASSER and P.L. SILVERSTON (op. cit., p.O.84 et. seq.).

These techniques can be used directly in optimisation models, but suffer from the serious disadvantage that a somewhat limited number of constraints and variables can be handled. Currently available linear programming routines can optimise between ten and a hundred times as many variables as hill-climbing.

G.G. STEPHENSON ("A hierarchy of models for planning in a division of ICI," Operational Research Quarterly, Vol. 21, No. 2, June, 1970, p.231) states the following:

> "Thus at present LP (Linear Programming) is the only way of handling large problems, and so has to be used for modelling large complexes of plants."

It is, however, possible to use a non-linear model to define the feasible alternatives in the region of the optimal solution. These can then be incorporated in the linear programme, which will then select the optimum alternative in respect of the system as a whole.

Whether or not all the constraints in a joint product model will be linear or can be "linearised" is an open question. P.V. YOULE (op. cit., p.78) mentions that all relationships between product yields and plant variables in the petrochemical complex which was modelled were linear. R.F. TUCKETT (op. cit., p.233) describes how multi-process product mix decisions were optimised using a linear programming model.

In the light of the above and the fact that variable costs only are incorporated, it can be assumed that the model described can be processed as a linear programme in the majority of cases.

4.7 USING THE MODEL FOR PLANNING AND DECISION-MAKING

For the model described, the optimal solution will, in the first place, supply the following information directly:

For maximum returns subject to the given constraints:

(a) The output of each saleable product and/or blend.

(b) The route by which these products are manufactured as indicated by the quantitative flow data.

(c) The qualitative and quantitative raw material consumption.

(d) The quantities of purchased intermediates.

(e) The quantitative and qualitative process material consumption.

(f) The blend compositions.

(g) The total standard realisable value less the total standard variable cost.

This information can be used directly for production decision-making with respect to throughput, product mix, blending formulations, raw and process material quality, quantity of purchased intermediates, etc. Its value as such can not be overestimated.

Furthermore, the model may be used to simulate the results of other types of managerial decisions. The International Business Machines Inc., (USA) linear programming system solution-reports contain a column entitled "solution activity" and a so-called "DO.D/J report" (Vide "Linear programming: system/360 - program description manual," Monograph, International Business Machines Inc., New York, 1969, p.22 et. seq.). These list information on all activities which are solved at the bound; i.e. at the maximum or minimum limit of the relevant constraint.

The value of this data as managerial decision-making information is significant. It is assumed, for example, that the optimum output of product A is solved at the upper limit of the throughput constraint relating to the process in which it is worked up. This means that if the capacity of the work-up process is increased, an increase in overall profit will result. The model may now be operated on by relaxing the constraint by an incremental amount. The increase in revenue less marginal cost under the relaxed constraint can then be compared with the outlay involved in increasing the process capacity.

Similarly the effect on profitability of decisions involving changes in various constraints can be "tested" prior to their execution. Conceivably, unit process capacities could be thus optimised until the only activities solved at the bound were those relating to exogenous factors such as raw material availability and product demand limits.

5 THE FEASIBILITY OF THE JOINT PRODUCT MANUFACTURING OPTIMISATION MODEL

5.1 CONCEPTUAL ASPECTS

Broadly speaking, returns for a given manufacturing system are total revenues less total costs. If all variable cost-incurring activities are related to realisable market value on a causal basis, and relevant technical considerations are taken into account; the set of resultant inequalities and relationships can be optimised with respect to returns using known mathematical routines.

The model is thus conceptually feasible.

5.2 PRACTICAL CONSIDERATIONS

The feasibility of the system may be limited by one or more of the following practical considerations:

(a) The validity of the optimal solution is dependent on the availability of the necessary cost and technical information comprising the constraints. The particularization process will in principle provide the necessary cost data, even if the costing system becomes more expensive to develop and maintain.

Accumulation of the technical data necessary may involve a large amount of careful observation, record analysis and possibly electronic data logging. The more complex the manufacturing system and the greater the number of products, the greater are the returns on optimisation. These same factors are those which make accumulation of the technical data more difficult and hence more expensive.

The Esso refinery model outlined by G. OWEN (op. cit., p.15) is reported to have cost £30,000 to develop. It is described as a "mathematical model for long range corporate analysis" and appears to be a combination input/output and econometric model. Although grossly dissimilar in application, the costs involved may serve as a guide. Somewhat pragmatically, considering the nature of this model, OWEN states that "the pay-off is hard to quantify."

A rough guide to the return on investment on the model described would be to assume all costs to be fixed and "optimise" revenue only for a past period, using sales records as the source of price data. Technical constraints based on maximum throughput for each process individually, subject to overall feasibility considerations can be built in. Comparison between actual and "optimum" revenue for the period can give an indication of the order of the benefits which can be expected if the product mix is optimised.

If by using the optimisation model, a company with sales exceeding R50 million gains 2% in nett value of production, it benefits profit-wise by R1 million plus.

Nevertheless, the feasibility of the model may be limited by the difficulty and expense of compilation.

(b) Where a large number of constraints are involved, access to a high capacity computer is prerequisite. Computers are built which can process a very high number of constraints, but access to them, especially in South Africa, is limited.

(c) Particularly if several of the constraints involved cannot be linearised, specialist programming techniques are required. Compiling the model requires a specialist team with extensive costing, engineering and data processing skills; as well as an intimate knowledge of the manufacturing system and the various markets. Such personnel are few and far between.

5.3 RESEARCH RESULTS

An extensive survey of literature on the subject revealed a number of references to manufacturing optimisation using mathematical models. The work done by R.F. TUCKETT (op. cit.) on combined cost and linear programming models is considered to be the most noteworthy.

TUCKETT's research is of value in multiple process and multiple product plants, but is not applicable to joint product manufacturing systems. His model takes by-products into consideration, but relies on cost allocation in this respect. (Op. cit., p.230).

> "It is also necessary to have some conventions about the costs assigned to recovery and other by-products. This is because no more than n unknowns can be solved uniquely in any n independent equations. Hence if the unknown at each cost centre is the cost of the main product, a value must be assigned to the by-products."

A number of references to the use of so-called "LP-models" in the petroleum refining industry appear. Many of these involve only the optimisation of revenue for a given input of crude oil. (Vide R.I. TRICKER, "The accountant in management," B.T. Batsford Ltd., London, 1967, p.302). Use of such models should not necessarily be rejected on the grounds that variable joint and work-up costs are not taken into consideration.

The petroleum-refining industry is capital-intensive to the point where variable costs may be as low as 20% of the total cost. Of this percentage the major portion is the raw material cost. As variable quantitative crude oil cost does not affect the product mix (or "slate," as it is termed in the industry), these LP revenue models can provide useful planning information.

Non-incorporation of costs in such programmes may be due to one or more of the following reasons:

(a) Non-linearity of cost functions.

(b) Lack of available computer capacity required to process the much larger model.

(c) Absence of a cost particularization system.

(d) Failure to appreciate the significance of the variable cost/product mix/profit relationship.

Of the above, (a) and (b) are justifiable; (c) and (d) are not. An enterprise using a costing system based on traditional Anglo-Saxon cost concepts and artificial joint cost allocation bases, will require a parallel normative system in order to incorporate cost constraints in the model. Furthermore many cost systems based on non-normative precepts do not provide enough cost information to enable accurate evaluation of the superiority of the particularized cost/realisable value model.

A number of joint product enterprises do use models incorporating the major variable cost streams. (Vide J.S. ARONOFSKY, "Linear programming models for business systems," in Chemical Engineering Progress, Vol. 64, No. 4, April, 1968, pp.87-92). In South Africa such a model is effectively used for certain types of decision-making by National Chemical Products Limited at their Germiston chemical manufacturing works. This model is independent of the factory costing system and is used primarily to process information pertaining to specific proposals.

Details of the costing aspects of integrated simulation models for joint product manufacturing systems could not be found in the literature. Consequently, in the course of developing the model described in this chapter, prototypes based on simplified mass balances were constructed. These pilot models were used to test the feasibility of various premises, and in particular the prerequisite feature of non-dependence on allocated joint costs.

An optimisation model of the type described is discussed as a case study in the following chapter.

6 CONCLUSIONS

The following represent the main conclusions arrived at in connection with the use of computer models for planning and decision-making for a joint product manufacturing system:

(a) As joint products are technically interdependent; for returns-maximisation purposes, the entire joint product manufacturing system must be considered as a whole.

(b) Unless all the variable costs included as constraints in an optimisation model conform to normative cost concepts, the

the solution will be fictitious. Sound particularization of all variable costs is consequently essential.

(c) A conceptually feasible overall optimisation model can be constructed for a joint product manufacturing system. Cost constraints are determinable by the particularization process, but the accumulation of the necessary technical data may prove to be onerous in practice.

(d) Compiling an optimisation model for a complex joint product manufacturing system requires a skilled optimisation team and a high capacity computer.

In the following chapter the setting-up and use of a managerial planning and decision-making optimisation model for a joint product manufacturing system is examined.

CHAPTER X

A PARTICULARIZED COST/REALISABLE VALUE OPTIMISATION MODEL FOR A JOINT PRODUCT MANUFACTURING SYSTEM

1 INTRODUCTION

In this chapter a managerial optimisation model for a hypothetical joint product manufacturing system is discussed. The model was developed in accordance with normative cost particularization principles, and is thus termed a "particularized cost/realisable value optimisation model." It is shown to constitute an effective managerial planning, control and decision-making information system.

In effect, use of the model permits the solution of those particular decision-making problems associated with joint product manufacturing, thus extensively facilitating the maximisation of returns.

The procedures whereby the model is complilied are detailed, and it is subsequently used to simulate the effect on returns of certain decisions.

2 THE JOINT PRODUCT MANUFACTURING SYSTEM

The manufacturing system for which the model has been developed involves a series of chemical processes in which a set of raw materials is converted into a range of saleable products.

See A.11, FIGURE X.1
A.33, TABLE X.1

The above figure is a flow diagram of the system, aspects of which are discussed. TABLE X.1 is the key to the abbreviations used in the flow diagram.

2.1 RAW MATERIALS

Two grades of what is essentially the same type of raw material may be used. The grades can be used in any proportions, but each yields a somewhat different quantitative product mix for the joint process. The materials are purchased on a fixed price long-term contract basis, and the purchase prices of the two grades are different.

2.2 PURCHASED INTERMEDIATE MATERIAL

Material equivalent to one of the products of the initial joint process may be purchased. Facilities exist for the storage of this material, which can be blended into the feedstock for the relevant work-up process.

2.3 THE JOINT PROCESS

The joint process is essentially an extractive process and consists of four unit operations performed sequentially on a continuous basis. These are:

(a) Blending of raw material grades on a weight basis.

(b) Filtration.

(c) Primary distillation.

(d) Fractional distillation.

In the primary distillation operation any water present in the raw material blend is obtained as a bottom product and run to waste. The overhead product is fed to a fractionating plant, where three joint products are obtained.

2.4 THE PRODUCT MIX

The products of the joint process are designated FLOW 1, FLOW 2 and FLOW 3.

See A.11, FIGURE X.1

Raw material I yields a product mix comprising

FLOW 1	-	25%
FLOW 2	-	30%
FLOW 3	-	45%

Raw material II yields a product mix comprising

FLOW 1	-	30%
FLOW 2	-	33%
FLOW 3	-	37%

The final product mix of the joint product manufacturing system is dependent on the following:

(a) The ratio of raw material 1 to raw material 2 in the feed to the joint process.

(b) The blending formulations.

Of the above, (a) is infinitely variable, while (b) is variable within certain limits. The final product mix is seen to be controllable to a limited extent.

Each of the seven final products manufactured in the base case has a different realisable value. Consequently decision-making with respect to the factors affecting the final product mix has an important bearing on the profitability of the system.

2.5 WORK-UP PROCESSES

Each joint product is worked up by means of separate work-up facilities. The processes involved are:

(a) A "dewatering" process to remove the small percentage of water which is carried over in the primary distillation operation and that comes through with the bottom product in the fractional distillation unit. This process consumes a chemical drying agent.

(b) A pressure oxidation process using oxygen as a process material.

(c) An extraction process in which a by-product is recovered.

Purchased intermediate material equivalent to the joint product worked up in the process described under (a) above, contains a small proportion of water, and is consequently blended into the feed to this process.

2.6 SALEABLE PRODUCTS

The by-product is sold as such without further work-up. The remaining three worked-up products may be sold as such or in the form of blends. These blends are "specification blends," and their composition is determined according to their properties and not directly by component proportions. A range of blend formulations meet the respective specifications.

2.7 ASSUMPTIONS

The following assumptions are made concerning the manufacturing system and its products for the duration of the period under consideration:

(a) The quantitative product mix for the joint process is fixed for a given qualitative input.

(b) All labour and overhead costs are fixed.

(c) Returns are positive.

(d) An established market exists for each final product.

(e) The demand curve for each product is horizontal in the feasible output range, and constant over the period under consideration.

3 COMPILING THE MODEL

3.1 THE OBJECTIVE FUNCTION

In the light of the above assumptions, the objective function is:

> Total manufacturing revenue less total variable material costs.

3.2 THE CONSTRAINTS

The constraints discussed below are those applying to what are termed base conditions. The optimal solution under these conditions will serve as a comparison basis for decision-result simulation discussed later in this chapter. It will be seen that all the constraints have been expressed as linear equalities or inequalities.

3.2.1 MATERIAL INPUT-OUTPUT CONSTRAINTS

See A.34, TABLE X.2

The above table lists the material input-output constraints for the relevant material flows shown in the flow diagram (FIGURE X.1). This table, read in conjunction with the flow diagram, constitutes what is in effect the mass balance for the system under base conditions.

3.2.2 COST AND REALISABLE VALUE CONSTRAINTS

See A.35, TABLE X.3

The above table reflects standard unit costs and realisable market value constraints.

Two direct cost factors are applicable in addition to the standard raw material purchase prices:

(a) DC 1; the cost of the oxygen consumed in the pressure oxidation process. The cost of this direct material is 26c/unit with 6 units being consumed for every 100 units of FLOW 22 processed in this work-up plant. The mass balance over the process takes the mass added by addition of this material into consideration.

(b) DC 2; the cost of trace quantities of inhibitor which it is necessary to add to FLOW 10 in order to render it suitable as a blending component. The cost of this material is equal to 2c per 100 units of FLOW 10 treated. The quantity of the inhibitor added is so small in relation to FLOW 10 that the mass added is negligible.

3.3 THE BASIC MATRIX

See A36, A37 and A38; TABLE X.4

The above table reflects the basic relationships comprising the framework of the model. "R," "INP" and "OBI" are programming codes. (Vide "ALPS I: a Burroughs ALGOL linear programming system," Monograph, Burroughs Corporation, Detroit, 1967). Other abbreviations used in the programme are reflected in TABLE X.1.

3.4 PROCESSING THE MODEL

The objective function and all constraints being linear, the model could be processed by means of a standard simplex linear programme. A Burroughs ALPS L (ALGOL) linear programming system was used and the model was processed on a Burroughs series B5500 computer. The matrix was stored on random access disc files, which enabled any constraint to be changed individually in a simple operation.

This system can handle matrices having up to 1022 rows and 1022 columns, 16,350 non-zero matrix entries and 31,682 non-zero transformations. The ALPS solution technique involves a revised simplex method with the product form of the inverse.

3.5 THE OPTIMAL SOLUTION FOR BASE CONDITIONS

See A.39, TABLE X.5

The above table shows the optimal solution for base conditions. It lists the quantity of each input and output stream including where the quantity is zero. The value of the objective function at optimum is R2,503.77/operating day.

The optimal solution in effect depicts the quantitative material flow pattern for the system at which maximum returns will be earned. Subject to the limiting constraints, any deviation from the flows given in the solution will result in diminished returns. Thus for any other raw material input, blend composition, quantity of purchased intermediate, product sales levels, etc., returns will be less.

4 USING THE MODEL FOR MANAGERIAL DECISION-MAKING PURPOSES

The model can be effectively used to simulate the results of managerial decisions as well as provide planning information in the event of a change in environmental conditions. This is illustrated by the following cases, which serve as examples of the decision-making uses to which the model may be put.

In practice the model is completely versatile and once the basic matrix has been compiled and stored, any alternative situation may be simulated quickly and simply by revising the particular constraints involved.

4.1 CASE ONE: INCREASING THE EFFICIENCY OF A WORK-UP PROCESS

4.1.1 THE ALTERNATIVE

The company's development engineer has calculated that by increasing the pressure in the oxidation work-up process (process b), the efficiency will be boosted by 6% to 96%. An additional compressor is required at an installed cost of R58,000. The company criterion for economic evaluation of modifications such as this is a maximum payback period of two years at 300 full operating days per year.

Should the compressor be installed?

4.1.2 EVALUATION USING THE MODEL

See A.40, TABLE X.6

The above table reflects the optimal solution under the new constraint condition of FLOW 6 equal to 96% of FLOW 22, Revenue less variable cost for the entire system is increased by R99.53 per operating day. (R2,603.30 less R2,503.77). Assuming that fixed costs are negligibly affected by the modification, the payback period is 583 operating days.

In terms of the stated criterion, the compressor should be installed.

4.1.3 COMMENTS ON THE SOLUTION

Considering only the information given in TABLES X.4 and X.5 it is possible to come to an erroneous decision by the following reasoning.

Flow 6 can be sold as such as Product 3 or as a blend. Sales of Blend A and Product 3 are at maximum, and additional sales of Blend B cannot exceed 134 units/day. It would appear on inspection that the additional quantity of Flow 6, namely 400 units/day would have to be sold as 134 units/day of Blend B at 24c/unit and 266 units/day of Blend C at 23c/unit.

This amounts to an additional nett income of R93.34 per operating day, compared with R99.53 obtained using the model to determine the optimum product mix.

The payback period on inspection is 621 operating days; and the outlay is not warranted in terms of the stated criterion.

4.2 CASE TWO: SETTING MINIMUM PRICES IN CONNECTION WITH A BID TO PURCHASE AN INTERMEDIATE

This case illustrates the manner in which the model can be used for price-setting under optimum conditions.

4.2.1 THE ALTERNATIVE

The company receives an enquiry from an existing customer wishing to purchase 600 units/day of a joint intermediate; namely PR5, on the flow diagram (FIGURE X.1).

What is the "floor price" of product 5; i.e., the price below which returns will be adversely affected, even if the system is optimised under the new product mix conditions?

4.2.2 EVALUATION USING THE MODEL

The solution can be obtained by using the model to simulate the optimum flow pattern under the alternative constraint condition of PR5 equal to 600 units; at various prices. Initially, the matrix is operated on to render constraint R10 equal to 600.

Various unit prices for this product are now substituted in the matrix. The price at which the objective function under the new conditions approximates to that obtained for the base case will be the floor price.

The value of the objective function pricing PR5 at 20c/unit was found to be R2,504.31.

See A.41 , TABLE X.7

The above table reflects the optimal solution for this condition.

Substiuting a unit price of 19, the objective function was R2,498.31.

See A.42 , TABLE X.8

Comparing the above values with R2,503.77 for the base case, the floor price for the product is seen to be fractionally lower than 20c/unit. Below this price, the tentative product should be worked up and not sold.

4.2.3 COMMENTS ON THE SOLUTION

The case serves to emphasise the usefulness of the model for pricing purposes.

Alternative realisable values for Product 5 are 26c/unit as Blend A, 25c/unit Product 3 and 24c/unit as Blend B. (Under base conditions Flow 16 is zero; i.e. it is less profitable to sell the product as Blend C).

The sum of the direct and particularized indirect costs saved by not working up this product in the oxidation process is 2.26c/unit. Subtracting this amount from the unit realisable value of the cheapest alternative form in which the worked-up product may be sold, namely 24c, an erroneous floor price of 21.74c/unit is obtained.

The fallacy of attempting to price the intermediate joint product in this case by subtracting unit variable work-up costs from the lowest alternative realisable value is aptly demonstrated.

The technical interdependency of the joint products renders it necessary to consider the system as a whole for decision-making purposes. Where a complex network of product streams is involved, the model provides invaluable pricing information which would otherwise be extremely difficult, if not impossible to obtain accurately and at short notice.

4.3 CASE THREE: EVALUATING A PROPOSAL WHEREBY SALES OF A PRODUCT ARE INCREASED AT ADDITIONAL UNIT SELLING COST.

4.3.1 THE ALTERNATIVE

The sales manager is well aware of the principle that the joint product mix should be maximised in favour of high-value products. The market for the most expensive product, PROD 2, is, however, limited. By expanding the area in which this product is sold, the sales manager has calculated that he can increase sales by 400 units/day to 2,900 units/day.

Transport costs for the new area are such that the average additional cost for all units of the product sold is 0.9c/unit.

Should the sales volume of Blend C be increased under these conditions?

4.3.2 EVALUATION USING THE MODEL

See A. 43, TABLE X.9

The above table reflects the optimal solution under the following changed constraint conditions:

(a) The maximum limit on the sales of PROD 2 is raised from 2,500 to 2,900 units/day.

(b) The standard realisable value of the product is reduced by 0.9c/unit to compensate for the additional transport cost.

Compared with base conditions, decreased returns are earned under the new conditions. The decrease is R2,503.78 less R2,490.25, i.e. R13.53/day. This amounts to a reduction in returns of R4,059/operating year.

Under these conditions the proposal should not be adopted.

4.3.3 COMMENTS ON THE SOLUTION

If a single-line product was involved, the advisability of increasing sales at additional selling cost could be determined by simple arithmetic. Selling 2,900 units at 27.1c/unit will earn R258 more per operating year than selling 2,500 units at 28.0c/unit.

In this case, however, the product is one of a set of joint products and being technically interdependent, it cannot be considered in isolation. The model shows that the optimum final product mix would be adversely affected if sales were increased under these conditions, and returns would be substantially decreased.

4.4 CASE FOUR: EVALUATING THE EFFECT ON RETURNS OF PROCESSING RAW MATERIAL I AT A DECREASED PURCHASE PRICE

4.4.1 THE ALTERNATIVE

In all the cases considered so far the optimal solution has shown that the less favourable joint product mix obtained precludes the use of Raw Material I despite its lower purchase price. The case is now considered where the supplier of this grade of raw material is prepared to drop his price from 3.875c/unit to 3.70c/unit.

It is known that greater quantities of FLOW 7 are obtained using Raw Material I. Although the market can absorb any additional quantities of Product 4, the sales manager has estimated that an initial advertising campaign will be necessary if more than 1,000 units/day extra of this material are to be marketed. This campaign will cost R10,000.

(a) What will be the optimum raw material mix at the new price of Raw Material I?

(b) What will be the optimum final product mix under these conditions?

(c) How will returns be affected over the first 300 operating days?

4.4.2 EVALUATION USING THE MODEL

See A.44, TABLE X.10

The above table reflects the optimal solution under the new constraint condition where the price of Raw Material I is reduced from 3.875c to 3.700c.

The solution shows that under these conditions Raw Material I only should be used if returns are to be maximised. The additional excess of revenue over variable cost is R34/day.

During the first 300 operating days the additional income will amount to R10,200, which will barely cover the advertising expenses involved in marketing the additional quantity of Product 4 reflected in the optimal solution.

4.4.3 COMMENTS ON THE OPTIMAL SOLUTION

The adverse effect on the joint product mix of using Raw Material I accounts for the fact that although R39 less per day is spent on the same quantity of raw material, the additional profit is only R34 per day. A proportionate decrease in the price of Raw Material II would result in an increase in returns of R41/day or R12,238/ operating year.

This type of situation, where joint product mix is related to variable cost, is frequently encountered. The model is shown to be aptly suited to this type of optimisation exercise, and can provide valuable decision-making information.

5 THE MODEL AS A SOURCE OF PLANNING, CONTROL AND DECISION-MAKING INFORMATION

Besides the uses described to which the model may be put, it provides valuable information in many other respects. Aspects of the various uses of the model as a source of planning, control and decision-making information are discussed.

5.1 PLANNING ASPECTS

5.1.1 RESOURCE ALLOCATION

Once forecasts have been made of the demands for each saleable product and the unit variable cost of each raw and process material for a forthcoming period, these may be incorporated as constraints in the model. The optimal solution will reflect the quantitative flow pattern at which maximum returns will be earned under these conditions.

The optimum resource allocation plan is obtained directly in this way. The model can be readily updated in the light of actual conditions, enabling revised plans to be compiled at short notice.

5.1.2 BUDGETING

Where unit material costs do not vary with volume, the quantities and therefore total cost of these materials, are given directly in the optimal solution. If one or more unit material costs vary with volume, constraints which have not been included in the model described, may be necessary. As such variable unit costs usually change in a stepwise fashion, these functions are readily linearised.

Total revenue for the period is easily computed from the optimal solution. This information facilitates cash budgeting.

5.1.3 SALES PLANNING

The complete solutions obtained using most standard simplex programmes reflect those constraints solved at the bound, and give an indication of the effect thereof on the objective function. Where such constraints are sales volumes, selling emphasis is indicated. In this way the model provides information which enables more effective use to be made of marketing resources.

The usefulness of the model with respect to the evaluation of purchase bids and price proposals has already been discussed. Discounts for bulk purchases and contract prices can be accurately evaluated using the model.

5.2 CONTROL ASPECTS

Actual manufacturing performance is neither completely predictable nor completely controllable. Depending on the degree of realism associated with the input-output standards in the constraints, actual performance will rarely coincide exactly with the optimal solution.

The optimal solution should be seen as a target with respect to controllable variables such as product mix, blending formulations and the material flow pattern in general. The model provides important control information in this respect. Once the optimal solution has been obtained, it is possible to use a normal standard costing system to full effect.

It will be seen that the standard yield and the standard realisable market value for every product and process have been built into the model. It consequently serves as a valuable source of control information regarding the material efficiency of the joint process.

5.3 DECISION-MAKING ASPECTS

With respect to decision-making, the primary advantage of the model is that it enables simulation of the effect of each alternative course of action on the objective function. It relates changes in cost-incurring factors to returns on a causal basis.

Decision-making using the model can be broken down into three phases:

(a) The creative phase:

This involves setting up and specifying the details of each feasible alternative course of action.

(b) The evaluation phase:

Programming the model under the set of constraints applicable for each of the above alternatives.

(c) The selection phase:

This involves the selection of the optimal course of action from the alternatives in the light of the simulated results; known factors which the model does not consider, and the intuitive judgement of the manager.

Several of the fields in which the model can be used for managerial decision-making purposes are listed.

5.3.1 PURCHASING DECISIONS

(a) Setting tender prices for bought-in intermediates.

(b) Evaluation of alternative or substitute materials.

(c) Setting target prices for negotiation purposes.

(d) Deciding on terms proposals for purchasing contracts.

5.3.2 DEBOTTLENECKING DECISIONS

The model will pinpoint those input-output constraints which are limiting returns, and to what extent the latter are affected thereby. It may be that a small outlay may ease a critical restriction and yield a high return. The model not only indicates such bottlenecks but enables the results of their elimination to be simulated.

The bottleneck may not be affecting total throughput but only the final product mix. In this case it may well go unnoticed until indicated in the optimal solution.

5.3.3 CAPITAL EXPENDITURE DECISIONS

The return on capital expenditure proposals which in any way affect the output of any product can be evaluated using the model.

6 CONCLUSIONS

The following are conclusions arrived at in respect of the particularized cost/realisable value optimisation model:

(a) Use of the model permits the solution of those particular managerial problems associated with joint product manufacturing, such as resource allocation, pricing, product mix optimisation and material efficiency control.

(b) The model can be used to simulate the effect on returns of any decision affecting any cost or revenue factor. It thus provides valuable decision-making information in a number of cases where the results obtained using alternative systems based on allocated joint costs would be invalid or misleading.

(c) Under the complex flow pattern conditions encountered in many joint product industries, the model constitutes an important source of managerial information.

PART FOUR

CONCLUSION AND SUMMARIES

CONCLUSION TO THE STUDY

This study represents an objective approach to joint product manufacturing management.

The technological nature of the joint process is such that no causal relationship can be traced between any individual product and a definable proportion of the joint manufacturing costs involved. The cost price of a jointly produced product is consequently indeterminable on a normative basis. Furthermore, although technically interrelated with respect to cost, quantity and in some cases, quality; joint products may each be entirely independent with respect to demand.

These factors give rise to managerial problems in respect of the maximisation of returns which are not encountered in other types of manufacturing. Approaches to these problems based on documented Anglo-Saxon cost concepts and procedures were shown to be largely ineffective.

In PART ONE the basic nature of the joint process was precisely defined. In the light of this definition and its practical implications, the underlying causes of the particular managerial problems associated with joint product manufacturing were examined and analysed.

In PART TWO of the study the principles of joint product costing were discussed in the light of the technical-economic concept of cost and normative cost particularization theory. Documented allocation methods were examined and it was shown that none of these was generally acceptable or universally applicable with significant results.

A specialised process costing system in which prior and post split-off costs are accumulated separately, was developed. This system conforms to normative cost particularization principles and was shown to provide valuable cost control information. By incorporating standard yields and realisable values in this system, yield-value variances can be computed which enable effective measurement of the material efficiency of the joint process.

In PART THREE of the study, pricing and demand forecasting procedures for joint products, and the overall economic optimisation of joint product manufacturing systems were examined. The two final chapters deal with the use of computer optimisation models for planning and decision-making purposes.

A particularized cost/realisable value optimisation model for a joint product manufacturing system was developed. This model is based on normative costing principles and relates variable cost-incurring and market factors to total revenue for the system as a whole. Subject to the availability of the necessary constraint data, it can be used to establish the optimum material flow pattern for a complex manufacturing system under various conditions; and to simulate the effect on returns of managerial decisions.

The model constitutes an important source of managerial information in a number of respects. It is particularly useful for resource allocation planning, pricing and material efficiency control purposes.

Joint product manufacturing plays an important industrial, economic and strategic role in the Republic of South Africa. This thesis is presented in the hope that it will contribute in some way to the more effective exploitation of our natural resources.

OPSOMMING

Daar word van medeprodukte gepraat sodra twee of meer ruweg-gelykwaardige produkte gelyktydig in 'n gesamentlike proses van dieselfde ru-materiale vervaardig word. Gedurende die afgelope twintig jaar het die vervaardiging van hierdie tipe produkte besondere ontwikkeling ondergaan. Dit geld veral vir petroleum en petrochemiese produkte, wat hoofsaaklik as medeprodukte vervaardig word.

Die tegniese onderlinge afhanklikheid van medeprodukte lei daartoe dat sekere van die bestuursinligtingstelsels en -tegnieke wat uiters behulpsaam is by besluitneming en kontrole by die vervaardiging van ander produksoorte, onvolwaardig is waar gesamentlike produksie betrokke is.

Die oogmerk met hierdie verhandeling is immers om die besondere bestuursprobleme verbonde aan kosprysberekening en maksimering van winsgewendheid wat betref die vervaardiging van medeprodukte, te ontleed; en stelsels en tegnieke te ondersoek wat tot die oplossing van diè probleme kan lei.

In HOOFSTUK I word die basiese aard en omvang van die gesamentlike proses gedefinieer. Die verskeie nywerhede waarin hierdie tipe proses voorkom, word genoem.

HOOFSTUK II handel oor ontwikkelinge in medeproduk-vervaardiging. Klem word gelê op die uitgebreide ontwikkeling van die petroleumraffinerings- en petrochemiese bedryf wat in Suid-Afrika, sowel as in die buiteland, plaasvind. Die ingewikkelde aard van die gesamentlike prosesse komplekse - wat die maksimering van winsgewendheid bemoeilik - word beklemtoon.

In HOOFSTUK III word saaklike aspekte van bestuurswese oor die algemeen bespreek, waarna bestuursprobleme verbonde aan gemeenskaplike produksie ontleed word.

Die verbesondering van gemeenskaplike koste word in die lig van die tegnies-ekonomiese kostebegrip, in HOOFSTUK IV ondersoek. Daar word tot die gevolgtrekking gekom dat dit onmoontlik is om die kosprys van 'n afgesonderde medeproduk op 'n normatiewe basis te bepaal.

HOOFSTUK V bestaan uit 'n kritiese ondersoek van verskeie gedokumenteerde metodes wat gebruik word om gemeenskaplike koste aan medeprodukte toe te deel. Daar word gestel dat, terwyl van hierdie metodes toepaslik is by die verbesondering van saamgevoegde koste, toedeling van gemeenskaplike koste volgens diè wyses tot misleidende resultate kan lei.

HOOFSTUK VI handel oor die ontwikkeling van 'n kostestelsel vir 'n medeproduk-vervaardigingsisteem. Aandag word gespits op die gebruik van sekere materiaalstandaarde wat effektiewe beheer van die doeltreffendheid van die gesamentlike proses kan bewerkstellig.

Prysbeleid en verkoopprysbepaling vir medeprodukte word in HOOFSTUK VII bespreek.

In HOOFSTUK VIII word sekere gevorderde beramingstelsels behandel.

HOOFSTUK IX handel oor die gebruik van rekenkundige simulasiemodelle as beplannings- en besluitnemingsmedia vir medeproduk-vervaardigingstelsels. Prosedures vir die samestelling van 'n optimiseringsmodel vir so'n stelsel, wat op gesonde kosteverbesonderingsbeginsels gebaseer word, word ontwikkel.

In HOOFSTUK X word besonderhede oor 'n verbesonderde koste/realiseerbare waarde optimiseringsmodel, vir 'n medeproduk-vervaardigingstelsel, verstrek. Afhangende van die beskikbaarheid van die nodige tegniese- en kostedata, is diè model 'n belangrike bron van waardevolle bestuursinligting.

ZUSAMMENFASSUNG

Kuppelprodukte entstehen, wenn gleichzeitig aus den gleichen Rohstoffen in dem gleichen Verfahren zwei oder mehr Produkte von ähnlichem Wert erzeugt werden.

Während der letzten 20 Jahre hat die Herstellung von dieser Art Erzeugnisse ausgedehnte Entwicklung erfahren, besonders im Hinblick auf Petroleum und Petroleumchemikalien, die primär in Kuppelprozessen erzeugt werden.

Die technische Verwandtschaft zwischen Kuppelprodukten hat zur Folge, dasz gewisse Betriebsführungs-Informationssysteme, welche die Überwachung und Entscheidung in anderen Produktionstypen wirksam unterstützen können, nicht ausreichend sind, wo es sich um Kuppelprodukte handelt.

Der Zweck dieser Studie ist der, die besonderen Betriebsführungsprobleme, die sich auf Kostenberechnungen beziehen und das Maximum an Wirtschaftlichkeit bei Kuppelprodukten bewirken sollen, zu analysieren und Systeme und Verfahren zu untersuchen, die zur Erreichung der optimalen Lösung dieser Probleme beitragen können.

In KAPITEL I wird die Grundlage des Kuppelprozesses definiert. Die verschiedenen Industriezweige, wo diese Art von Prozessen vorkommen, werden erwähnt.

KAPITEL II behandelt Entwicklungen in der Erzeugung von Kuppelprodukten. Die ausgedehnte Entwicklung der Petroleumraffinerie- und petroleumchemischen Industrie, sowohl in Süd-Afrika wie auch im Ausland, wird betont. Die komplexe Art vieler Kuppelprozesse, ein Faktor, der die Erzielung maximaler Profite kompliziert, wird betont.

In KAPITEL III werden wesentliche Führungsgesichtspunkte im allgemeinen diskutiert, worauf Führungsprobleme, die sich im besonderen auf die Herstellung von Kuppelprodukten beziehen, analysiert werden.

Die Aufgliederung von gekoppelten Kosten, im Lichte des technisch-ökonomischen Begriffs von Kosten, wird in KAPITEL IV untersucht. Es wird gefolgert, dasz es unmöglich ist, den Selbstkostenpreis eines einzelnen Kuppelproduktes auf einer genormten Grundlage zu bestimmen.

KAPITEL V besteht aus einer kritischen Prüfung verschiedener veröffentlichter Methoden, die gewöhnlich benutzt werden, um gekoppelte Kosten den Produkten zuzuordnen. Es wird festgestellt, dasz, während diese Methoden für die Zuordnung von Gemeinkosten möglich sind, die Zuordnung von gekoppelten Kosten nach diesen Methoden zu irreführenden Ergebnissen führen kann.

KAPITEL VI beschäftigt sich mit der Entwicklung eines Kostenberechnungssystems für die Herstellung von Kuppelprodukten. Es wird auf den Gebrauch gewisser Materialnormen aufmerksam gemacht, die eine Kontrolle der Nutzleistung des Kuppelprozesses möglich machen.

Preisberechnungspolitik und -verfahren für Kuppelprodukte werden in KAPITEL VII diskutiert.

In KAPITEL VIII werden gewisse moderne Vorausschätzungsverfahren untersucht.

KAPITEL IX beschäftigt sich mit dem Gebrauch von Komputer-Ersatzmodellen als Planungs- und Entscheidungshilfsmitteln für Kuppelprodukt-Herstellungssysteme. Verfahren zur Zusammenstellung eines Optimationsmodelles für ein solches System, das auf gesunden Kostenaufgliederungsprinzipien beruht, werden entwickelt.

In KAPITEL X wird ein Optimationsmodell aufgegliederte Kosten/erzielbarer Wert für ein Kuppelprodukt-Herstellungssystem im einzelnen zusammengestellt. Vorbehaltlich der Verfügbarkeit der nötigen technischen und Kostendaten, ist dieses Modell eine wichtige Quelle für wertvolle Betriebsführungsinformation.

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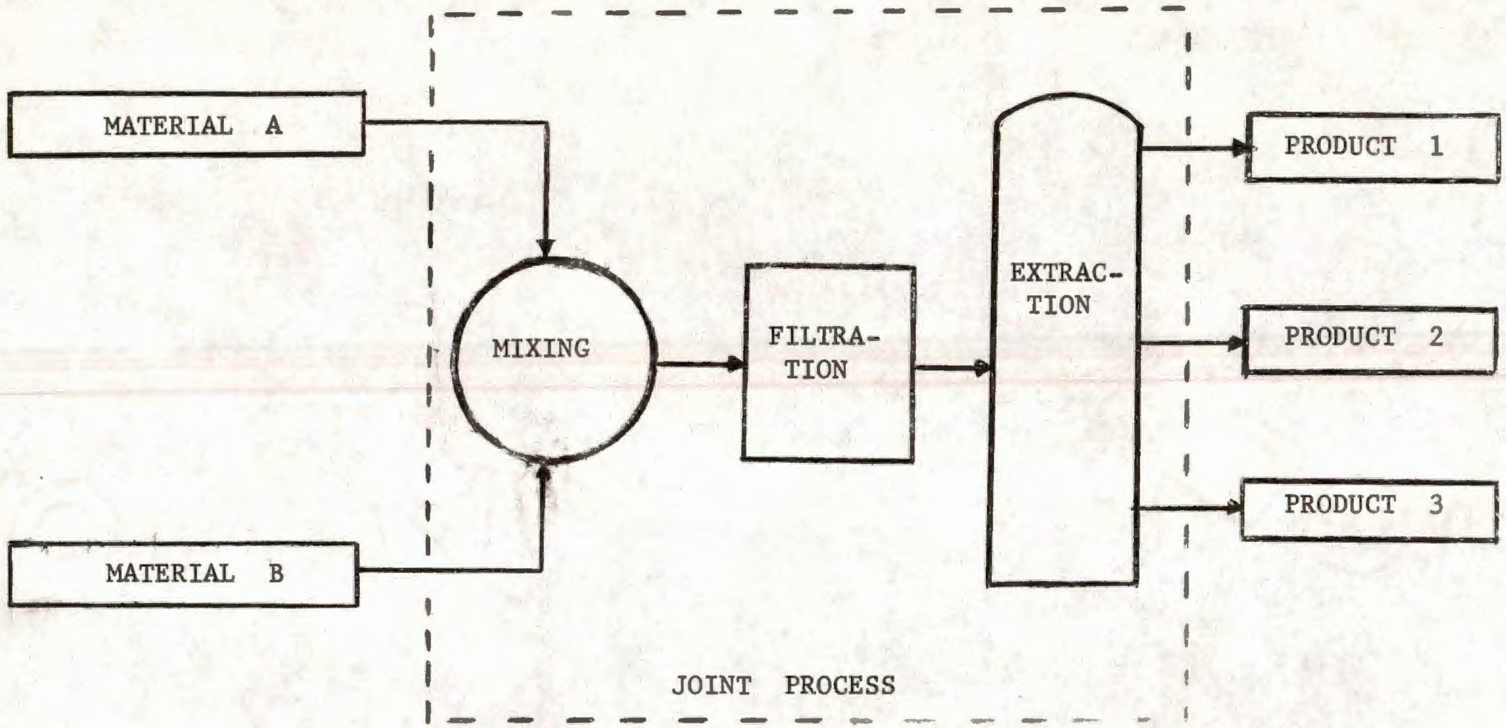
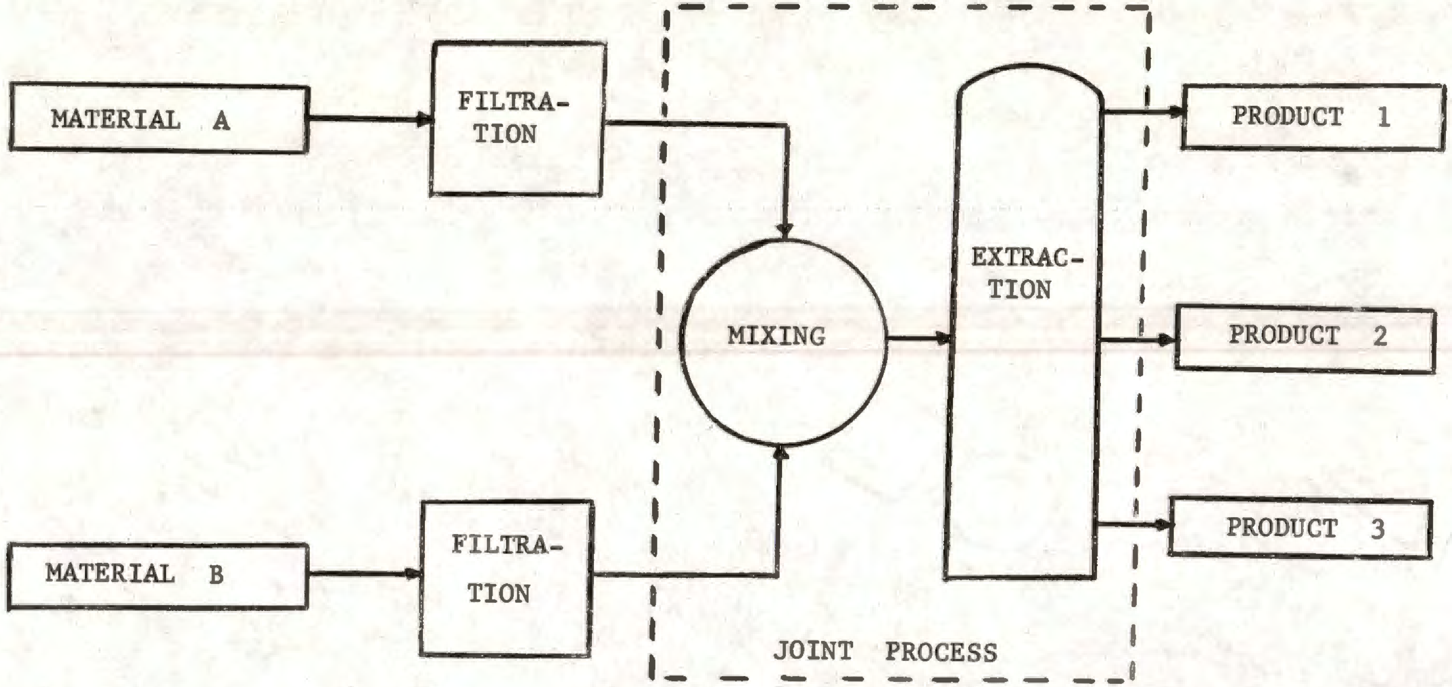
A.1

F I G U R E I.1



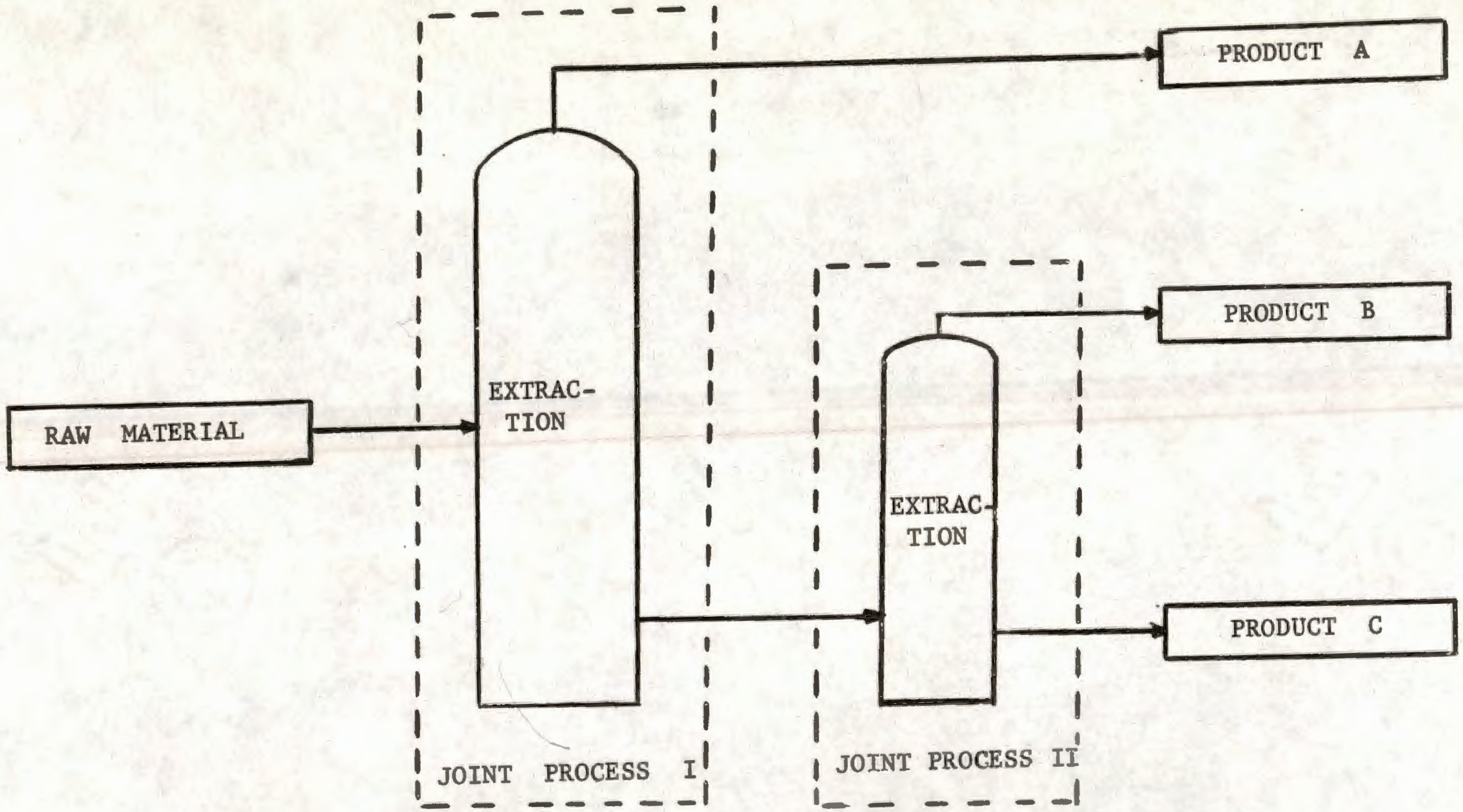
A JOINT PRODUCT MANUFACTURING SYSTEM SHOWING THE UNIT OPERATIONS COMPRISING THE JOINT PROCESS

FIGURE I.2



A JOINT PRODUCT MANUFACTURING SYSTEM SHOWING THE UNIT OPERATIONS COMPRISING THE JOINT PROCESS

F I G U R E 1.3



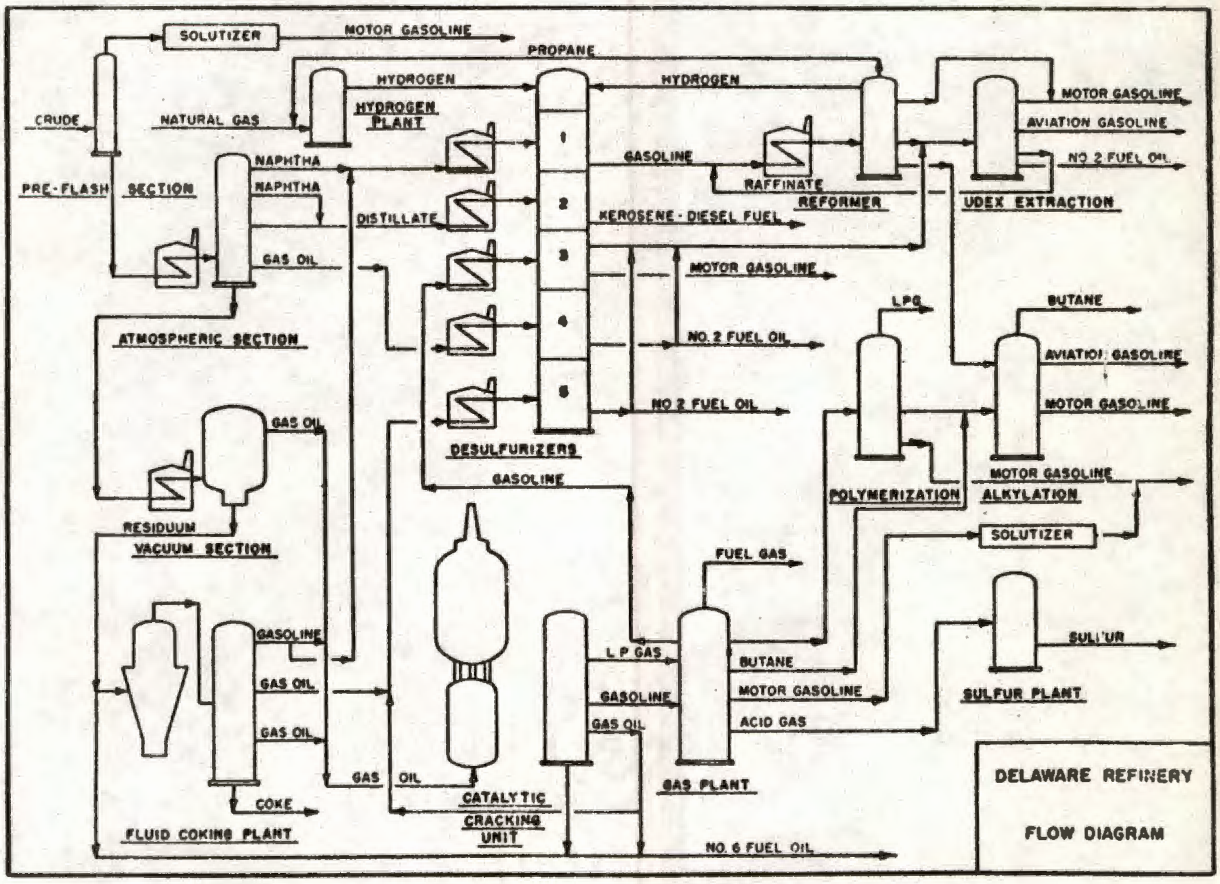
A JOINT PRODUCT MANUFACTURING SYSTEM

COMPRISING TWO JOINT PROCESSES

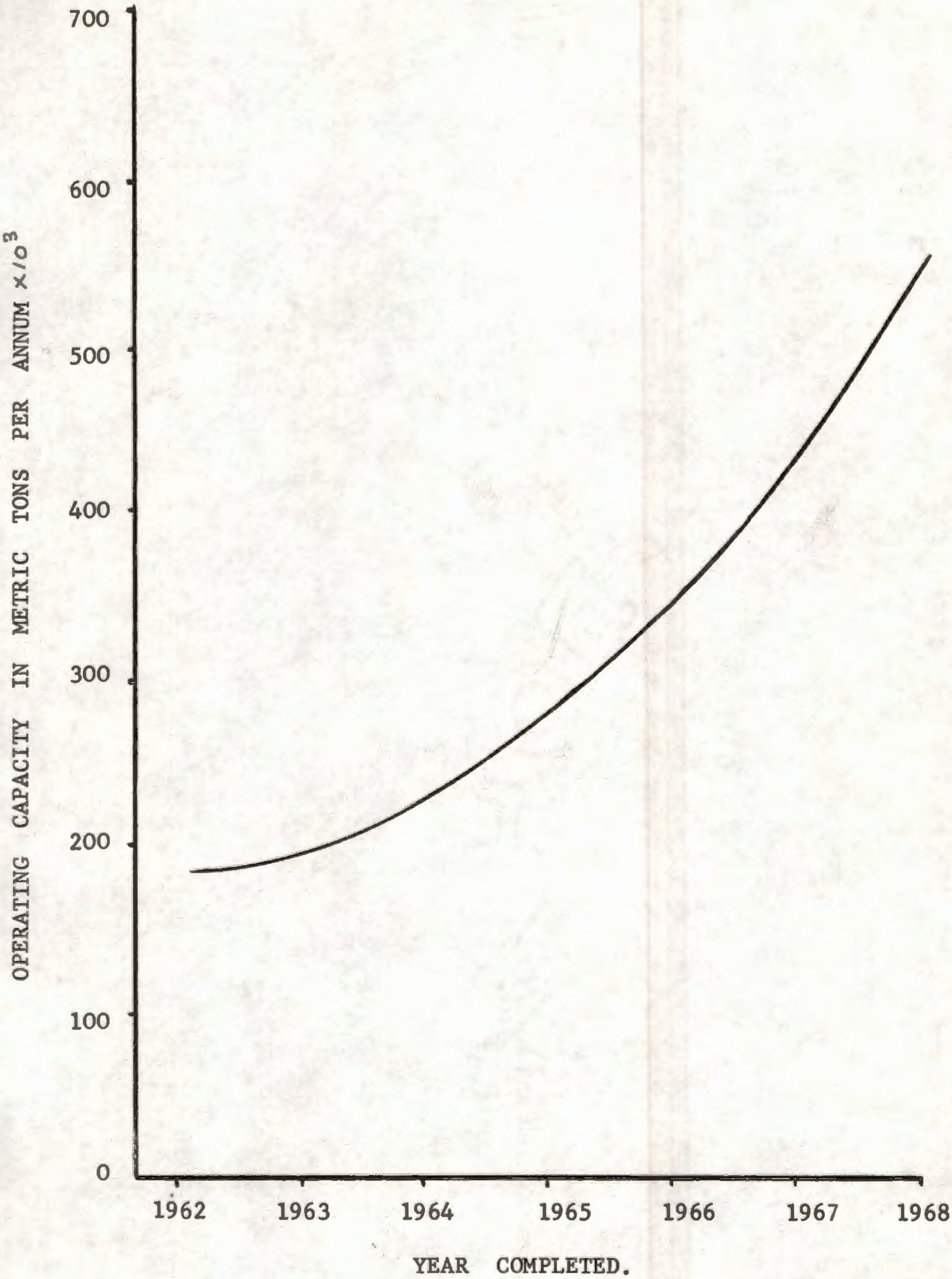
A.3

FIGURE II.1

FLOW DIAGRAM OF THE TIDEWATER OIL COMPANY'S DELAWARE REFINERY



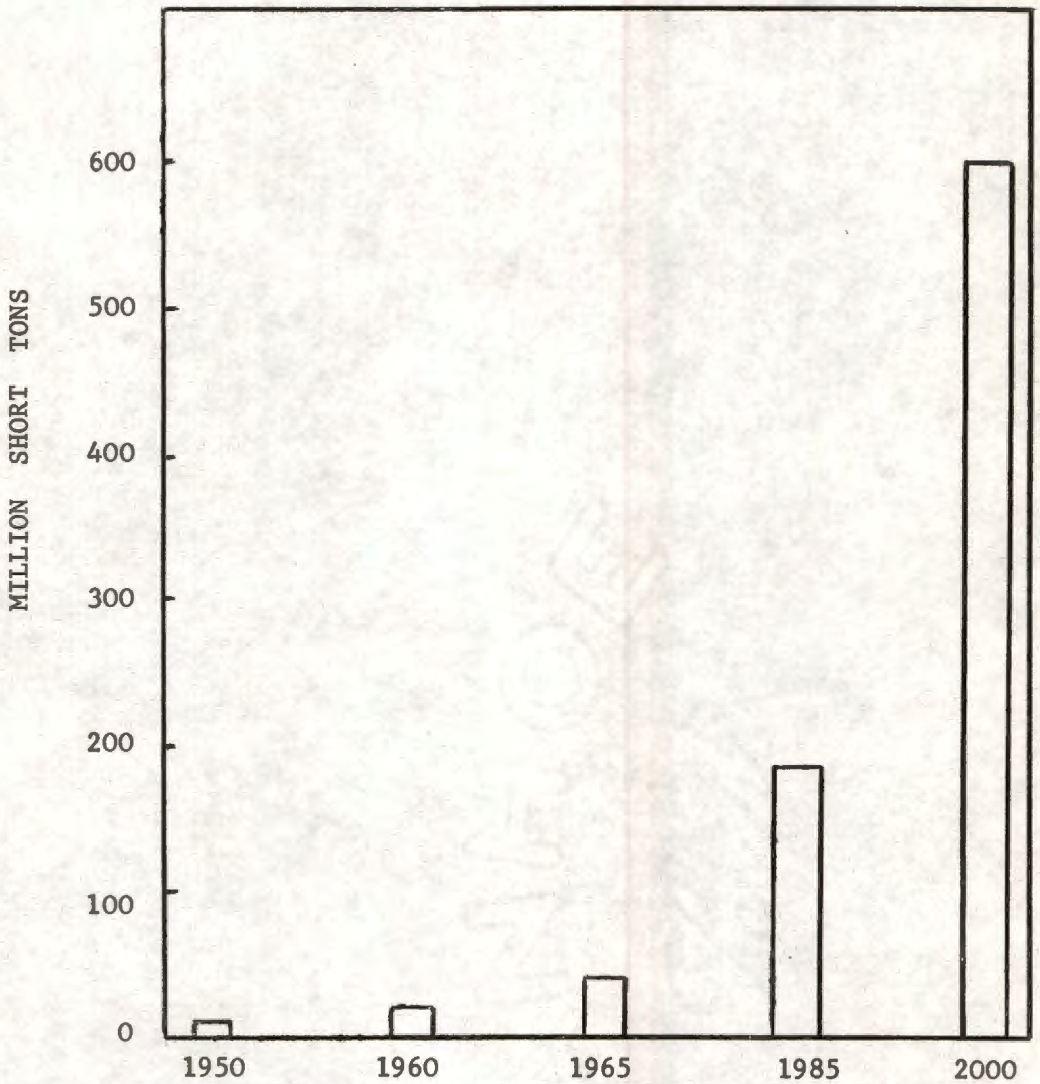
SOURCE: S.S. MILLER and D.G.D. ROGERS (op. cit., p.705).



CAPACITY OF THE LARGEST ETHYLENE-PRODUCING PLANT: 1962-1968

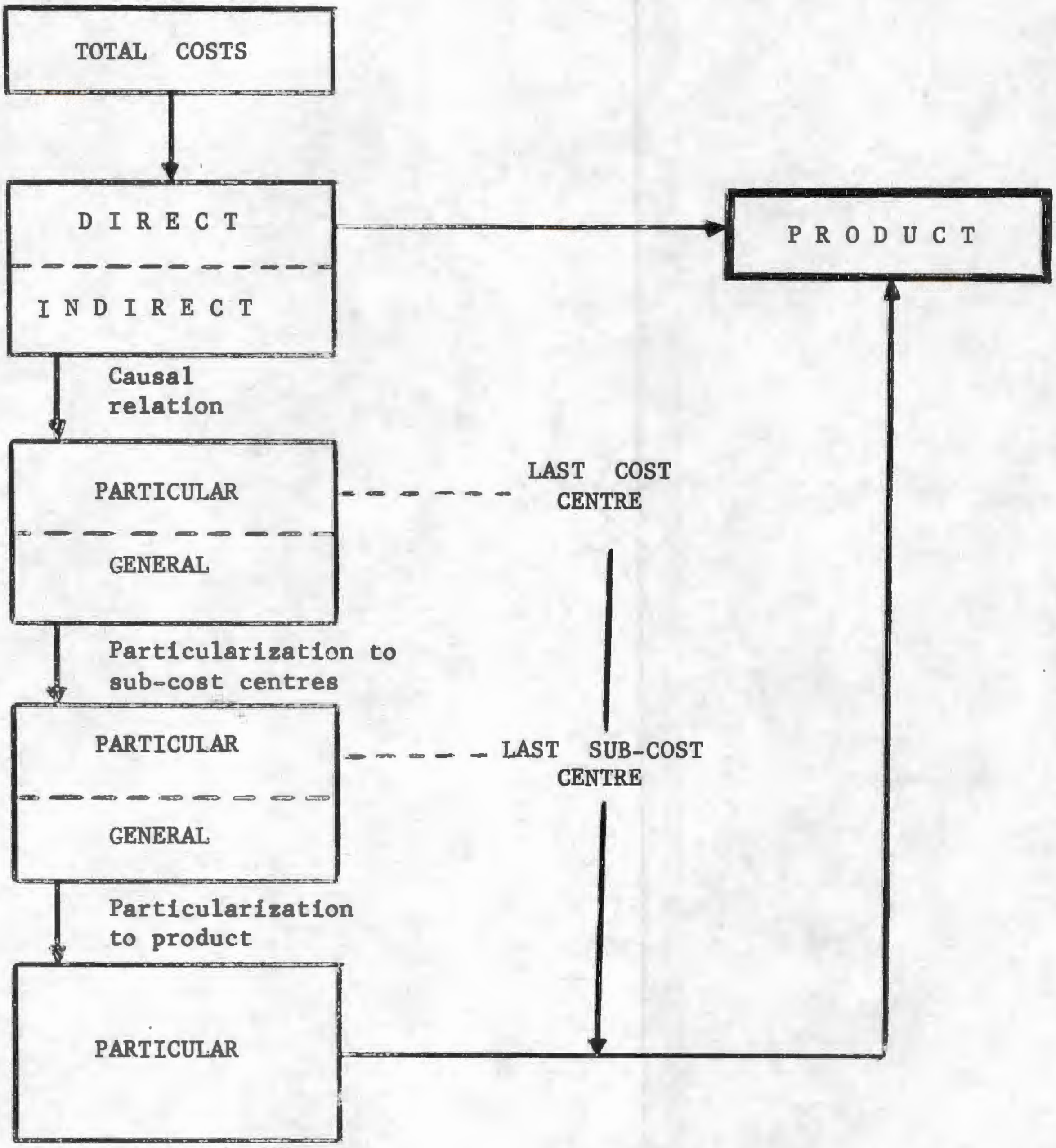
SOURCE: from "Petrochemical report," supplements to Oil and Gas Journal, 1962-1968.

PETROCHEMICAL PRODUCTION IN THE FREE WORLD: 1950-2000.



SOURCE: INTERNATIONAL PETROLEUM ENCYCLOPEDIA, (op. cit., p.7).

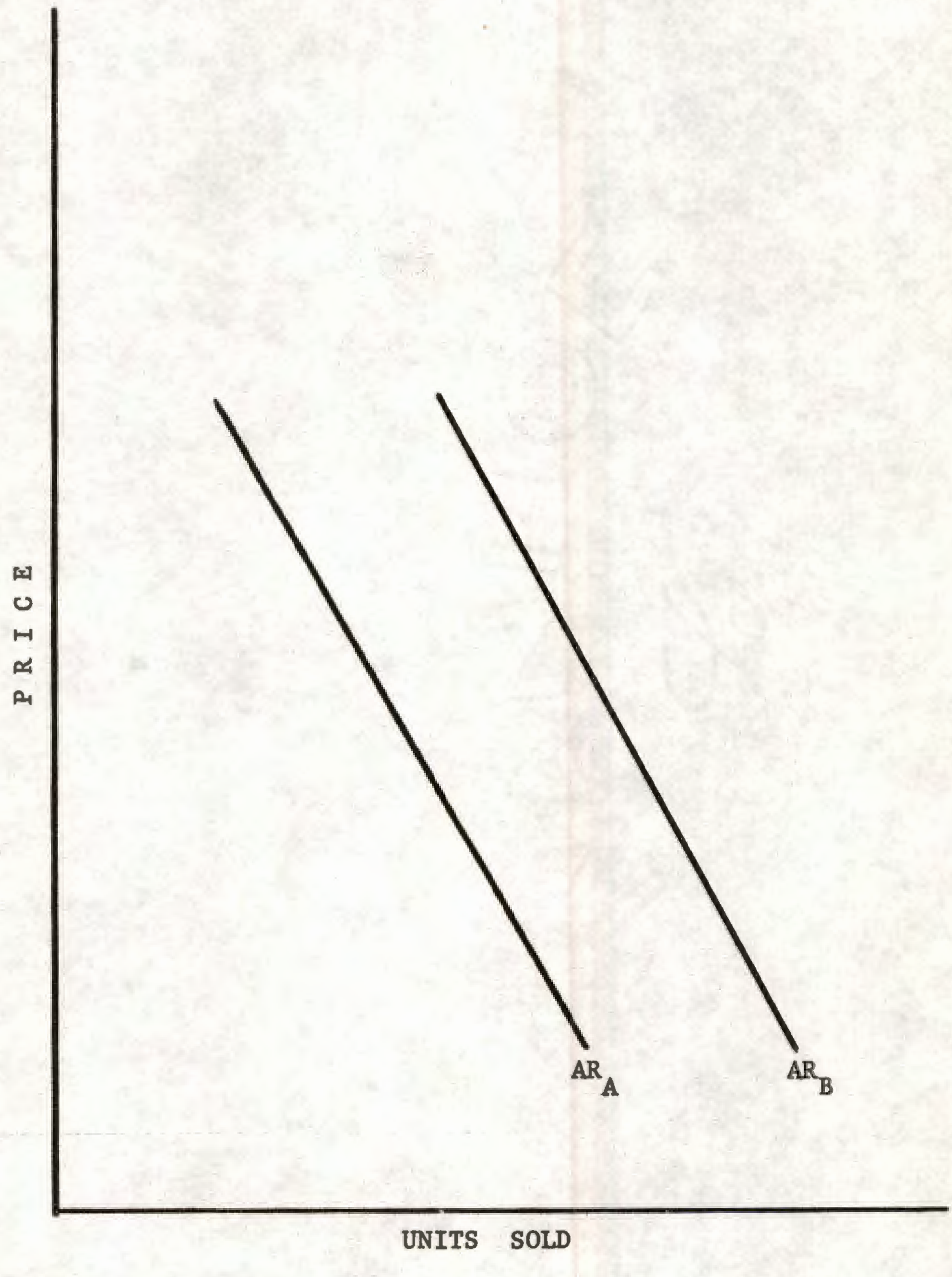
FIGURE IV.I



PARTICULARIZATION OF INDIRECT COSTS

SOURCE: A.J.E. SORGDRAGER (op. cit., 1964, p.73).

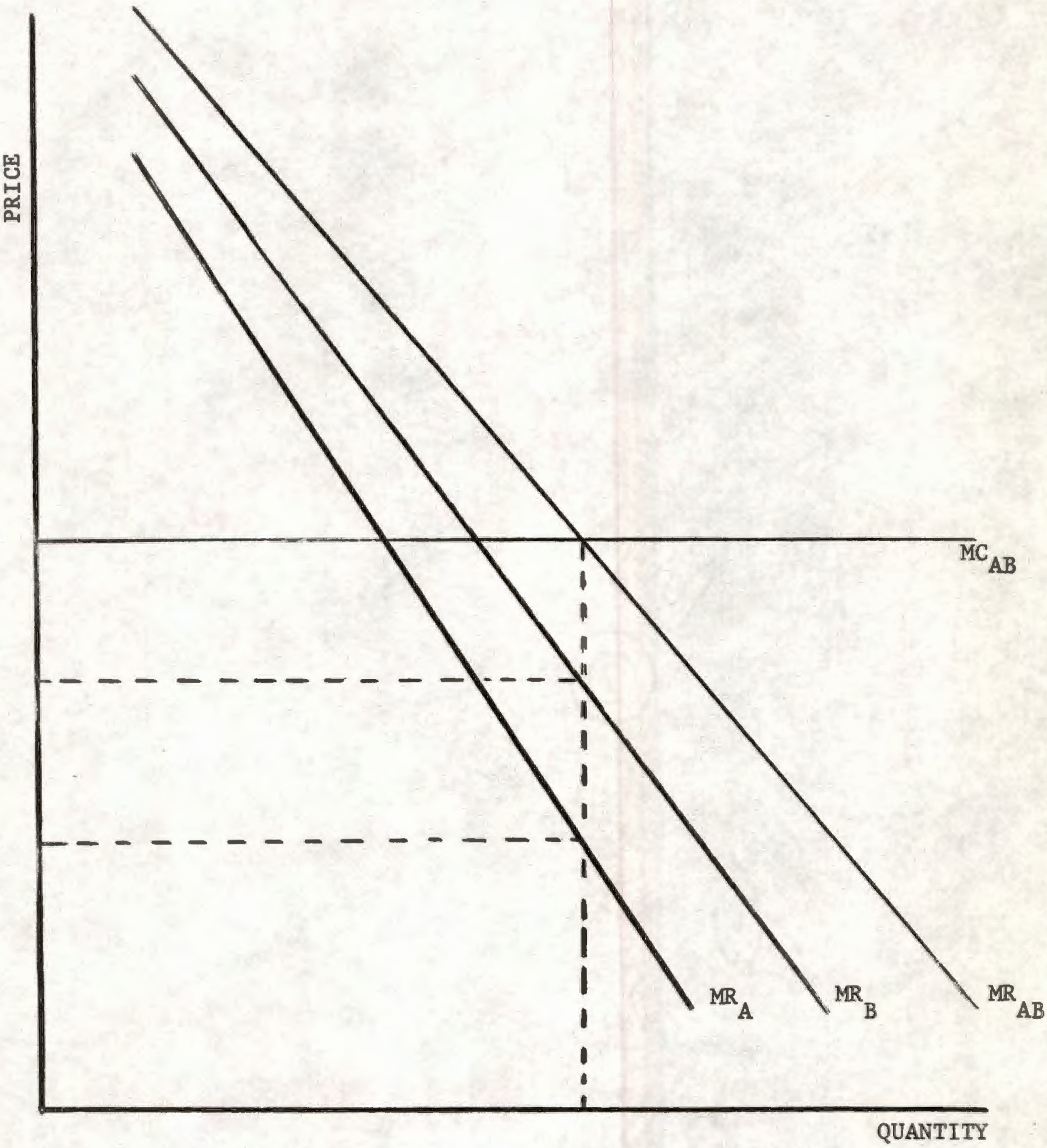
FIGURE VII.1



DEMAND CURVES FOR TWO JOINT PRODUCTS

SOURCE: H. BIERMAN, (op. cit., p.65).

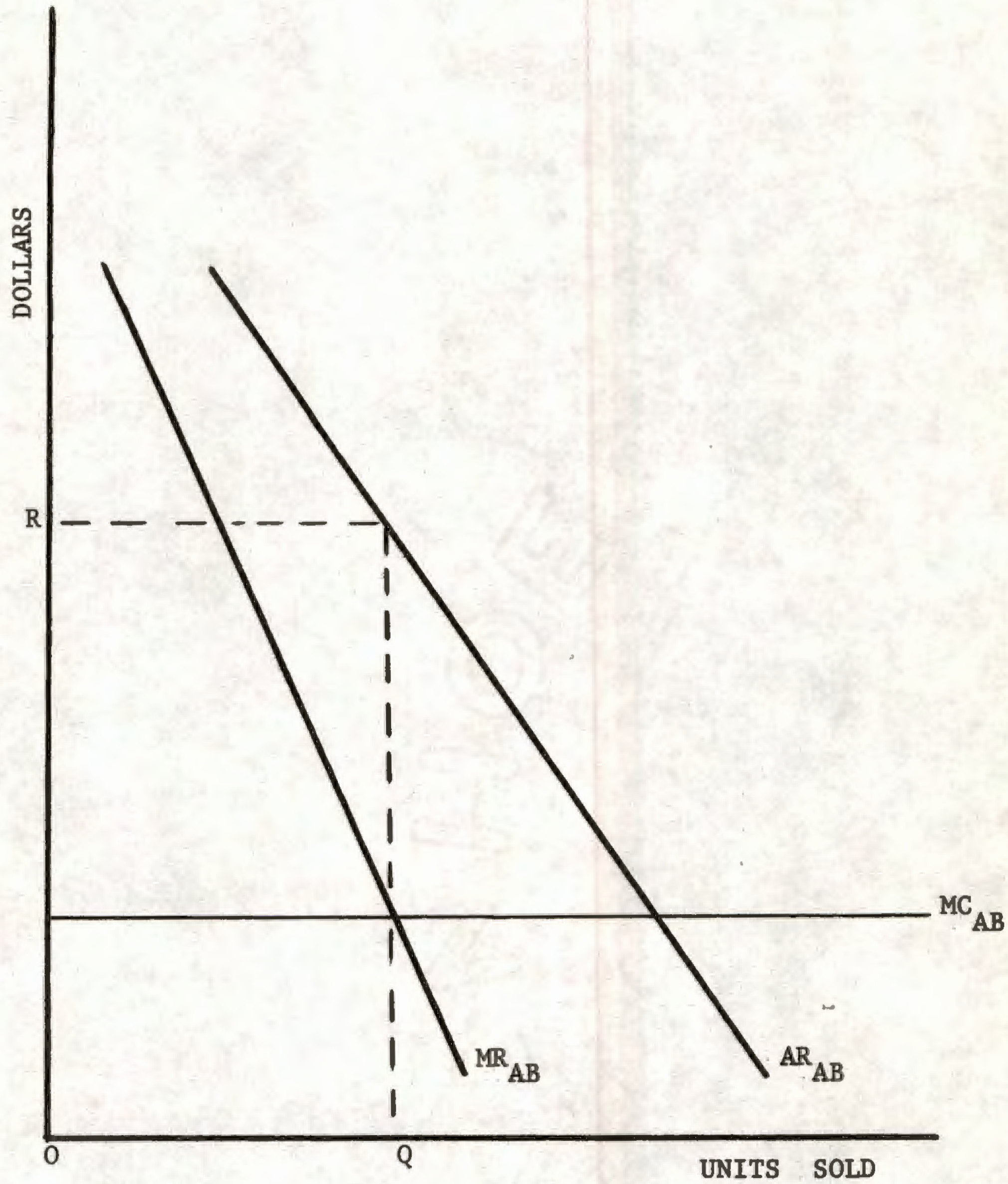
FIGURE VII.2



DETERMINING MARGINAL REVENUE OF PRODUCT

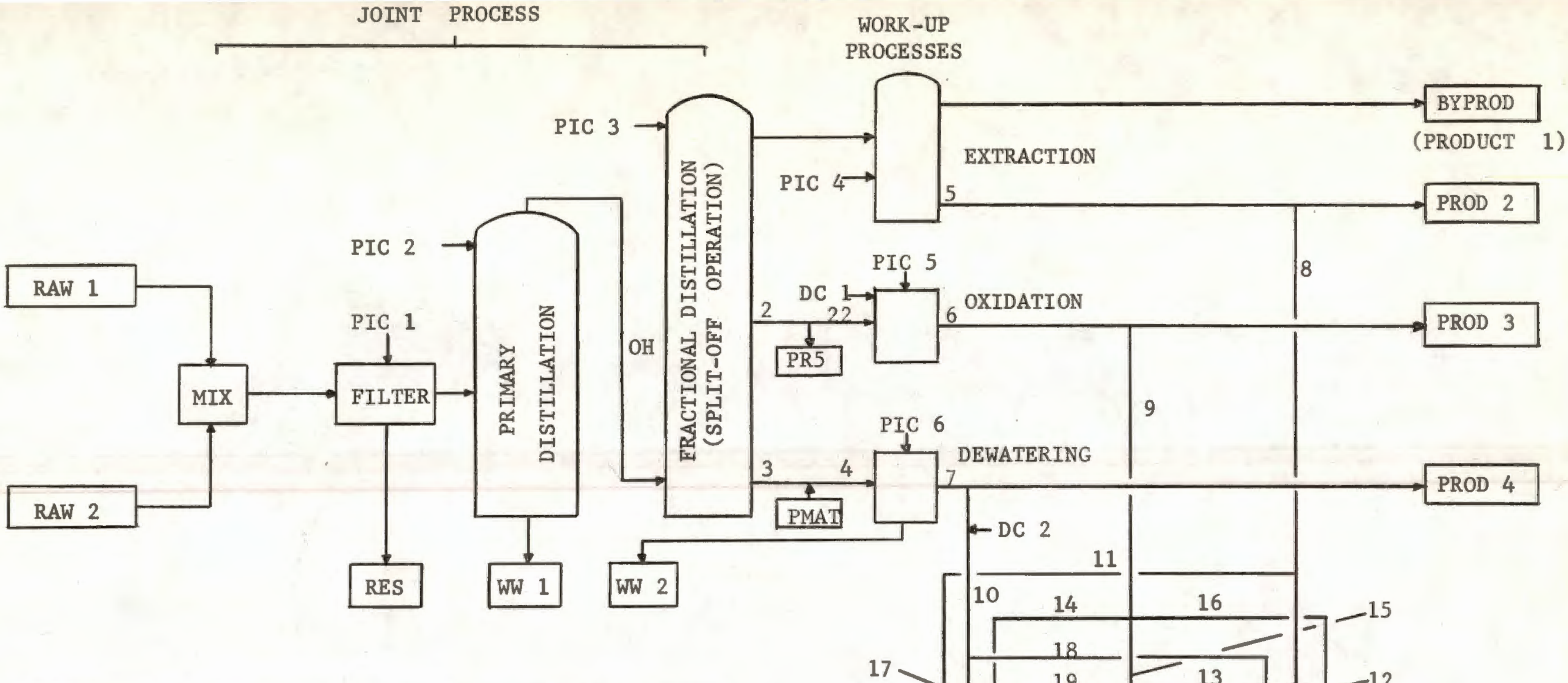
SOURCE: H. BIERMAN (op. cit., p.66)

FIGURE VII.3



MARGINAL ANALYSIS FOR TWO JOINT PRODUCTS

SOURCE: H. BIERMAN (op. cit., p.66)



KEY TO ABBREVIATIONS	
RAW	RAW MATERIAL
RES	RESIDUE
WW	WASTE WATER
OH	OVERHEAD PRODUCT
PMAT	PURCHASED INTERMEDIATE MATERIAL
PR/PROD	PRODUCT
PIC	PARTICULAR INDIRECT COST
BL	BLEND
DC	DIRECT COST

FIG. X.1 PARTICULARIZED COST/REALISABLE VALUE MODEL: FLOW DIAGRAM

TABLE I.1

INDUSTRIES IN WHICH JOINT PROCESSES ARE PREVALENT

Industry	Jointly Produced Products
Flour milling	Patent flour, clear flour, middlings, bran, wheat germ
Meat packing	Meat hides, fertilizer, shortening, hair, etc.
Cotton ginning	Cotton fibre, cotton seed.
Fishing	Fresh fish, canned fish, fish meal, fish oil, fertilizer.
Cottonseed processing	Cottonseed oil, meal, hulls and linters.
Diary products	Cream, skim milk, butter, ice cream, etc.
Copper mining	Copper, gold, silver, etc.
Sawmill operation	Grades of lumber, slabs, sawdust.
Petroleum refining	Naphtha, gasoline, kerosene, diesel and fuel oils, paraffin, tar, etc.
Gold mining	Gold, silver, copper, etc.
Soap making	Soap, glycerine.
Coke manufacturing	Coke, ammonia, coal tar, gas, benzol, etc.
Manufactured gas	Gas, coke, ammonia, coal tar and sulphur compounds.

SOURCE: L.L. VANCE, (op. cit., p.325).

TABLE II.1

FREE WORLD PETROLEUM REFINING
CAPACITY: 1940-1968

YEAR	CAPACITY IN MILLIONS OF SHORT TONS
1940	329.5
1950	525.2
1955	757.5
1958	1,061.6
1959	1,045.8
1960	1,105.1
1961	1,175.1
1962	1,219.7
1963	1,319.9
1964	1,438.2
1965	1,536.2
1966	1,617.6
1967	1,747.1
1968	1,926.8

SOURCE: INTERNATIONAL PETROLEUM ENCYCLOPAEDIA (op. cit., p.271).

TABLE 11.2

PETROLEUM REFINING CAPACITY AND PETROLEUM PRODUCT CONSUMPTION IN SOUTH AFRICA: 1940 TO 1971

YEAR	REFINERY CAPACITY	CONSUMPTION OF PETROLEUM PRODUCTS
1940	0.1	1.5
1945	0.1	1.5
1950	0.1	2.4
1955	0.8	3.2
1960	1.2	4.0
1961	1.3	3.9
1962	1.5	4.1
1963	1.6	5.0
1964	4.9	6.5
1965	5.2	6.4
1966	5.5	6.3
1967	7.6	7.3
1968	8.2	11.1
1969	8.9	12.0
1970	8.9	-
1971*	11.4	-

(MILLIONS OF SHORT TONS)

* ESTIMATED

SOURCE: INTERNATIONAL PETROLEUM ENCYCLOPEDIA, 1970, The Petroleum Publishing Company, Tulsa, 1969.

TABLE II.3

TYPICAL RANGE OF YIELDS OF A PETROLEUM REFINERY PROCESSING MIDDLE EAST CRUDE

PROGRAMME MAXIMISING	YIELD % WT.				
	GASOLINE	KEROSINE	DIESEL OIL	LPG & FEUL OIL	NORMAL
LPG	2	2	2	4	2
PREM. & REG. GASOLINE	27	15	23	18	21
KEROSINE/JET FUEL	0	21	0	12	13
DIESEL OIL	22	13	29	10	15
FUEL OIL	43	43	40	50	43
LOSS	6	6	6	6	6

SOURCE: S. VAN DER BAAN, in "Modern petroleum technology," Institute of Petroleum, London, 1962.

TABLE II.4

PETROLEUM COMPANIES LISTED AMONG THE TWENTY LARGEST INDUSTRIAL CORPORATIONS IN THE FREE WORLD (1969)

COMPANY	SALES $ MILLION	ASSETS $ MILLION	INVESTED CAPITAL $ MILLION	EMPLOYEES THOUSANDS
STANDARD OIL (NJ)	14,930	17,538	10,093	145
ROYAL DUTCH SHELL	9,738	15,409	8,392	173
MOBIL OIL	6,621	7,163	4,309	76
GULF OIL	4,953	8,105	5,040	60
STANDARD OIL (CALIF)	3,825	6,145	4,428	47
SHELL OIL	3,537	4,356	2,668	40
STANDARD OIL (IND)	3,469	5,151	3,213	48
BRITISH PETROLEUM	3,424	5,874	3,088	68

SOURCE: From FORTUNE, May, 1970, and August, 1970.

TABLE II.5

SALES PER EMPLOYEE AND PER INVESTED CAPITAL FOR THE COMPANIES LISTED AMONG THE 500 LARGEST U.S. INDUSTRIAL CORPORATIONS

INDUSTRIAL MEDIAN	SALES PER EMPLOYEE $	SALES PER INVESTED CAPITAL $
PETROLEUM REFINING	83	1.46
MINING	55	1.18
FOOD, BEVERAGES	46	3.91
TOBACCO	34	1.53
SOAPS, COSMETICS	32	2.63
METALS (MANU.)	32	1.60
PAPER, WOOD	31	1.84
CHEMICALS	31	1.90
PUBLISHING, PRINTING	29	2.25
MOTORS	28	2.70
PHARMACEUTICALS	26	1.73
GLASS, CEMENT	26	1.78
MACHINERY	25	2.27
RUBBER	24	2.69
AIRCRAFT	24	3.54
SCIENTIFIC EQUIPMENT	23	2.10
METALS (ENG.)	22	2.75
ELECTRICAL	22	2.64
TEXTILES	20	2.66
OFFICE EQUIPMENT	19	2.13
APPAREL	16	3.30
ALL INDUSTRIES	28	2.41

SOURCE: From FORTUNE, May, 1970, pp.202, 203.

TABLE II.6

PRODUCTION OF PETROCHEMICALS IN THE USA: 1935-1966

YEAR	TOTAL CHEMICALS PRODUCED	TOTAL PETROLEUM CHEMICALS PRODUCED	PETROLEUM CHEMICALS %
1935	8.9	0.5	5
1940	11.2	1.1	10
1945	29.0	4.5	15
1950	33.5	7.2	21
1955	60.2	14.4	24
1960	82.3	24.7	30
1965	129.3	42.3	33
1966	141.1	48.2	34

(MILLIONS OF LONG TONS)

SOURCE: A.L. WADDAMS (op. cit., p.225).

TABLE II.7

CONSUMPTION OF ETHYLENE IN
THE USA: 1930-1970

YEAR	METRIC TONS OF ETHYLENE CONSUMED
1930	14,000
1935	48,000
1940	122,000
1945	320,000
1950	630,000
1955	1,040,000
1960	2,350,000
1965	4,250,000
1970*	5,600,000

* ESTIMATED

SOURCE: S.A. MILLER, Ed., "Ethylene and its industrial derivatives," Ernest Benn Ltd., London, 1969, p.46.

TABLE II.8

ORGANIC CHEMICALS MANUFACTURED FROM PETROLEUM IN WESTERN EUROPE: 1950-1966

	1950	1955	1960	1964	1966
UNITED KINGDOM	34	198	567	992	1,050
WEST GERMANY	41	110	504	1,332	1,644
NETHERLANDS	3	26	90	320	548
FRANCE		37	230	612	661
ITALY		26	243	879	947
BELGIUM			24	80	n.a.
DENMARK			4	18	n.a.
AUSTRIA				12	n.a.
SPAIN			6	30	n.a.
SWEDEN				39	54

(Thousands of metric tons carbon content)

SOURCE: A.L. WADDAMS (op. cit., p.226).

TABLE II.9

TYPICAL YIELDS OF BASIC PETROCHEMICALS AND OTHER GASES FROM CATALYTIC CRACKING OF GAS OIL

PRODUCT	WT. %
HYDROGEN	0.1
METHANE	1.3
ETHYLENE	0.6
ETHANE	1.9
PROPYLENE	2.7
PROPANE	2.3
BUTYLENES	4.0
BUTANES	3.6
TOTAL GAS YIELD	16.5

SOURCE: A.L. WADDAMS (op. cit., p.20).

TABLE II.10

TYPICAL YIELDS OF BASIC PETROCHEMICALS AND OTHER GASES OBTAINED BY MEANS OF THE PYROLYSIS OF PROPANE

PRODUCT	VOL. %
HYDROGEN	16.1
METHANE	30.8
ACETYLENE	0.3
ETHYLENE	24.0
ETHANE	3.9
PROPYLENE	11.1
PROPANE	11.3
C_4+	2.5

SOURCE: A.L. WADDAMS (op. cit., p.22).

TABLE II.11

TYPICAL YIELDS OF PETROCHEMICALS AND OTHER PRODUCTS PRODUCED JOINTLY BY MEANS OF NAPHTHA CRACKING

PRODUCT	YIELD %
ETHYLENE	24
PROPYLENE	17
C_4 PRODUCTS	10
FUEL GAS	19
GASOLINE	25
FUEL OIL	3
LOSS	2

SOURCE: A.L. WADDAMS (op. cit., p.31)
(Also see S.A. MILLER, op. cit., p.129).

TABLE II.12

PRODUCT YIELDS OBTAINED BY THE PARTIAL REFINING OF CRUDE PETROLEUM

PRODUCT	YIELD % WT.	ESTIMATED REALISABLE VALUE
HEAVY FUEL OIL	55	± 10c
CRACKER FEEDSTOCK	30	9c
DIESEL OIL	10	15c
C4/C5 FRACTION	5	CONSUMED INTERNALLY

TABLE V.1

JOINT COST ALLOCATION BY THE
AVERAGE UNIT COST METHOD

DETERMINATION OF THE AVERAGE UNIT COST

	Quantity in Cubic Meters	Percentage
RAW MATERIAL:	680	-
PRODUCTS:		
GRADE A (1 m. lengths)	66	10.0
GRADE B (2 m. lengths)	180	27.4
GRADE C (3 m. lengths)	210	32.0
GRADE D (4 m. lengths)	80	12.3
GRADE E (5 m. lengths)	120	18.3
TOTAL	656	100.0
OFFCUTS	20	-
LOSSES	4	-
TOTAL	680	-

	R
TOTAL COST	8,968.90
LESS INCOME FROM OFFCUTS	309.70
NETT JOINT PRODUCT COST	8,659.20

AVERAGE UNIT COST .... R13.20 /CUBIC METER

TABLE V.2

JOINT COST ALLOCATION BY THE AVERAGE UNIT COST METHOD

ALLOCATED GRADE COSTS

Grade	Quantity (Cub. Meters)	Percentage (%)	Cost (R)	Unit Selling Price (R)	Revenue (R)
A	66	10.0	871.20	11.00	726.00
B	180	27.4	2,376.00	13.00	2,340.00
C	210	32.0	2,772.00	14.20	2,982.00
D	80	12.30	1,056.00	15.00	1,200.00
E	120	18.3	1,584.00	16.00	1,920.00
Total	656	100.0	8,659.20	-	9,168.00

TOTAL REVENUE LESS TOTAL COST ... R508.80

TABLE V.3

JOINT COST ALLOCATION BY THE WEIGHTED AVERAGE METHOD

QUANTITY AND COST OF PRODUCTION

TOTAL MANUFACTURING COST ... R28,590

Grade	Quantity (Kg.)	Yield (%)	Mats Added (R)	Packaging Cost (R)	Weighting Ratio	Composite Factor %
Technical	15,000	32.6	-	750	0.8849	28.8477
Cosmetic A	11,000	23.9	990	770	1.0619	25.3794
Cosmetic B	12,000	26.1	1,440	840	1.1102	28.9762
Superfine	8,000	17.4		800	0.9654	16.7979
Total	46,000	100.0	2,430	3,160		100.0000

AVERAGE UNIT COST ... R0.621521/Kg.

TABLE V.4

JOINT COST ALLOCATION BY THE WEIGHTED AVERAGE METHOD

EQUIVALENT UNITS AND ALLOCATED COST

Grade	Composite Factor (%)	Quantity Produced (Kg)	Equivalent Units	Allocated Cost (R)	Packed Unit Cost (R/Kg)
Technical	28.8477	15,000	13,269	8,250	0.55
Cosmetic A	25.3794	11,000	11,673	7,260	0.66
Cosmetic B	28.9762	12,000	13,329	8,280	0.69
Superfine	16.7979	8,000	7,729	4,800	0.60
Total	100.0000	46,000	46,000	28,590	-

TABLE V.5

JANKOWSKI'S BASIC CASE COMPUTATION OF JOINT COSTS IN THE FRUIT PACKING INDUSTRY

YELLOW CLING PEACHES (A) QUANTITATIVE CASES			
ACTUAL CASES PACKED	CASE SIZE	FACTOR	CASES, BASIC 2½ SIZE
100	48/8 OZ.	0.60	60
170	24/303	.57	97
370	24/2½	1.00	370
360	6/10	.91	327
1,000			854
(B) QUALITATIVE CASES			
CASES, BASIC 2½ SIZE	GRADE	FACTOR	CASES, BASIC 2½ STD. GRADE
50	FANCY	1.30	65
460	CHOICE	1.15	529
270	STANDARD	1.00	270
74	PIE	.50	37
854			901

SOURCE: R.I. DICKEY (op. cit., p.13.11)

TABLE V.6

JOINT COST ALLOCATION BY
THE BASE UNIT SYSTEM

	R
RAW MATERIAL COST	3,000
PROCESSING COSTS	6,500
	9,500
LESS INCOME FROM SALE OF SLACK WAX @ 10c/1	300
NETT JOINT PRODUCT COST	9,200

Grade	Quantity (1)	Specific Gravity	Base Units (Kg)	Allocated Joint Cost (R)	Unit Cost (R/1)
L/MED. MVIP	23,000	0.8875	20,413	2,110	0.09173
L/MED. HVI	30,000	0.9120	27,360	2,828	0.09425
HEAVY MVIP	18,000	0.9321	16,778	1,734	0.09633
HEAVY HVI	26,000	0.9410	24,466	2,528	0.09725
SLACK WAX	3,000	-	-	-	-
TOTAL	100,000	-	89,017	9,200	-

TABLE V.7

TOTAL JOINT COST: R36,900/DAY

PRODUCT	YIELD GALLS/DAY	UNIT REALISABLE VALUE c/gall.	REALISABLE VALUE (R)	PERCENTAGE TOTAL REAL. VALUE	ALLOCATED JOINT COSTS	UNIT COST c/gall.
MED. OCT. GASOLINE	173,350	9.75	16,088	38.4	14,170	8.08
HIGH OCT. GASOLINE	83,370	12.0	10,004	23.9	8,819	10.58
BENZENE	25,914	22.0	5,701	13.6	5,018	19.36
TUOLENE	36,750	19.19	7,052	16.8	6,199	16.87
L.P.G.	27,930	11.00	3,072	7.3	2,694	9.65
FUEL GAS*	≡ 696 b	-				
HYDROGEN*	723m. c.ft.	-				
TOTAL	-	-	41,917	100	36,900	-

*CONSUMED INTERNALLY

JOINT COST ALLOCATION BY THE REALISABLE VALUE METHOD

TABLE IX.1

SUMMARY OF PREREQUISITES FOR A PROCESS SIMULATION

1 Must have realistic and worthwhile objectives.

2 Access to a computer of reasonable size.

3 Must be possible to model all process units.

4 Suitable data must be available for models.

5 Some computational and programming experience is necessary.

6 Well co-ordinated team effort usually required.

7 Operating data required for verification of simulation.

8 Preliminary simulation using simple models often useful to establish accuracy level and programming requirements.

SOURCE: D. GLASSER and P.L. SILVERSTON (op. cit., p. S.20).

TABLE X.1

PARTICULARIZED COST/REALISABLE VALUE MODEL

KEY TO ABBREVIATIONS USED IN FIGURE X.1
AND THE PRINT-OUT OF THE MATRIX AND SOLUTIONS

ABBREVIATIONS	MEANING
RAW	RAW MATERIAL
RES	RESIDUE
WW	WASTE WATER
OH	OVERHEAD PRODUCT
PMAT	PURCHASED INTERMEDIATE MATERIAL
PR/PROD	PRODUCT
BYPROD	BY-PRODUCT
PIC	PARTICULAR INDIRECT COST
BL	BLEND
DC	DIRECT COST
FUNCT	FUNCTION
R.H.S.	RIGHT HAND SIDE
ITER	ITERATION

TABLE X.2

PARTICULARIZED COST/REALISABLE VALUE MODEL

MATERIAL INPUT-OUTPUT CONSTRAINTS
FOR BASE CONDITIONS

STREAM	ADDRESS IN THE MATRIX	CONSTRAINT FUNCTION
RES	R42	= 0.01 (RAW1 + RAW2)
WW1	R2	= 0.09 (RAW1 + RAW2)
OH	INP	≤ 20,000 UNITS/DAY
FLOW1	R7	= 0.2275(RAW1) + 0.273(RAW2)
FLOW2	R8	= 0.273(RAW1) + 0.3003(RAW2)
FLOW3	R9	= 0.4095(RAW1) + 0.3367(RAW2)
PMAT	R33	≤ 3,000 UNITS/DAY
WW2	R6	= 0.02(FLOW4)
PR5	R10	= 0.000
BYPROD	R13	= 0.06(FLOW1)
FLOW5	R14	= 0.86(FLOW1)
FLOW6	R15	= 0.90(FLOW22)
FLOW7	R16	= 0.95(FLOW4)
PROD2	R32	≤ 2500 UNITS/DAY
PORD3	R31	≤ 4000 UNITS/DAY
FLOW14	R29	≤ 0.35(BLA)
FLOW17	R28	≤ 0.20(BLA)
FLOW18	R25	≤ 0.65(BLC)
FLOW19	R34	≤ 0.30(BLB)
BLA	R35	≤ 2500 UNITS/DAY
BLB	R26	≤ 3000 UNITS/DAY

TABLE X.3

PARTICULARIZED COST/REALISABLE VALUE MODEL

COST AND VALUE CONSTRAINTS FOR BASE CONDITIONS

STREAM	ADDRESS IN THE MATRIX	CONSTRAINT FUNCTION
RAW 1	OB1	= 3.875c/UNIT
RAW 2	OB1	= 4.065c/UNIT
WW 1	OB1	= 1.0 c/UNIT
WW 2	OB1	= 1.0 c/UNIT
PIC 1	R36	= 0.21 (RAW 1 + RAW 2)c
PIC 2	R37	= 1.5 (RAW 1 + RAW 2)c
PIC 3	R38	= 2.5 (OH)c
PIC 4	R39	= 0.7 (FLOW 1)c
PIC 5	R40	= 1.2 (FLOW 22)c
PIC 6	R5	= 1.0 (0.02 FLOW 4)c
DC 1	R12	= 21.0 (0.06 FLOW 22)c
DC 2	R41,R19	= 2.0 (FLOW 10) c, 2 (FLOW 17)c
BYPROD	OB1	= -30c/UNIT
PROD 2	OB1	= -28c/UNIT
PROD 3	OB1	= -25c/UNIT
PROD 4	OB1	= -20c/UNIT
PR 5	OB1	= -20c/UNIT
BLA	OB1	= -26c/UNIT
BLB	OB1	= -24c/UNIT
BLC	OB1	= -23c/UNIT

NOTE: A minus sign (-) in the constraint function denotes "negative cost," i.e. revenue.

TABLE X.4

PARTICULARIZED COST/REALISABLE VALUE MODEL:

MATRIX FOR BASE CONDITIONS

See A.36, A.37, A.38
on the following pages.

```
L
100  D.DAY 100 100
200 CONTROLS
300 OUTPUT
400  ,,3 4 4
500 END
600 HEADING
700  SIMULATION MODEL. JOINT PRODUCT MANUFACTURING SYSTEM
710  PARTICULARIZED COST/REALISABLE VALUE MODEL.
800 END
900 READ DATA
1000 CARD
1100 ROW ID
1200  4, OB1, INP, R2, R3
1300  5, R4, R5, R6, R7, R8
1400  5, R9, R10, R11, R12, R13
1500  5, R14, R15, R16, R17, R18
1600  5, R19, R20, R21, R22, R23
1700  5, R24, R25,+R26,+R27,+R28
1800  5,+R29,+R30,+R31,+R32,+R33
1900  5,+R34,+R35, R36, R37, R38
1910  4, R39, R40, R41, R42
2000 END
2100 CARD
2200 MATRIX
2300  RAW1,OB1,3.875
2500  ,R2,-0.09
2600  ,R3,1.0
2700   ,R7,-0.2275
2800  ,R8,-0.273
2900  ,R9,-0.4095
2910  ,R36,-1.0
2920  ,R37,-1.0
2930  ,R42,-0.01
3000  RAW2,OB1,4.065
3200  ,R2,-0.09
3300  ,R3,1.0
3400  ,R7,-0.273
3500  ,R8,-0.3003
3600  ,R9,-0.3367
3610  ,R36,-1.0
3620  ,R37,-1.0
3630  ,R42,-0.01
3640  RES,R42,1.0
3650  ,R3,-1.0
3700  WW1,OB1,1.0
3800  ,R2,1.0
3900  ,R3,-1.0
4000  OH,R3,-1.0
4010  ,R38,-1.0
4020  ,INP,1.0
4100  FLOW1,R7,1.0
4200  ,R13,-0.06
4300  ,R14,-0.86
4310  ,R39,-1.0
4400  FLOW2,R8,1.0
4500  ,R11,-1.0
4700  WW2,OB1,1.0
4800  ,R6,-1.0
4900  ,R16,0.95
```

```
5000  FLOW3,R4,-1.0
5140  ,R9,1.0
5200  FLOW4,R4,1.0
5300  ,R5,0.02
5400  ,R6,0.02
5500  ,R16,-0.95
5600  PMAT,OB1,15.0
5700  ,R4,-1.0
5800  ,R33,1.0
5900  PIC6,OB1,1.0
6000  ,R5,-1.0
6100  PR5,OB1,-20.0
6200  ,R10,1.0
6300  ,R11,1.0
6400  FLOW22,R11,1.0
6500  ,R12,-0.06
6510  ,R15,-0.9
6520  ,R40,-1.0
6600  PIC1,OB1,0.21
6700  ,R36,1.0
6800  BYPROD,OB1,-30.0
6900  ,R13,1.0
7000  FLOW5,R14,1.0
7100  ,R17,-1.0
7200  FLOW6,R15,1.0
7300  ,R18,-1.0
7400  FLOW7,R16,1.0
7500  ,R19,-1.0
7600  PROD2,OB1,-28.0
7700  ,R17,1.0
7800  ,R32,1.0
7900  PROD3,OB1,-25.0
8000  ,R18,1.0
8100  ,R31,1.0
8200  PROD4,OB1,-20.0
8300  ,R19,1.0
8400  FLOW8,R17,1.0
8500  ,R20,-1.0
8600  FLOW9,R18,1.0
8700  ,R21,-1.0
8800  FLOW10,OB1,2.0
8900  ,R19,1.0
9000  ,R22,-1.0
9100  FLOW11,R20,1.0
9200  ,R23,1.0
9300  FLOW12,R20,1.0
9400  ,R25,1.0
9500  FLOW13,R20,1.0
9600  ,R24,1.0
9700  FLOW14,R21,1.0
9800  ,R23,1.0
9900  ,R29,1.0
```

```
10000  FLOW15,R21,1.0
10100  ,R24,1.0
10200  FLOW16,R21,1.0
10300  ,R25,1.0
10400  FLOW17,R22,1.0
10500  ,R23,1.0
10600  ,R28,1.0
10610  ,R41,1.0
10700  FLOW18,R22,1.0
10800  ,R25,1.0
10900  ,R30,1.0
11000  FLOW19,R22,1.0
11100  ,R24,1.0
11200  ,R34,1.0
11300  BLA,OB1,-26.0
11400  ,R23,-1.0
11500  ,R28,-0.2
11600  ,R29,-0.35
11610  ,R35,1.0
11700  BLB,OB1,-24.0
11800  ,R24,-1.0
11900  ,R26,1.0
12000  ,R34,-0.3
12100  BLC,OB1,-23.0
12200  ,R25,-1.0
12400  ,R30,-0.65
12410  PIC2,OB1,1.5
12420  ,R37,1.0
12430  PIC3,OB1,2.5
12440  ,R38,1.0
12450  PIC4,OB1,0.7
12460  ,R39,1.0
12461  PIC5,OB1,1.2
12462  ,R40,1.0
12463  DC1,OB1,21.0
12464  ,R12,1.0
12465  DC2,OB1,2.0
12466  ,R41,-1.0
12500 FIRST B1
12600 INP 20000.0
12700 R26 3000.0
12900 R31 4000.0
13000 R32 2500.0
13100 R33 3000.0
13110 R35 2500.0
13200 NEXT BB2
13300 INP 20000.0
13400 R26 3000.0
13600 R31 4000.0
13700 R32 2500.0
13800 R33 3000.0
13900 R35 2500.0
13901 R10 600.0
13910 EOF
14010 START PHASE ONE
14100 OB1 B1
14101 COMPUTE
```

TABLE X.5

PARTICULARIZED COST/REALISABLE VALUE MODEL:
OPTIMAL SOLUTION FOR BASE CONDITIONS

COMPUTE

MAXIMUM ERROR ON ROW 3 5.96046@-08. SUM 5.18747@-07

MAXIMUM ERROR ON COL 3 0.00000@+00. SUM 0.00000@+00

ITER	OBJECTIVE	FUNCT.	ENTER.	EXIT.	R.H.S.	ARTFCLS	#DJ	#TRAN
33	-2.50377573@+05	OB1	DC2	R28	B1	0	0	193

VARIABLE NAME	VALUE	LINE COUNT	REDUCED COST	POS. IN BASIS
RAW1	0.00000000	1	0.02366800	0
RAW2	22222.22221810	2	0.00000000	44
RES	222.22222179	3	0.00000000	5
WW1	1999.99999632	4	0.00000000	4
OH	20000.00000000	5	0.00000000	3
FLOW1	6066.66662510	6	0.00000000	9
FLOW2	6673.33329590	7	0.00000000	10
WW2	209.64444211	8	0.00000000	8
FLOW3	7482.22221790	9	0.00000000	6
FLOW4	10482.22221790	10	0.00000000	35
PMAT	3000.00000000	11	0.00000000	11
PIC6	209.64444211	12	0.00000000	7
PR5	0.00000000	13	0.00000000	12
FLOW22	6673.33329590	14	0.00000000	13
PIC1	22222.22221810	15	0.00000000	38
BYPROD	363.99999644	16	0.00000000	15
FLOW5	5217.33329403	17	0.00000000	16
FLOW6	6005.99995640	18	0.00000000	17
FLOW7	9758.94887940	19	0.00000000	18
PROD2	2500.00000000	20	0.00000000	34
PROD3	4000.00000000	21	0.00000000	33
PROD4	7067.04422780	22	0.00000000	21
FLOW8	2717.33329403	23	0.00000000	19
FLOW9	2005.99995637	24	0.00000000	20
FLOW10	2691.90465152	25	0.00000000	32
FLOW11	2000.00000186	26	0.00000000	25
FLOW12	717.33329219	27	0.00000000	22
FLOW13	0.00000000	28	0.00000001	0
FLOW14	0.00000000	29	0.00000001	0
FLOW15	2005.99995637	30	0.00000000	23
FLOW16	0.00000000	31	0.00000001	0
FLOW17	499.99999814	32	0.00000000	30
FLOW18	1332.19039100	33	0.00000000	26
FLOW19	859.71426240	34	0.00000000	24
BLA	2500.00000000	35	0.00000000	37
BLB	2865.71421885	36	0.00000000	36
BLC	2049.52368313	37	0.00000000	27
PIC2	22222.22221810	38	0.00000000	39
PIC3	20000.00000000	39	0.00000000	40
PIC4	6066.66662510	40	0.00000000	41
PIC5	6673.33329590	41	0.00000000	42
DC1	400.39999657	42	0.00000000	14
DC2	499.99999814	43	0.00000000	43

PARTICULARIZED COST/REALISABLE VALUE MODEL:
OPTIMAL SOLUTION FOR OXIDATION PROCESS
EFFICIENCY OF 96%

COMPUTE

MAXIMUM ERROR ON ROW 16 -1.19209e-07. SUM 4.47966e-07

MAXIMUM ERROR ON COL 16 0.00000e+00. SUM 0.00000e+00

ITER	OBJECTIVE	FUNCT.	ENTER.	EXIT.	R.H.S.	ARTFCLS	#DJ	#TRAN
36	-2.60330373e+05	OB1	DC2	R28	B1	0	0	213

VARIABLE NAME	VALUE	LINE COUNT	REDUCED COST	POS. IN BASIS
RAW1	0.00000000	1	0.06438400	0
RAW2	22222.22221810	2	0.00000000	44
RES	222.22222179	3	0.00000000	5
WW1	1999.99999632	4	0.00000000	4
OH	20000.00000000	5	0.00000000	3
FLOW1	6066.66662510	6	0.00000000	9
FLOW2	6673.33329590	7	0.00000000	10
WW2	209.64444211	8	0.00000000	8
FLOW3	7482.22221790	9	0.00000000	6
FLOW4	10482.22221790	10	0.00000000	35
PMAT	3000.00000000	11	0.00000000	11
PIC6	209.64444211	12	0.00000000	7
PR5	0.00000000	13	0.00000000	12
FLOW22	6673.33329590	14	0.00000000	13
PIC1	22222.22221810	15	0.00000000	38
BYPROD	363.99999644	16	0.00000000	15
FLOW5	5217.33329403	17	0.00000000	16
FLOW6	6406.39995770	18	0.00000000	17
FLOW7	9758.94887940	19	0.00000000	18
PROD2	2500.00000000	20	0.00000000	34
PROD3	4000.00000000	21	0.00000000	33
PROD4	6457.73001080	22	0.00000000	21
FLOW8	2717.33329403	23	0.00000000	19
FLOW9	2406.39995766	24	0.00000000	20
FLOW10	3301.21886855	25	0.00000000	36
FLOW11	1125.00000279	26	0.00000000	25
FLOW12	1023.73324645	27	0.00000000	26
FLOW13	568.60004473	28	0.00000000	22
FLOW14	874.99999907	29	0.00000000	31
FLOW15	1531.39995861	30	0.00000000	23
FLOW16	0.00000000	31	0.00000000	0
FLOW17	499.99999814	32	0.00000000	30
FLOW18	1901.21887404	33	0.00000000	32
FLOW19	899.99999665	34	0.00000000	24
BLA	2500.00000000	35	0.00000000	37
BLB	3000.00000000	36	0.00000001	28
BLC	2924.95212048	37	0.00000000	27
PIC2	22222.22221810	38	0.00000000	39
PIC3	20000.00000000	39	0.00000000	40
PIC4	6066.66662510	40	0.00000000	41
PIC5	6673.33329590	41	0.00000000	42
DC1	400.39999657	42	0.00000000	14
DC2	499.99999814	43	0.00000000	43

PARTICULARIZED COST/REALISABLE VALUE MODEL:
OPTIMAL SOLUTION WITH PRODUCT 5 SOLD AT
20c PER UNIT

COMPUTE

MAXIMUM ERROR ON ROW 38 -2.38419e-07. SUM 9.60194e-07

MAXIMUM ERROR ON COL 38 0.00000e+00. SUM 0.00000e+00

ITER	OBJECTIVE	FUNCT.	ENTER.	EXIT.	R.H.S.	ARTFCLS	#DJ	#TRAN
35	-2.50430715e+05	OB1	BLC	RAW1	B1	0	0	193

VARIABLE NAME	VALUE	LINE COUNT	REDUCED COST	POS. IN BASIS
RAW1	0.00000000	1	0.02366800	0
RAW2	22222.22221810	2	0.00000000	44
RES	222.22222179	3	0.00000000	5
WW1	1999.99999632	4	0.00000000	4
OH	20000.00000000	5	0.00000000	3
FLOW1	6066.66662510	6	0.00000000	9
FLOW2	6673.33329590	7	0.00000000	10
WW2	209.64444211	8	0.00000000	8
FLOW3	7482.22221790	9	0.00000010	6
FLOW4	10482.22221790	10	0.00000000	35
PMAT	3000.00000000	11	0.00000000	11
PIC6	209.64444211	12	0.00000000	7
PR5	600.00000000	13	0.00000000	12
FLOW22	6073.33329590	14	0.00000000	13
PIC1	22222.22221810	15	0.00000000	38
BYPROD	363.99999644	16	0.00000000	15
FLOW5	5217.33329403	17	0.00000000	16
FLOW6	5465.99995726	18	0.00000000	17
FLOW7	9758.94887940	19	0.00000000	18
PROD2	2500.00000000	20	0.00000000	34
PROD3	4000.00000000	21	0.00000000	33
PROD4	7298.47279760	22	0.00000000	21
FLOW8	2717.33329403	23	0.00000000	19
FLOW9	1465.99995726	24P	0.00000000	20
FLOW10	2460.47608173	25	0.00000000	32
FLOW11	2000.00000186	26	0.00000000	25
FLOW12	717.33329219	27	0.00000000	22
FLOW13	0.00000000	28	0.00000001	0
FLOW14	0.00000000	29	0.00000001	0
FLOW15	1465.99995726	30	0.00000000	23
FLOW16	0.00000000	31	0.00000001	0
FLOW17	499.99999814	32	0.00000000	30
FLOW18	1332.19039100	33	0.00000000	26
FLOW19	628.28569258	34	0.00000000	24
BLA	2500.00000000	35	0.00000000	37
BLB	2094.28564996	36	0.00000000	36
BLC	2049.52368313	37	0.00000000	27
PIC2	22222.22221810	38	0.00000000	39
PIC3	20000.00000000	39	0.00000000	40
PIC4	6066.66662510	40	0.00000000	41
PIC5	6073.33329590	41	0.00000000	42
DC1	364.39999668	42	0.00000000	14
DC2	499.99999814	43	0.00000000	43

TABLE X.8

PARTICULARIZED COST/REALISABLE VALUE MODEL:
OPTIMAL SOLUTION WITH PRODUCT 5 SOLD AT
19c PER UNIT

COMPUTE

ITER	OBJECTIVE	FUNCT.	ENTER.	EXIT.	R.H.S.	ARTFCLS	#DJ	#TRAN
33	-2.498307150+05	OB1	DC2	R28	B2	0	0	193

VARIABLE NAME	VALUE	LINE COUNT	REDUCED COST	POS. IN BASIS
RAW1	0.00000000	1	0.02366800	0
RAW2	22222.22221810	2	0.00000000	44
RES	222.22222179	3	0.00000000	5
WW1	1999.99999632	4	0.00000000	4
OH	20000.00000000	5	0.00000000	3
FLOW1	6066.66662510	6	0.00000000	9
FLOW2	6673.33329590	7	0.00000000	10
WW2	209.64444211	8	0.00000000	8
FLOW3	7482.22221790	9	0.00000000	6
FLOW4	10482.22221790	10	0.00000000	35
PMAT	3000.00000000	11	0.00000000	11
PIC6	209.64444211	12	0.00000000	7
PR5	600.00000000	13	0.00000000	12
FLOW22	6073.33329590	14	0.00000000	13
PIC1	22222.22221810	15	0.00000000	38
BYPROD	363.99999644	16	0.00000000	15
FLOW5	5217.33329403	17	0.00000000	16
FLOW6	5465.99995726	18	0.00000000	17
FLOW7	9758.94887940	19	0.00000000	18
PROD2	2500.00000000	20	0.00000000	34
PROD3	4000.00000000	21	0.00000000	33
PROD4	7298.47279760	22	0.00000000	21
FLOW8	2717.33329403	23	0.00000000	19
FLOW9	1465.99995726	24	0.00000000	20
FLOW10	2460.47608173	25	0.00000000	32
FLOW11	2000.00000186	26	0.00000000	25
FLOW12	717.33329219	27	0.00000000	22
FLOW13	0.00000000	28	-0.00000001	0
FLOW14	0.00000000	29	0.00000001	0
FLOW15	1465.99995726	30	0.00000000	23
FLOW16	0.00000000	31	0.00000001	0
FLOW17	499.99999814	32	0.00000000	30
FLOW18	1332.19039100	33	0.00000000	26
FLOW19	628.28569258	34	0.00000000	24
BLA	2500.00000000	35	0.00000000	37
BLB	2094.28564996	36	0.00000000	36
BLC	2049.52368313	37	0.00000000	27
PIC2	22222.22221810	38	0.00000000	39
PIC3	20000.00000000	39	0.00000000	40
PIC4	6066.66662510	40	0.00000000	41
PIC5	6073.33329590	41	0.00000000	42
DC1	364.39999668	42	0.00000000	14
DC2	499.99999814	43	0.00000000	43

PARTICULARIZED COST/REALISABLE VALUE MODEL:
OPTIMAL SOLUTION WITH ADDITIONAL SALES OF
A PRODUCT AT INCREASED SELLING COST

COMPUTE

MAXIMUM ERROR ON ROW 18 1.33179e-07. SUM 5.50412e-07

MAXIMUM ERROR ON COL 18 0.00000e+00. SUM 0.00000e+00

ITER	OBJECTIVE	FUNCT.	ENTER.	EXIT.	R.H.S.	ARTFCLS	#DJ	#TRAN
35	-2.58884715e+05	OB1	BLC	R28	B1	0	0	219

VARIABLE NAME	VALUE	LINE COUNT	REDUCED COST	POS. IN BASIS
RAW1	0.00000000	1	0.02366800	0
RAW2	22222.22221810	2	0.00000000	44
RES	222.22222179	3	0.00000000	5
WW1	1999.99999632	4	0.00000000	4
OH	20000.00000000	5	0.00000000	3
FLOW1	6066.66662510	6	0.00000000	9
FLOW2	6673.33329590	7	0.00000000	10
WW2	209.64444211	8	0.00000000	8
FLOW3	7482.22221790	9	0.00000000	6
FLOW4	10482.22221790	10	0.00000000	35
PMAT	3000.00000000	11	0.00000000	11
PIC6	209.64444211	12	0.00000000	7
PR5	0.00000000	13	0.00000000	12
FLOW22	6673.33329590	14	0.00000000	13
PIC1	22222.22221810	15	0.00000000	38
BYPROD	363.99999644	16	0.00000000	15
FLOW5	5217.33329403	17	0.00000000	16
FLOW6	6005.99995640	18	0.00000000	17
FLOW7	9758.94887940	19	0.00000000	18
PROD2	2900.00000000	20	0.00000000	34
PROD3	4000.00000000	21	0.00000000	33
PROD4	7944.18714620	22	0.00000000	21
FLOW8	2317.33329403	23	0.00000000	19
FLOW9	2005.99995637	24	0.00000000	20
FLOW10	1814.76173317	25	0.00000000	36
FLOW11	1125.00000279	26	0.00000000	25
FLOW12	0.00000000	27	0.00000000	0
FLOW13	1192.33329124	28	0.00000000	22
FLOW14	874.99999907	29	0.00000000	31
FLOW15	907.66671211	30	0.00000000	26
FLOW16	223.33324522	31	0.00000000	23
FLOW17	499.99999814	32	0.00000000	30
FLOW18	414.76173842	33	0.00000000	32
FLOW19	899.99999665	34	0.00000000	24
BLA	2500.00000000	35	0.00000000	37
BLB	3000.00000000	36	-0.00000001	28
BLC	638.09498358	37	0.00000000	27
PIC2	22222.22221810	38	0.00000000	39
PIC3	20000.00000000	39	0.00000000	40
PIC4	6066.66662510	40	0.00000000	41
PIC5	6673.33329590	41	0.00000000	42
DC1	400.39999657	42	0.00000000	14
DC2	499.99999814	43	0.00000000	43

PARTICULARIZED COST/REALISABLE VALUE MODEL:
OPTIMAL SOLUTION WITH RAW MATERIAL I
PURCHASED AT 3.7c PER UNIT

COMPUTE

MAXIMUM ERROR ON ROW 3 5.960460-08. SUM 5.187470-07

MAXIMUM ERROR ON COL 3 0.000000+00. SUM 0.000000+00

ITER	OBJECTIVE	FUNCT.	ENTER.	EXIT.	R.H.S.	ARTFCLS	#DJ	#TRAN
35	-2.537405060+05	OB1	FLOW14	RAW2	B1	0	0	212

VARIABLE NAME	VALUE	LINE COUNT	REDUCED COST	POS. IN BASIS
RAW1	22222.22221810	1	0.00000000	44
RAW2	0.00000000	2	0.15133201	0
RES	222.22222179	3	0.00000000	5
WW1	1999.99999632	4	0.00000000	4
OH	20000.00000000	5	0.00000000	3
FLOW1	5055.55553472	6	0.00000000	9
FLOW2	6066.66662510	7	0.00000000	10
WW2	241.99999699	8	0.00000000	8
FLOW3	9099.99997910	9	0.00000000	6
FLOW4	12099.99997910	10	0.00000000	35
PMAT	3000.00000000	11	0.00000000	11
PIC6	241.99999699	12	0.00000000	7
PR5	0.00000000	13	0.00000000	12
FLOW22	6066.66662510	14	0.00000000	13
PIC1	22222.22221810	15	0.00000000	38
BYPROD	303.33333119	16	0.00000000	15
FLOW5	4347.77775687	17	0.00000000	16
FLOW6	5459.99995363	18	0.00000000	17
FLOW7	11265.09997420	19	0.00000000	18
PROD2	2500.00000000	20	0.00000000	34
PROD3	4000.00000000	21	0.00000000	33
PROD4	10204.62381820	22	0.00000000	21
FLOW8	1847.77775687	23	0.00000000	19
FLOW9	1459.99995363	24	0.00000000	20
FLOW10	1060.47615597	25	0.00000000	27
FLOW11	1847.77775687	26	0.00000000	25
FLOW12	0.00000000	27	0.00000000	22
FLOW13	0.00000000	28	0.00000000	0
FLOW14	152.22224498	29	0.00000000	32
FLOW15	1307.77770859	30	0.00000000	23
FLOW16	0.00000000	31	0.00000000	0
FLOW17	499.99999814	32	0.00000000	30
FLOW18	0.00000000	33	0.00000000	26
FLOW19	560.47615784	34	0.00000000	24
BLA	2500.00000000	35	0.00000000	37
BLB	1868.25386643	36	0.00000000	36
BLC	0.00000000	37	0.00000000	0
PIC2	22222.22221810	38	0.00000000	39
PIC3	20000.00000000	39	0.00000000	40
PIC4	5055.55553472	40	0.00000000	41
PIC5	6066.66662510	41	0.00000000	42
DC1	363.99999644	42	0.00000000	14

POSTULATES

1 In South Africa jointly produced products account for a significant percentage of the gross national product and their manufacture is of major industrial, economic and strategic importance. Consequently the optimal solution of the particular managerial problems associated with joint product manufacturing is of considerable importance.

2 Comprehensive empirical definition of the nature of the processes whereby joint products are produced is essential for the concepts "joint products" and "joint costs" to be meaningful.

3 The prevailing lack of such definition, coupled with the use of "different costs for different purposes," has resulted in the adoption of cost allocation practices which are useful for common cost proration, being applied to joint costs with what are frequently meaningless results.

4 Any deviation from forecasted demand on which optimum resource allocation has been based tends to result in a greater deviation from maximum returns than otherwise if the products are technically interdependent.

5 Allocated joint costs and cost-volume-profit relationships for individual joint products are unsuitable for certain planning and decision-making purposes. Alternative managerial information systems are essential if resource allocation to products is to be optimised.

6 Joint product pricing is a particularly important and complex function. Specialised procedures which do not depend on artificial joint product cost prices are necessary.

7 Documented cost-variance analysis procedures for single-line products provide insufficient control information regarding the efficiency

with which a joint process is operated.

8 Optimisation of the joint process with respect to returns is in effect an exercise involving the causal relationship between revenue and sacrifice factors. Subject to the availability of the necessary constraint data, an optimisation model incorporating particularized costs conforming to normative costing concepts constitutes a powerful tool with respect to the maximisation of returns on joint products.

9 The joint product manufacturing sequence must be considered as a whole for optimisation purposes.

10 Unless sound particularization of indirect costs is practised, the joint product manufacturing system cannot be optimised.

11 Many cost systems based on non-normative concepts do not provide enough cost information to enable accurate evaluation of the superiority of the particularized cost/realisable value model.

12 There is an unfortunate tendency in South Africa to attempt to increase profits by adopting Amercian-type high-pressure marketing methods, the cost of which is inevitably borne by the consumer. This short-sighted and inflationary policy is frequently pursued while optimisation of production processes is neglected.

Postulates accompanying the thesis "Joint products: a study in costing and maximiation of returns," to be defended during the Viva Voce examination.