COMPUTER AIDED PROCESS PLANNING (CAPP) FOR FLAT ROLLING OF COPPER ALLOYS

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Summary

The manufacture of copper alloy flat rolled metals involves hot and cold rolling operations, together with annealing and other secondary processes, to transform castings (mainly slabs and cakes) into such shapes as strip, plate, sheet, etc. Production is mainly to customer orders in a wide range of specifications for dimensions and properties. However, order quantities are often small and so process planning plays an important role in this industry.

Much research work has been done in the past in relation to the technology of flat rolling and the details of the operations, however, there is little or no evidence of any research in the planning of processes for this type of manufacture.

Practical observation in a number of rolling mills has established the type of manual process planning traditionally used in this industry. This manual approach, however, has inherent drawbacks, being particularly dependent on the individual planners who gain their knowledge over a long span of practical experience. The introduction of the retrieval CAPP approach to this industry was a first step to reduce these problems. But this could not provide a long-term answer because of the need for an experienced planner to supervise generation of any plan. It also fails to take account of the dynamic nature of the parameters involved in the planning, such as the availability of resources, operation conditions and variations in the costs. The other alternative is the use of a generative approach to planning in the rolling mill context.

In this thesis, generative methods are developed for the selection of optimal routes for single orders and then for batches of orders, bearing in mind equipment restrictions, production costs and material yield. The batch order process planning involves the use of a special cluster analysis algorithm for optimal grouping of the orders.

This research concentrates on cold-rolling operations. A prototype model of the proposed CAPP system, including both single order and batch order planning options, has been developed and tested on real order data in the industry. The results were satisfactory and compared very favourably with the existing manual and retrieval methods.

KEYWORDS:

ROLLING MILL
PROCESS PLANNING
GENERATIVE CAPP
BATCH ORDER PROCESS PLANNING
CLUSTER ANALYSIS

بِسْمِ ٱللَّٰهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

In the name of God, the Compassionate, the Merciful

To my family
for their affection and support
in childhood and later life.

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CHAPTER 1

INTRODUCTION

1.1. An Overview

The manufacturing productivity increases in recent years are largely due to new technological developments, in particular automation and the application of computers in various areas of manufacturing such as CAD, CAM, CAPM and CIMS.

Process planning is an important subsystem of manufacturing which is responsible for the determination of effective methods of utilising manufacturing resources for the production of quality products. It also plays the role of a link between other activities in the system, e.g. between CAD and CAM. However, Blore (1984), Sutton (1989) and many other researchers are agreed that effective application of computing power into this planning function has been long overdue. A major reason for this delay, besides the complexity of the development itself, is that process planning is a function that is dependent upon the particular manufacturing environment. Therefore, despite existing developments, much more research work is necessary before this computerisation can be effectively applied over a reasonable range of manufacturing industries.

One area of manufacture which has not yet effectively exploited the potential of such computerisation is the rolling mill industry for flat copper-alloy materials. A modern high-production rolling mill for these products represents an enormous capital investment. Their manufacture covers a wide range of operations including both hot and cold rolling processes each accompanied by a series of associated processes. Many of the rolling mill companies also produce the main part of their own castings, usually called slabs or cakes. The overall manufacturing function can be grouped into three operational departments: *foundry and casting, hot rolling* and *cold rolling*. The process planning function can therefore be split accordingly, so that each department is basically planned separately, but provisions are required for linking plans made for different departments.

The method used for the study of this process planning problem includes both theoretical and practical considerations. A series of visits to a number of rolling mills identified the need for research on the practical requirements for a planning system to be used in this industry.

Two copper-alloy rolling mill companies (referred to as Company A and Company B in this thesis) were then selected to carry out an initial feasibility study to discover the current state of process planning, as well as identifying the unique issues, difficulties and considerations particular to this type of industry. The experience gained at these companies also enabled the writer to identify a general structure for the planning problem.

The next phase of the practical study concentrated on one of the companies (Company B). This company had implemented a computerised process planning system. It is a broad based company manufacturing a wide range of products utilising a diverse range of manufacturing technologies. The necessary manufacturing rules and routing data was obtained from this company. Based on this information, the proposed methodology was established and the prototype computer system was developed. The system was then tested at the same company.

Chapters 2 to 4 in this thesis will review the manufacture of flat-rolled copper-alloy materials, the background to the process planning and the CAPP developments, and the particular process planning problems for this industry. Based on these, a solution methodology has been developed for the planning of any individual order. This is discussed in Chapter 5. Batch order process planning is a second planning option considered in this project; the aim of this is the optimisation of a batch of orders rather than treating individual orders separately. This is discussed in Chapters 6 to 8. Chapters 9 to 11 are devoted for the description of the computer implementations and the development of a prototype CAPP system based on the proposed methodologies.

The results of the extensive trials proved that the system operated in the manner intended. Whilst the provisional results from the prototype system were discussed in Beaumont and Moattar Husseini (1988), full results are included in this thesis. From these, it can be concluded that although further research is required to refine the system before it can be fully implemented in the rolling mill industry, the main points have been established.

A significant result of this research has been to collect and consolidate detailed industry-based knowledge. The identification of key issues and the relationship between various elements within the industry has proved difficult and time consuming. However, the acquisition of such information has resulted in the development of a bespoke CAPP system which meets the real needs of this industry.

1.2. State of Process Planning in the Industry: Particular Problems

Process planning in the copper-alloy flat-rolling industry, like that many other manufacturing industries, is traditionally accomplished manually by an skilled planner who has gained his knowledge through a long span of experience. This *manual* *approach* , however, has its particular drawbacks. It is highly dependent on the planners, who are not usually easy to find or even to train. The approach is also incapable of guaranteeing the production of optimal plans, since the task is complex and requires the evaluation of a large space of possible options at various stages of planning. The task is time consuming and there are also other problems associated with this approach (these are discussed in some length in Chapter 4).

There are two possible approaches to computer aided process planning (CAPP): *variant CAPP systems* and *generative CAPP systems.*

The variant (also called retrieval) CAPP systems are based on the formation of *part families* and storing standard process plans for each family in the computing system. These plans can then be retrieved and modified for any similar part. The generative CAPP systems, on the other hand, do not use any pre-established plan, but work on the basis of the *manufacturing decision logic*. They apply this logic to planning for each product individually, considering the existing manufacturing capabilities and data against the product requirements.

Practical investigation in a number of rolling mill companies and the study of the literature established the variant type CAPP approach as the most advanced state of computerisation of process planning in this industry. This approach has been effective in reducing some of the problems mentioned for the manual approach, but it could not provide a long-term answer, as there are still a number serious problems. These are:

1. Process plans stored in the system are initially produced manually, therefore are not necessarily optimal.

2. The effectiveness of any process plan in terms of its approach to some optimality is dependent on such dynamic factors as the availability of material,

preferences for the utilisation of resources and so on. Therefore, if conditions have changed, most of the plans stored in the system are less effective at the time they are retrieved than they were originally. They might even become completely useless.

3. Modification of ineffective plans requires considerable time from an experienced planner. In practice a planner on the shopfloor has the responsibility of checking the plans with respect to the current parameters.

4. Material yield (which is the weight ratio of the output product to the corresponding input material) is not satisfactory, according to the management of the company. A lower material yield results in the circulation of redundant material in the system. This increases material cost, operation cost and many other costs. It also reduces the effective capacity of the whole production system. Material yield, which is an important factor, is partly determined by the process planning function.

5. Total time required from a skilled planner is high.

6. The millstock level is high.

7. Very large amounts of computer storage are required.

Bearing in mind the above problems, the literature was searched for a better approach. This was provided by generative CAPP. Since this approach works on logic and realistic manufacturing information it has the potential capability to reduce the above problems significantly.

This study also showed that no particular generative system or solution methodology had been developed for tackling this specific process planning problem. Therefore, a decision had to be made on how to develop an appropriate solution methodology which could then be implemented in a computerised system in order to evaluate its practical applicability in the industry.

1.3. Scope of the Research Project

The separate operation of three production departments (foundry, hot rolling and cold rolling) was noted above in Section 1.1.

This research project concentrates on the process planning for a cold rolling department and it specifically deals with planning for plates and sheets.

With regard to the metal types, although this project concentrates on coppers and brasses of general application type, the proposed methodology is also applicable for other copper alloy metals.

1.4. Objectives for Research

Apart from the general study of the of the process planning problem, the following particular objectives were set for this research project.

1) The prime objective is to develop the methodology and a prototype model of a generative type CAPP system for the production of copper-alloy plates and sheets.

2) The method is to provide two capabilities:

- planning for individual orders (*single order process planning*)
- planning for a batch of orders in accordance with a criterion for the optimisation of the batch (*batch order process planning*).

3) As a major feature, the method is required to include provisions for the improvement of material yield and lowering the overall route cost for the individual orders or for the batch.

4) The resulting process planning system is required to operate on desk-top microcomputer systems.

CHAPTER 2

A REVIEW OF COPPER-ALLOY FLAT ROLLED PRODUCTS AND THEIR MANUFACTURE

2.1. Introduction

Copper-alloy flat rolled products are generally produced in the form of strip, plate or sheet, from which a variety of common shapes (circles, etc.) can also be configured. These products are mainly specified by their alloy type, dimensions, tolerances, metallurgical and mechanical properties, and surface condition.

The flat rolled products, themselves, constitute one of the major groups of raw materials for a variety of industrial applications. They are widely used because of their excellent electrical and thermal conductivity, outstanding resistance to corrosion, ease of fabrication, and good colour, together with good strength and fatigue resistance. Their major areas of application include heating units and heat exchangers, electrical and electronic products, industrial machinery and equipment, building construction, consumer and general products.

Castings in the forms of cakes or slabs are major raw materials for the production of these rolled metals, and their manufacture is accomplished through appropriate sequences of rolling and annealing processes, accompanied by other operations such as flattening, cleaning, trimming, blanking and some other metal cutting operations.

The manufacture of copper-alloy flat rolled metals is briefly discussed in the following sections. A short review of copper-alloy metals is also included below.

2.2. Copper-Alloy Metals

Copper alloys can be grouped into six families: coppers, dilute copper alloys, brasses, bronzes, copper nickels, and nickel silvers. However, as was stated in the previous chapter, our project mainly concentrates on coppers and brasses.

Copper is essentially 'commercially pure copper ' containing less than 0.7% total impurities. Two common types of copper are:

(i) tough-pitch high-conductivity copper, which is a general-purpose copper, used for many electrical, light engineering and building purposes;

(ii) phosphorus-dioxide copper use of which has benefits in certain specialised applications, for instance when the metal is subject to a reducing atmosphere at elevated temperatures.

Brasses are those copper alloys in which the major alloying addition is zinc. The generic term 'brass' covers a wide range of materials with quite different properties and fields of application. The copper content in brasses varies from 54 to 97%. Those with 85 to 95% copper content are generally known as the gilding metals. Some of the commercially available rolled brasses are: 97/3 Cap Copper, 90/10 and 85/15 Gilding Metals, 80/20 Brass, 70/30 Brass and 64/36 Brass.

The dilute copper alloys contain small amounts of various alloying elements that modify one or more of the basic properties of copper. Each of the remaining copper-alloy families contain one additional element as its primary alloying ingredient. Further details of copper-alloy metals can be found in, for example, Metals Handbook (American Society of Metals, 1979).

2.3. Raw Material for the Production of Flat Rolled Metals

The rolled metals which we are considering are usually produced from castings in the form of slabs and cakes. A number of rolling mill companies purchase these materials from outside foundries, but some of them produce all or part of their casting requirements.

Production of castings in a rolling mill generally consist of melting, casting and machining processes. The melting operation is usually accomplished by charging the furnaces with correct quantities of virgin metals and realloyed ingots, alloying elements and scrap material. Different methods are used for the casting of slabs and cakes and these methods vary from discontinuous to continuous types. The surfaces of the cast metal are often machined before any rolling operation.

2.4. Concept of Flat Rolling

During flat rolling, the desired shape of metal is obtained by plastic deformation taking place between two cylindrical rolls mounted with their axes parallel and revolving in opposite directions. The space between the rolls is somewhat less than the thickness of the entering material. Due to friction the material is drawn into the gap between the rolls and undergoes deformation. As a result the ingot height is reduced, while the breadth and the length of the stock increase, the latter usually much more than the former. In this method of rolling, the metal moves forward along a straight line perpendicular to the roll axes and the plastic deformation takes place mostly in this direction.

During the rolling process, in addition to the change of the shape affected purely in a mechanical way, the metal undergoes structural changes, which in turn result in variation of physical properties. Among these changes are:

- changes due to inhomogeneity of the ingot material (e.g. slab),
- changes of structure and properties, resulting from hot working of metal,
- changes of structure and properties, resulting from cold working of metal.

In a rolling process, the plastic working consists of displacement of the metal particles from one part of the given workpiece to another. Such a displacement can be accompanied by the following phenomena:

- disturbance of the equilibrium on grain boundaries,
- disturbance of the equilibrium within grains themselves,
- fragmentation of grains.

However, such a displacement should always take place without destruction of the workpiece as a whole. More detailed discussion of the mechanics of rolling can be found in Wusatowski (1969) and Starling (1962).

Rolling operations are divided into *hot rolling* and *cold rolling*, with respect to their working temperature.

2.5. Rolling Mills

While rolling of plates and sheets is usually done on single stand mills, it is more common for the strips to be rolled on a continuous rolling line consisting of a number of rolling stands.

Rolling mill stands are available in a variety of roll configurations, as illustrated in Fig. 2.1. Early reductions, often called *breaking down* usually employ a two-high or three-high configuration with roll diameter 600 to 1000 mm. The three-high mill is equipped with an elevator on each side of the stand for raising or lowering the slab and mechanical manipulators for turning the workpiece and shifting it for the various passes as it is rolled back and forth. Four-high and cluster roll arrangements use backup rolls to provide the necessary work-roll support. These configurations are used in the hot rolling of wide plates and also in some cold rolling operations. The planetary mill configuration enables much larger reductions to be performed in a single pass. Particular uses of each type of these configurations for the rolling of copper alloys are discussed later in the sections below. Further details with regard to the configuration of the mills can be found in Larke (1967) and The Metal Society (1979). A more exhaustive description of the mechanical design of rolling mills is given by Tseclikov and Smirnov (1965).

2.6. Manufacturing processes

As noted above, the two main processes involved in the manufacture of flat rolled products are: *hot rolling* and *cold rolling*. An important associated process is *annealing*. Other associated operations include: heating, cleaning, flattening and cutting of circles or other shapes. Description of these processes is given in the following sections.

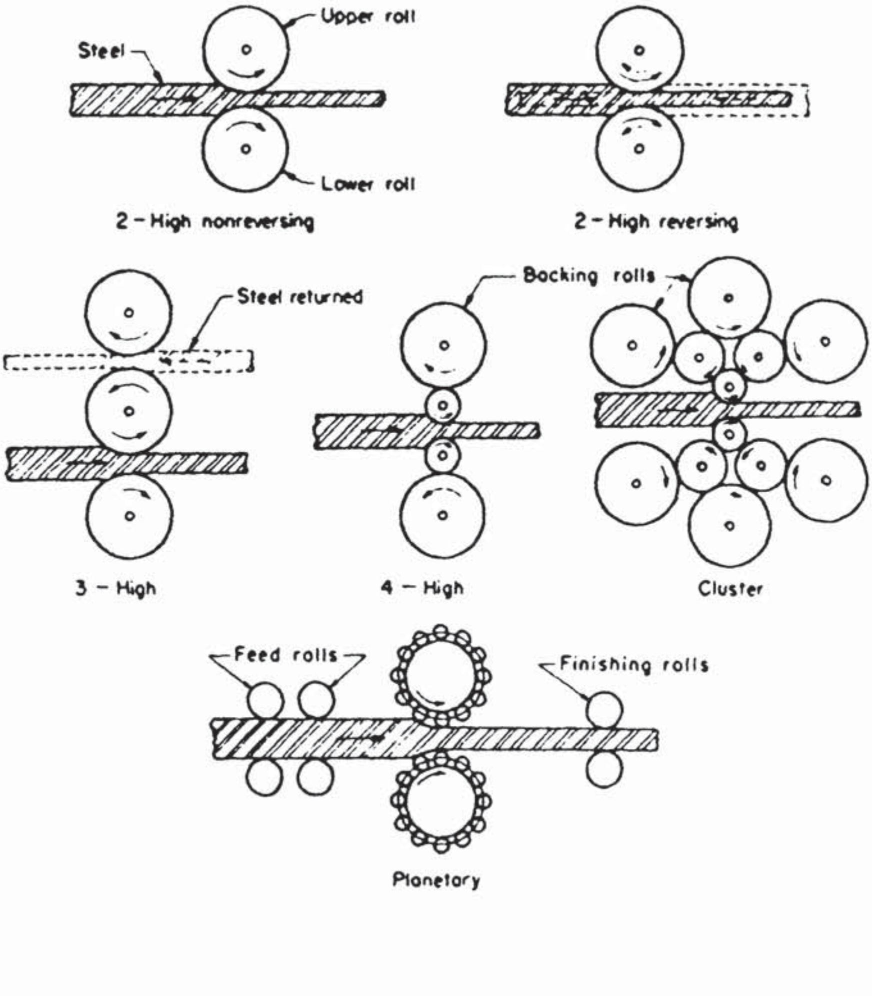


Fig. 2.1 Types of roll configuration (after DeGarmo, 1979)

2.6.1. Hot Rolling

Hot rolling can be effectively used for copper alloys as they remain ductile above the recrystalisation temperature. This operation permits more extensive changes in shape than cold rolling, so that a single hot rolling can replace a sequence of cold rolling and annealing processes. This also helps to avoid undesirable orientation and textures, as well as to achieve processing economy. Hot working reduces as-cast grain size and yields a soft, texture-free structure suitable for cold finishing. Products produced by this operation have minimum directional properties and are relatively free of residual stresses.

In a hot rolling it is very important that the metal be heated uniformly throughout to the proper temperature before processing. The hot rolling operation is normally accomplished through a number of passes which are to be applied as fast as possible to prevent cooling of the metal. In this operation it is also common to turn and cross roll the metal during the passes in order to produce the specified width.

With regard to the practical scope of the application, however, the use of hot rolling for copper alloy metals is restricted to the production of heavy plates, or some breaking down operations. Details of hot rolling differs for different alloys of the copper.

With regard to the mill types, two-high reversing mills are more popular for the hot rolling of copper-alloy flats. These can produce relatively uniform thickness of the metal at a good rate. Rolls are made of chilled iron which are cylindrically ground. Provisions are also made for cooling the rolls with water. Also rolls have to be lubricated to prevent scaling or metal pickup.

Because of the hot and heavy metal being handled the mills are normally fully mechanised with conveyors and other handling devices.

2.6.2. Cold Rolling

The term cold rolling refers to a rolling operation which takes place with the workpiece at ambient temperature. A characteristic of cold rolling, like any other cold working operation, is the preservation of structure and properties obtained as a result of deformation. Cold rolling produces strain hardening in the metal, increasing both tensile and yield strength of the metal, but the effect is more pronounced on the latter.

After a small amount of cold work the material is said to be of "half hard temper". Further cold work takes the material into the "hard temper" range. As an approximate guide, "soft temper" (or annealed) material, has a hardness value below 55 Hv (diamond pyramid indenter, Vickers scale), "half hard" in the range 70 - 90 Hv and "hard" in excess of 100 Hv.

Copper and copper-alloys are soft metals and therefore can be easily rolled cold. Even in the case of copper, once the flow has been started it takes little energy to continue, and thus extremely large reductions are possible in a single pass. For instance a reduction of as high as 90% in one pass can be planned for the coppers. However, heavy reductions may induce directional properties (i.e.preferred crystal orientation or texturing), which is undesirable for some applications.

Copper alloys also respond well to sequential cold rollings and the use of tandem rolling is common for these metals.

With regard to the equipment, use of a nonreversing two-high mill (e.g. with 30 in. diameter rolls made of forged alloy steel, hardened and ground) is very common for the cold rolling of copper-alloy flats. Rundown operations for the strips can also be done in tandem installations with 2 to 5 stands of rolls in series. These stands are four-high nonreversible mills. Single stand four-high mills are also used in some brass mills. Sendzimir mills with 12 to 20 rolls have also been used in some recent installations.

In two-high or some four-high mills, since the rolls are subject to deflection during a heavy roll pass, it is common to compensate for this by grinding them with a crown (also called a chamber). This prevents such problems as a heavy centre or wavy edges in the rolled strip.

2.6.3. Annealing

Annealing is the process of heating a work hardened metal in a furnace at a steady rate through which the following phenomena occurs.

- At a temperature below recrystallisation (e.g. 150 ° C for copper) *recovery* occurs. This results in the relief of internal stress within the metal. Mechanical properties, are not affected, so the enhanced strength due to the cold working is maintained. This process is generally called *stress relief annealing*.

- As the temperature progressively increases, recrystallisation occurs, The effect of this is that the distorted and strained grains are replaced by a complete new set of fine grains. The effect on the mechanical properties is a reversion to the soft ductile condition which existed before the cold working operation. This process is normally referred to as *annealing*.

- If the temperature is further increased after recrystallisation, grain growth occurs.

Coarse-grained metal is somewhat softer than fine-grained metal and therefore can be more easily worked cold. Fine grain sizes on the other hand can enhance the strength and surface quality of the metal.

The temperature at which recrystallisation occurs depends on different factors including alloy type and the amount of work hardness in the metal.

2.6.4. Other Related Processes

Apart from the main processes in a rolling mill which were discussed in the previous sections, a number of other operations may also be used. These are briefly reviewed below.

Heating

In a hot rolling process, it is very important that the metal be heated uniformly throughout to the proper temperature before processing. This usually requires prolonged heating at the desired temperature, a process known as *heating* or *soaking*. If the heating is not uniform or the temperature is not accurate, cracking, tearing, and associated problems may result in the subsequent deformation process.

Copper-alloys are usually heated in gas or oil-fired furnaces. The tunnel type of furnace using combustion gases as an atmosphere and fitted with continuous metal feed and discharge, is in general use.

Cleaning and Pickling

During the course of processing copper alloys may become coated with lubricating oils, oxides, dirt, metallic particles, etc. which must be removed by cleaning. The type of cleaning employed will depend on the type of material to be removed, the equipment available, and the degree of the cleanliness required. Some common methods are: solvent cleaning, degreasing, alkaline scouring, and electrolytic cleaning.

Oxide scale formed during annealing or joining operations is removed by pickling, normally by using a warm 10% solution of sulphuric acid in water. Thorough washing in water is necessary after the pickling operation, to remove all traces of acid.

Flattening

Rolled products may require special flatness properties. These are achieved by one of two methods. For coiled stock and material in length gauge and hardened tempers, roller flattening involving staggered rolls is used. In the other method, the flat product is gripped on both ends in a leveling machine and stretched slightly.

Slitting

Slitting is used to cut rolls of strip or sheet metal into several rolls of narrower width. The shearing blades are in the form of circumferential mating grooves on cylindrical rolls, the ribs on one roll mating with the grooves in the other. The process is continuous and can be done rapidly and economically. Also, the width of the slit strip is very accurate and constant.

Blanking

Blanking is used to cut or to punch flat pieces of desired shape from rolled flat products, and offers a rapid method of cutting identical flat pieces.

Trimming

Trimming is used to remove the excess metal, e.g. irregular metal edges left after a deformation process.

Final shear

After the final stage of transforming the metal, a final shearing operation produces the exact width and length of the plate or sheet.

Circle cutting

The methods such as blanking with the use of press machines, nibbling, sawing, etc, are used to cut circles, ovals and other curved shapes of strips, plates or sheets.

2.7. Summary

Copper-alloy flat rolled products are mainly produced in the forms of strip, plate and sheet (or circle) with a considerable range of properties.

They are widely used as input materials for industrial applications and their properties of importance are good resistance to corrosion, good electrical conductivity, colour and ease of fabrication. Strength, resistance to fatigue and ability to take a good finish are also among the advantages which these metals have over some other materials.

Commercial coppers and brasses are the most common types of copper alloys used in flat rolling mill industry. Two major types of the commercial coppers are the "tough pitch high conductivity copper" and the "phosphorus-dioxide copper". Brasses are those copper alloys in which the major alloying addition is zinc. This covers a wide range of alloys, with the copper content ranging from 54 to 97% and with quite different properties and field of application.

Materials used in flat rolling mills are mainly cakes and slabs for hot rolling and slabs, plates and strips for the cold rolling operations. Hot and cold rolling are the two main processes which transform the material into products. Annealing is another important process and other associated processes include: heating, cleaning, flattening, different cutting operations, etc.

Hot rolling is performed at a temperature above the recrystallisation point and it is therefore very important that the metal be heated uniformly throughout to this temperature before processing. Hot rolling operation does not produce any work-hardening, and can therefore be used to produce more extensive reductions in the metal without any need for annealing. Products produced by this operation are normally soft, with a texture-free structure particularly suitable for cold finishing. Design of the roll pass and determination of the operation parameters are the most important operation planning requirements for hot rolling. The use of hot rolling for copper alloy metals is in practice restricted to the production of heavy plates, or some breaking down operations. Two-high reversing mills are commonly used for this operation.

The term cold rolling refers to a rolling operation which takes place with the input material at ambient temperature. Cold rolling produces strain hardening in the metal, increasing its strength. After small amount of cold work the material is said to be of "half hard temper". Further cold work takes the material into the "hard temper" range.

Copper and copper-alloys are soft metals and can therefore be easily rolled cold. For instance a reduction of as high as 90% is possible in one pass. However, large reductions may induce directional properties, which is undesirable for some applications. Copper alloys also respond well to sequential cold rollings and the use of Tandem rolling is common for these metals.

With regard to the equipment, nonreversing two-high mill is very common for the cold rolling of copper-alloy flats. Rundown operations for the strips can also be done in Tandem installations with 2 to 5 stands of four-high nonreversible mills. Single stand four-high mills are also used in some brass mills. Sendzimir mills with 12 to 20 rolls has also been used in some recent installations.

Annealing is referred to the heating of work-hardened metal above recrystallisation temperature which is performed at a steady state rate through which the soft ductile condition which existed before the cold working operation can be reproduced. Stress relief is an aspect of annealing process in which metal is heated below recrystalisation and as the result internal stress is eliminated but mechanical properties are not affected.

CHAPTER 3

BACKGROUND TO PROCESS PLANNING AND THE CAPP SYSTEMS

3.1 Process Planning: Introduction

Process Planning has been defined by the Society of Manufacturing Engineers (Dallas, 1976) as "the systematic determination of the methods by which a product is to be manufactured, economically and competitively". The task of process planning consists of preparing a set of instructions that describe the effective utilisation of manufacturing resources in order to produce a part (or build an assembly) in accordance to a given set of specifications. The resulting set of instructions specifies the required processes in sequence, in addition it may include any or all of the following:

machines
tools, jigs, fixtures
process parameters
operations methods
standard times
standard costs
setup details
inspection criteria
graphical representations

There are variations in the level of detail found in process plans among different companies and industries. The degree of detail is often dependent upon the complexity of the product and the process, and the level of management control exercised.

Process planning is a complex task which has a great influence on the quality, cost, and rate of production. Therefore it is of utmost importance to the production system. There are three main different approaches to process planning. These are:

1. Manual approach.
2. Variant computer aided process planning (Variant CAPP) approach.
3. Generative computer aided process planning (Generative CAPP) approach.

A Hybrid CAPP approach, which is the combination of the variant and generative CAPP approaches can also be added to the above list.

To show the basic concept of each approach they are reviewed in the following sections.

3.2 Manual Process Planning

Manual process planning, which is the traditional approach, is carried out by a person with a high level of experience and a broad knowledge of manufacturing, who has the responsibility of determining the optimal plan. This approach requires the planner to carry out a careful examination of the product specification. Then, based on the available range of material, current manufacturing information and the relevant time and cost data, he goes through different decision-making stages in order to determine the most effective plan for the production of the product. At each decision making stage, the planner utilises appropriate techniques and applies his personally acquired manufacturing logic to analyse and evaluate possible options.

The advantage of using this approach is its low initial cost and its great potential flexibility. But this approach in general suffers from several problems. Major drawbacks of manual process planning, as discussed by Steudel (1984) and Groover (1984, ch13) and agreed by many other researchers, can be described as follows.

1. It is a complex and time-consuming task.
2. It is highly dependent on individual skill, human memory, reference manuals, and above all experience. According to Halevi (1980), even mood should probably be added to the list of controlling parameters.
3. Very often the plans suffer from inconsistency and inaccuracy.
4. The plans may reflect the preference and prejudices of the planner.
5. The dimension of the task can easily become too large for the planner to manage effectively.
6. It is a poor utilisation of engineering skill because of the high clerical content in most of the functions

In general, due to the problems associated with manual process planning, this approach does not prove to be really suitable for many manufacturing situations even though it is still very widely used (Bullinger, 1986).

3.3. Variant CAPP Approach

The variant approach is a computer assisted extension of manual process planning. In this approach using a coding and classification system (often based on Group Technology) parts are analysed and grouped into part families according to the similarity of their design and manufacturing attributes. For each part family, standard process plans are developed and stored in the computer system. The process planning task for a new part starts with coding the part. Then, based on the part code, the part family is searched and accordingly a standard process plan is retrieved. Since this standard plan may not be exactly what is required for the part at hand, editing is provided. If no similar plan can be found, then the planner must create a new plan.

The advantage of this approach over the manual methods mainly consists of reducing the clerical work content and simplifying the planning task (therefore increasing planning efficiency) and improving the accuracy and consistency of planning. With regard to the need for an experienced planner, although the approach reduces the dependency on the planner, it still relies on him in planning for new product families or when there are some major modifications. Variant CAPP systems, in general, are suitable in situations where the majority of parts can be classified and grouped into clearly identifiable families.

The two typical examples of this approach are: (i) the CAPP system developed under the sponsorship of CAM-I (Computer Aided Manufacturing - International) described in Link (1976) and (ii) MIPLAN developed by OIR (The Organisation for Industrial Research, Inc.) as described in Houtzeel (1976). Many other systems of this type have been developed; a summary of these can be found in Chang (1985).

3.3.1 Requirements of Variant CAPP systems

A variant CAPP system generally consists of five elements namely:

1. Coding and classification.
2. Database creation and maintenance.
3. Logic processor.

4. Production of documentation.
5. File maintenance

Coding and Classification

Coding and classification (mainly group-technology based), provides data administrative capabilities that address the problem of data retrieval in a variant CAPP system. Coding and classification systems may be:

1. Based on parts design attributes.
2. Based on parts manufacturing attributes.
3. Based on both design and manufacturing attributes.

However, systems in the Categories 2 and 3 are more useful for CAPP applications.

There are three basic code structures used in these systems. These are:

1. Hierarchical structure (monocode, or tree structure).
2. Chain-type structure (polycode).
3. Hybrid structure (a combination of 1 and 2).

Further details of coding and classification methods can be found in Gallagher and Knight (1973) and Groover & Zimmerman (1984).

Database Creation and Maintenance

The design of the database, its creation and maintenance depends upon the needs of the specific manufacturing company. However, typical contents of a system database might be:

- Part family matrix,
- Standard machine sequence file,
- Standard operations sequence file,
- Work elements standard times file,
- Standard costs file,
- Operation parameters file,
- Facility capability file,
- Documentation text file.

Logic Processor

The logic processor is the heart of a CAPP system. By using a coding method, it examines all the relevant attributes of the parts which are being analysed and determines matching part families in a consistent manner.

Production of Documentation

Typical documents normally required to be produced by a CAPP system are:

1. Method sheets - manufacturing instructions at operations level, including details of speeds, feeds, tooling etc.
2. Routing sheet - details of the job, process sequences, time values.
3. Tool kitting sheets.

File Maintenance

File maintenance covers the storage and control of records and the ability to retrieve and edit data as required. Normally there is also a need to store the output documentation. It is important that the database management system is well organised, so that no duplication or obsolete records are kept.

3.4. Generative CAPP Approach

In the generative CAPP (also called automated process planning) approach, as described by Steudel (1984), process plans are generated by means of decision logic, formulae, technology algorithms and geometry based data, where the many processing decisions for converting a part from rough to a finished state are uniquely determined. In this approach, the rules of manufacturing and the equipment capability information are stored in the computing system.

The essential requirements in generating process plans are stated by Chang (1985) to be:

1. Part description.
2. Process and manufacturing capability information.
3. Manufacturing decision logic.

These must be in a format which is compatible and accessible to the computing system.

Compared with the two previous approaches, this approach provides a much better capability for the automation of process planning, reduction of the dependency on the planner and the production of optimal plans. Major difficulties in the implementation of a generative CAPP system are related to difficulties in trying to identify, understand, extract and collect the process planning logic, and to the lack of a unique and systematic method to perform process planning.

In recent years much successful research has been reported in the area of developing generative type process planning systems. With the progress in the application of AI to the manufacturing decision making area, many more effective applications of generative CAPP systems are expected.

3.4.1. Part Description

This requires that part data to be available to the system in a compatible format. Among the various methods used for part description, the two most powerful techniques are: *detailed GT based coding*, and *geometric modelling* .

With regard to the flat rolled products which are considered in this project, part description is not a difficult task. Here, part information such as dimensions, tolerances, and properties together with other specifications for each order can be easily stored in a database file.

3.4.2. Process and Manufacturing Capability Information

This requires the establishment of database files containing the process capabilities available in the manufacturing system. These capabilities vary as between different types of facilities. They are also affected by the tools, and the operators' skill. The basic capabilities would usually include :

- Shape of the part which can be produced,
- The dimensional limitations,
- The dimensional and geometric tolerance limits,
- Surface finish attainable,
- Time and cost factors.

3.4.3. Manufacturing Decision Logic

This requires the "process decision model" that contains the manufacturing rules to be defined and maintained in the system. The major function of decision logic is to match the process capabilities with the required part specifications in order to determine the required processes and the sequence to produce a part. Brief descriptions of the main methods used for decision making in CAPP systems are given below, together with a few examples of their applications in CAPP systems. These and other applications are described more fully in the surveys given by Chang (1985) and Alting and Zhang (1989).

A *decision tree* is composed of a *root, nodes* and *branches*. The root is the source of the tree. Each branch communicates a value which is either true or false. APASS (Wysk, 1977-a) and DCALSS (Schaffer, 1981) are among the systems which use the decision tree method.

A *decision table* is a structure for a set of related rules which are in turn defined as statements. These statements describe the set of conditions to be satisfied in order to execute a series of actions (see Milner, 1977). AUTAP (Eversheim, 1980), and

CADCAM(Chang, 1985) are two of the generative CAPP systems which use the decision table approach.

The use of *artificial intelligence* and *expert systems* improves the emulation of human decision making. Many recent researches in CAPP have considered the application of these techniques. GARI developed by Descotte and Latombe (1981) is one of the first developments of this type.

Due to the importance of the AI based approach to process planning and because of our application of some of its techniques in the proposed CAPP system , this approach will be considered in more detail in the following section.

3.5 Artificial Intelligence Oriented Techniques

Artificial intelligence (AI) is concerned with making computers perform tasks that would require intelligence if the tasks were performed by human beings. *Problem solving and searching for solution* and *expert systems* are two of the specialised areas in AI.

As part of this research for process planning in the rolling mill industry,an investigation has been made into the above areas with the intention of evaluating their application to the problem under consideration. As a result, some of the fundamental techniques of AI and expert systems such as state-space problem representation, forward and backward reasoning and the depth-first search method have been used in developing a prototype CAPP system. In addition a rule-based approach has been selected. This provides the proposed system with the capability of utilising the manufacturing rules for the planning of the processes. The Prolog language, which greatly facilitates the programming of AI oriented problem solutions and the use of rules for decision making, has been used for the development of the programs.

In the following sections a brief review of some relevant areas is provided. The particular application of the techniques to this process planning problem will be detailed later in the chapters devoted to the description of the methodology which has been developed.

3.6. Problem Solving and Searching for Solutions

There are basically two types of problems. The first can be solved by using some type of deterministic procedure: this is called a *computation*. The second type includes problems that do not lend themselves to computational solutions: AI oriented procedures can be applied to this type of problem.

Problem solving systems mainly consist of three components (Barr, 1981):

(i) a database, which describes the task-domain situation and the goal;
(ii) a set of operators that are used to manipulate the database and perform the transformation task;
(iii) a control strategy which determines the actions to be taken, in particular the application of the operators.

There are two types of reasoning approaches commonly used for this problem: forward reasoning, and backward reasoning.

Forward reasoning (also called *forward chaining*), searches for the goal through the application of an appropriate set of operators to an initial domain situation in such a way that each application of an operator modifies the situation in some way. Alternatively, *backward reasoning* (which is also called *backward chaining*) starts with the application of a set of appropriate inverse-operators to the goal situation, and hence produces subgoals. The operators are then applied to these subgoals in order to produce new subgoals. This process is repeated until the current task domain is reached. Much human problem-solving behaviour is observed to involve backward reasoning.

Problem representation is a major task in problem solving. Among the many available methods, one which is commonly used is *state-space analysis*. This is discussed below.

3.6.1. State-Space Representation

This is a popular and efficient approach for problem representation. The state space of a problem is all the states that can be searched from a given initial state to the goal state through a series of transformations.

States of a problem can be represented by various means such as symbol strings, vectors, graph (tree), lists, etc. Graph or tree structure is a useful method. In this method the nodes represent the states and the operators are represented by the arcs (Fig 3.1). Each arc may be labelled with the associated cost, therefore the method can be used for finding the minimum cost path.

When a problem is properly represented, it can usually be reduced to searching for a solution. There are many possible search techniques but for our problem the most appropriate type is based on *systematic node examination.*

Search techniques can be used in both forward and backward reasoning approaches. For the backward reasoning approach the search starts from the goal situation and uses inverse operators. However, any selection of a search technique should be in accordance with the nature of the problem and the way it is represented. The searching by systematic node examination which is used in this work is described below.

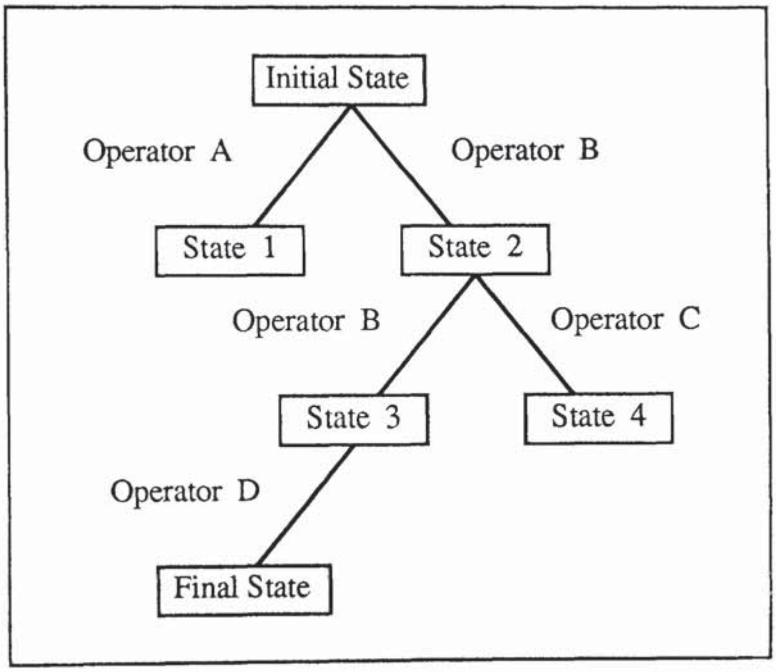


Figure 3.1 A state - space graph

Searching by Systematic Node Examination

In this method the state space of the problem is examined in some predetermined sequence until the goal state is found. This method can be subdivided into: *depth-first search* and *breadth-first search* methods.

Using either of these two techniques, the total number of the nodes examined before finding the goal is usually very large. One way to reduce this search space (and thus increase the search efficiency) is to add heuristics to the search technique. In this context, 'heuristics' means information about the properties of the specific problem domain, or some rules that qualify the selection of the nodes to be examined.

Depth-First Search (Vertical Search)

In this method each possible path to the goal is explored to its conclusion before another path is tried. For example, the problem represented by the tree given in Fig.3.2. This method of search starts with node S. The graph is then traversed, trying the nodes in the order SACDBEHG until the goal node G is found. If the node *n* that is being checked does not satisfy the goal condition, and if *n* has a child node, the child node is examined next. If n has no child node, the search returns to the parent node of *n*, say *m*. Then the next child node for *m* is checked in the same way. This procedure is continued until either the goal is found or all the nodes have been examined.

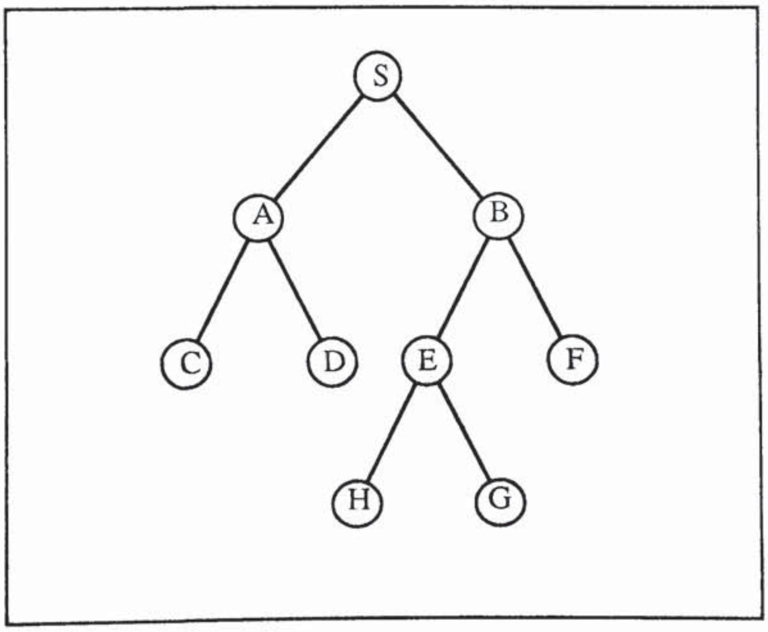


Fig. 3.2. A tree representation - Example for search techniques

Breadth-First-Search (Horizontal Search)

This method is preferred for problems in which there is less possibility of finding the goal in the deeper nodes. Here each node on the same level is checked before the search proceeds to the next deeper level. Applying this method to the tree given in Fig. 3.2. the search order is SABCDEFHG.

3.7. Expert Systems

An expert system is a computer program that exhibits a degree of intelligence similar to that of a human expert in some field, usually a field that is narrowly defined. From the earliest days of work on expert systems it was recognised that there would be important applications in manufacturing. Recent accounts of such applications are considered in Alting and Zhang (1989).

There are three major components in an expert system (Harmon and King, 1985):

1. A General Database (also called Working Memory)
2. A Knowledge Base (KB)
3. An Inference Engine (INE)

Other elements usually included in an expert system are: User Interface, Knowledge Acquisition, and Explanation and Reasoning modules.

The major difference between an expert system and a conventional program is in the implementation of the problem solving logic. For the conventional approach, the solution logic and the control logic are implemented in the program. Therefore, for a new problem or a change this approach requires a considerable amount of changes in the program. In the expert system approach, the problem solving logic is stored in the knowledge base in the form of decision rules. The knowledge base can be modified independently without affecting the entire program.

Another difference is in the type of problem for which each approach can be applied effectively. Conventional programming techniques are most usefully applied to problems of a repetitive or algorithmic nature. The knowledge for solving this type of problem is firm, fixed and formalised. However, when either the knowledge for solving a problem is subjective and judgemental, or the precise steps for solving problems are not known in advance, the expert system approach is preferable.

With regard to the application of the expert system approach in process planning, a number of successful attempts have been described in the literature. Some examples are: EXCAP (Davies et al, 1986-a), XPLANE (Erve & Kals, 1986) and XPS-E (Latomb & Dunn,1984). However, the majority of the expert-system based process planning systems are still in the experimental stage and not yet fully used in practice. There are a number of difficulties in developing expert system process planning systems. Knowledge acquisition is usually a difficult and time-consuming task and according to Waterman (1986, Chapter 16), the development of practical systems, generally requires a long term involvement of both manufacturing and computing expertise. One other problem with many existing expert systems appeared to be their relying on the "dialogue session with the user" for the acquisition of part of the information. Such a dialogue can be boring, time consuming and even error prone. However, there is evidence that this problem is being overcome in the recent developments by using some kind of internal sources for this information (e.g. Joseph et al, 1988).

3.7.1. The General Database (Working Memory)

This contains information thought appropriate for the particular task. Part of the data are permanent, while the other part may relate only to the solution of the current problem.

3.7.2. The Knowledge Base

This is a central part of an expert system. It contains experts' knowledge describing relations of phenomena, methods, and information for solving problems in the systems area of expertise. The knowledge base can be thought of as consisting of factual knowledge and inferential knowledge.

The first important step in constructing a knowledge base is developing a method to represent the experts' knowledge. Among the many methods of knowledge representation, the production rules method is probably most popular. This method is also effective for the representation of the manufacturing knowledge (for other methods see Barr, 1981).

Using this method the knowledge is represented by an ordered set of rules. A rule can be considered to consist of a *condition* and an *action* : e.g.

IF C THEN A

This means "if the conditions C are true then perform the action A".

The system operates by matching the conditions of the rules against the database and carrying out the actions of one of the rules that successfully matches the database. Conditions are statements about the contents of a global database, and the actions are procedures which may modify the contents of that database. When the conditions of a production rule are true, that rule can "fire", which means that the actions associated with the true conditions are executed.

3.7.3. The Inference Engine

The inference engine (also called the knowledge or rule interpreter) consists of operating rules and principles. The inference engine makes use of the knowledge base system in such a way that reasonably consistent conclusions can be drawn. The inference engine runs the expert system by determining which rules are to be invoked and accessing the appropriate rule in the knowledge base. The inference engine follows these rules and determines when an acceptable solution has been found. Then it may pass the results to the user interface.

3.8. Benefits as a Result of CAPP System Applications

Benefits to be expected from each type of CAPP system approach were discussed in the previous sections. These, in general, can be summarised as:

1. Less dependency on the planner.
2. Increased productivity of process planner.
3. Process rationalisation.
4. Improved legibility of plans.

5. Incorporation of other application programs.

More details about these and other benefits of CAPP systems can be found in Schaffer (1981).

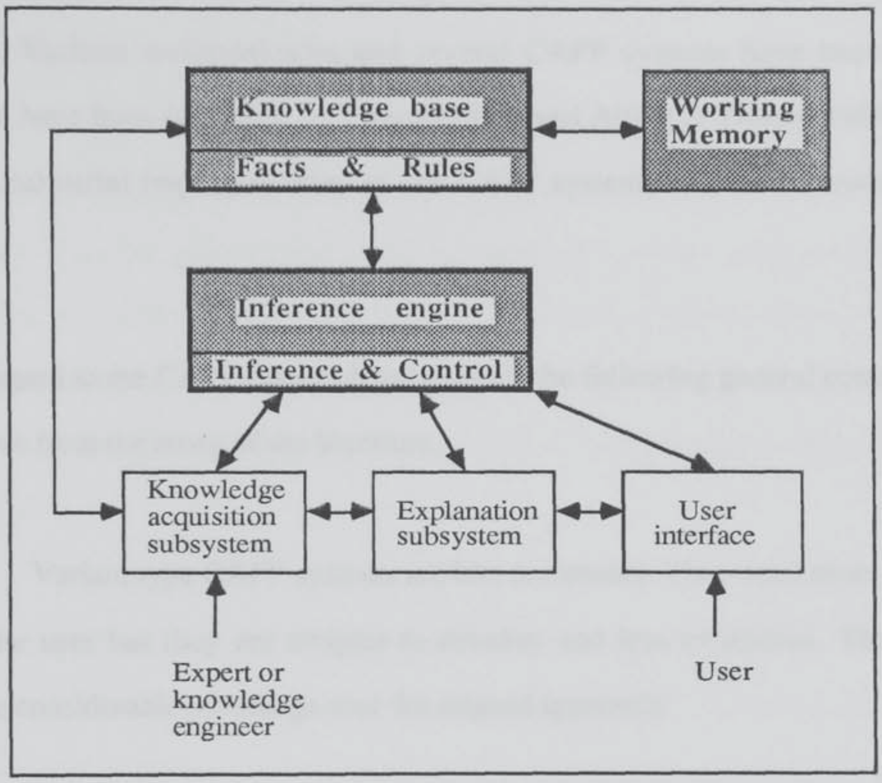


Fig. 3.3. The structure of expert system

3.9. Concluding Summary

Process planning is recognised as a complex function having great influence on the criteria of cost, quality and lead time in production systems. Manual and computerised approaches to process planning were discussed in the previous sections. The manual approach was found to be inefficient, with a number of inherent problems: being highly dependent on an experienced planner, being time consuming and less capable of producing accurate and optimal plans. Despite these problems, a great number of industries still rely on this approach.

Computerised approaches on the other hand have shown that they are potentially capable of reducing the above problems. Developments of CAPP systems since their origin in 1970s has received increasing attention from both academic and industrial sectors. Various methodologies and several CAPP systems have been developed. Surveys have been published by Chang (1985) and Alting & Zhang (1989). A survey on the industrial implementation of the CAPP systems is also discussed by Sutton (1989).

With regard to the CAPP system developments the following general conclusions may be drawn from the study of the literature.

1. Variant type CAPP systems are less automated. They need more intervention from the user but they are simpler to develop and less expensive. These systems, provide considerable advantage over the manual approach.

The generative approach represents more automation of process planning and provides the potential capability to produce results which are more accurate, consistent, and up-to-date. In addition, the productivity of the generative type systems is higher and they rely less on the planners. These systems are more difficult to develop than the variant type. The generative systems constitute only a small portion of total CAPP systems presently in use in manufacturing industry.

2. Most CAPP systems have limited capabilities in terms of type of manufacturing processes, machining operations, and products. Therefore, because process planning is a function which varies according to the manufacturing system concerned, much research work is needed before this concept can be applied to a

reasonable range of manufacturing industries.

3. Regarding the range of planning activities covered by the CAPP systems, the early developments were mainly designed to deal only with process selection and sequencing, or in some cases to provide time and cost estimates. Then, gradually, the range of activities covered expanded by including the selection and sequencing of tools, fixtures, and details of the operations. In addition, some systems include cost optimisation capabilities.

4. The application of AI techniques, in particular expert systems to generative CAPP systems has offered new areas of research with the goals of improving the capability and quality of these systems. This will also enhance the process description and the decision mechanism. Davies et al. (1986-b), Mill and Spraggett (1984) and Tonshoff et al (1987) provide more evidence of AI being useful in automating process planning.

5. Integration of CAPP systems with other systems in manufacturing has been considered as one important issue in the context of CAPP research in recent years. In the past much effort was concentrated on applying computers in individual manufacturing areas such as CAD, CAM, CAPM, etc. Certainly each function benefits from computer application. However, the total benefit to the manufacturing enterprise will be increased if appropriate links could be developed between various functions. CAPP has been recognised as a most appropriate linking element in this respect. This has been discussed in many publications, including Wolfe (1985), Nordland (1985) and Alting and Zhang (1989).

The present state of the integration of CAPP with other functions is very much limited, in terms of the functions included and the types of manufacturing. However, these highlight the potential and the important role of the CAPP in this respect.

6. After carrying out a survey of the literature of the CAPP developments, it was concluded that there was no particular development for tackling the specific process planning problem with which we were faced in the rolling mill industry. The requirements for process planning in this industry are described in the next chapter.

CHAPTER 4

PROCESS PLANNING FOR FLAT-ROLLED COPPER-ALLOY PRODUCTS -- PROBLEM ANALYSIS

4.1. Introduction

Having studied the range of the copper-alloy flat-rolled products, the processes employed in their manufacture, and the theoretical aspects of process planning as discussed in the two previous chapters, we must now consider a number of practical problems which must be fully understood before a workable process planning methodology can be developed. To find out what these problems were, we proceeded in three stages as outlined below.

Initially, a number of flat-rolling companies were visited, their process planning practices were observed, and the planning personnel were interviewed on the particular advantages and difficulties of their existing (mainly manual) planning methods. This first stage of the study showed that the industry, in general, suffers from a number of major problems which are directly associated with the process planning function; in particular, low material yield and high production cost. Therefore, further study of this process planning problem proved justified.

As the second step, through two case studies, the problem of process planning was studied in more detail in two of the copper-alloy flat rolling companies. These two companies which for the purpose of confidentiality will be referred as "Company A", and "Company B" are both among the leading manufacturing companies in their range of products in the UK. Details of this stage of the practical study together with the analysis of the problem are discussed in Sections 4.5 and 4.6 below.

As the third step, more specific and detailed study of the process planning problem was carried out in Company B. Part of this study is discussed in Section 4.6 of this chapter and further details are given in Chapter 5.

In the present chapter, the grouping of manufacturing processes, some appropriate layout arrangements, the two problems of material yield and production cost and the selection of a suitable process planning approach is discussed. The chapter also highlights the scope of the project and the objectives of the research.

4.2 Process Classifications and Layout Arrangements

Generally speaking, in the manufacture of flat-rolled copper-alloy three distinct classes of primary processes can be identified. These are: (i) melting and casting, (ii) hot rolling, and (iii) cold rolling. Secondary processes such as heating, annealing, cleaning, welding, flattening, and different kinds of trimming and cutting are also used in conjunction with the primary processes. Classifying the processes in this way leads naturally to considering the production system organised into corresponding departments, namely:

(1) foundry and casting,
(2) hot rolling,
(3) cold rolling.

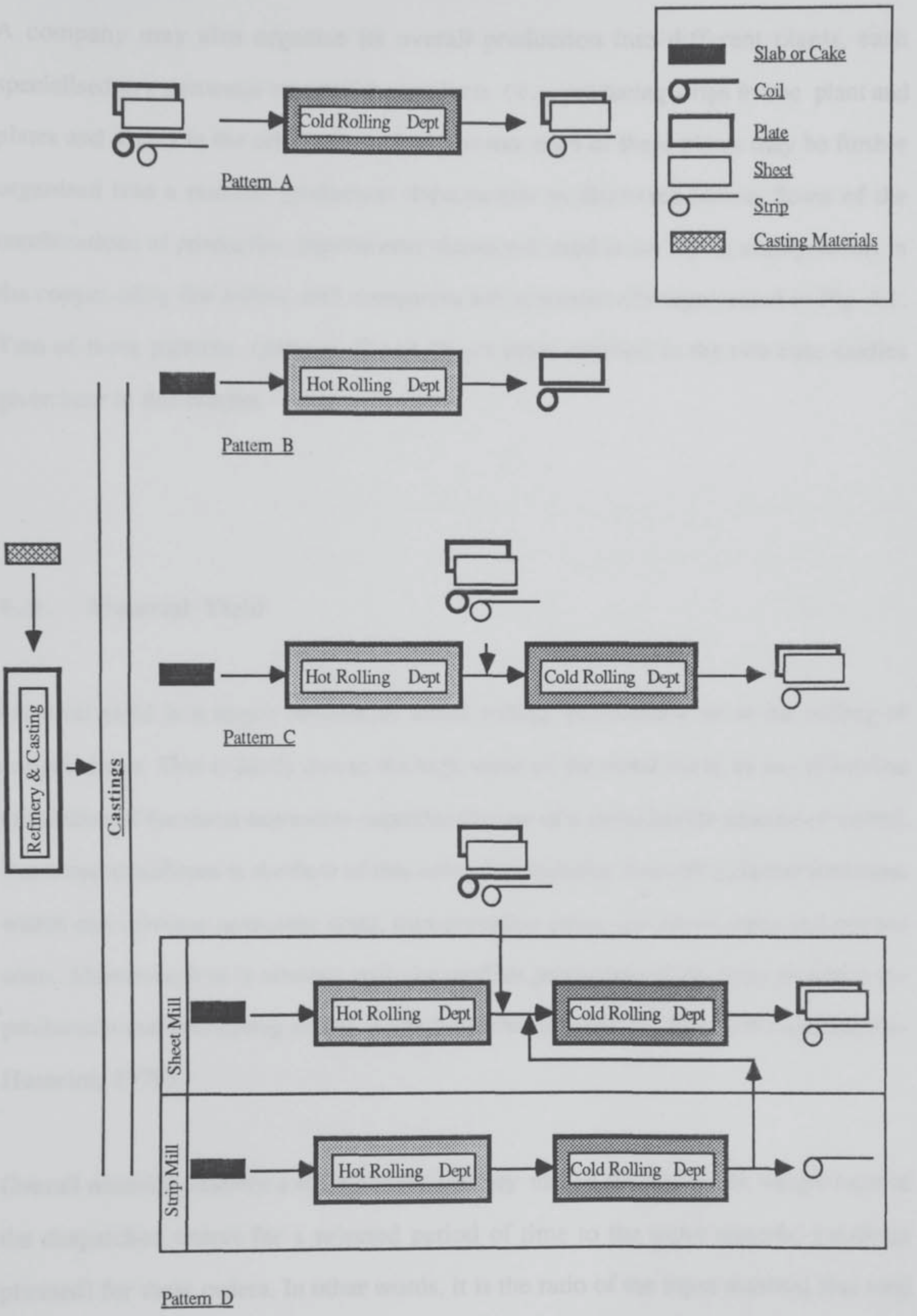


Fig. 4.1. Some of the most commonly used patterns for combining the production departments in layout arrangements in the copper-alloy flat rolling industry

A company may also organise its overall production into different plants, each specialised in a particular range of the products (e.g. producing strips in one plant and plates and sheets in the other). In such a case too, each of these plants may be further organised into a number production departments as discussed above. Some of the combinations of production departments commonly used in the layout arrangements in the copper-alloy flat rolling mill companies are schematically represented in Fig. 4.1. Two of these patterns, (patterns C and D) are more detailed in the two case studies given later in this chapter.

4.3. Material Yield

Material yield is a major concern in metal rolling, particularly so in the rolling of copper alloys. This is partly due to the high value of the metal itself, as any redundant circulation of the metal represents unproductive use of a considerable amount of capital. But more significant is the flow of this redundant material through different processes which can increase operation costs, transportation costs, inventory costs and control costs. Moreover, it is in contrast with the modern production philosophy in which the production and processing of any waste has to be avoided (Suzaki, 1987 and Moattar Husseini, 1979).

Overall material yield for a rolling mill company can be defined as the weight ratio of the despatched orders for a selected period of time to the input material (castings planned) for these orders. In other words, it is the ratio of the input material less total "material loss" to the input material itself, where we use the word "loss" to describe material which is processed but not despatched to satisfy customers' orders. Defined in this way, material loss mainly consists of the following:

(i) Scrap -- this includes any reject or trimmed part which cannot be used to satisfy an order.

(ii) Mill stock material -- these are processed or semi-processed materials which are surplus or down graded 'in process', but, could be used to satisfy future orders.

(iii) Excess products -- these are the products produced in excess of the order quantity. They are to be offered to the customer or kept in the stock for future orders.

Material losses can be categorised into two types. One is largely unavoidable loss due to the allowances allocated with regard to the technology and equipment employed. The other is considerably affected by the process planner's decision in determining raw material and process routes, and his calculation of excess material to compensate for uncertainty or inaccuracy within the plan.

Any improvement in the material yield factor (i.e. reduction in material losses) reduces the amount of the redundant material circulating in the system, and thus improves the overall production cost in two ways:

(i) through reduction in the amount of the capital locked up in the redundant circulating material and

(ii) through reduction in the amount of the material processed in the system, hence lower related costs.

Note that the second saving will normally be far greater in absolute terms.

A model such as the one given in Fig. 4.2-a can be used illustrate the overall flow of material in a rolling mill industry. We use a simplified form of this model, as shown in Fig. 4.2-b to study the effect of yield improvement of the amount of material in circulation.

In this model A represents the input stage (refinery and casting department) and B represents the finishing stage (at which finished products are despatched to customers).

Working on a weekly basis, we define:

Q = weekly tonnage output at B(sales);

W = total material required to pass through the production system to deliver output Q at B;

R = tonnage recycled.

Assuming a steady state, because the unproductive material can be remelted and recycled through the system, the weekly tonnage input at A is equal to the output at B. Therefore,

the yield is $Y = Q/W$

and tonnage recycled, $R = W - Q = Q(1/Y - 1)$.

Note that W differs from usual definition of work in progress by a factor corresponding to the lead time required for material to progress from A to B.

When yield is improved from Y1 to Y2, supposing Q remains constant, the saving in R as a percentage of output product tonnage (Q) is

$$U = 100(R1 - R2)/Q = 100((1/Y1 - 1) - (1/Y2 - 1))$$
$$= 100(1/Y1 - 1/Y2)$$

or if the calculation is based on the circulated material tonnage (W1) we have

$$V = 100(R1-R2)/W1 = 100(Q/W1)(1/Y1 - 1/Y2)$$
$$= 100(1 - Y1/Y2).$$

Thus, for instance, if yield is increased from 75% to 80% (a 5% increase), the actual yield improvement is 8.35 based on the product weight or 6.25 based on the weight of metal processed in the given period of time.

$U = 100(1/75 - 1/80) = 8.33$ % of the output product tonnage

$V = 100(1 - 0.75 / 0.80) = 6.25$ % of metal processed tonnage

However, the latter is a more suitable representation of the yield difference.

It is interesting to note that, the actual improvement in yield is not only determined by the amount of increase in the yield factor, but also by the initial yield itself. This is demonstrated through some examples given in Table 4.2.c. For instance, if the yield factor is increased from 20% to 25%, the actual saving in the material is 20% based on the V factor.

Questions of material yield are best considered in detail for each department. We shall return to the subject several times later in this chapter.

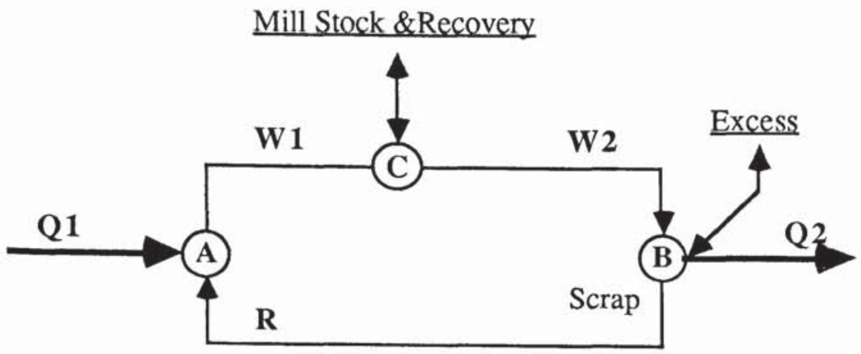


Fig. 4.2-a A model to represent the flow of material in a rolling mill

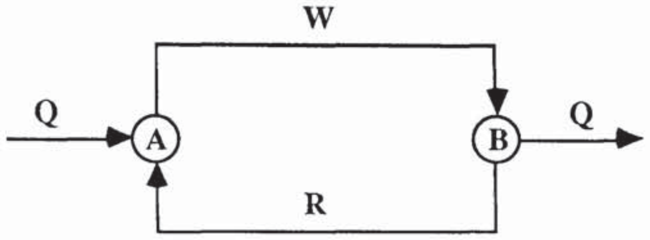


Fig. 4.2-b A simplified model to represent the flow of material in a rolling mill

Y1	Y2	U	V
.20	0.25	100.00	20.00
.40	0.45	27.78	11.12
.60	0.65	12.82	7.70
.75	0.80	8.33	6.25
.95	1.00	5.20	5.00

Table 4.1 Examples of yield improvements and corresponding values for 'U' and 'V'

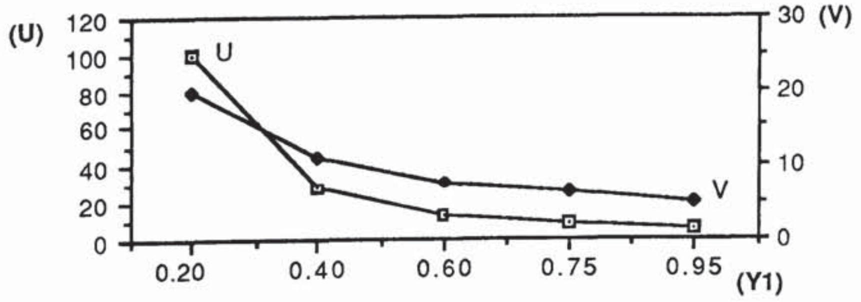


Fig. 4.2-c Values for U and V for 5% improvement in yield at different regions

4.4. Production Cost

Production cost, of course, is one of the most important factors which greatly affect the profitability of the company as a whole. This cost is the accumulation of several cost elements. Some of the major elements are: material cost, operation cost, transportation cost, inventory and work in progress (WIP) costs, and the overhead costs. These costs are greatly affected by the process planning function through which an appropriate chain of processes together with the utilisation of manufacturing resources (i.e. materials, machines, labour, etc.) are determined. As we shall see later, operation cost and material yield seem to be particularly important in the industry we are considering. Detailed discussion of the cost is given in Chapter 5.

4.5. Case Study at Company A

This case study has been carried out in a medium size company which manufactures different types of copper and copper-alloy products including flat rolled metals (plates, sheets, circles, etc.). As regards the flat rolled products, the company mainly specialises in relatively thick and large sizes. The thickness varies from 2mm up to 150 mm and the maximum width and length are 3500 mm and 6700 mm respectively. Within this range the products are tailored to the customers' requirements which usually involve few repeated orders, small quantities, and special metallurgical properties.

A considerable proportion of the orders are from abroad, including the U.S. and some European countries. There are a number of competitors, at least one in the UK. Quality and the cost are of prime importance to the company's business, while short delivery time and keeping to delivery deadlines are also important.

The sequence of processes used to manufacture the company's products can best be understood from a typical example of the process flow as given in Fig. 4.3. The company has organised its manufacture into three production departments, for which the overall layout and the flow of work between departments is depicted in Fig. 4.4.

The initial preparation of the raw material and scrap returned from production lines is carried out in the foundry and casting department. The required metal is cast in the form of cakes in standard sizes. The cakes are then cropped and colour coded before being passed into the hot rolling department.

In the hot rolling department, processes are designed to convert the cakes into plates which are either to the requirements of the customer or of the cold rolling department.

The first stage of production in this department is to machine the top and bottom of the castings and place them into the furnace to be heated. The cakes are then rolled into a size which can be trimmed and cut into blanks and, where possible, these blanks are made to standard sizes which are called the "uncut blanks". Major processes employed in this department are surface milling, heating, hot rolling, shearing, sawing, and flattening. Hot rolling is the main operation which is accomplished in several passes on a reversing mill. This mill has the capability to roll down cakes of up to 7 tons into plates of maximum width 3500 mm. Operation of the mill normally requires five operators. The main operator controls the mill while others perform tasks such as driving the conveyor, checking the dimensions, and cleaning the scales off the work.

Blanks produced for the requirement of the cold rolling department are then further processed in this department to produce customer order specifications. Major processes are: rolling, annealing, cleaning, shearing, blanking, and flattening.

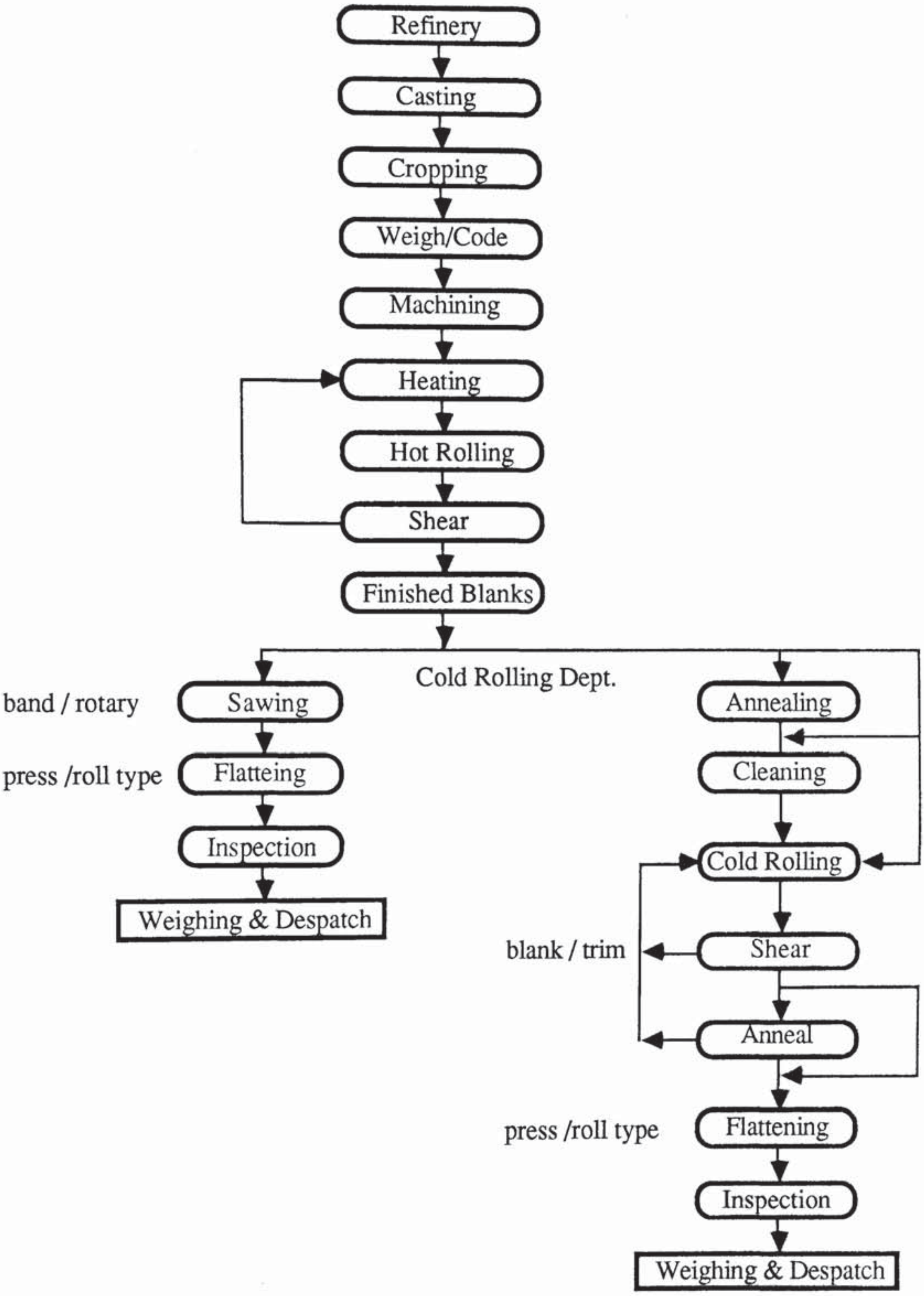


Fig. 4.3. An example of the process flow chart for Case Study A

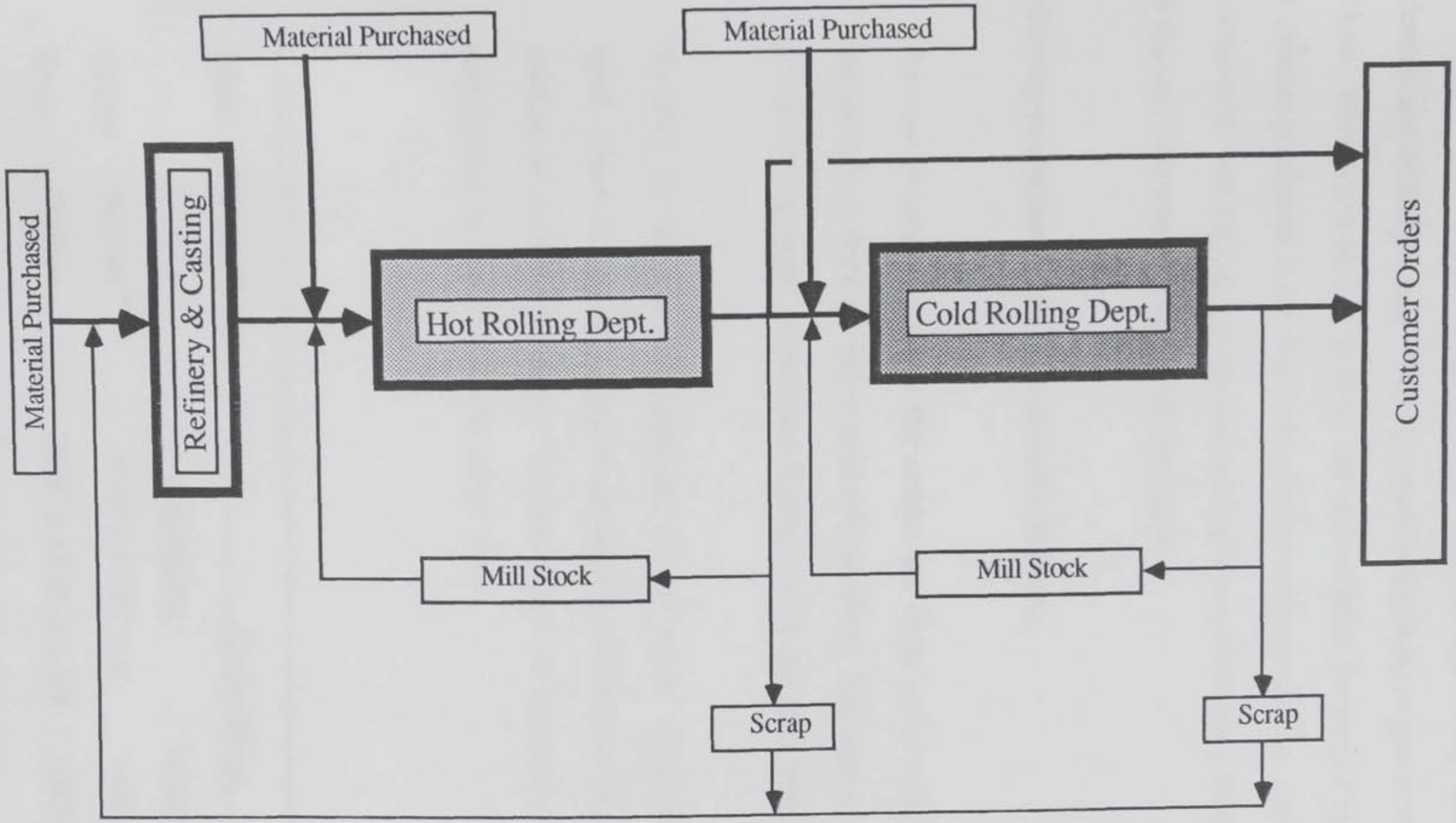


Fig. 4.4. Flow of material and work (for Case Study A)

4.5.1 Present Method of Process Planning

The present method of process planning is manual. This job is carried out by an experienced and skilled planner who has a good background of practical manufacturing know how. Planning is mainly done for the requirements for some standard plates (the uncut blanks) produced in the hot mill, and accordingly for the castings. For other operations in the hot rolling and the cold rolling departments the planning is, in effect, left to the shop foremen and the skilled operators.

The planning procedure can be summarised as follows:

1. Process planner classifies the orders for each metal type of the hot-roll products (e.g. thick plates) or cold-roll products. The majority of the products are of the first type, i.e. products finished in the hot-roll department.

2. To plan for the hot-roll products, one or more uncut blanks are to be used. These blanks are of preset dimensions which can be produced by hot rolling of standard castings. Two examples of standard castings and the corresponding uncut blanks are given below.

Metal	Casting Code	Uncut Blank	
		dimensions	weight
Copper	90 Cwt *	6'-0" x 17'-0" x 2"	4300 kg (approx)
Brass	70 Cwt	5'-6" x 15'-0" x 1 3/4	2800 kg =

* A Cwt pronounced a "hundred weight" is an imperial weight measure which is equal to 112 lb.

The planning procedure seeks to use these blanks efficiently by filling each blank with as many orders as possible, subject to the allowances required for losses in rolling operations.

3. Planning the processes for the cold rolling department mainly consists of: (i) determination of a blank which can be rolled to produce a given requirement for plate or sheet, (ii) planning the appropriate secondary processes in conjuction with the rolling operations. The planner then seeks for a way to produce these blanks by hot rolling new material or by using existing mill stock.

4. The requirements for the cakes are based on the uncut blanks planned for orders for the period concerned, subject to the allowances for losses in the operations subsequent to the hot rolling process. The calculated cake requirements are then included in the weekly casting programme.

5. In some cases where the customer's order is small, it may be possible to use stock material (mill stock) left over from a previous job and, therefore, such orders are not included in the calculation for castings.

The cakes received into the hot rolling department each have associated with them one or more works orders for finished products. Each works order includes the job cards for each product; these mainly detail finished product specifications for this stage.

The blanks received in the cold rolling department are accompanied by the works order and job card for each product; these mainly provide the finished product specifications. Blanks are then rolled at different stages, and the secondary operations are carried out as appropriate, until finished product requirements are achieved.

4.5.2. Specific Problems Associated with the Present Method of Process Planning

Besides general problems inherent in manual process planning, the present manual method has the following specific drawbacks:

1. Material yield is low and often unpredictable;
2. Production costs tend to be high;
3. The planning task is partly left to the shop foremen and skilled operators;
4. Inefficient communication between the process planning office and other sections such as the sales office and the production shops.

However, the management of the company emphasises the need to tackle the first two problems (low yield and high production cost).

The overall material yield, according to figures available during our study, falls well below 60%. It is even worse for some particular jobs. This indicates the redundant circulation of a large amount of material, hence capital, and the high cost of the unproductive work on these material performed at different stages of the production. The types of the material losses and their causes differ between departments.

<u>Material Yield - Refinery and Castings</u>

In the refinery and the casting shop the losses are mainly due to metallurgical and casting problems. Cropping and machining the castings produces another type of material loss. These losses are generally considered to be unavoidable, but, of course, to some extent they can be improved through the application of more advanced technology and better operation controls. Moreover, a carefully prepared process plan can also help to reduce these losses. In other words, a bad plan or a plan which is not comprehensive may produce extra losses as the result of inappropriate use of material, operation parameters, production capabilities, tools and standards.

Material Yield - Hot Rolling

In the hot rolling department, apart from the requirement for the machining of the top and bottom surfaces of the cake, other material losses are directly affected by process planning at this stage. As illustrated in Fig. 4.5, part of the loss is due to trimming of the edges of the uncut blank (Type a), and the other significant loss is due to the inefficient filling of the uncut blank, which results in parts of the blank not being utilised (Type b). Very often the unused parts are large enough to be stored in the mill stock for possible future use (Type c).

As stated in the previous section, for the planning for the hot rolling department, after making provision for blanks of various sizes, the planner then determines suitable patterns for cutting these so as to provide the blanks for the next stage. This, in fact , is a very complex task and becomes more complex when blanks of different thickness are to be planned. Therefore, the planner has to consider some additional rolling operations and the number of possible options can become extremely large. This is because a plate can be rolled in either of its length or width directions, or in a combination of both directions. The real problem in fact is much more complex, as there are a several alternative uncut blanks with different thickness to be selected. Moreover, this complexity increases if blanks of optimal dimensions are to be utilised instead of the present method of using standard range of the uncut blanks.This becomes a complex Cutting Stock Problem which can not be solved in the time available without a computer package based on an efficient optimisation algorithm. Solutions for this problem have been discussed by Wilson et al. (1988) and Gilmore and Gomory (1961

& 1964).

From the description of the complexity of the planning for uncut blanks, it becomes obvious that the plans produced manually (which is the present method) can not produce efficient utilisation of the material. Therefore, new methods are required to improve the corresponding material yield.

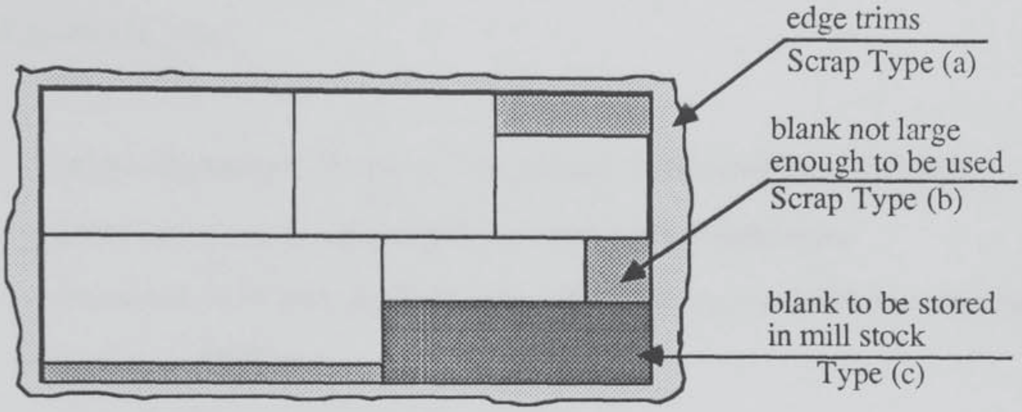


Fig. 4.5. Types of material loss in hot rolling department

Material Yield (Material loss) - Cold Rolling

Process planning for this department, as discussed earlier, consists of: selection of a suitable blank and determination of the cold rolling and the secondary processes to convert the blank into the required product. Any determination of the blank for this stage directly affects the material yield for the hot rolling department. That is, different sets of the blanks required can produce different levels of the efficiency in filling the uncut blanks. Material yield is also affected by the chain of the processes planned for the transformation of the blanks to the finished products. This is because different trim allowances are required by different processes.

4.6. Case Study at Company B

This case study was carried out in a large company with a high capacity for the production of copper-alloy strips, plates, sheets, circles and other flat shapes. The company is a leading manufacturer in its range of products in the UK. However, the competition is keen, particularly from abroad. The management considers the production cost as the most influential factor in such a competitive market. The range of the products for this company differs from the range used for the Case Study A in that it mainly includes:

i) strips (thickness 0.17 mm to 2.0 mm and width 10 mm to 1000 mm),

ii) plates and sheets of relatively thinner and smaller dimensions (thickness 0.40 mm to 10.00 mm, width 450 mm to 1500 mm, and length maximum 3500 mm);

iii) circles within the plate and sheet limitations;

iv) temper in the range of soft, 1/4 hard, 1/2 hard, 3/4 hard and hard;

v) the metal range is general purpose coppers and brasses of different copper content.

Within this range, products are made to a large variety of order specifications and in different quantities. Some of the orders are repetitive and predictable.

The sequence of the processes used in the manufacture of these products differs for different products. It also depends on the utilised material and the production departments included in the manufacture of the products. Figure 4.6 represents a typical process flow chart used for the production of plates and sheets in this company.

The overall production system is organised into two plants corresponding to the two categories of products: (i) strips, (ii)plates, sheet, circles, and other flat shapes. These two plants will be referred to as "The Strip Plant" and "The Sheet Plant" respectively. The flow of work for these plants are schematically represented in Fig. 4.7.

Strip Plant

The Strip Plant includes three production departments of foundry and casting, hot rolling, and the cold rolling. The foundry and casting department melts virgin metals, alloying elements, and scrap (returned either from the production system or from the customers) to cast slabs to the requirements of the plant or any external order. These slabs are mainly sent on for hot rolling. Products for this department are either plates (mainly of 10 mm gauge, 635 mm width and 15000 mm length) or strips of width 635 mm and in coiled form. Plates are sent to the Sheet Plant, but strips are further processed through the cold rolling group of operations to produce thiner gauges. One significant group of standard strips are those which are made to the requirements of the Sheet Plant. These are 635mm wide, in a number of gauges e.g. 3.0, 3.8, 4.3, 5.0, 6.4, 7.6 millimeters. Strips can also be produced to any gauge required.

Since strip products are in less variety and they are generally produced in large quantities, there is less difficulty in process planning for these products. Therefore, this plant is excluded from our detailed study of the process planning problem. However, the Sheet Plant, in which the process planning greatly affects the production cost and the material yield, has been studied in detail.

Sheet Plant

The Sheet Plant consists of two departments: the hot rolling and the cold rolling. The hot rolling department uses slabs (which are mainly purchased), or materials which have been milled previously. Production at this stage is for plates and coils which are required either by the cold rolling department or by the customers. The maximum width limit for the hot rolling mill is 1250 mm and the minimum gauge is limited to around 5.0 mm. The majority of the coils to be used in cold rolling are produced to the minimum gauge (5.0 mm) and to some preset standard width in the range 635 to 1025mm (e.g. 635, 650, 680, 720, etc.).

Production for the cold rolling department is planned for customer requirements for strips, plates, sheets and circles. Raw material for this department (called base material) is mainly the coils and plates produced within the plant, mill stock material (plate, sheet, strip, etc.), strips and plates produced in the Strip Plant. However, some material is also purchased from outside suppliers.

Strips are produced in bulk through a number of continuous rolling of a suitable coil material with annealing as required between rolling operations. When the finished gauge is obtained then the strip can be trimmed or slit to produce the required width.

Plates and sheets can be produced from coils, strips, or plates and sheets of appropriate dimensions and of identical materials. Production of plates and sheets from coils or strips can be considered in two stages. In the first stage a coil or a strip is rolled down to a planned gauge. In the second stage, the strip produced by the initial rolling is blanked into pieces (plates or sheets) which are then further processed until finished product specifications are reached. Circles are blanked from either strips or plates or sheets.

Plates and sheets constitute a considerable share of the whole production in a copper-alloy flat rolling mill industry. Moreover, process planning for this group of products is relatively more difficult than that for strips and, also, considerably affects the production cost and the material yield.

In the following sections some major causes of material loss are discussed and then the present method of process planning is described.

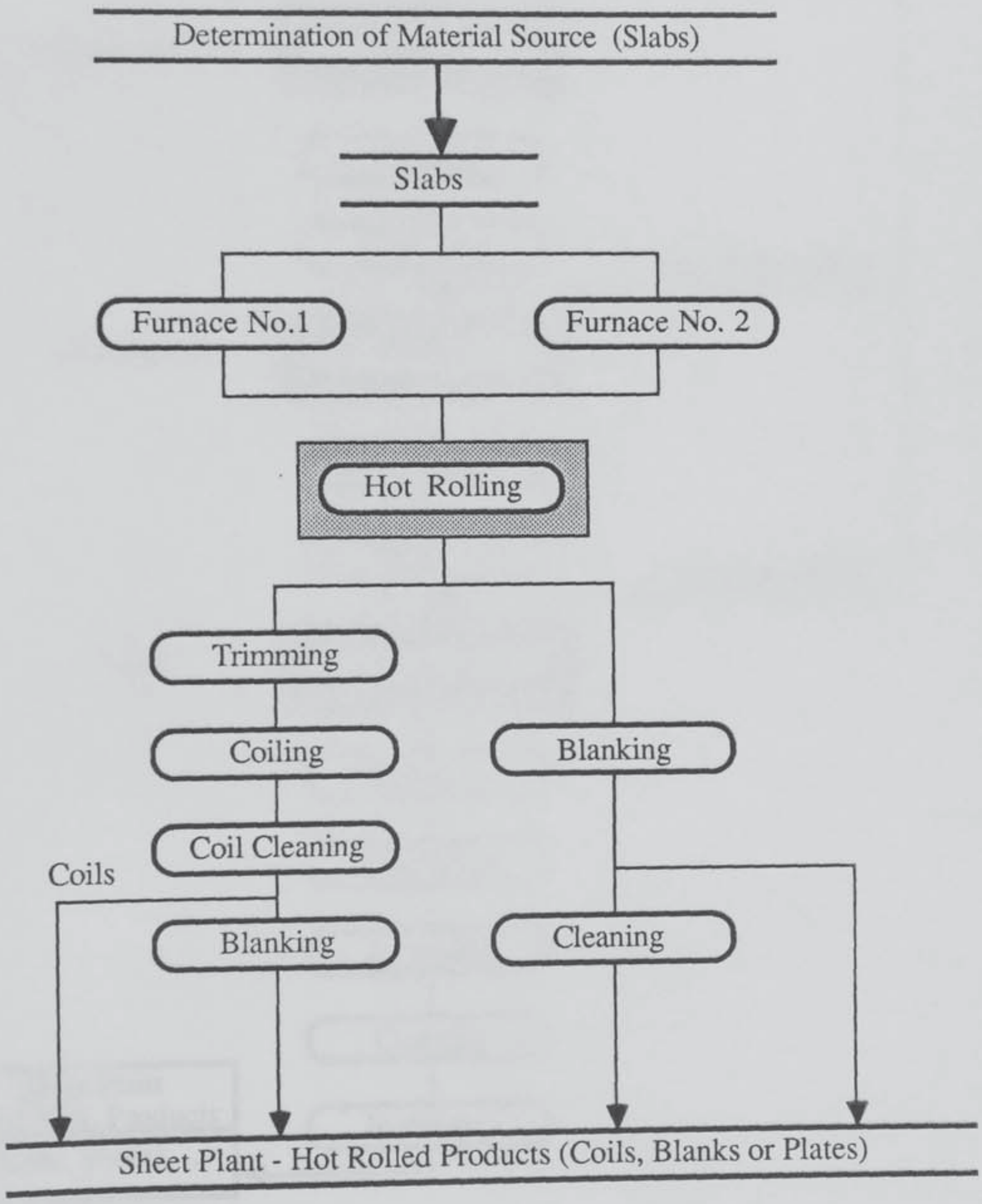


Fig. 4.6-a. A sample process chart for the production of hot rolled products in the Sheet Plant

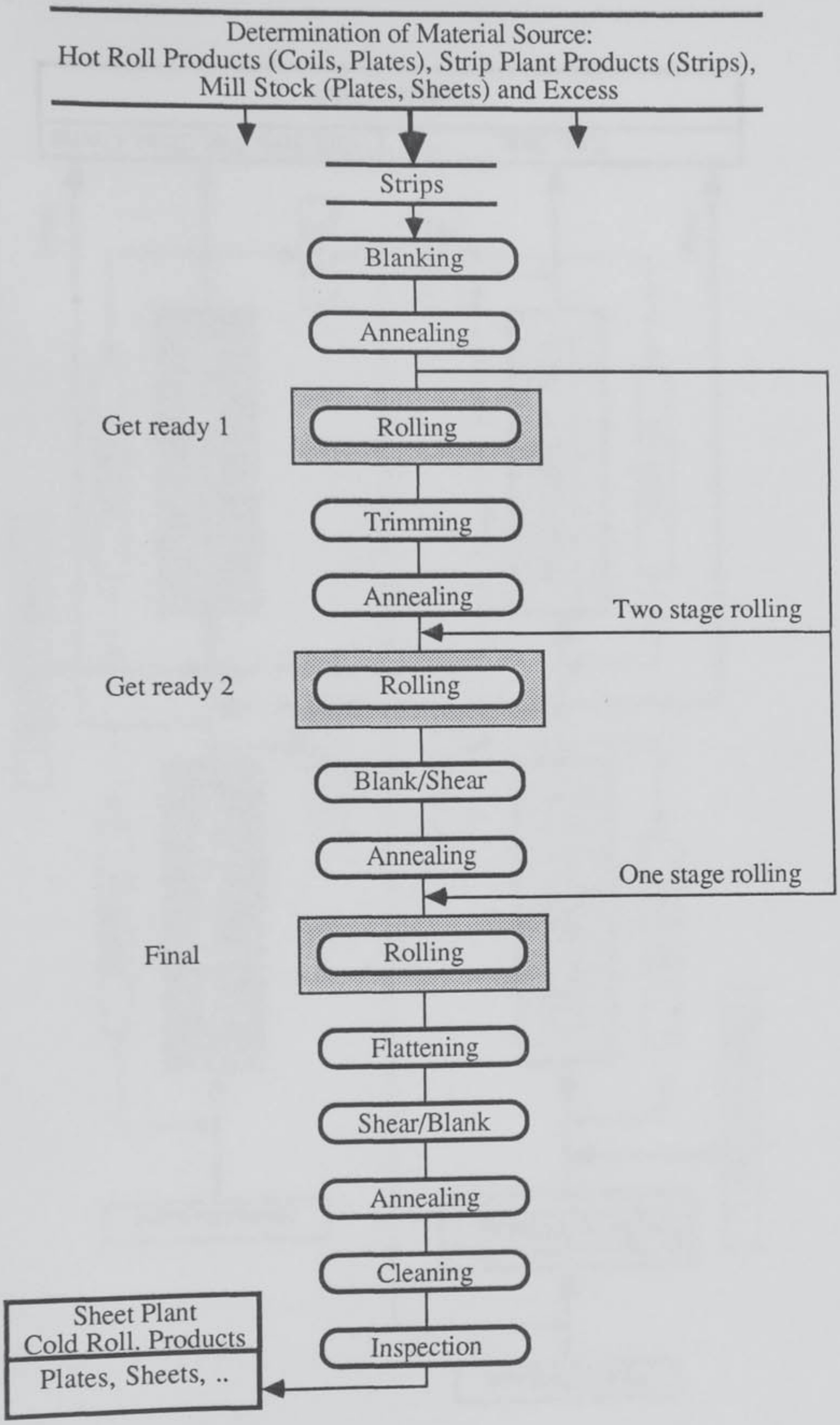


Fig. 4.6-b

A sample process chart for the production of plates and sheets

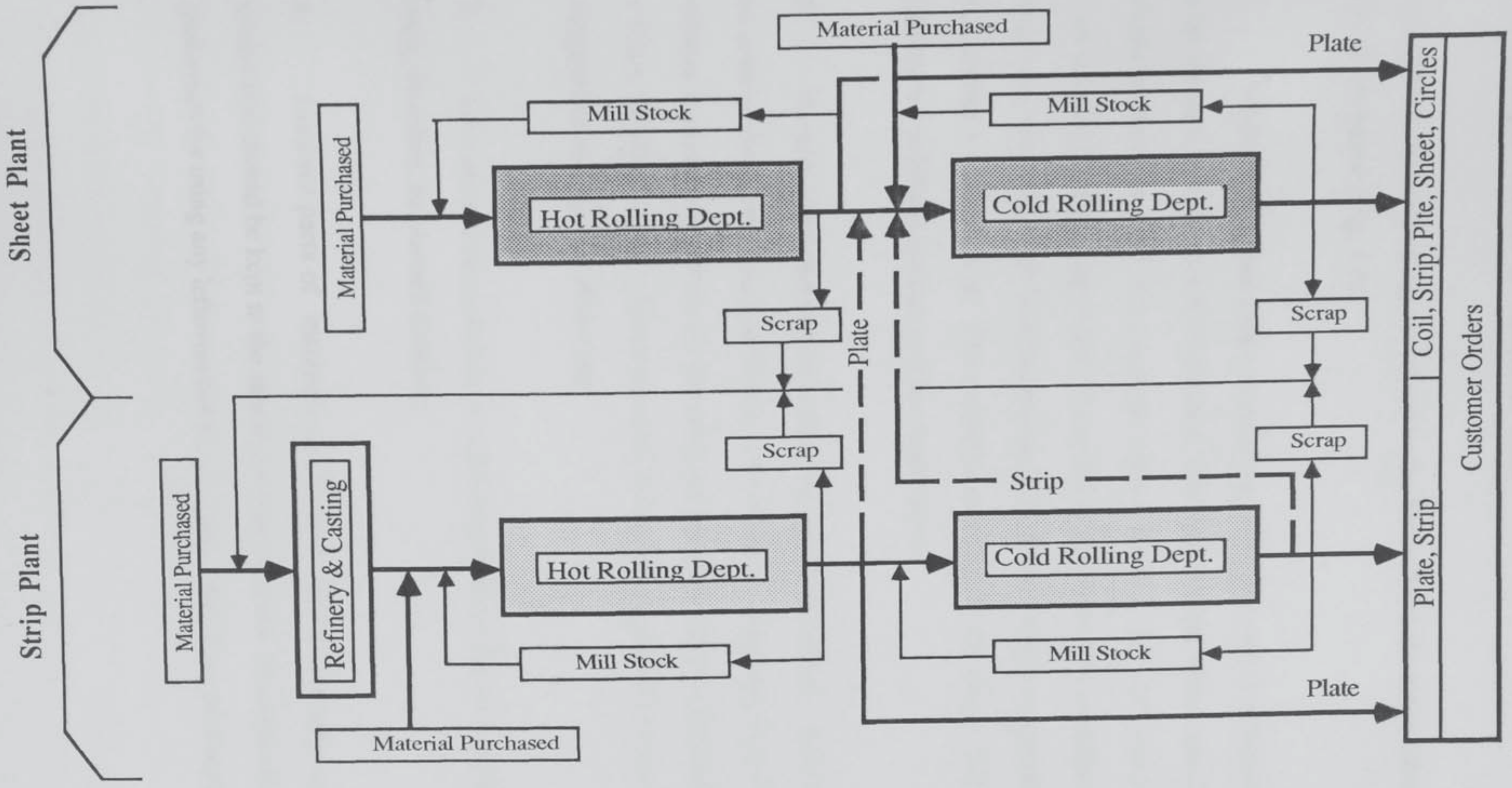


Fig. 4.7. Flow of material and work (for Case Study B)

4.6.1 Major Causes of Material Loss

In relation to the cold rolling operations in the Sheet Plant, the major causes of material loss are as below (Fig. 4.8).

1. When the standard range of strips (or coils) are used, the nearest larger gauge to the theoretical gauge has to be selected. This results in the allocation of extra material which reduces the yield. For instance, when a gauge of say, 5.6 mm is required, the nearest standard strip gauge is 6.4; this selection produces 14% material loss. The strip width may also be greater than the requirement, but the length of the blank to be cut is determined by the planner. The unusable end part of the strips and the coils also produce material loss but this is of less importance.

2. In much the same way as in the case considered above, when material has to be selected from the available blanks, very often the allocated material is greater in volume than the requirement for the particular product. Thus, when standard plates (10 x 635 x 15000 from Strip Plant) are used, the remaining part of the plate is either to be scrapped or stored for a future use.

3. Trim allowances constitute a major proportion of the total material loss. These must, therefore, be planned carefully.

4. Leftover parts of materials and mill stocks are normally unwanted. Their production should be kept to the minimum possible level. Meantime there should be a preference for using any leftovers before allocating other types of material.

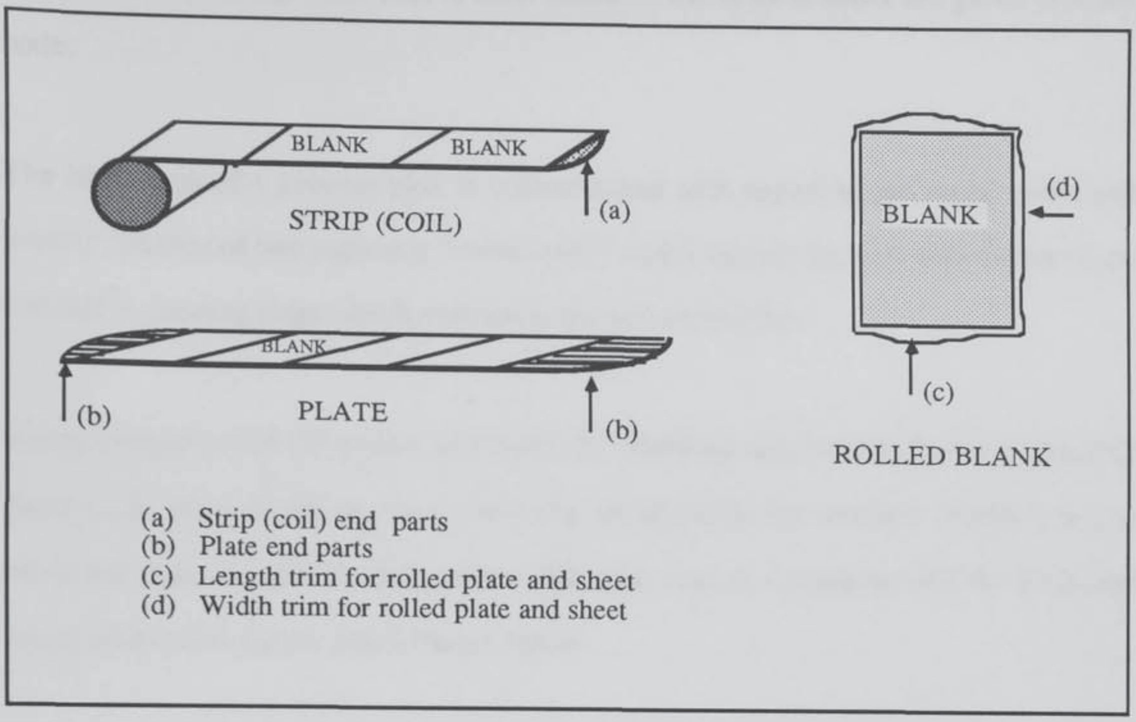


Fig. 4.8. Major types of scrap or material loss in relation to the Sheet Plant

4.6.2. The Present Method of Process Planning - General Discussion

The company uses a type of computer-aided retrieval process planning system, which works on the mainframe computer. The computing services are provided under contract by an affiliated company.

Process planning starts with a search for the plan for a product with a code identical to that specified on the customer's order. If a plan is available, it is retrieved, reviewed, and modified if required. Then order variable information (i.e. order number, order weight and piece count, due date and due week number, special order-dependent instructions, etc,) are added. Finally the plan is stored and hard copies of the plan are produced. If a plan is not found for the given product code, then the plan is made from scratch and manually. This plan is then stored in the system under the given product code.

The hard copy of a process plan is colour coded with regard to the metal codes and usually consists of two copies: a "metal copy" which eventually goes with the metal on site and a planning copy which remains in the planning office.

Using a retrieval CAPP system as a basis, the planning task is limited to two cases: (i) there is no plan stored in the system for an identical (or similar) product, ii) the retrieved plan requires modifications. The first case is considered for the Plate and Sheet production (in the Sheet Plant) below.

Process planning for the two production plants is accomplished independently, but each plant can be considered as either a customer or a supplier to the other one. Preset criteria are used to determine which plant is to be selected for the final production of any given product.

With regard to the planning for the Sheet Plant, certain special rules have been established for determining whether a particular product would be produced by hot rolling or by cold rolling.

Process planning for the hot rolling department mainly consists of the design of the roll passes and the determination of the rolling parameters in order to produce the required quality products most efficiently. Because the products are mainly in the standard range of coils or plates, some preset plans can be used in this department. Behaviour of the rolling mill is a very important factor to be considered. Therefore very often the detailed determination of the rolling pass and the parameters are left for the skilled mill foreman and the operators.

4.6.3. Process Planning for Plate and Sheet Production - Cold Rolling Department

Having completed the initial preparation of the order information, the calculations for weight, count, and tolerances, and the provisions for special instructions, the following procedures are used in the planning of processes.

1. Backward-search method. The, planner starts with the finished product state, then plans backward through processes, intending to evaluate several alternative routes which could lead to a suitable material state. However, the method is manual, therefore, is not always used systematically, or exhaustively. The planner very often follows short-cut procedures. For instance, his prejudgement of a route or source material may prevent him from trying other alternatives. Or, when a particular material seems to be suitable, he may use a forward planning method to evaluate the corresponding route.

2. Alternative choices at each decision-making point. Determination of each choice is based on the use of some predetermined rules and measures. These are detailed in the next chapter. However, the measures are mainly based on:

(i) geometrical calculations,
(ii) consideration of the material properties and hardness conditions and
(iii) manufacturing capabilities.

3. Geometrical calculations. These are based on the assumption that volume and width of material remains constant during cold rolling operations. That is, assuming G1, W1, L1, and G2,W2, L2 are the gauge, width, and length of the material for before and after the rolling operation respectively, and R is the reduction ratio, the following relations exist.

$$W2 = W1$$

$$R = (G1-G2)/G1$$

$$L2 = L1/(1-R)$$

4. Provisions for material allowances (e.g.trim allowances). For instance, width and length trim allowances are added mainly with regard to the material type, reduction ratio, rolling conditions, and the direction of the rolling. Length trim allowance is usually calculated as a percentage of the length of the rolled metal, for instance 8% is very often used when material is below 800 mm wide, and reduction is within the range of 50 to 80 %. For the width trim allowances, usually some fixed figures are used. These are based on the range of such parameters as material type, quality grade, length of the rolled part, and rolling conditions. Normally 20 to 30 mm is the allowance used for width trimming.

5. Hardness. This is controlled through both rolling and annealing operations. Certain rules are used for the selection of appropriate reduction ratios. These rules are mainly based on the work-hardening characteristics of the particular metal (a sample of the graph is given in Appendix A.1). For instance, when a half hard condition (60 to 90 Hv) is required and the metal is initially annealed, a 6 to 12% reduction ratio can be used for the production of this hardness. The annealing schedule is determined through consulting pre-established tables for each metal on various operation conditions. A sample of such table is given in Appendix A.2.

6. Alternative routes. Some of the major factors considered in the evaluation of alternative routes are:

(i) Material yield. This is determined by the processes included in the route (in particular the number of the rolling stages), rolling directions, reduction rates, planned allowances, and the degree of efficiency in using source material (e.g. strip or plate) for the group of products.

(ii) Production cost. This in fact is an overall factor which includes many of the other factors. It is mainly determined by the processes included in the route, the operation conditions, the cost of the material selected, and the yield. It is also affected by other costs such as those related to work in progress, mill stock, transportation and control.

(iii) Production capacity. It is important to avoid increasing load on the bottleneck operations or producing new bottlenecks. Selection of the material and processes affects the balance of the load in the system. Also, a low material yield, results in more unproductive load, hence, reduces the productive capacity of the system.

7. <u>Material sources</u>. The principal sources are standard materials such as coils, strips and plates and the millstock material which is the nonstandard type.

8. <u>Process and machine selection.</u> The rules for the selection of processes and machines are based on the capability information for the various processes and equipment.

4.6.4. Specific Problems associated with the Present Method of Process Planning - plate and Sheet Production

Particular problems associated with the present method of process planning are summarised below.

1. Process plans are initially produced manually. With a manual method, due to its inherent problems and the limitation in time, it is very difficult and almost impossible, to manipulate complex problems such as material yield and production cost, and at the same time to ensure that all feasible routes are evaluated. Therefore, these plans are not necessarily optimal.

2. The effectiveness of any process plan in terms of its approach to some sort of optimality is dependent on such elements as: the availability of materials, their preference of usage, the condition of the manufacturing facilities, the planning policies adopted, and the degree of similarity in any one batch of orders. These factors are of a dynamic nature, therefore, the majority of the plans stored in the system are not necessarily near-optimal at the time they are retrieved.

3. Ineffective and unworkable plans have to be either modified or replanned. This is supposed to be done in the planning office but in practice the plans are very often issued as they were retrieved; then the planner on the shopfloor has the responsibility to check the effectiveness of the plans with respect to the current parameters. A considerable number of these plans are then changed and replanned.

4. Material yield is not satisfactory. The yield figures for the cold rolling department for plates and sheets, are mostly in the range 65 to 80%, while the weighted average yield is below 75%. As it will be discussed in the next chapter, an attempt to increase the yield may also increase the cost of production (by increasing the rolling stages required), which is not desirable.

5. In a production system it is very often required to evaluate the effect of changes in the procedures or the parameters. This is normally known as "what if analysis". However the present method, will not allow such evaluation procedures for process planning. This is mainly because of the immense time and effort required for this

process, as usually a large number of existing plans have to be checked and replanned. Such a problem occurs when for instance, new trim allowance values are to be considered, or when there are some changes in the manufacturing capabilities.

6. In the present method no provision is included for batch order process planning. That is, as the plans are initially produced manually, the method does not have the capability to manipulate the problem of optimising a batch of orders, where an extremely large set of options has to be searched and evaluated.

7. Mill stock level and excess production are among the problems which require improvement.

8. Lack of effective communication with other planning and monitoring sections (e.g. production control) is also recognised.

9. Total time spent on initial planning and modifying and replanning the retrieved routes is very considerable.

10. Process plans are stored in the system for the individual products rather than the families or groups of the products, therefore the computer storage capacity required is very large.

11. The computer services cost for the existing planning system, which works on the mainframe, is very high (the annual cost is a four digit figure in Sterling).

4.7. Concluding Summary -- Setting the Objectives

Practical study of the problem outlined in the previous sections, together with the study of the literature as discussed in Chapter 3, has led to the following conclusions and the establishment of the objectives for this project. These are discussed below.

4.7.1. Division of the Overall Process Planning into Functional Modules

In general, the process planning function in a typical rolling mill company can be categorised under three production departments namely: foundry and casting, hot rolling and cold rolling.

For planning purposes, these departments can be considered independent from each other as the manufacturing processes and resources used in each department and their end products are different. However, a customer-supplier relationship exists between them as, for instance, the cold rolling department obtains its raw material requirements from the hot rolling department as well as outside suppliers. A similar relationship exists for the two other departments, i.e. hot rolling and foundry.

Such a consideration of independent process planning functions implies that the overall planning system can be designed to include three distinct modules each corresponding to one of the production departments. The overall system would also require a common supervisory system and a method of identification and sorting of customer orders against the internal departments.

In general, the process planning exercise in a cold rolling department mainly consists of planning for strips, plates, sheets and circles as specified by the customers. To produce such parts and features, appropriate materials have to be selected and an economically viable route be planned so as to transform materials into end products. This process also incorporates machine selection and determination of some related operation parameters. Generally, higher material yield is aimed at, but optimisation of the route cost is the prime objective of this planning. There are less problems with the process planning of the strips, as they are mainly produced in continuous form and in large quantities. With regard to plates and sheets, however, planning is more difficult, as their production involve more operations and they are generally produced in large varieties but very often in small lots. In addition, material yield and route cost for this case can be greatly affected by the process planning decision.

Process planning for the hot rolling department consists of selection of material and planning for the manufacture of coiled strips in different gauges and widths (those materials which are wider than 635 mm will be called *coils*, and *strips* refers to the rest), and thick plates with different ranges of dimensions. Material has to be selected from a limited range of available castings, and planning for manufacture mainly consists of roll pass design and determination of associated parameters. However, this can be considered as a detailed operation planning rather than a process planning function.

Casting requirements are mainly based on materials which are planned for the hot rolling operations for the period concerned, subject to the allowances for losses in the operations. Planning for this department is completely different in nature as compared with the other two departments. It consists of detailed consideration of the charge composition, operation parameters and the selection of casting types. This, in itself constitutes a completely different exercise which needs a comprehensive and detailed study before any decision can be made on the development of a particular tailor-made process planning system or the use of any commercially available package.

The main focus of this study is the development of a process planning methodology for the cold rolling department, a detailed review of which is described in the later part of this chapter. With regard to the other two departments, they are not included in this research project; only their relationships with the cold rolling department have been studied.

4.7.2. Evaluation of the Use of Different Process Planning Approaches

The application of the two process planning approaches (i.e. the manual method and the retrieval type CAPP system) to the copper-alloy flat rolling mill industry were discussed earlier in this chapter. The manual method was found to be less effective because it is highly dependent on the planner, more time consuming and less capable of producing optimal plans. The retrieval CAPP approach indicated some advantage over the manual type, particularly, when a relatively large part of the orders were of a repetitive nature. However, a major problem with this approach is its inability to handle the dynamic nature of the parameters involved in the planning and therefore, very often the plans retrieved are less effective, or even not workable. As discussed in Case Study B, in many occasions plans had to be changed on the shopfloor where a planner was responsible for checking them with the real parameters such as the availability of material, etc.

The existence of the problems mentioned above with the two basic methods used in process planning was also confirmed through the literature survey. Therefore, it was clear that there was a need for a more effective method to deal with such problems. The generative type of CAPP system is an alternative solution and this method (as discussed in the previous chapter) uses planning logic and algorithms to generate the plan for incoming orders, based on the actual manufacturing data. Such a method has the capability to use current cost data to evaluate different alternative routes and thereby select the most cost effective route for any order. However, as can be seen from the literature review, we found no evidence of any published work on generative type CAPP systems being developed for this particular industrial application.

4.7.3. Scope of the Research Project

Division of the overall process planning problem under three production departments namely: foundry and casting, hot rolling and cold rolling were discussed in previous sections.

This research project concentrates on the process planning for the cold rolling department and deals specifically with planning for plates, sheets and circles.

With regard to the metal types, although this project concentrates on coppers and brasses (of general application type), the proposed methodology is also applicable for other copper alloy metals.

4.7.4. Objectives of Research

Apart from the general study of the process planning problem, the following particular objectives were set for this project.

1) The prime objective is to develop the methodology and a prototype model of a generative type CAPP system for the production of copper-alloy plates, sheets

and circles in the rolling mill industry.

2) The method has to provide two capabilities:

   - planning for individual orders (*single order process planning*)
   - planning for a batch of orders in accordance with a criterion for the optimisation of the batch (*batch order process planning*).

3) As a major feature, the method is required to include provisions for the improvement of material yield and lowering the overall route cost for the orders.

4) The resulting process planning system is required to operate on micro-computer system.

CHAPTER 5

SOLUTION METHODOLOGY

5.1. Introduction

The previous chapter divided the process planning problem for flat-rolled products into three major areas: foundry and casting, hot rolling and cold rolling. Planning the processes for cold rolling departments is the major concern in this research project, and in this chapter we show how to start tackling the problem systematically. A notation is developed for describing transformations undergone by the workpiece. Using this, different planning routes can be described in an efficient and unambiguous way.

Apart from the general requirements of any generative CAPP system, the cold rolling environment introduces requirements for our system to deal with subproblems as material yield and route cost.

The system is designed to deal with either single orders or batches of orders. The present chapter is designed to outline the development of the overall process planning methodology for the single order situation. The major techniques employed in the methodology are discussed here. The batch order process planning will be discussed in later chapters.

The overall process planning for a single order can be considered in two planning phases (Fig. 5.1), for:

(i) preparation of blank material and

(ii) main processing.

In the planning for the main processing, three general categories of routes were defined. These are: *one stage rolling routes*, *two stage rolling routes* and *three stage rolling routes*. Each category is further classified into a number of types named *macro routes* which describe the overall stuctures of the routes in that category. Following sections show how the macro-routes and other concepts have been combined to make a complete planning system for single orders.

Operations in the cold rolling department mainly consist of rolling, annealing, cleaning, flattening, trimming, blanking and some other metal cutting processes. Rolling is considered as the *primary operation* while the others are frequently referred to as the *secondary operations*.

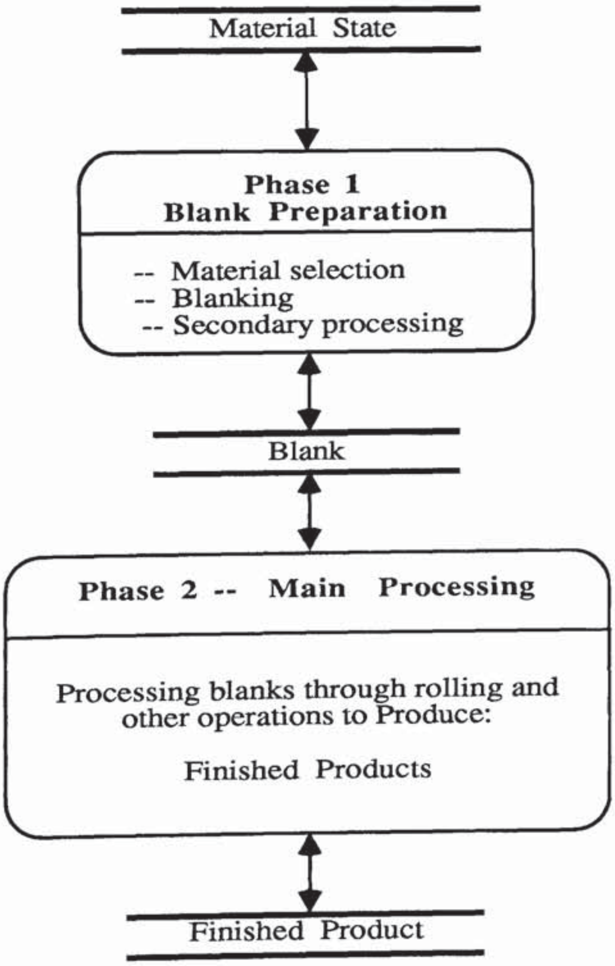


Fig. 5.1 The two phases for the production of plates and sheets

5.2. Phase 1: Blank Material Preparation

In order to prepare a blank (or group of alternative blanks), the following operations must be carried out:

(i) selection of material,
(ii) determination of blanking pattern,
(iii) planning secondary processes for the production of required properties for the blank.

The performance of these operations is combined in a single procedure which consists of ten main steps as outlined below.

1. Search for satisfactory material options. Major factors considered for this search are metal type, quality grade, hardness requirements, and the unit costs of materials.

2. Apply dimensional relationships for the purpose of initial evaluation of the the particular selection with regard to the sufficiency of material and the yield factor.

3. Determine the blanking pattern.

4. Calculate material yield for each selected pattern.

5. Evaluate the resulting material yield. That is, all those materials which do not appear to result in a satisfactory yield are rejected. For instance, any yield less than 70% can be considered unsatisfactory for this stage.

6. If the above steps are satisfactory then store the data for this selection for the

list of material choices.

7. Repeat the procedure until all the available material is searched.

8. When the above steps are complete, compare the choices of material available in the list in order to produce a limited number of preferred options.

9. Plan secondary processes for the selected options of material in order to produce the required properties -- mainly, the hardness or the surface condition.

10. Store the information for the selected choices of material in the relevant database file. This information must include: material code and data, blanking pattern, and data related to the secondary processes planned.

The above procedure can equally well be used for all the three types of material (i.e. mill stock, strips and coils), except that the methods employed for steps 2, 3 and 4 are different for each type. These applications are discussed in the subsections below, where, the following notation is used.

Gb,Wb,and Lb represent the Gauge, Width and Length for Blank;
Gp,Wp,and Lp represent the Gauge, Width and Length for Plate; and
Yb is blanking yield factor (as defined for each base material type).

5.2.1 Mill Stock Material

Millstock is previously processed material which is mainly in the form of plates (or sheets). In the application of the above procedure for this type of material the following methods are used for Steps 2,3, and 4.

Step 2. This consists of the following evaluations:

(i) The gauge for the plate must be within the range required for the blank gauge.

Gp_min <= Gb_max,

Gp_max >= Gb_min.

(ii). The width and the length for the plate must be equal to or greater than the corresponding dimensions for the blank:

Wp_min >= Wb_min,

Lp_min >= Lb_min.

Step 3. An extremely large number of patterns can be used for blanking in particular when the size of the blank is very small compared with the size of the plate. We have already noted this problem in Section 4.5.2 above. However, in our case, due to dimensional limitations and the costs associated with the cutting operations, the use of complex patterns is very much limited.

We shall only consider the simple pattern, which is illustrated in Fig 5.2. This is based on the filling of the plate area by the blanks in such a way that the width and the length for the blanks are parallel to the width and the length for the plate. For this pattern, the number of cuts corresponding to the width and length of the plate (N and M) have to be calculated as follows:

$$N = \mathrm{int}(Wp\_min / Wb\_min),$$

$$M = \mathrm{int}(Lp\_min / Lb\_min).$$

Step 4. The calculation for material yield is as below:

$$Yb = (N.M)(Wb\_min)(Lb\_min) / (Wp\_min)(Lp\_min).$$

With regard to Step 5, if the planning policy pursues the use of available mill stock rather than the other two types of material, this can be arranged in the procedure by setting the acceptable limit of yield for mill stock lower than the limit for the other types. The unit cost for these materials, also has to be set lower.

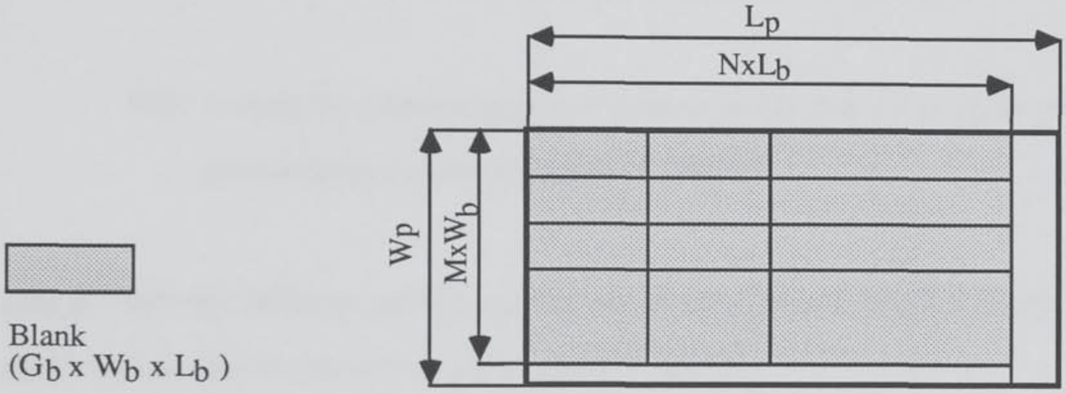


Fig. 5.2. The cutting pattern considered for mill stock material

5.2.2. Strip Materials

These constitute coiled strips in a standard width, e.g. 635 mm, comparatively very long length, and in a range of gauges. A common range for instance is 3.0 mm to 10.0 mm, but usually they are produced in a number of standard gauges, for instance: 3.0, 3.8, 4.3, 5.0, 6.4, and 7.6 mm.

In the application of the blank preparation procedure for strip materials the following measures are used for the steps 2, 3, and 4.

Step 2. The measures consist of:

(i) The gauge required for the blank has to be within the range of the gauges available for the strips.

(ii) It has to be checked whether the blank length can efficiently fit in the strip width. That is: Yw has to be greater than a preset minimum limit (say 70%), where, Yw = Lb / Ws. This condition is set with regard to the blanking pattern which is described in the following step.

(iii) Among the standard gauges for the strips the one which is the nearest greater gauge to the blank gauge is selected.

Step 3. Although different cutting patterns can be used, for the practical reasons we shall consider only the pattern which is shown in Fig. 5.3.

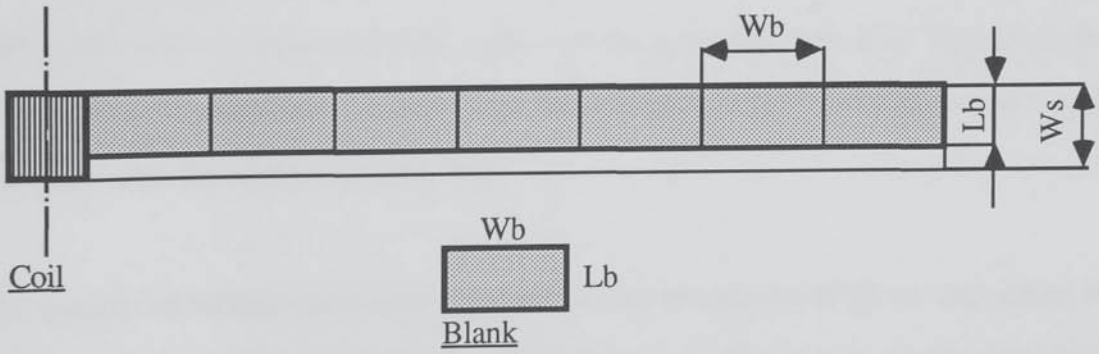


Fig. 5.3. Blanking pattern used for the strips

Step 4. Blanking yield is calculated as follow:

$$Yb = (Gb.Wb.Lb)/(Gs.Ws.Lb) \quad \text{or}$$

$$Yb = (Gb.Wb)/(Gs.Ws).$$

5.2.3. Coil Materials

Coils are received directly from the hot-roll department. They differ from strip materials mainly in their range of dimensions and material unit cost. However each of these types is commonly used for particular types of metals. Coils are preferably produced in the minimum gauge suitable for the mill, i.e. 4.50 mm. Their width variation is from 635 mm to 1025 mm, but some preset widths (i.e. 635, 650, 680, 720, etc.) are usually preferred.

The blanking procedure can be applied to these materials in a way similar to that explained for the strips. However, it should be taken into account that the gauge for the coils is kept constant while the width is varied.

5.3. Phase 2: Main Processing

This phase transforms blanks into finished products through a number of rolling operations, each accompanied with a group of the secondary processes. However, for the purpose of simplicity, at this stage we consider only those operations which somehow alter the workpiece geometry.

The number of rolling operations required for the production of plates and sheets is mainly determined by such factors as: the range of material available and their dimensions, product specifications, reduction limitations for the metal, and the capabilities of the equipment. However; with regard to the ranges included in this study for materials, products and the equipment, the number of rolling operations required for the manufacture of any product is one, two, or at most three.

Based on the required number of the rolling stages, process routes can be considered into following categories:

(1) *One-stage rolling*
(2) *Two-stage rolling*
(3) *Three-stage rolling*

A *zero-stage rolling,* which consists of no rolling process but only some secondary operations such as annealing, cleaning, blanking, etc., can also be considered as an additional category, but this type can also be considered as a blank preparation stage.

A number of general blocks can be identified with regard to the construction of the above route types. These blocks which represent the processes that somehow alter the geometry of the workpiece are: ROLL, TRIM, FSHEAR and 'Turn'.

Following sections outline these process blocks and their use for different route categories. These sections use the following notation.

Notation:

- G,W and L represent gauge, width and length of the workpiece
- subscripts 'i' and 'o' (for 'input' and 'output' represent the states of the workpiece before and after the operation
- R is rolling reduction ratio
- H represents the hardness of the metal
- Tw and Tl represent width and length trim allowances
- a_n is length trim allowance in percentage for stage 'n'
- R_m is rolling reduction ratio for stage 'm'

5.3.1. Description of the Blocks

ROLL

This represents a rolling process which rolls the workpiece in the direction of its length in order to reduce the gauge and increase the length. It is also assumed that the volume of the material remains constant for this operation. For this transformation we have:

$$G_o = G_i\,(1 - R),$$

$$W_o = W_i\,,$$

$$L_o = L_i\,/\,(1 - R).$$

Hardness of the material is also increased ($H_o > H_i$) and some directional properties are produced. This operation may also alter some other properties of the workpiece, but in this definition for the ROLL, we are not concerned with these changes.

TRIM

This represents the trimming operation which is used to shear the excess material (i.e. width and length trim allowances or any other allowances) off the edges of the workpiece, as required for the particular operation. The following relations exist when shearing off the trim allowances.

$$G_o = G_i$$

$$W_o = W_i - Tw$$

$L_o = L_i - Tl$

Values for the trim allowances generally depend on such factors as reduction ratio, width and length of the workpiece, equipment utilised, etc. Certain rules, mainly experience based, have to be used for the determination of these allowances. The type of these rules will be shown later for some of categories of routes.

Length trim allowance can be considered as a percentage of the length for the workpiece (a). Therefore, $T_l = (L_i)x(a)$ and $L_o = L_i (1- a)$.

Width trim allowance can also be considered as a percentage of the width, or most commonly, constant allowances are used for different operation situations.

FSHEAR

Final shear, removes trim allowances and other extra material off the edges and produces accurate width and length requirements. This block is similar to TRIM which was discussed earlier, but here the state of the workpiece after operation is the finished product state. Therefore:

$G_o = G_i$

$W_o = W_i - Tw$

$L_o = L_i - Tl$

where,

G_o, W_o, and L_o represent the gauge, width and length for finished product.

'Turn'

This block represents two operators: the TURN and the NTURN. The "TURN" operator when applied to any object (i.e. plate or sheet), turns it 90 degrees horizontally. The old width of the object becomes the new length and the old length as the new width, but no other alteration occurs. Dimensional relations for this application are:

$$G_o = G_i$$

$$W_o = L_i$$

$$L_o = W_i$$

The "NTURN" is an identity operator. When applied it does not produce any change, therefore, the new state for the object is identical to its old state. Dimensional relations are:

$$G_o = G_i$$

$$W_o = W_i$$

$$L_o = L_i$$

The blocks described above can be used for both forward and backward planning. For the backward planning, however, the inverted form of the relations are used to produce the less processed state (state 'i') from the more processed state of the workpiece (state 'o').

Each of the categories of routes (i.e. one, two or three-stage routes), based on the use of these blocks is further divided into sub-categories named *macro-routes*. In specifying a macro-route we are describing the overall structure of the type of the route concerned, not its detail.

The three main categories of routes, together with the macro-routes for each type, are detailed in the following sections.

5.3.2. One-Stage Rolling Routes

One-stage rolling routes are simple and usually result in lower operation costs when compared with the other two types of route. The sequence of the process blocks included for these routes produces four macro-routes, as indicated in Table. 5.1. A schematic representation of the dimensional transformations is also given for these macro-routes in Fig. 5.4.

The TURN block used before the rolling operation represents two options for the direction of the rolling. This block is also used to produce the two alternative positions of the finished product.

Dimensional relationships between different states of the workpiece can be produced for each macro-route using the specified sequence of the blocks for that route. Such relationships for the two blank and finished product states are summarised in Table 5.2. These relations can be used to establish rough-cut procedures in the evaluation of the routes for different product and blank situations.

Trim allowances were discussed in the previous section. The type of the rules for determination of these allowances, in relation to "one stage rolling routes", can be understood from the following samples.

1). A sample rule for width trim allowance:

```
IF   <macro-route 1-1>,
     < metal is copper >,
     < reduction is in the range 30 - 50% >,
             <length is less than 1800 mm >,
             THEN < Tw = 20 mm>.
     or
             <length is greater than 1800 and less than 2200 mm >
             THEN  <Tw = 25 mm>.
```

2). A sample rule for length trim allowance:

```
IF   <macro-route 1-1>,
     <metal is copper >,
     <reduction is in the range 30 - 50% >,
     <width is greater than 800 and less than 1000 >,
     THEN  <a = 10% >.
```

Relationships given in Table 5.2. indicate that, having selected trimming allowances, either width or length of the blank can be directly determined from finished product dimensions. Determination of the blank gauge together with the other dimension is related to the choice of the reduction ratio; this has to be selected with respect to the hardness limitations and both finished product and blank specifications.

Table 5.1. The sequences of process blocks for "one stage rolling macro-routes"

Route Code	Sequence of the process blocks			
1 - 1	NTURN	ROLL	FSHEAR*	NTURN
1 - 2	=	=	=	TURN
1 - 3	TURN	=	=	NTURN
1 - 4	=	=	=	TURN

* the block is either FSHEAR or FBLANK

Table 5.2. Summary of the dimensional relationships for the two blank and finished product states (one stage rolling).

Macro-Route	Finished Product		
Code	Gauge (G_f)	Width (W_f)	Length (L_f)
1-1	G_b(1-R1)	W_b - Tw	L_b (1-a1) / (1-R1)
1-2	G_b(1-R1)	L_b (1-a1) / (1-R1)	W_b - Tw
1-3	G_b(1-R1)	L_b - Tw	W_b (1-a1) / (1-R1)
1-4	G_b(1-R1)	W_b (1-a1) / (1-R1)	L_b - Tw

* Note that: values for the parameters (R1, Tw, And a) can be different for different routes.

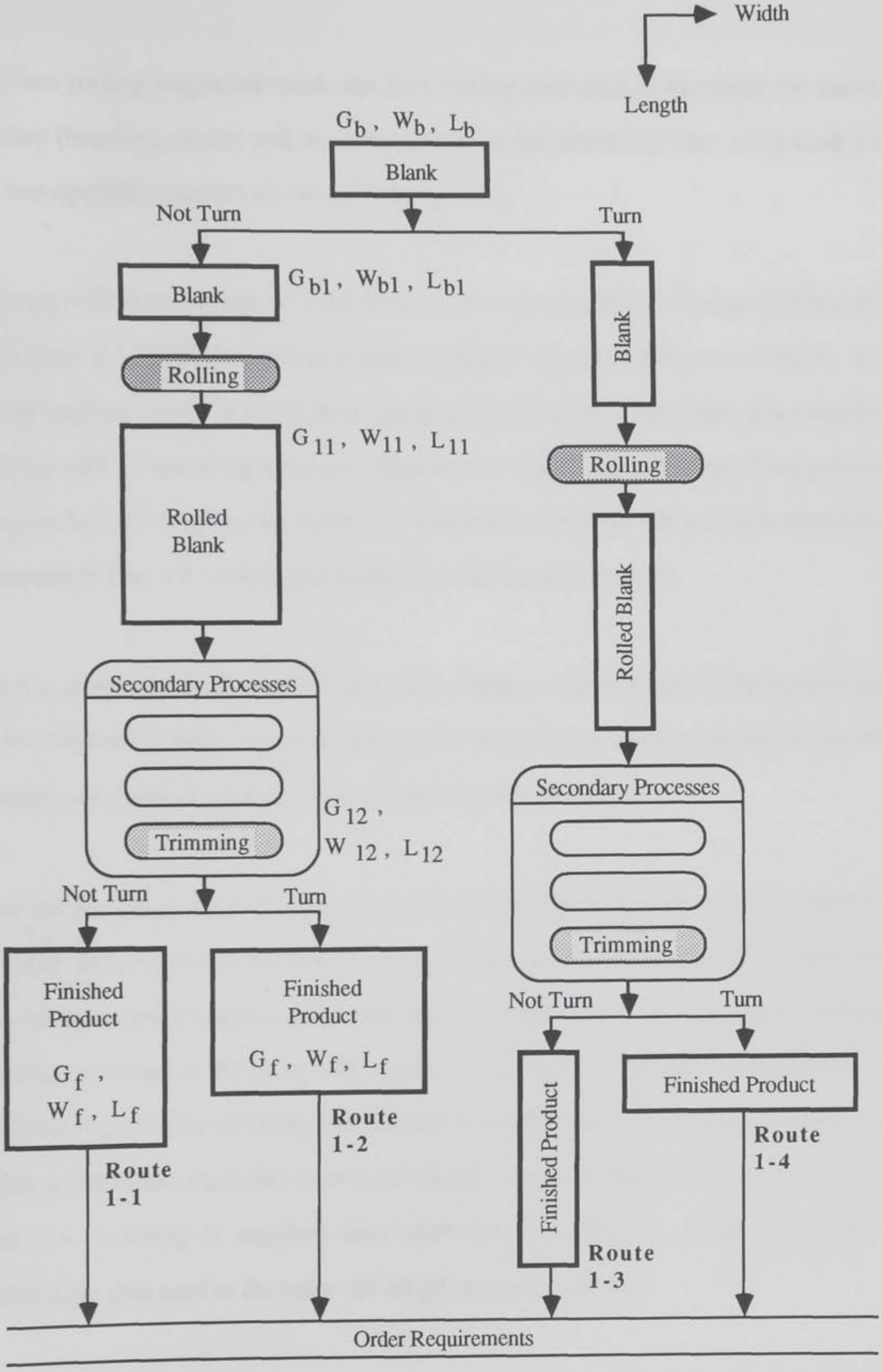


Fig. 5.4. One stage rolling macro-routes

5.3.3. Two-Stage Rolling Routes

When two rolling stages are used, the first rolling operation is normally for heavy reduction (breaking down) and the second one for the finishing. The mills used for these two operations are usually of different groups.

Two stage rolling routes can be considered as the routes produced through adding one rolling stage (i.e. a rolling operation and a group of the secondary processes) to the one-stage rolling routes. These routes, using the classification procedure described for one-stage rolling, are categorised into eight macro-routes, the sequence of the process blocks for which are given in Table 5.3. These macro-routes are also schematically represented in Fig. 5.5. with regard to dimensional transformations.

Using the procedure described for one-stage rolling, relationships can be established between different states of work in progress for these routes. Such relationships for the two blank and finished product states are summarised in Table 5.4.

Values for the parameters (R1, R2, a1, a2, Tw1 and Tw2) have to be determined for each route with respect to the operation conditions concerned. Types of the rules are similar to those samples illustrated in the previous section. However, further conditions have to be included in the rules with regard to the stage of rolling. For instance: for route 2-1or route 2-2 in which the two rolling operations are unidirectional, for practical reasons, width is trimmed only after final rolling; while for some other routes such as 2-3 or 2-4 trimming is required after each rolling operation. Similar additional conditions are also used in the rules for length trim parameters.

Use of the above rules for trimming after second rolling is very simple. But, for the case of the first rolling, width and length of the workpiece have to be determined in advance.

Determination of the reduction rates (R1 and R2) has to be in such a way that both dimensional and hardness requirements could be satisfied. For instance when the finished product is specified hard (i.e. hardness greater than 90 Hv), R2 can be determined with regard to this hardness. Therefore the need for a final annealing operation could be eliminated. On the other hand if the product is to be finished soft (hardness maximum 55 Hv.), annealing is needed in any case, therefore, R2 can be selected irrespective of this hardness.

Secondary operations are planned for the routes with regard to the requirements for each state the workpiece. For instance, after being processed through first rolling the workpiece has to be prepared for the second rolling. For this, annealing might be required. Cleaning is normally determined with respect to metal type, quality grade and the surface produced in the annealing process. Flattening is usually a requirement for the final stage. Other processes such as blanking and circle cutting might also be required for this stage.

Table 5.3. The sequences of process blocks for "two stage rolling macro-routes"

Route Code	Sequence of the process blocks						
1 - 1	NTURN	ROLL	TRIM	NTURN	ROLL	FSHEAR*	NTURN
2 - 2	=	=	=	=	=	=	TURN
2 - 3	=	=	=	TURN	=	=	NTURN
2 - 4	=	=	=	=	=	=	TURN
2 - 5	TURN	=	=	NTURN	=	=	NTURN
2 - 6	=	=	=	=	=	=	TURN
2 - 7	=	=	=	TURN	=	=	NTURN
2 - 8	=	=	=	=	=	=	TURN

* the block is either FSHEAR or FBLANK

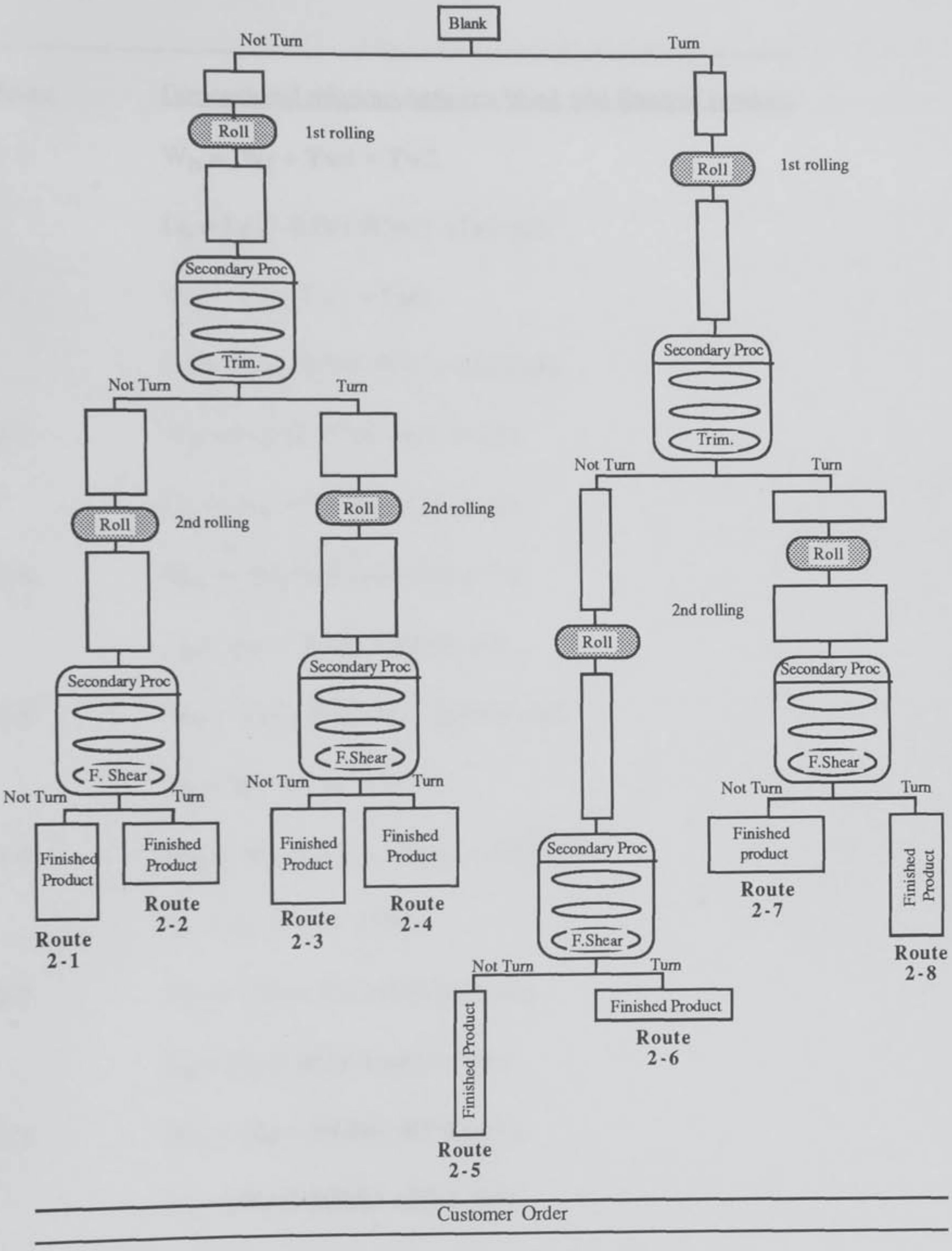


Fig. 5.5. Macro-routes for two-stage rolling

Table 5.4 Dimensional relations between blank and finished products states for the two-stage rolling routes.

Route	Dimensional relations between blank and finished product
2-1	$W_b = W_f + Tw1 + Tw2$, $L_b = L_f (1-R1)(1-R2)/(1-a1)(1-a2)$.
2-2	$W_b = L_f + Tw1 + Tw2$, $L_b = W_f (1-R1)(1-R2)/(1-a1)(1-a2)$.
2-3	$W_b = [L_f (1-R2)/(1-a2)] + Tw1$, $L_b = (W_f + Tw2)(1-R1)/(1-a1)$.
2-4	$W_b = [W_f (1-R2)/(1-a2)] + Tw1$, $L_b = (L_f + Tw2)(1-R1)/(1-a1)$.
2-5	$W_b = L_f (1-R1)(1-R2)/(1-a1)(1-a2)$, $L_b = W_f + Tw1 + Tw2$.
2-6	$W_b = W_f (1-R1)(1-R2)/(1-a1)(1-a2)$, $L_b = L_f + Tw1 + Tw2$.
2-7	$W_b = (W_f + Tw2)(1-R1)/(1-a1)$, $L_b = [L_f (1-R2)/(1-a2)] + Tw1$.
2-8	$W_b = (L_f + Tw2)(1-R1)/(1-a1)$, $L_b = [W_f (1-R2)/(1-a2)] + Tw1$.
**	For all these routes: $G_b = G_f / (1-R1)(1-R2)$.

5.3.4. Three-Stage Rolling Routes

Different macro routes in this category are represented in Fig. 5.6 and construction of the process blocks is similar to the other two categories described in the earlier sections.

Most of these routes included in these types (e.g. 3-5, 3-6, 3-7 and 3-8) can be used to produce any size of plates and sheets, provided a material with a sufficient volume is available. Therefore, there is no practical reason to consider more than three stages for the production of the range of plates and sheets included for this project.

As the number of the rolling stages for these routes is higher than for the two other categories, the route operation cost is higher and in also the corresponding yield for most of the routes is lower.

In the planning these routes, reduction ratio and trim allowances have to be determined for each stage. For this purpose dimensional relationships together with the established manufacturing rules have to be used. Rules are similar to those described for the other two categories. However, for many cases, a wide range of alternative choices exist for each parameter, which increases the difficulty in selecting the appropriate values.

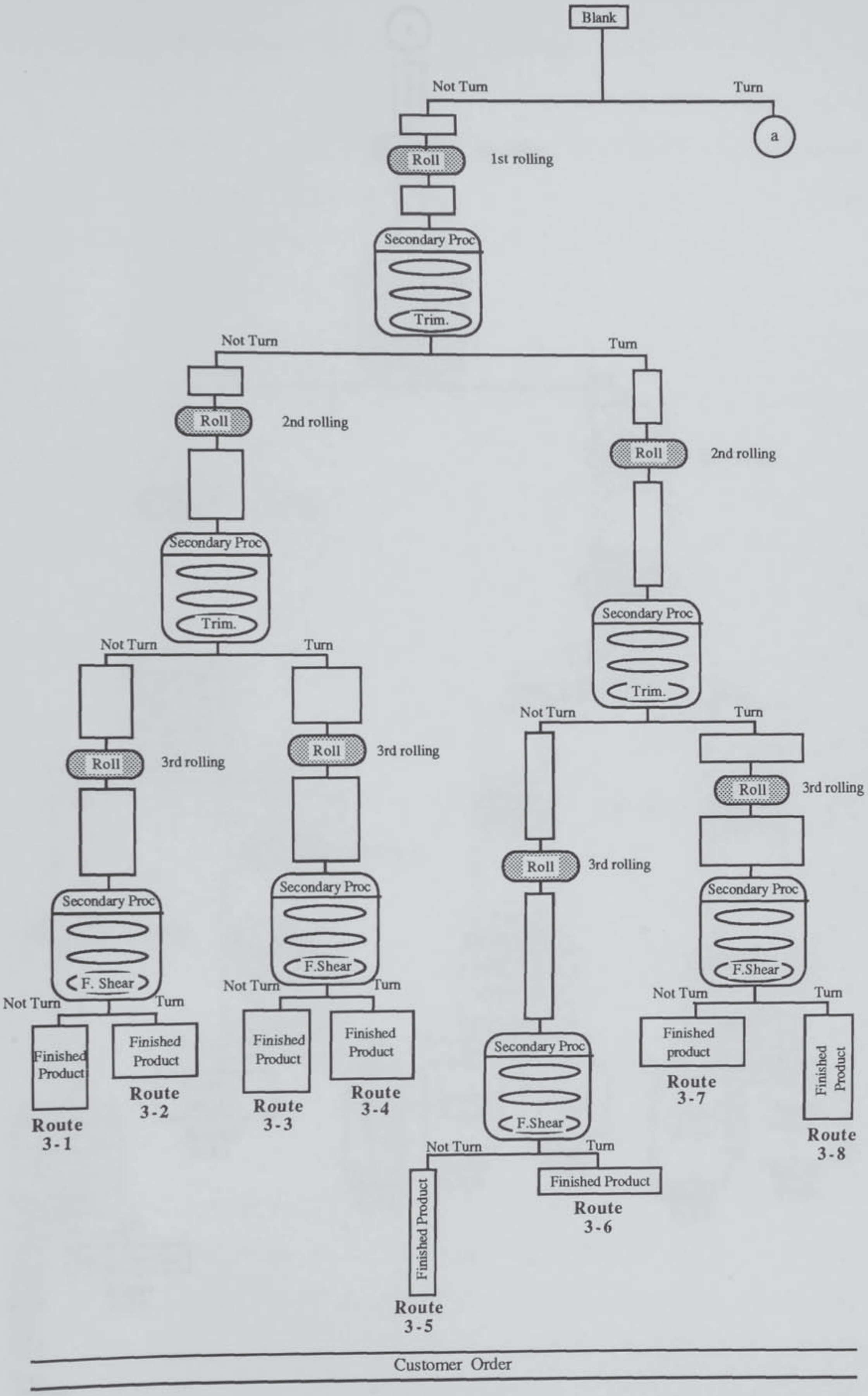


Fig. 5.6 - a. Macro-routes for three-stage rolling

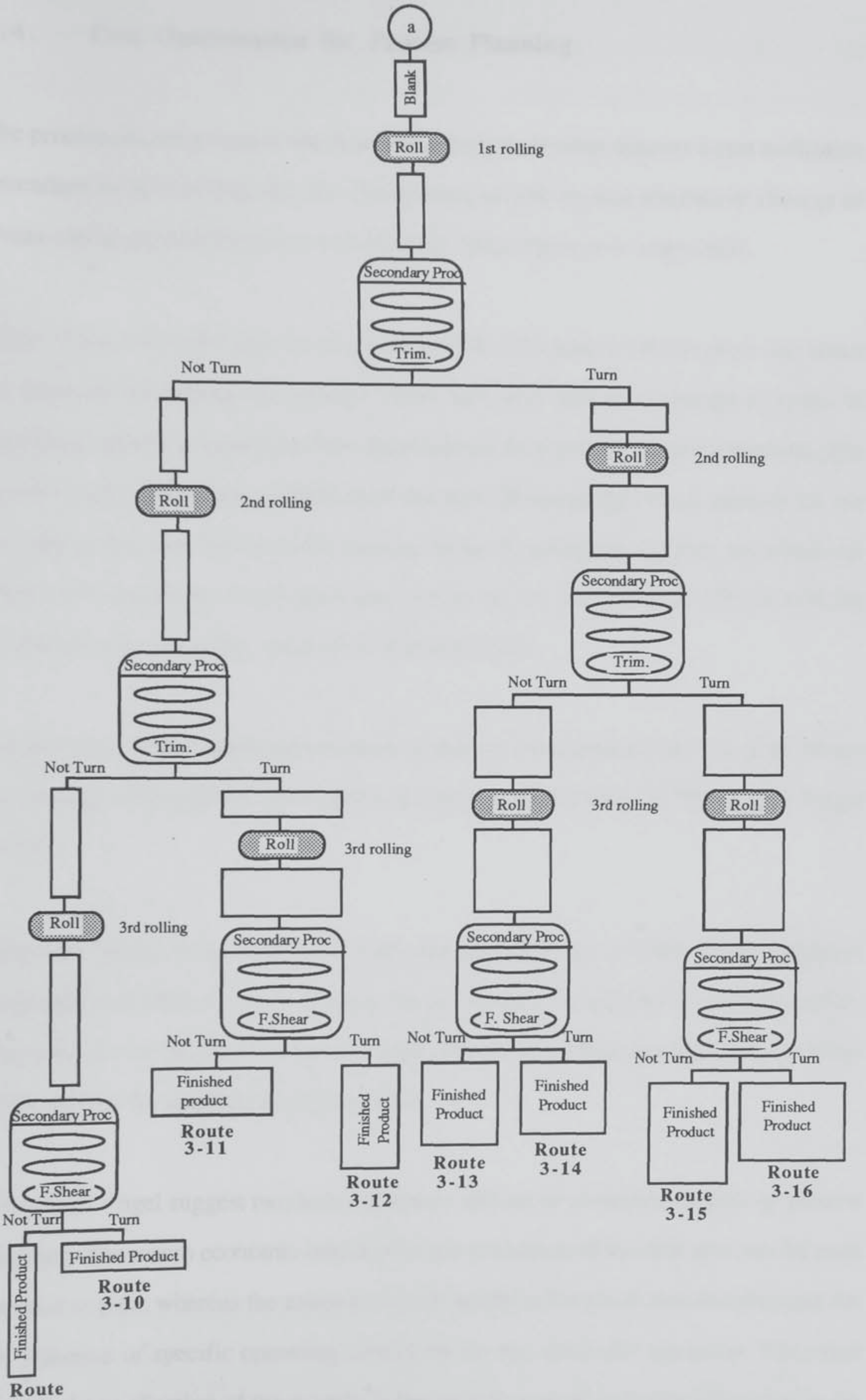


Fig. 5.6 - b. Macro-routes for three-stage rolling

5.4. Cost Optimisation for Process Planning

The process planning system which we are aiming to develop requires a cost evaluation procedure to be incorporated into the system, so that several alternative choices of routes can be evaluated before a cost-effective (optimal) route is determined.

Some of the 'economic' process planning models described in the literature are based on classical machining economics, where time and cost relationships in terms of individual operating conditions have been derived for some machining operations. The model described by Chang (1986) is of this type. However this is not suitable for our purpose as they are: (i) mainly for material removal operations, (ii) they are mostly for micro-level purposes (where operation parameters are planned) and (iii) the tool life relationships are generally assumed to be deterministic.

Another type of the model includes those which are more generalised, two of which are the models proposed by: (i) Iwata and Takano (1973) and (ii) Tipnis and Vogel (1978).

Iwata and Takano consider the process planning optimisation problem in the context of integrated manufacturing for a jobshop (large number of small batch type) production, they propose mathematical models for this purpose. They also describe the application of the models for metal removal processes.

Tipnis and Vogel suggest two levels of macro and micro-economic models for process planning. The macro economic model is for the evaluation of the time and cost for each alternative plan, whereas the micro economic model is for use in detailed planning for the selection of specific operating conditions for any particular operation. They also discuss the application of the models in the manufacture of 'airframe structures' in the aerospace industry.

The Iwata-Takano and Tipnis-Vogel procedures both indicate that it is possible to deal with the cost optimisation problem for the rolling mill industry. But as these procedures are developed for some more complex manufacturing environments, they involve extremely large amounts of detailed evaluations. Such detailed consideration does not seem to be needed for the planning in rolling mills, nor are such detailed time and cost data usually available in this industry.

Therefore, based on the main ideas presented by Iwata and Tipnis, we have developed a simplified method of cost evaluation for the use in the process planning system at which we are aiming. This is described in the following section.

5.4.1 Proposed Method for Cost Evaluation

The elements of cost for any state of work in progress (state i) are represented in Fig. 5.7, for which following relationship exists.

$$C_i = C_{(i-1)} + CP_i + CT_i + CE_i - CS_i \qquad (1)$$

where,

C_i = Cost for the workpiece produced at the ith state,

C_{i-1} = Cost for the workpiece produced at the (i-1)th state - input to the ith state,

CP_i = Cost for the ith process,

CT_i = Cost for the transportation for the ith process,

CE_i = Extra costs involved in the ith process (e.g. costs due to delays),

CS_i = Cost (value) for the scrap produced in the ith state.

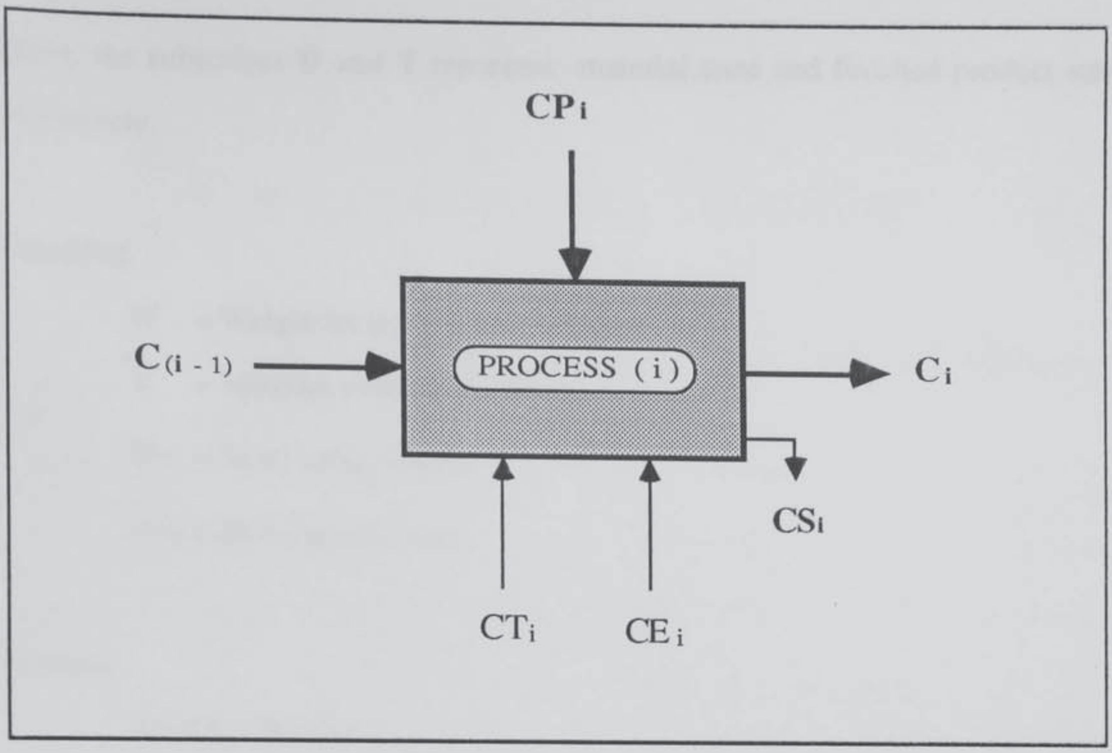


Fig. 5.7. Cost elements for any state of work in progress

Note that scrap is considered to be produced by 'cutting processes' such as: blanking, trimming, final shear, etc.

Considering the above cost equation for different WIP states we have:

$$C_1 = C_0 + CP_1 + CT_1 + CE_1 - CS_1$$

$$C_2 = C_1 + CP_2 + CT_2 + CE_2 - CS_2$$

$$\cdot$$

$$C_i = C_{(i-1)} + CP_i + CT_i + CE_i - CS_i$$

$$\cdot$$

$$C_f = C_{(f-1)} + CP_f + CT_f + CE_f - CS_f$$

or,

$$C_f = C_0 + \Sigma(CP_i + CT_i + CE_i) - \Sigma CS_f \qquad (i = 1, 2, \ldots, f) \quad (2)$$

where, the subscripts '0' and 'f' represent material state and finished product state respectively.

Assuming,

W = Weight for the allocated material,

Y = Material yield for the route,

Ws = Total scrap weight,

Um = Material unit value

we have,

$$Y = (W - Ws)/W$$

or $$W_s = W(1-Y).$$

Assuming equal unit values for the scrap produced at any process (Us),

$$CS_i = (Ws_i)\,(Us)$$

$$\Sigma CS_i = (\Sigma Ws_i)\,(Us)$$

or $$\Sigma CS_i = W(1-Y)\,(Us)$$

By substituting total scrap value in equation (2) we have,

$$C_f = (Um)(W) + \Sigma(CP_i + CT_i + CE_i) - W(1-Y)\,(Us)$$

or

$$C_f = W\,[Um - Us(1-Y)] + \Sigma(CP_i + CT_i + CE_i) \qquad (3)$$

This equation can further be simplified if the transportation cost and the extra costs are not included in the evaluation of the routes. The simplified form of the equation which will be used in the proposed evaluation method is given below.

$$C_f = W\,[Um - Us(1-Y)] + \sum CP_i \qquad (i = 1, 2, \ldots, f) \qquad (4)$$

For the calculation of the processing cost (CP_i) at different state of work in progress a procedure is developed which is described below.

Procedure Used for the Calculation of Processing Cost

The proposed procedure which is schematically represented in Fig. 5.8. is principally based on two of the macro-economic models proposed by Tipnis. The models are:

$$t = m_0 + m_1/H_t \quad \text{and}$$

$$C = (t)(M) + k3$$

where,

t = time function,

C = cost function,

m_0 = setup time + load/unload time, etc.,

m_1 = processing time coefficient,

H_t = productivity function,

M = work centre rate ($/min.),

$k3$ = preparation and material cost.

In the above equation the productivity function must be established for each process mathematically. However, in our case it is difficult to determine this, instead we can use some form of tabulated data, prepared for the different ranges of each process. We can also use a productivity factor (H) for minor adjustments of selected range to obtain the required operating condition. The proposed method is represented by the following equations.

$$T_{ikl} = t_{k0} + (t_{kl} . q_i)/H_{kl} \tag{5}$$

$$CP_i = (T_{ikl})(M_{kl}) \tag{6}$$

where,

T_{ikl} = time for the ith process ('k' represents work centre or machine and 'l' is for the operating condition),

t_{k0} = setup time for the ith process,

t_{kl} = time for the unit of work-load for the selected process

q_i = units of work-load processed,

H = productivity factor,

M_{kl} = machine (work centre) rate for the operation condition 'l'.

The establishment of appropriate ranges for each operation is of prime importance, in that various factors influencing the particular operation time have to be considered. In relation to the rolling operation, for instance, keeping the roll diameter and the roll surface condition constant, the major factors affecting the operation time can be considered as: reduction ratio, initial hardness and initial dimensions of the workpiece. The unit of work-load (q_i) also has to be appropriately selected for each process. For a rolling operation a workpiece with appropriate dimensions can be considered as a work-unit, based on this the productivity factor can be established for different sizes of the workpice. The example shown in Fig. 5.9. demonstrates the application of the above considerations.

Similar procedures can also be used to establish the operation ranges and the work-unit for other processes in a rolling mill.

The procedure proposed above is much more simple than the methods given by Tipnis and Vogel, even though, there is a difficulty of obtaining accurate relevant data in real manufacturing companies. However, if real data is not available, a set of carefully prepared relative time or cost factors could be used for certain conditions and within certain accuracy limits. These will be more detailed in Chapter 10.

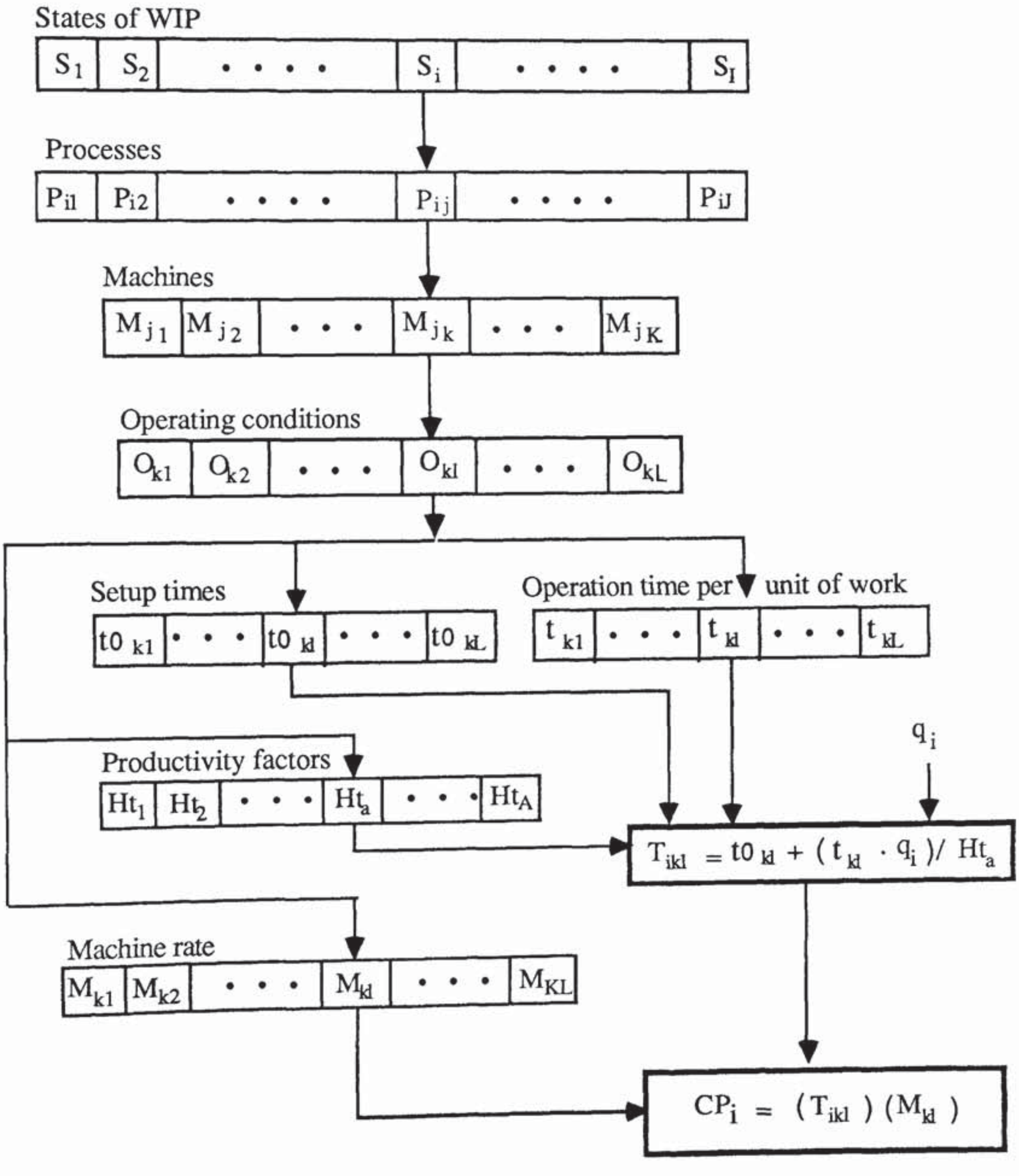


Fig. 5.8. Schematic representation of the procedure for operations time and cost calculation.

Standard time data for rolling

Machine: G3
Metal code 103

Typical values

Machine: G3,
Metal: 103 (Copper),
Reduction rate: 50%
Starting gauge: 5.0 mm,
Starting hardness: 1/2 H,
W=900,
L = 635.

Then:
Time per unit of work = 28,
H = 1.10,
Time unit for each plate = 28/1.1 = 25.5

Reduction range (%)

below 20	20 - 40	40 - 60	above 60

Soft	1/4 H	1/2 H	3/4 H or greater

Initial Gauge	below 2.0	2.0-4.0	4.0-6.0	6.0-8.0	above 8.0
Std time per unit of work*	24	26	28	30	32

* selected width and length for the work-load unit are: W= 800 mm and L= 1200 mm.

Area ratio = (800x900)/(800x1200) = 0.75

Area ratio	0.40 to 0.60	0.60 to 0.80	0.80 to 1.20	1.20 to 1.50	1.50 to 2.00	...
H	1.20	1.10	1.00	0.90	0.80	...

Fig. 5.9 An example illustrating the method proposed for the determination of processing time for each workpiece in rolling operation.

5.5. Machine Selection

Machine selection is principally based on the search for the purpose of matching the process requirements with the available machine capabilities. Preferences for using particular machines, together with the operation costs for the machine are also to be considered in this decision making process. With regard to the types of the processes in a rolling mill (cold rolling), machines are divided into following groups:

- sheet metal cutting machines,
- rolling mills,
- annealing furnaces,
- cleaning,
- flattening presses.

Some general procedures for the selection of the above types of machines for process planning purpose are discussed below. Sample capability data for these pieces of equipment is given in Appendix B.

Sheet Metal Cutting Machines

Sheet metal cutting machines used in rolling mill industry mainly include blanking, trimming and final shear, slitting, circle cutting and machines for cutting other shapes. Capability information for these machines mainly consist of limitations on size of workpiece, production accuracies and tolerances, hardness limitations, and restrictions for particular metals.

Rolling Mills

These are cold rolling machines classified into two types:

(i) Breaking down or get ready rolling mills which are used to produce heavy reductions.

(ii) Final rolling machines which are used for temper rolling and finishing operations. These can produce small reductions normally 5% to 25%. Final rolling can also be planned for the production of required hardness for the product.

Capability information for these machines mainly consists of: type of application (i.e. breaking down or final rolling), maximum starting gauge, minimum finishing gauge, maximum width and length, minimum planned width and length, and the level of gauge accuracy achievable.

Annealing furnaces

Two types of furnaces, i.e. open-bath type and continuous type are included. Capability information mainly consists of limitations on metal types, maximum thickness, width and length of the workpiece and maximum weight for the workpiece or the batch of work.

Cleaning

Cleaning is used to remove the unacceptable scale produced on the metal during hot rolling or some annealing operations, or any other material such as lubricating oils, oxides, dirt, etc. off the surface of the metal. Selection of the cleaning equipment depends on the type of the material to be removed, and the the dimensions of the part itself.

Flattening

This is normally used at the final stage of production. Capabilities include dimensional limitations and the measure of the flatness which can be produced.

5.6. Forward and Backward Planning Methods

The two methods of forward and backward planning were discussed in Chapter 3. Either of these methods can be used for process planning, however, each may have its own advantages and disadvantages depending on the particular applications.

In the proposed planning method, as outlined in the next section, backward planning is used in an initial stage in order to evaluate the overall solution space for the selection of a number of feasible routes. This approach uses reverse processing, in which the input for each stage is a processed workpiece, while the output is a less processed workpiece. As an example, a reverse rolling process increases the thickness, reduces the length, and reduces the strain hardness of the workpiece. The use of backward planning at this initial stage produces more specific requirements on material and therefore facilitates the selection of suitable materials.

Forward planning on the other hand is used for detailed planning in a later stage for which material and some route information have already been determined.

5.7. Proposed Methodology (for Single Order Process Planning)

Having outlined major elements involved in the planning of processes for single orders in the previous sections, it is appropriate to discuss the overall methodology proposed for this planning situation.

The concept for this methodology is searching the solution space for an optimal choice of solution. The optimisation criterion for this particular planning option is minimisation of the route cost for each single order. This methodology consists of following major steps on the planning for any order received from the customers.

Step 1. Searching for feasible macro-routes and determination of acceptable material range for each route.

Step 2. Searching available sources of material to find suitable choices for each feasible route. This step also includes rough procedures for the evaluation of routes in order to discard less effective ones.

Step 3. Determination of the cost for each route in the above list of "preferred routes".

Step 4. Selection of the optimum route, i.e. the least cost route.

Step 5. Production of the process plan for the optimal route.

These steps are discussed in the following sections. Further details of the above steps can be found in the description of the system in Chapter 10.

5.7.1. Step 1. Searching for Feasible Macro-Routes and the Acceptable Ranges of Material

This step provides a rough-cut procedure through which the solution space for the problem is reduced to a workable limit. It evaluates every macro-route against the given order requirements. The evaluation procedure uses a backward planning approach through which reverse processes (process blocks) set for each macro-route are applied upon the workpiece states. This starts from the finished product state and proceeds until material state is reached. If the route is found successful and it leads to an acceptable range of material, then that route is considered feasible. Information for feasible routes has to be stored in the database files.

There are two alternative methods for the evaluation of the macro-routes on any order situation. The first method evaluates each macro-route individully. The second method, on the other hand, applies the evaluation procedure on the combination of these macro-routes. The combination of macro-routes produces a form of decision tree, and therefore, the overall evaluation is a *tree structure search* (Fig. 5.7). This method is more complex than the first method, but it is more efficient as the information produced for the nodes is used in the evaluation of different macro-routes. This option has been used in the present implementation, where the branches are evaluated in a depth-first search procedure.

5.7.2. Step 2. Determination of Suitable Material for each Route

This step consists of procedures for the searching of available material sources against the acceptable ranges specified for each feasible route. The available types of material sources are: millstock material, strips and coils. These types of materials together with their corresponding search procedures have been discussed earlier in this chapter in Section 5.2. In searching these sources for any route if the search fails the route is discarded from the list. However, there is also the possibility of finding alternative choices of material for any route. Therefore the number of feasible routes can be reduced as well as increased.

The number of feasible routes so produced can be very large. But, however, some of the routes are much less efficient compared to the others. This step also provides rough evaluation procedures, as the result of which routes which are clearly less efficient compared to the others are discarded from the list. Criteria employed in these evaluations are mainly based on the yield and number of rolling stages for the route and the type of material utilised.

Remaining routes are called *preferred routes*. Costs for these routes have to be determined before they can be further evaluated.

5.7.3. Step 3. Determination of the Cost for the Routes

The purpose of this step is to calculate the *route cost (route cost indicator)* for the list of preferred routes which were produced through previous steps. This requires both a planning method to plan the details for the routes and a costing method to determine costs for the plan so produced.

The planning method uses a forward planning technique which starts from blank material state and proceeds to finished product state, applying the sequence of process blocks specified for the particular macro-route. It also uses appropriate rules to determine annealing and other supplementary operations (cleaning etc.) as required.

Operation conditions as well as machines for the processes are also to be determined for each route based on which operation costs can be calculated. The costing system also calculates material cost and then based on these two costs it works out the route cost.

5.7.4. Step 4. - Determination of the Optimal Route

This step is designed to evaluate the available choices of routes (included in the list of preferred routes) against a given criterion for optimisation. Different criteria can be used at this step. With regard to single order process planning, the criterion is the minimisation of the overall route cost.

5.7.5. Step 5. - Production of the Process Plan for the Optimal Route

This step is designed to make use of information previously determined for the optimal route in order to produce the final process plan. Confirmation of the plan by the user of the system is a requirement before the plan can be issued for the production. Inclusion of the yield and cost information into the plans can be useful for the purpose of evaluating these plans. Further more, an editing option can be advantageous at this stage, in particular for any additional instructions which the planner might wish to include.

5.8. Concluding Summary

This project mainly concentrates on process planning for the cold rolling department, in particular the production of plates, sheets and circles. Two process planning options are considered in this work. The first option, single order process planning, was outlined in this chapter. This planning option which is also referred to as "process planning" in short, provides the background for the second option, batch order process planning, which is discussed below in Chapter 6.

The overall production of plates, sheets and circles, is considered in two phases. The first phase, which consists of such operations as blanking, shearing, annealing, cleaning, is for the purpose of preparing the required blank specification from the selected type of material.

The second phase, which is for the purpose of main processing, includes a number of rolling operations, each accompanied by other operations such as annealing, cleaning, trimming, blanking, final shear, flattening etc. Process routes for this phase are categorised into: one stage rolling, two-stage rolling and three-stage rolling types. These are further divided into subcategories called macro-routes. A macro-route describes major operations, but not details, for a route. These major operations have been considered as process blocks and their sequence has been determined for the construction of different macro-routes. The main use of the macro-routes is in the initial stages of planning, where they work as a guiding structure in searching the overall solution space. They also provide appropriate coding for the overall structure of the routes.

The overall planning methodology described in this chapter consists of five major steps. The first step evaluates different macro-routes in a backward search method against the requirements of the end product. In this method the sequence of process blocks included for each macro-route is applied to the workpiece as a reverse process. The result ofthis evaluation is a list of feasible macro-routes with their corresponding range of material requirements. Feasible routes so produced are also referred to as "routes" in short.

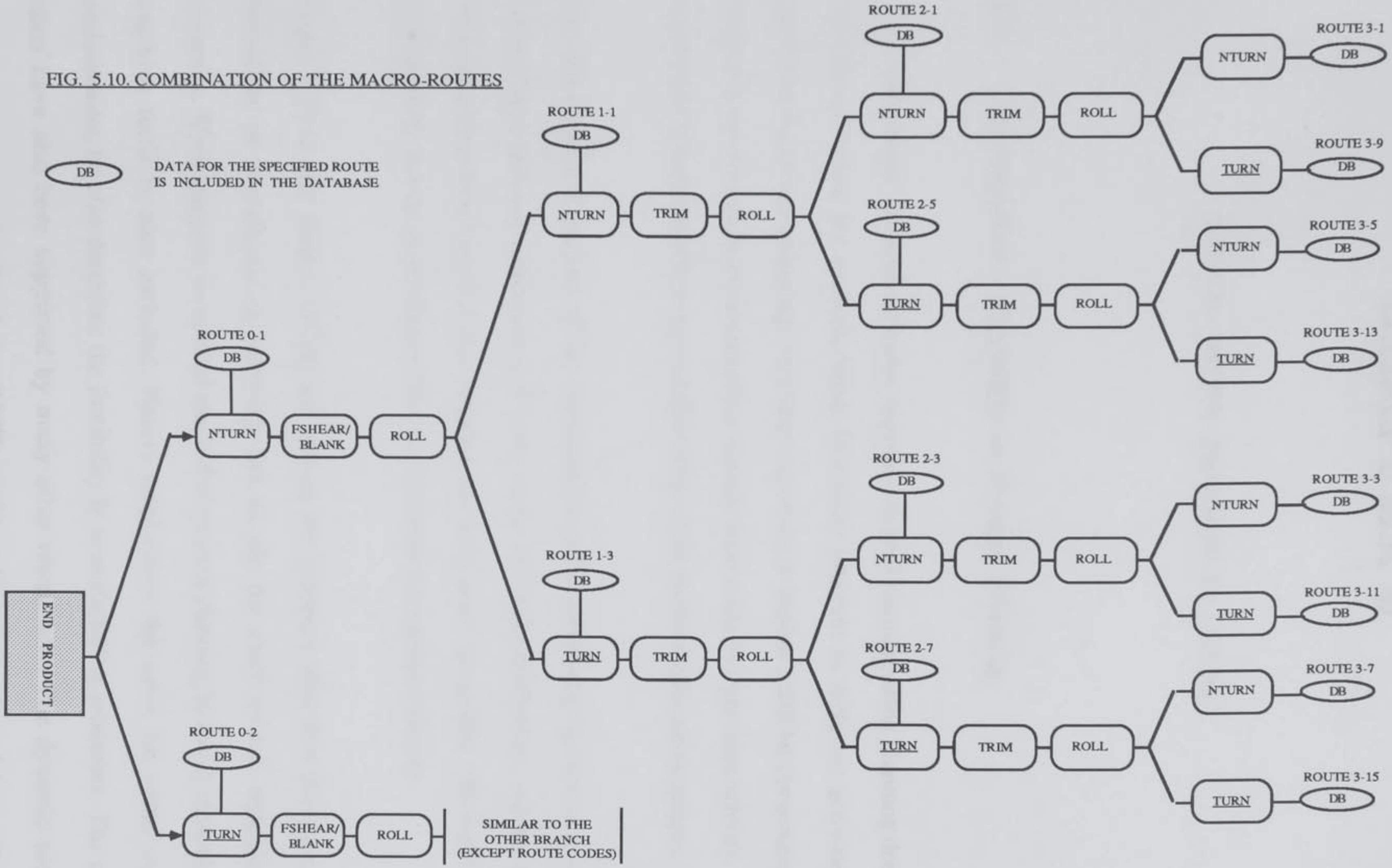
The second step is designed to examine available material types against the requirements for each route. Successful routes are then compared for their efficiency, using a rough evaluation method. Routes so produced are called "preferred routes". They require costing for further evaluation.

The purpose of the third step is to calculate the overall cost for the list of preferred routes. This step makes use of a costing method which considers both material and operation costs. Operation costs are determined for each process on the basis of the type of the process and machine and the operation conditions. This step also uses a detailed planning method to determine the operations, machines and other details of the routes.

The fourth step, is designed to optimise the choice of route. The optimisation objective for single order process planning is simply the selection of the least cost route.

The final step is designed to produce the process plan. For this, the system makes use of the details of the optimal route produced through the previous steps. The plan at this stage requires confimation by the planner before it can be issued to the production. Editing provisions (for instance, to include any additional instructions) are also required in this final stage.

FIG. 5.10. COMBINATION OF THE MACRO-ROUTES



CHAPTER 6

BATCH ORDER PROCESS PLANNING

6.1 Introduction - Flexibility in Process Planning

The conventional 'chain of activities' approach to total manufacturing planning does not effectively utilise the manufacturing flexibility inherent in different activities, in particular the process planning. This approach tends to impose artificial constraints, that exist only because a certain decision has already been made in a previous activity. Such constraints reduce the efficiency and flexibility of the total manufacturing system.

The importance of the idea of the optimisation of the production system as a whole, rather than a separate optimisation of every single and isolated function, and the use of manufacturing flexibility for this purpose, has long been recognised. However, it is only recently that the realisation of this idea has been considered seriously.

Wysk (1977) and Halevi (1980) are among the pioneers who first discussed the flexibility of manufacturing planning and its use for some overall optimisation purposes. Wysk suggests an optimal method of process planning in which allocation of machine tools is also included. Halevi emphasises the need for some overall optimisation, he also describes the flexibility in manufacturing processes. The above ideas have also been supported by many other researchers. The dynamic process planning system proposed by Iwata (1987) considers the optimisation of the availability of the production system parallel to the planning of manufacturing. Mill & Spraggett

(1984) indicate a similar opinion, as they suggest a process planning approach including additional optimisation criteria such as the optimisation of: machine set up, machine-to-machine movement of the parts and machine overloading.

Although these (and many other similar attempts) do not show an overall optimisation, they do indicate the trend which is the *extension of the area of optimisation,* in particular in relation to process planning.

Such a flexibility was identified in relation to the planning of processes for flat metal production, as it is usually found that a number of alternative routes can be used for the production of these products. Some major features of these alternative routes and their possible use for some optimisation purpose are discussed below.

6.2 The Need for "Batch Order Process Planning"

As discussed in the previous chapter, the CAPP module developed for single order process planning provides the capability to produce a "short list" of alternative routes (i.e. preferred routes) that meet some criteria but have to be examined further to find the optimal route plan.

Different alternative process plans provide different utilisation of manufacturing resources, and therefore imply different production efficiency and cost. Through the study of the results of the single order CAPP module, and the practical investigations carried out in rolling mill, the following points have been recognised. Sample data given in Table 6.1. demonstrates some of these points.

1. For a given batch of orders the selection of routes based on the optimisation

criteria of each individual order does not necessarily imply the optimisation of the whole batch. The consequence of such phenomena is either an increase in costs or unbalanced utilisation of manufacturing resources and the introduction of bottlenecks in the system. This has been shown in Table 1, where the selection of the least cost route for each order leads to a less optimal situation for the batch as compared with the selection of the routes on a grouping basis (i.e. a difference of 36 in overall cost).

2. Raw materials (i.e. coil, strip, plate, etc.) are generally available only in standard or pre-established dimensions. Therefore material obtained for each individual plan usually exceeds the required amount. The excess material is either stocked for subsequent usage, or scrapped. However, in either case the cost is increased.

3. Usually, the theoretical gauge required for the blank does not match with the list of the standard gauges available. Therefore the closest larger material has to be selected. An example is when theoretically a coil with 4.4 gauge is required (order number 3 in the table). The gauge for the closest coil is 5.0. Therefore, by selecting this coil an extra 13.6% of material (100x(5.0-4.4)/4.4 = 13.6) is allocated. This extra material allocation has been recognised as one of the main reasons for low material yield in plate and sheet production.

4. Some of the alternative plans for a given product can have overall route costs very close to each other while they can have different requirements for material dimensions.

5. There exist similarities in gauge for materials selected in some of the plan alternatives for different products required within a given span of time (i.e. a batch of orders). That is, they may require strips with gauges which are very close to each other.

Table 6.1. Sample data to demonstrate some of the characteristics of the alternative routes for a number of products

A	B	C	D	E	F	I			II		
weight	order no.	route no.	theoret. gauge	oper'n cost	closest std. gauge	Cost			Cost		
						a %	b	c	a %	b	c
200	1	1	**4.9**	345	5.0	2	4	-	6	12	-
		2	6.8	358	7.6						
		3	3.6	370	3.8						
400	2	1	5.2	555	6.4				-	-	-
		2	**7.4**	585	7.6	2.7	11	30			
300	3	1	**4.4**	490	5.0	13.6	41	-			
		2	5.1	510	6.4				2	6	20
		3	5.4	525	6.4						
300	4	1	3.4	480	3.8						
		2	**5.0**	500	5.0	-	-	20	4	12	20

Group gauge = 5.2

56 50 30 40

Total cost increase for: I --> 106 + II --> 70 +

Cost improvement by II 36

Key to the columns in Table 6.1

A = order weight
B = order number
C = alternative route number
D = theoretical gauge required by the route
(bold figures represent selection in single order cse)
(circled figures represent selection by grouping)
E = route cost (based on theoretical gauge)
F = closest standard gauge to the teoretical gauge
I = cost increase as the result of selecting standard gauge
II = cost increase as the result of selecting group gauge
a = extra material required (% of the initial quantity)
b = cost of extra material
c = cost difference for the selected route with the least cost route (on theoretical gauge basis)

Having in mind the need for overall optimisation using the flexibility inherent in process planning, the study of the points mentioned above led to the recognition of the need for batch order process planning. The main objective of the batch order process planning is the optimisation of the process planning for the batch of orders through collecting the orders in a number of groups, while each group is provided with some freedom to efficiently utilise a raw material with the dimensions common among its members. This as a result would increase material yield, improve material stock and mill stock conditions, while preventing an increase in operation costs.

6.3 Grouping the Orders - Two Possible Methods

A batch of orders consists of a number of different types of products each at specified quanties. For each product a number of alternative process routes are produced as the result of the first phase of process planning. Each route specifies the theoretical gauge for the strip material required by that route, the relevant material yield, route relative cost and some other information.

The objective is to divide the products into a number of groups in such a way that each group can utilise the material for which its gauge is the most common (or similar) among the group members. Meanwhile the route operation costs should be taken into account, so that the overall cost optimisation for the batch can be helped. In this problem the products are the objects and each object is characterised by a number of alternative routes, therefore, by a number of variables specified through the routes. Thus, the objective is to group the objects on the basis of the similarities between some of their characterising variables. This is essentially the kind of the problem for which the statistical techniques known as "Cluster Analysis" have been developed. Various cluster analysis methods have been studied. As a result two grouping methods have been developed. The first method which was developed in the initial stages of this project, uses a tree structure search to produce grouping options. This, however, has some similarity with the *partitioning method* of cluster analysis. The second method which is much more fully developed is based on the *linkage method* of cluster analysis. These and other methods of clustering are described below.

The implementation of the two product grouping methods will be discussed in the following two chapters.

6.4 Cluster Analysis

Cluster analysis has been widely employed as an effective tool for data analysis and classification in investigations in various scientific fields such as social sciences, market research, psychology, biology, archaeology etc. Examples of these applications can be found in Everitt (1977) and Anderberg (1973). Concerning manufacturing planning, in recent years, some interest has been shown in the application of a cluster analysis approach to this area, in particular in coding and classification of the parts and group technology applications. Two examples of these applications can be found in Han & Ham (1986), and Mc Auley (1972).

Cluster analysis as defined by Tryon (1970) is "the general logic formulated as a procedure by which we objectively group together entities on the basis of their similarities and differences".

The basis of any cluster analysis is that N objects are measured on p variables. The initial raw data consists of an N by p matrix of measurements say X, where:

$$X = \begin{bmatrix} X_{11} & X_{12} & .. & X_{1p} \\ X_{21} & X_{22} & .. & X_{2p} \\ .. & .. & .. & .. \\ X_{N1} & X_{N2} & .. & X_{Np} \end{bmatrix}$$

and in which X_{ij} is the score on the jth variable for the ith object.

From this matrix, using one of the available techniques, the *similarity (or difference) matrix* is developed. A general form of similarity matrix is as below.

$$S = \begin{bmatrix} S_{11} & S_{12} & .. & S_{1N} \\ S_{21} & S_{22} & .. & S_{2N} \\ .. & .. & .. & .. \\ S_{N1} & S_{N2} & .. & S_{NN} \end{bmatrix}$$

where S_{kl} is the measure of the similarity (difference) between products k and l. This matrix provides the basic data which is used by the relevant clustering technique at different stages in order to group the objects.

Types of Cluster Analysis

Several techniques for cluster analysis have been developed. A broad classification of these techniques suggests the two hierarchical and non-hierarchical types.

A more detailed classification as given by Everitt is as the following.

(i) *Hierarchical Techniques* - In which the classes themselves are classified into groups, the process being repeated at different levels to form a tree.

(ii) *Partitioning Techniques (optimisation)* - In which the clusters are formed by (locally) optimisation of a 'clustering criterion'. The classes are mutually exclusive, thus forming a partition of the set of entities.

(iii) *Density or Mode-seeking Techniques* - In which the clusters are formed by searching for regions containing relatively dense concentrations of entities.

(iv) *Clumping Techniques* - In which the classes or clumps can overlap.

(v) *Others* - Methods which do not fall clearly into any of the four previous groups.

Only the first two of the above techniques were thought appropriate for our purpose and are discussed briefly below.

6.4.1. Hierarchical Clustering Techniques

Hierarchical methods can be divided into two kinds: agglomerative and divisive. In agglomerative methods the clustering procedure begins with N clusters and the clusters are succesively joined to finally form, one cluster.

There are three basic agglomerative methods. These are:

i. Linkage methods
ii. Centroid methods
iii. Error sum of squares methods

Differences between methods arise because of the different ways of defining distance (or similarity) between an individual and a group containing several individuals, or between two groups of individuals.

All the agglomerative methods consists of the following two stages.

Stage I). Search the similarity matrix for the most similar pair of clusters (a cluster can consist of only one item). These are just the two for which distance between them is the minimum (the two nearest neighbours). Let the chosen cluster be labelled 'p' and 'q' and let their associated similarity be 'S_{pq}'.

Stage II). Reduce the number of clusters by one through merging the clusters 'p' and 'q'. Label the new cluster 't' and update the similarity matrix items in order to reflect the revised similarities between cluster 't' and all existing clusters, putting 't' in place of 'q' in the similarity matrix. Delete the row and column pertaining to cluster 'p'.

The criteria of similarity and the method of updating the matrix are different for each of the different methods but the two stages form the basis.

In the divisive methods the items all begin in one cluster which is succesively divided into smaller clusters.

Both types of hierarchical techniques may be viewed as attempts to find the most efficient step, in some defined sense, at each stage in the progressive synthesis or subdivision of the population.

Single Link Method

The single link method, also called the 'nearest neighbour method', is comparatively simple and one of the most commonly used techniques of clustering. For this method the distance between groups is defined as the distance between their closest members. Consequently this method leads to clusters in which each item is nearer to another member of its own cluster than it is to any item in any other cluster.

This method follows Stages I and II as stated above, but uses the two following definitions.

i. The criterion of similarity - which is defined as the distance between the two closest members of any pair of clusters.
ii. Method of updating the similarity matrix - which uses the formula below to calculate the similarity between the new cluster (t) and any other object (r).

$$S_{tr} = \min(S_{pr}, S_{qr})$$

This completes the first pass and there are now (N-1) clusters. Altogether (N-1) passes are to be done and after this all the objects are in the same cluster. Alternatively, the clustering can be stopped at any stage in accordance with any given termination condition.

Complete Link Method

This method also called the 'furthest neighbour method', is very similar to the single link method, but here the distance between groups is defined as the distance between their most remote pair of individuals. Accordingly the two stages (i.e. Stage I and StageII) are the same as for the single link method except the formula used to update the similarity matrix which is:

$$S_{tr} = \max(S_{pr}, S_{qr})$$

Average Link Method

This method is similar to the single link method except that the similarity matrix should be updated so that it gives the sum of the distances between all the objects in one cluster and in another. The general rule for updating the similarity matrix when we merge clusters 'p' and 'q' to form cluster 't' is:

$$S_{tr} = S_{pr} + S_{qr}$$

Any calculated sum of differences is to be divided by the total number of distances involved in order to obtain the average distance. Average distances are then compared to select the two most similar clusters.

Centroid Method

By this method, when any two objects (or clusters) are merged, the new cluster thus formed is designated by its centroid. Different weighting methods can be used for the calculation of the centroids.

In this method the similarity matrix is scanned in the euclidean distance between the centroids of the clusters formed at each stage. The two clusters with the smallest distance are then merged. The matrix is then updated. The updating formula depends on what method is used for calculating the position of the centroid.

Error Sum of Squares Methods

This method works on the principle of forming clusters which increase the total within cluster error sum of squares (ΔE_{pq} for clusters p and q) as little as possible. Therefore in the stage I the similarity matrix is to be converted to a matrix of ΔE_{pq}. In Stage II an appropriate formula is used to update the similarity matrix.

Divisive Hierarchical Methods

Using divisive methods, all the objects are first assumed to be in one cluster. Then this is successively divided into smaller clusters, until the required number of clusters is achieved. By this method, at each step the cluster is divided into two clusters so as to maximise the distance between the two clusters.

Divisive methods can be classified into two types: *monothetic*, which are based on the possesion or otherwise of a single specifed attribute, and *polythetic*, which are methods based on the values taken by all the attributes.

In the polythetic type a splinter group is utilised. The splinter group is accumulated by sequential addition of the entity whose total dissimilarity with the remainder less its total dissimilarity with the splinter group is maximum. When the difference becomes negative the process is repeated on the two sub-groups.

Divisive methods are computationally inefficient and in particular impractical for a large set of data. This is due to the large number of possibilities of dividing a given set of objects into two clusters. The number of alternatives to be considered is $2^{N-1} - 1$.

This method does not guarantee an overall optimal solution as it is based on local optimisation (like most of the hierarchical methods).

6.4.2 Partitioning Techniques

These techniques are based on attempts to partition the set of entities so as to optimise some predefined criterion. Most of these techniques begin the clustering with an initial partitioning of the data. This is done in one of two ways, either by dividing the p-dimensional space into sections and letting all the objects in one section form a cluster or by choosing 'seed points' and putting each in the cluster whose seed point is the nearest to it. In general most of the partitioning techniques employ three distinct procedures, which are as follows:

(a). A method of initiating clusters;
(b). A method of allocating entities to initiated clusters;
(c). A method of reallocating some or all of the entities to other clusters once the initial classificatory process has been completed.

The difference between the techniques lies primarily in (a), and (c).

The greatest advantage of these methods over hierarchical types is that they admit relocation of the entities, thus allowing poor initial partitions to be corrected at a later stage.

6.5 Selection of the Most Suitable Clustering Technique

The question of which is the best method for a particular application can be defined in two ways: either the best clustering *mathematically* or the best *practically* .

Mathematical Criteria

The mathematically best clusters can only mean global optimum clustering according to the criterion used in the method under investigation. This implies selection of the techniques which utilise total enumeration procedures. Some partitioning techniques claim to cover total enumeration. However, one major problem of these types of the clustering techniques is that they are extremely expensive from the computational point of view. Therefore they are impractical for relatively large amounts of data.

Practical Criteria

Solomon (1971) has shown on one set of data that most of the methods available lead to very similar results. Perhaps one obvious implication of this is that as a start the best method to use is the simplest and the cheapest.

The problem of grouping the rolled products, as it is detailed in Chapter 8, in fact can be reduced to a problem of one-dimensional cluster analysis, where material gauge is the only variable which (together with the associated costs) characterises the objects. This reduction of the problem to one dimension greatly reduces the complexity of the similarity calculations. That is, one dimensional measurement would be sufficient and there is no need for euclidean geometry in multidimensional space. This simplification implies that some of the simple clustering techniques can work as efficiently and accurately as some complicated procedures would do.

When two products are joined into one group, one of the products acts as the head of the group (P_h) while the other product is just a member of the group (P_m). Then the gauge for the group-head is taken as the gauge for the whole group. This predetermined procedure for group-gauge calculation eliminates the need for the use of the centroid methods or any clustering technique somehow based on centroid calculations.

Any divisive method initially divides the objects into two groups, then proceeds with further dividing each group into two sub-groups until a satisfactory grouping is obtained. This is not applicable in this particular work because, due to a maximum preset range for the theoretical material gauges, initial division of the products into just two groups is almost impossible. Another problem associated with this technique arises from the very large number of possibilities of the division of 'N' object into two groups, which is equal to 2^{N-1} -1. This makes the technique very expensive.

An advantage of the hierarchical methods is that once two items are joined together in a cluster they are there permanently and there is no need to consider their position at subsequent levels. This greatly cuts down the number of clustering possibilities to be considered, which can be a problem in other methods. This can also be considered as a disadvantage of these methods, as it could lead to a suboptimal result.

From the above discussion it can be concluded that among the clustering techniques the linkage methods, in particular the Single Link Method best suits our purpose for the grouping of the products. The Single Link method is comparatively simple and cheap. It is in fact the basis for many of the other techniques. This method also provides sufficient flexibility for the use of particular ways of calculating group gauges.

The application of the single link technique to the order grouping problem with which we are concerned has shown satisfactory results.This application will be discussed in Chapter 8.

6.6. Numerical Example - Linkage Method

Suppose five individuals are to be classified, and the matrix of similarity (distance) between the individuals, namely S, is as follows:

S 0 similarity matrix

	1	2	3	4	5
1	-	-	-	-	-
2	3	-	-	-	-
3	8	5	-	-	-
4	9	7	4	-	-
5	10	9	8	6	-

Originally, five clusters are assumed as shown in the table below.

cluster no.	1	2	3	4	5
contents	1	2	3	4	5

PASS 1

Stage I

Find the two most similar clusters. The smallest distance in the original similarity matrix is '3' so clusters '1' and '2' merge to make a new cluster '6' (p=2, q=1 and t=6).

cluster no.	3	4	5	6
contents	3	4	5	1, 2

Stage II

Compute the new matrix. Those clusters not affected by the merger are taken straight from the last table. For the new cluster:

$$S_{tr} = \min(S_{pr}, S_{qr})$$

$$S_{6r} = \min(S_{1r}, S_{2r})$$

This must be calculated for r=3,4, and 5.

$$S_{63} = \min(S_{13}, S_{23}) = \min\ (8, 5)\ \ = 5$$

$$S_{64} = \min(S_{14}, S_{24}) = \min\ (9, 7)\ \ = 7$$

$$S_{65} = \min(S_{15}, S_{25}) = \min\ (10, 9) = 9$$

The new similarity matrix and the clusters are given below.

S1 similarity matrix

	6	3	4	5
6	-	-	-	-
3	5	-	-	-
4	7	4	-	-
5	9	8	6	-

PASS 2

Stage I

Find the two most similar clusters. The smaller distance in the matrix is 4, so clusters '3' and '4' merge to make a new cluster '7' (p=4, q=3 and t=7).

cluster no.	5	6	7
contents	5	1, 2	3, 4

Stage 2

Compute the new similarity matrix. S_{tr} for ' r=5, 6' must be calculated.

$$S_{76} = \min(S_{46}, S_{36}) = \min(7, 5) = 5$$

$$S_{75} = \min(S_{45}, S_{35}) = \min(6, 8) = 6$$

S 2 similarity matrix

	6	7	5
6	-	-	-
7	5	-	-
5	9	6	-

PASS 3

Stage I

The most similar clusters are '6' and '7' which merge to make cluster '8'. That is p=7, q=6 and t = 8.

cluster no.	5	8
contents	5	1, 2, 3, 4

Stage 2

Compute the new similarity matrix.

$$S_{85} = \min(S_{75}, S_{65}) = \min(6, 9) = 6$$

S 3
similarity matrix

	5	8
5	-	-
8	6	-

PASS 4

This is the (n-1)th pass (where n is 5), and result is all the objects has been grouped in one cluster.

cluster no.	9
contents	1, 2, 3, 4, 5

6.7. Summary

Flexibility of manufacturing planning and its use for some overall optimisation purpose has been considered by many researchers. Such flexibility exists in the planning of rolling mill operations, where a number of alternative routes can be usually determined for the production of the products. Since different alternative routes provide different utilisation of manufacturing resources, use of an appropriate combination of the routes for the orders in a batch could lead to the optimistion of the batch on some particular criteria. Grouping the orders on the basis of the similarity of their material gauges, whilst aiming to optimise total cost for the batch is an example of such a broader optimisation objective.

Various methods including cluster analysis techniques, have been considered for this order grouping problem. Two methods have been developed. Method I, which is based on a search technique and a procedure for the evaluation of the groups will be detailed in the next chapter. Method II, which is based on the linkage technique of cluster analysis has been found much more suitable for this grouping problem. The implementation of this method will be detailed later in Chapter 8.

CHAPTER 7

ORDER GROUPING FOR BATCH ORDER PROCESS PLANNING -- METHOD I

7.1. Introduction

Batch order process planning was discussed in the previous chapter. A major requirement for this process planning option, apart from the planning capabilities, is the grouping of the orders in such a way that each group can use a gauge common among the orders in the group. The whole grouping process is required to minimise both the number of the groups (producing heavier groups) and the overall route cost for the batch.

As mentioned earlier in the previous chapter, two grouping methods have been developed in conjunction with this project. The methods are namely *Method I* and *Method II*, the first method is detailed in this chapter and the other method will be described later in Chapter 8.

A typical batch of orders has been selected for the purpose of demonstrating the above methods. The values of the parameters for this batch are typical practical cases. The batch (named "batch 1") consists of 10 products each with a number of alternative routes. The essential process planning data required for the grouping of these orders is given in Table 7.1. The table indicates the gauge theoretically required for each particular route (i.e. Theoretic. Gauge), and the maximum limit of the gauge economically feasible for that route (i.e. Max Gauge). The "Yield Rel Cost" in this table represents the cost of extra material utilised by each route compared with the route with the maximum yield. Similarly the columns for "Op Rel Cost" and "Route Rel Cost" represent the difference of each cost compared with corresponding minimum cost situation. The batch considered in this sample consists of orders with different weights, two of which, i.e. order number 1 and order number 10 are comparatively very heavy.

When a batch is planned in single order process planning (SOPP) situation, as discussed in the previous chapter, because of the variety of the gauges and the weight for the orders being low, some standard gauges have to be utilised. Therefore, although an optimal route can be selected for each order, the route costs and the overall cost for the batch will be much higher than the theoretical gauge situations. Major data for the above batch (Batch 1) in SOPP situation is summarised in Table 7.2. It can be seen from this table that resulting yields for selected routes are much lower and their costs are higher compared to the corresponding theoretical figures. For instance, in the above example the overall batch yield is 0.83, which shows nearly 4% reduction and the overall cost compared with the theoretical situations has increased by 459. This table will be used for the comparison of the grouping results in both the methods.

Table 7.1. Route data for Batch Number 1

Order No. (Weight)	Route No.	Theoretic Gauge	Max Gauge	Matl. yield	Yield Rel Cost	Op Rel. Cost	Route Rel. Cost
1 (1200)	1	5.15	5.60	0.91	0	0	0
	2	4.62	5.10	0.90	11	0	11
	3	4.79	7.60	0.84	100	0	100
	4	10.0	10.0	0.84	100	15	115
	5	5.13	5.50	0.91	0	60	60
	6	6.45	7.60	0.80	150	60	210
2 (281)	1	4.39	4.89	0.91	0	0	0
	2	3.80	7.60	0.82	34	0	34
	3	5.00	5.40	0.91	0	20	20
	4	3.79	7.60	0.83	30	20	50
3 (500)	1	5.90	6.10	0.88	0	0	0
	2	4.80	5.15	0.88	0	20	20
	3	6.17	7.60	0.79	65	40	105
4 (427)	1	5.38	5.79	0.87	0	0	0
	2	4.90	5.30	0.87	0	20	20
	3	5.81	7.60	0.79	50	40	90
5 (220)	1	5.30	5.64	0.91	0	0	0
	2	9.80	10.0	0.84	55	20	75
6 (439)	1	5.88	6.31	0.87	0	0	0
	2	5.80	6.20	0.87	0	20	20
	3	5.87	7.60	0.79	64	40	104
7 (283)	1	6.00	6.73	0.87	0	0	0
	2	5.10	5.43	0.87	0	0	0
	3	6.00	6.56	0.87	0	20	20
	4	9.65	10.0	0.79	33	45	87
8 (220)	1	5.20	5.89	0.91	0	0	0
	2	4.33	4.85	0.89	5	0	5
	3	4.49	7.60	0.84	20	0	20
	4	9.70	10.0	0.84	20	5	25
	5	5.20	5.89	0.91	0	20	20
	6	5.23	7.60	0.83	23	20	43
9 (300)	1	2.80	3.10	0.88	0	0	0
	2	5.25	5.70	0.88	0	0	0
10 (900)	1	7.40	7.60	0.88	0	0	0
	2	5.80	6.20	0.88	0	0	0

Table 7.2. Data for the routes planned for the batch in single order process planning situation

		A	B	C	D	E	F	H
order number	route number	theoretical gauge	route original yield	route rel. cost	nearest std gauge	new yield	cost of gauge diff.	cost for this selection
1	2	4.62	0.90	11	5.00	0.83	109	120
2	2	3.80	0.82	34	3.80	0.82	00	34
3	2	4.80	0.88	20	5.00	0.84	23	43
4	2	4.90	0.87	20	5.00	0.85	10	30
5	2	9.80	0.84	75	10.00	0.82	5	80
6	1	5.88	0.87	00	6.40	0.80	45	45
7	1	6.00	0.87	00	6.40	0.82	22	22
8	4	9.70	0.84	25	10.00	0.81	8	33
9	1	2.80	0.88	00	3.00	0.82	24	24
10	1	7.40	0.88	00	7.60	0.86	28	28
Results for the batch:							total	459

number of gauges utilised = 5
overall yield for the batch = 0.83 or 83%
overall cost increase for the batch = 459

$H = F + C$
$F = [((D-A)/A))x(W/B)]xUc$

where,
W = order weight
Uc = material unit cost (and assuming Uc = 1)

7.2. Description of the Method (Method I)

The principal idea for this method is to consider each theoretical gauge, which is specified for a route, as a grouping seed and collect as many orders (or as much weight) as possible in that group. Then, evaluate these groups in order to select those which are optimal in accordance to some given criteria. The implementation of the above idea has been accomplished through the use of a search procedure combined with a method for the evaluation of the groups. These are discussed below.

7.2.1. The Search Procedure

The overall search procedure is depicted in Fig. 7.1. The search starts with selecting one order from the batch, for which then a route is selected. The gauge for this route is considered as the gauge for the current group. The search then proceeds through various loops in order to select, in turn, other orders and their alternative routes, evaluating their suitability for joining to the current group. Whenever a case is successful, the corresponding order is grouped using its selected route and then the group data is updated accordingly. Having tried all the orders for the current gauge, then, the procedure is repeated for other routes for the currently selected order. When the routes for this order is complete, the whole process is then repeated for other orders in the batch. At this stage, the first pass of the search is complete and the groups so produced have to be evaluated and compared on the basis of some appropriate criteria before an optimal group for this pass can be determined. The method of the evaluation of the groups will be discussed later in the following sections.

Having selected the optimal group for the first pass, the batch is updated; that is, orders already included in the above optimal group are discarded from the batch list. The above grouping procedure is then repeated for the rest of the batch. Repetition of the whole process is then continued until every order in the batch is grouped or alternatively an exit condition is satisfied.

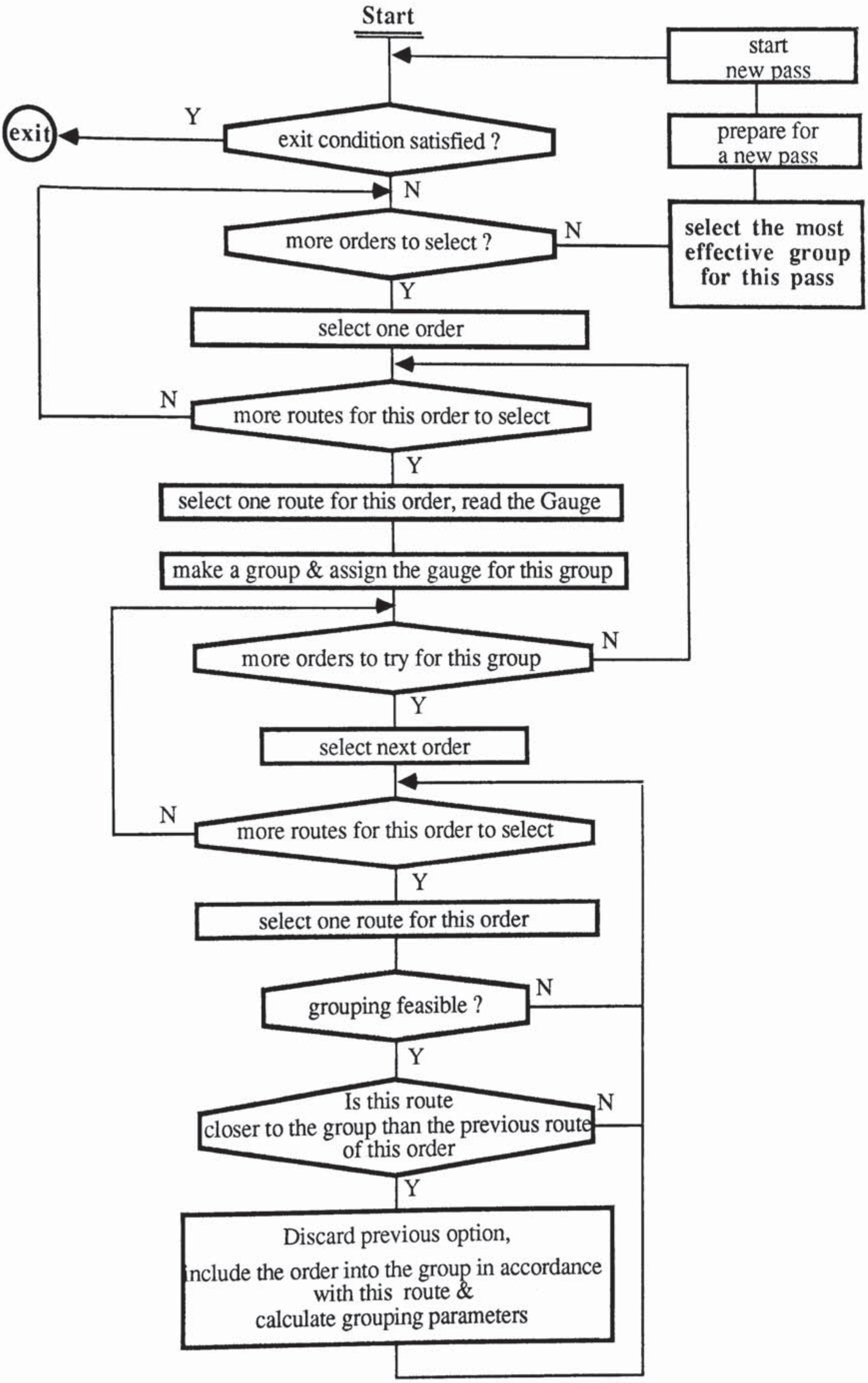


Fig. 7.1. Overall structure of Method I of order grouping

7.2.2. Method for the Evaluation of the Groups

The development of the criterion for the evaluation of the groups has been accomplished in 3 stages as described below.

Stage1.

The method of evaluation at this stage is purely based on the weights collected into the groups. This is the most simple form of the method, but in practice, not a satisfactory one. However, it was used to study some characteristics of the problem.

Results of the application of this method for Batch 1 are given in table 7.1. This shows that the grouping, although very good with regard to the weight factor, is very poor with respect to cost and material yield criteria. Material yield (0.80) and the overall cost increase (718) in this case are even worse than those found in the single order process planning situation. This stage, however, highlights the need for the inclusion of the yield and cost factors in the evaluation technique.

Stage2

This stage is designed to study the effect of the introduction of material yield factor in the evaluation method. Here, groups are evaluated in accordance with both their total weight and yield. The result as shown in Table 7.3-(b) is far better than the previous stage. In particular the yields are very good. Overall yield (0.875) and total cost increase for the batch (189) also indicate some improvements compared with the single order process planning situation.

A major problem with the method at this stage is that some routes with higher operation costs can be equally selected for the groupings, therefore could increase the costs. An example of this problem is the selection of Route Number 5 for Order Number 1 (i.e.

Route 1-5) in the second group whereas the operation cost for this route, as shown in Table 7.1. is very high (60). Two of the other routes, i.e. route 3-2 and 4-2 in the same group also increase the operation cost, and therefore the route cost for the group.

Stage3

The method for this stage is improved by including the route cost factor in the evaluation criteria. Since route cost also represents both the original yield and the operation cost for the route, this can replace the two factors in the above criteria. Group weight is the other factor which has to be considered in these criteria. These two factors are combined to form an indicator of the efficiency of the groups which we shall call the *group efficiency index*. We define this as:

$$Eg = Wg\,(M) - Cg$$

where,

Eg = Group Efficiency Index

Wg = Group Weight

M = Credit or Mark given for the weights collected into the group (on a percentage base, say 3% of the group weight)

Cg = Group Cost (or group cost increase)

The value for M, which considerably affects the grouping results, has to be selected with respect to the overall planning policy.

The development at this stage is the complete form of the method for the evaluation of the groups which has been incorporated into Method I for grouping. Results of the use of this method for Batch Number 1 is shown in Figures Table 7.3. (c-1 and c-2). where, the values of M for these two tables are 3% and 4% respectively.

Both these results indicate improvement in the grouping. For instance, Table (c-1) shows that the cost has been considerably improved compared to the result for stage 2.

Table 7.3. Results for the application of Method I on Batch No. 1 -- for various stages of the development of the group evaluation method.

(a)

Group No.	Group Members 'Order-no' - 'Route-no'	Group Data					
		Gauge	Weight	Matl-weight	Yield	Op-cost	Total cost
1	3-3, 1-1, 2-3, 4-3, 6-1, 7-1, 8-3, 10-2	6.17	4250	5405	0.79	100	715
2	5-1, 9-2	5.30	520	585	0.91	0	3
Total Batch: Number of the Groups = 2,				Yield =	0.80	Cost =	718

(b)

Group No.	Group Members 'Order-no' - 'Route-no'	Group Data					
		Gauge	Weight	Matl-weight	Yield	Op-cost	Total cost
1	2-1, 8-2	4.39	501	559	0.90	0	8
2	1-5, 3-2, 4-2, 7-2	5.13	2410	2766	0.87	100	64
3	6-1, 10-2	5.88	1339	1541	0.87	0	14
4	5-1, 9-2	5.30	520	585	0.89	0	3
Total Batch: Number of the Groups = 4,				Yield =	0.875	Cost =	189

(c-1)

Group No.	Group Members 'Order-no' - 'Route-no'	Group Data					
		Gauge	Weight	Matl-weight	Yield	Op-cost	Total cost
1	2-1, 8-2	4.39	501	559	0.90	0	8
2	9-2, 1-1, 4-2, 7-2	5.25	2210	2545	0.87	20	90
3	3-1, 6-1, 10-2	5.90	1839	2114	0.87	0	19
Total Batch: Number of the Groups = 3 one single order (order no. 5)				Yield =	0.872	Cost =	117

(c-2)

Group No.	Group Members 'Order-no' - 'Route-no'	Group Data					
		Gauge	Weight	Matl-weight	Yield	Op-cost	Total cost
1	1-2, 2-1, 8-2	4.62	1701	1922	0.88	0	48
2	4-2, 3-2	4.90	927	1070	0.87	40	51
3	6-1, 10-2	5.88	1339	1541	0.87	0	14
4	5-1, 7-2, 9-2	5.30	803	923	0.87	0	16
Total Batch: Number of the Groups = 4,				Yield =	0.874	Cost =	129

While material yield is almost unchanged. Three groups have been resulted and Order Number 5 is left ungrouped. This, however, is not much different from the four group situation produced in the previous stage.

Results given in Table 7.3.(c-2) shows a slightly increase in the cost (129 against 117) and some replacements in the groups. There are four groups in this case instead of three groups and a single order in the previous case. This however does not represent much difference, but it indicates the sensitivity of the method with respect to the values assigned to the policy factor ' M'.

7.2.3. Grouping Parameters

Assuming the gauge for the jth route of the ith order selected as the grouping gauge (grouping seed), parameters for different states of this group are described below. This group is represented by G_s , where 's' stands for group number.

Notation

g_s = group number s
Gg_s = gauge for group number s
Gg_{s0} = gauge for group number s at state 0
Gg_{sn} = gauge for group number s at state n
Gp_{ij} = gauge for route j of order i
Wp_i = weight of product i
Ωg_{sn} = material weight for group number s at state n
Ω_{ij} = material weight for order i based on route j
Yg_{sn} = Yield for group s at state n
Y_{ij} = Yield for route j of order i
$Copg_{sn}$ = cost of operation for group s at state n
Cop_{ij} = cost of operation for order i based on route j
$Crtg_{sn}$ = route cost for group s at state n
Crt_{ij} = route cost for order i based on route j

Initial state (State 0)

group gauge $= Gg_{s0} = Gp_{ij}$

group weight $= Wg_{s0} = Wp_i$

group material weight $= \Omega g_{s0} = \Omega_{ij}$

where, $\Omega_{ij} = Wp_i / Y_{ij}$

group yield $= Yg_{s0} = Y_{ij}$

group operation cost $= Copg_{s0} = Cop_{ij}$

group route cost $= Crtg_{s0} = Crt_{ij}$

When another order, say P_k joins this group in accordance to, say its lth route (Rt_{kl}), then the above parameters are updated for this state of grouping (state 1) as below.

Grouping State 1

group gauge $= Gg_{s1} = Gg_{s0} = Gp_{ij}$

group weight $= Wg_{s1} = Wg_{s0} + Wp_k$

group material weight $= \Omega g_{s1} = \Omega g_{s0} + \Omega_{kl} + \Omega_e$

where, $\Omega_{kl} = Wp_k / Y_{kl}$

and Ω_e $= ((G_{ij} - G_{kl}) / G_{kl})\, \Omega_{kl}$

group yield $= Yg_{s1} = Wg_{s1} / \Omega_{kl}$

group operation cost $= Copg_{s1} = Copg_{s0} + Cop_{kl}$

group route cost $= Crtg_{s1} = Crtg_{s0} + Crt_{kl} + Ce$

where, Ce $= (\Omega_e)(U_c)$

Further states of the group

The above procedure is repeated for further states of the group until the final state is produced. Then the same procedure is repeated for other groups initiated at different stages of search procedure.

Groups so produced are then evaluated in accordance to their group efficiency index values, as discussed in the previous section.

7.2.4. The Total Number of the Grouping Search Attempts Required

Assuming that Rt_{i1} (Route Number 1 for P_i) is selected as the grouping seed point, then the group is called $Group_{i1}$ and the maximum number of the search attempts required for this group during the first pass is:

$$S_{i1} = \sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij} - \sum_{j=1}^{j1} S_{ij}$$

where j is the number of the alternative routes for order i. By expanding this to all the routes for product i, we have

$$S_i = \sum_{j=1}^{j1} \left(\sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij} - \sum_{j=1}^{j1} S_{ij} \right)$$

Then by expanding S_i to all routes for all the orders we have

$$S_{p1} = \sum_{i=1}^{I} \Big(\sum_{j=1}^{j1} (\sum_{i=1}^{I} \sum_{j=1}^{J} s_{ij} - \sum_{j=1}^{j1} s_{ij}) \Big)$$

The maximum number of possible groups produced during the first pass is equal to the total number of the different gauges specified by the process routes.

For the second pass and other succeeding passes the number of search attempts reduce considerably. This is because the orders already grouped in the previous passes are not present in the order list for the current pass.

7.3. Concluding Summary

The method described in this chapter, i.e. Method I, was developed at the initial stages of the batch order process planning development for the purpose of order grouping. The method consists of a search procedure and a method of evaluation of the grouping options in order to determine the optimal group at each pass of the search.

Various stages of the development of the grouping evaluation technique used in Method I of batch order grouping were reviewed. The advantages of the final version of the method over initial versions and the single order process planning situation were demonstrated. This method was tested on several situations of real industrial data and the results were good. The criterion used in the evaluation method uses a parameter called the group efficiency index which represents both group weight and cost for the grouping. That is:

$$Eg = Wg\,(M) - Cg$$

where,

Eg = Group Efficiency Indicator
Wg = Group Weight
M = Credit or Mark given for group weight on percentage basis.
Cg = Grouping cost

In the above relation, M is a policy factor which is used to establish the relative importance of the weight against the cost.

The method has been tested on different order grouping situations and gave good results. However, the method is sensitive with regard to the values assigned for M. This can be considered as a practical problem for the method, as different values for the factor might be suitable in different grouping situations.

The level of optimisation achieved is another problem. This is because groups are optimised locally for each grouping pass. This however, can be greatly improved by considering a number of best groups, say three best groups, instead of the best group for each pass. This of course would increase the grouping time and could make the method expensive.

Many of these problems were overcome by the development of Method II, which uses a cluster analysis technique and is discussed in the next chapter. The same chapter will also discuss the comparison of two methods.

CHAPTER 8

ORDER GROUPING FOR BATCH ORDER PROCESS PLANNING -- METHOD II (A CLUSTER ANALYSIS TECHNIQUE)

8.1. Introduction

Batch order process planning as discussed in Chapter 6 requires a method of order grouping to divide the orders into a number of batches in such a way that each group can use a gauge common among the orders in the group. Two methods of order grouping namely: Method I and Method II have been developed in this project from which Method 1 was discussed in the previous chapter.

Method II is detailed in the current chapter. Performance of the method has also been demonstrated using a sample data. This is the same data as used for Method I in the previous chapter. The reader may refer to this in Tables 7.1 and 7.2. in Chapter 7.

8.2. Product Grouping - Method II

This method is mainly based on the *linkage technique of cluster analysis*. It groups the orders on the basis of the similarities of their routes. The method, however, differs from the classical cluster analysis techniques mainly in the definition of the *distance* (or similarity) and the *updating procedure.*

The method uses a search procedure in order to produce various possible options of grouping at different passes of clustering before an optimal group can be determined for each pass. This procedure as shown in Fig. 8.1. consists of several loops which enable a very large field of options to be examined. In this procedure initially each route in the batch, in turn, is given the opportunity to use its gauge as the group gauge and try to attract other routes, therefore, to produce different grouping options. When all the routes are tried in this way the best group is then selected based on the given criteria for the most similarity or the least distance for the grouping. The batch is then updated, and the above procedure is repeated until an exit condition is satisfied.

The development of this method, with regard to the definition of the distance, has mainly been accomplished through five stages. In the first stage route gauge is the only product feature used in the measurement of the similarity between any two products and the construction of the similarity matrix. Then during each succeeding stage one more feature has been incorporated until all the influential features are included in the final stage. These stages are detailed in the sections below in which the following notations have been used:

Notation

Gg_k = Gauge for group k
Wg_k = Weight for all orders in group k
Ωg_k = Weight of material for group k
Yg_k = Yield for group k
Cg_k = Cost for group k
Gp_{ij} = Gauge for route j of order i
Wp_i = Weight for order i
Ωp_{ij} = Weight of material for route j of order i
Yp_{ij} = Yield for route j of order i
Cop_{ij} = Operation cost for route j of order i
Cr_{ij} = Route cost for route j of order i
D_{kij} = Distance between group k and route j of order i
Dc_{kij} = Distance on the cost basis between group k and route j of order i
Uc = Unit cost of material

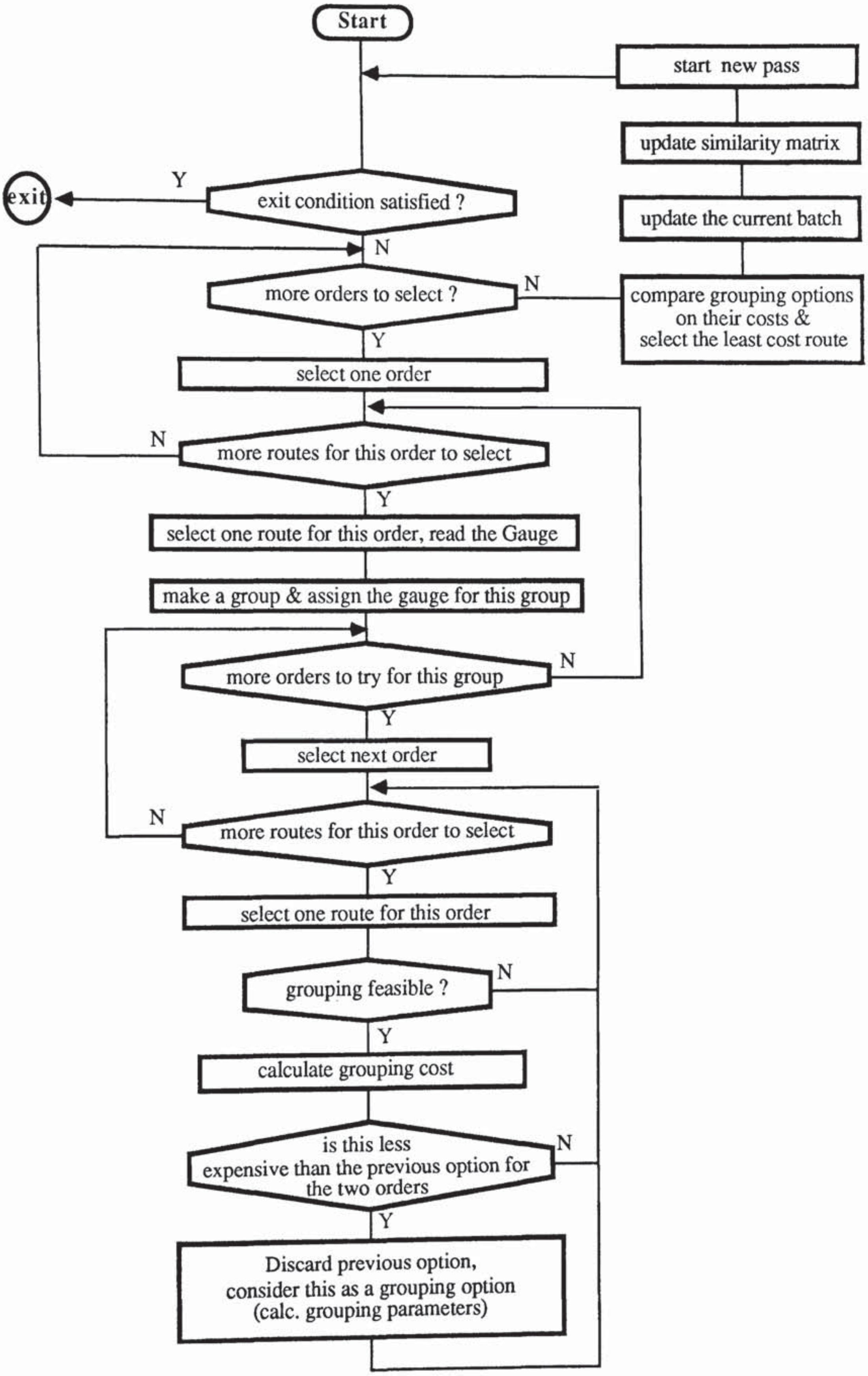


Fig. 8.1. Overall structure of Method II of order grouping

8.2.1. General Definitions

A number of new terms have been used in the following sections, definitions of which are given below.

1. Product gauge (route gauge) - The gauge as specified by the selected route for the product .

2. Product yield (route yield) - The yield as specified by the selected route for the product.

4 Group - A group is composed of a number of individual orders and/or groups. Any group collected into another group is considered as a single product for that group. When two products are merged into one group, one of the products is named the *group head* and the other product the *member product..*

5 Group gauge - The gauge for the group head (which is the gauge for its selected route) is selected as the gauge for the group.

6. Group weight - This is the total weight of the products collected into the group.

7. Group material weight -This is the total material weight required by the products collected into the group utilising the group gauge.

8. Group yield - This is: "group weight" divided by "group material weight"

9. Grouping cost - This is the cost of grouping (decision making cost) at each pass of the clustering.

10. Group cost - This is the total cost accumulated in any group as the result of the collection of the members into that group.

11. Number of the groups - Total number of the groups into which the batch is divided.

12 Distance - This definition differs for different stages of the method development and therefore will be defined at each stage.

8.2.2. Development of the Clustering Method - Stage1

The most simple form of the distance definition was used in this initial stage, which is described below.

Distance

Here the distance is defined as the gauge difference between the group and the member product which is joining the group. The gauge for the member product is the gauge for its selected route for this grouping.

$$D1_{kij} = Gg_k - Gp_{ij}$$

where,

$D1_{kij}$ is the gauge distance between "jth route for the ith order" and the kth group as measured for stage 1 of the method development.

Group weight

$$Wg_k = \Sigma\ Wp \qquad \text{(for the orders collected into the group k)}$$

Group material weight

$$\Omega g_k = \Sigma\ \Omega p \qquad \text{(for the orders collected into the group k)}$$

Group yield

group yield = (group weight) / (group material weight)

or

$$Yg_k = (Wg_k)/(\ \Omega g_k)$$

Updating

The updating process consists of the following steps.

i. Group data is calculated and assigned to the group.

ii. The produced group is assumed as a new (hypothetical) order with the type 'g' ('g' stands for group) for which a code number is issued. This is then included in the list of orders.

iii. A hypothetical route with the relevant data is generated for the new order.

iv. The similarity matrix is updated according to the data for the new order (using the distance as defined for this stage).

v. The two head and member products together with their original routes are deleted from the relevant matrices.

Example 8.1

In this example the above method has been applied in order to group the given batch of orders. The resulting dendrogram and the clustering data are shown in Fig. 8.2. These indicate reasonable distances, for the clustering steps which start from a minimum (i.e. 0.01) and increase through the steps. However, there were some problems with the method used in this example. These are discussed below.

Problems

Three types of problem were found with this method:

(i) weight problem

(ii) yield problem

(iii) route cost problem

The first type is selected to be discussed in this section and the solution will be suggested in the next section. Then each of the other two types will be studied through the succeeding sections.

Weight problem

In any grouping, the gauge for the group is either equal to or larger than the gauge required by the product (for the selected route). When it is greater, it results in some extra material allocation the magnitude of which depends on both the gauge difference and the weight of the product joining the group. This implies that both gauge difference and weight of the product have to be considered in the distance calculation. However, the method at this stage does not cater for the weight factor, therefore it can not be satisfactory. This problem is shown in the above example as the two heavy orders (Order 1 and Order 10) have joined a group with a greater gauge during the initial stages of clustering.

8.2.3. Development of the clustering method - Stage2

Here as a solution to the problem discussed for Stage 1, the distance is defined as: the extra material required for moving a product (a member product) into a given group. That is:

$$D2_{kij} = ((Gg_k - Gp_{ij})/Gp_{ij})\ \Omega p_{ij}$$

where,

$D2_{kij}$ is the extra material required as the result of using Gg_k (group gauge) for the ith product of this group selecting jth route of this product.

$$\Omega p_{ij} = Wp_i/Yp_{ij}$$

therefore

$$D2_{kij} = ((Gg_k - Gp_{ij})/Gp_{ij})(Wp_i/Yp_{ij})$$

or

$$D2_{kij} = (Wp_i\ (Gg_k - Gp_{ij}))/(Gp_{ij} x Yp_{ij})$$

Other definitions for this stage are the same as for Stage 1.

Example 8.2

Here we use the method developed at this stage for the purpose of the grouping the above batch. The resulting data and the dendrogram are given in Figure 8.3. From this figure it can be seen that the weight problem has been reduced. Now Product 1 has become the head for Group 103 and will use its own theoretical gauge for its selected route. Product 10 is still a member product, but it has moved from Pass 1 to Pass 3.

Problems

The two problems of yield and route cost, from the above three types of problem, are still present. Here we discuss the yield problem first. As a result of the distance definition for stage 1 or stage 2, provided that the gauges specified by two different routes for any product are the same, no matter what the yield is, both routes will have equal chance for being selected for grouping. Therefore, although one major objective is material yield improvement, in many cases routes with lower material yield might get selected. Examples for this problem are the selections of Route 3 for Product 4 with yield 0.79, and Route 6 for Product 8 with yield of 0.83, yields which are much lower than those from other routes for the corresponding products.

8.2.4. Development of the clustering method - Stage3

As a solution to the yield problem discussed in the previous section, at this stage a "second level of distance" is defined. This distance is to represent a comparative yield factor. We select the highest yield for each product as the origin for its yield comparison. Then from "yield difference" the extra material required to compensate for each yield difference is calculated. Therefore the "yield distance (Dy_{kij})" is defined as the weight of the material required to compensate for the selection of a lower yield route for any product.

$$Dy_{kij} = W_i(1/Yp_{ij} - 1/Yp_{ij'})$$

Here j' refers to the route with the highest material yield.

The distance to be used in grouping is the sum of the gauge distance and the yield distance. That is:

$$D3 = D2_{kij} + Dy_{kij}$$

substituting $D2_{kij}$ and Dy_{kij} we have

$$D3 = ((Gg_k - Gp_{ij})\ Wp_i)/(Gp_{ij}\ Yp_{ij}) + W_i\ (1/Yp_{ij} - 1/Yp_{ij'})$$

Other definitions for this stage are the same as for stage 2.

Example 8.3

Results for this stage of the method are given in Figure 8.4. These indicate that the yield problems are now eliminated. Here, route 2 with 0.87 yield is selected for Product 4 and this is much better than the selection in the previous stage for which the yield was 0.79.

Similarly for Product Number 8, Route Number 6 with 0.83 yield has been replaced by Route Number 1 with the 0.91 yield. These results also show that the routes selected for the other orders are those with almost the highest yield. In addition the weight problem does not appear here, therefore the method at this stage is capable of dealing with two of the problems, i.e. weight problem and yield problem. However, the third problem has to be investigated. This is discussed below.

Problems

Since the operation cost factor has not been incorporated in the grouping procedure the third type of problem, i.e.the operation cost problem, can be still troublesome. That is, some higher operation cost routes can easily get selected for grouping. This is a very important problem as it increases not only the operation costs, but also the production lead time, work in progress, etc. An example for this kind of problem is the selection for Order 1 of Route Number 5, for which the operation cost is relatively high.

8.2.5. Development of the clustering method - Stage4

At this stage the objective is to improve the method in such a way that it can also cater for the operation cost problem. For this we can use the same principle as we used for the yield problem at the previous stage. That is somehow to include the relative operation cost in the distance calculation. But, there is a better way than this. Since the route cost includes both the yield and operation costs, if this is used for the distance calculation the method could be able to handle the problems related to both cases. Therefore, we define the distance for any clustering step as the total cost produced in that step. This cost includes:

(i) the cost related to extra material allocation due to the gauge difference and

(ii) the relative cost for the route which is selected.

That is:

$$D4 = Dr_{ij} + Uc(D2_{kij})$$

in which,

$$Dr_{ij} = Rc_{ij} - Rc_{ij'}$$

and

$$Uc = \text{material unit cost.}$$

Here, j' refers to the route with the lowest operation cost, and Uc is material unit cost.

By substituting $D2_{kij}$ from Stage 2 we have,

$$D4 = Uc\ ((Wp_i\ (Gg_k - Gp_{ij})/(Gp_{ij} x Yp_{ij})) + (Cr_{ij} - Cr_{ij'})$$

This is the complete form of the distance calculation proposed for the method considered in this chapter. This is, in fact, the decision cost incurred at any time that two products are grouped. For any group the accumulation of this cost for different grouping passes will be called the group cost. We define group cost rate as the group cost per unit of the product weight satisfied by that group. Group cost rate will be used as the clustering stopping criterion (discussed in the next stage).

Example 8.4.

Results for this version of the method are illustrated in Fig. 8.5. These indicate improvement in the operation cost problem. For instance the selection of Route Number 5 for order 1 in the previous version is now replaced by the selection of route number 1 which has the least operation cost for this order. Comparing this result with the result for the previous version, which had already solved the two other problems, we see that there is no other change.

Problems

Now the clustering result is satisfactory except for some final groupings which happen to be very expensive (e.g. joining Order Number 4 into Group Number 107). Therefore conditions are required in order to stop clustering when the cost exceeds a given limit.

8.2.6. Development of the clustering method - Stage 5

The objective for this stage is to determine the number of the groups, or in other words to choose the clustering stopping condition which is to be incorporated in the method. For this purpose the following methods were considered.

1. The user suggests the number of the clusters.

2. Stop the clustering when the cost rate for the group exceeds a predefined limit. Here the cost rate is the total grouping costs collected in a group per unit weight.

3. Stop clustering when the distance cost exceeds the given limit. For example when the distance cost for the pass is more than the given limit.

4. A combination of 2 and 3. Here both limits are checked and the clustering stops whichever limit is exceeded.

5. Stop clustering when the total grouping cost accumulated in the batch exceeds a preset limit. This limit can be determined as a percentage of the total batch product weight.

Concerning these exit procedures the following points are worth noting.

- Stopping Method Number 1 seems impractical. As it is not easy for the user to determine the number of the clusters. This method is inefficient too, as there is very small chance for the user's selection being the appropriate one.

- The problem with Number 2 is that grouping less expensive members in the early stages allows the acceptance of more expensive members at the later stages.

- Number 3 and Number 4 seem very reasonable, and the results produced are good.
- Problem with Number 5 is that when the group costs for the initially

established groups are low, the method allows more expensive groupings at the later stages.

Having considered these points, stopping procedure Number 4 has been selected for the proposed method. That is, the clustering terminates when either distance cost (as for Number 2), or group cost rate (as for Number 3) exceed their predetermined limits.

Example8.5.

Figure 8.6. illustrates results for the application of the final version of the method to batch 1. Here, as the result of the included exit condition the grouping for pass number 8 has been rejected and the clustering has been terminated, leaving product number 4 not grouped. This rejection is reasonable, as, nearly 12% extra material would be required for order number 4 if this step of clustering took place. As the result of this grouping, only three types of material gauges (for Groups 105 and 107 and Order 4) are required for the batch. Overall yield in 0.87 and total grouping cost is 117. These results indicate great improvement as compared to the results for single order process planning situation; in which 5 types of gauges were used, overall yield was 0.83 and total cost increase was 459. Comparing the results of this stage with those of the application of Method I (given in Table 7.3 'c-1 and 'c-2'), it can be seen that although they are not much different, but results for Method II are much better. Grouping produced by Method II requires less types of material gauge compared to both situations given in Tables 7.3 'c-1' and 'c-2'. Its grouping cost is less as compared to 129 for one of the situations (7.3. 'c-2'), but the same as compared to the other situation. Moreover, selection of a suitable value for the M factor in Method I makes this method practically difficult, whereas, there is no such problem with Method II.

8.2.7. Description of the Final Form of the Method

The overall search structure for the method at this stage is the same as discussed earlier in Section 7.2.1. However different grouping parameters were developed through Sections 7.2 to 7.6. These are summarised below, where definitions of the terms are the same as those given in Section 7.2.1.

Group gauge

Gg_k = the gauge for the route which has been considered as the head for the group (Group k).

Group weight

$$Wg_k = \Sigma\ Wp \qquad \text{(for the products collected into the group)}$$

Extra material

This is extra material required for joining a product (a member product) into any given group

$$W_{kij} = (\,(Gg_k - Gp_{ij})/Gp_{ij})\ \Omega p_{ij}$$

where

$$\Omega p_{ij} = Wp_i\ /\ Yp_{ij}$$

therefore

$$W_{kij} = ((Gg_k - Gp_{ij})/Gp_{ij})(Wp_i/Yp_{ij})$$

or

$$W_{kij} = ((Gg_k - Gr_{ij})Wp_i)/(Gp_{ij}Yp_{ij})$$

Group material weight

This is total material required by the products within the group. Material required by each product is composed of two parts: material required by the selected route, and the extra material required in order to use group gauge for this route. That is:

$$\Omega g_k = \Sigma\, \Omega p + \Sigma\, W_{ij} \qquad \text{(for orders collected into the group)}$$

By substituting W_{kij} in this relation we have,

$$\Omega g_k = \Sigma\, (((Gg_k - Gp_{ij})/Gp_{ij}) + 1)\Omega p_{ij}$$

or

$$\Omega g_k = \Sigma\, (((Gg_k - Gp_{ij})/Gp_{ij}) + 1)(Wp_i/Yp_{ij})$$

Group yield

group yield = (group weight) / (total group material weight)

or

$$Y_k = (Wg_k)/(\Omega g_k)$$

$$Y_k = \Sigma\, Wp \;/ \Sigma(((Gg_k - Gp_{ij})/Gp_{ij}) + 1)(Wp_i/Yp_{ij})$$

Grouping cost

This is the clustering decision cost at any stage. It is composed of two different types of cost. These are: the gauge difference cost and the route relative cost.

$$D4 = Uc\ ((Wp_i\ (Gg_k - Gp_{ij})/(Gp_{ij} x Yp_{ij})) + (Cr_{ij}\ - Cr_{ij'})$$

Group cost

Group cost (Cg_k) is total cost of collecting orders into the group. That is:

$$Cg_k = \Sigma\ D4$$

where,

Cg_k = cost for group k,

D4 = cost of the collection of the ith product into the kth group.

therefore

$$Cg_k = \Sigma\ (\ Uc\ ((Wp_i\ (Gg_k - Gp_{ij})/(Gp_{ij} x Y_{ij})) + (Cr_{ij}\ - Cr_{ij'}))$$

Group cost rate

Group cost rate is the group cost per unit product weight for the group. Therefore,

$$\text{Group cost rate is} = Cg_k / \Sigma\ Wg_k$$

Updating

The updating process consists of the following steps.

i. Group data is calculated and assigned to the group.

ii. The produced group is assumed as a new (hypothetical) order with the type 'g' ('g' stands for group) for which a code number is issued. This is then included in the list of orders.

iii. A hypothetical route with the relevant data is generated for the new order.

iv. The similarity matrix is updated according to the data for the new order (using the distance as defined for this stage).

v. The two head and member products together with their original routes are deleted from the relevant matrices.

Clustering stopping condition

Clustering terminates when either grouping cost (grouping decision cost) or the cost rate for any group exceed its predetermined limit.

8.2.8. Calculation of the Total Number of Searches for Clustering

Assuming:

I = Number of the products in the batch

J = Number of the routes for the selected product

Selecting Product 1 as the group head, and selecting Route 1 for this product, then all the routes for all other products must be evaluated before the least expensive grouping can be selected. Therefore the total number of evaluations required (S_{11}) is:

$$S_{11} = \sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij} - \sum_{j=1}^{j1} S_{ij}$$

By expanding S_{11} to all the routes of Product 1 we have:

$$S_{1j} = \left(\sum_{j=1}^{j1} S_{11} \right)$$

or

$$S_{1,j} = \sum_{j=1}^{j1} \left(\sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij} - \sum_{j=1}^{j1} S_{1j} \right)$$

where, S1j is the total number of alternative groupings for all the routes of Product 1. Now by expanding this to all products we have the total number of grouping alternatives for the first pass of clustering. This number (N1for Pass 1) is:

$$N_1 = \sum_{i=1}^{I} \left(S_{1j} \right)$$

or

$$N_1 = \sum_{i=1}^{I} \left(\sum_{j=1}^{J} \left(\sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij} - \sum_{j=1}^{J} S_{ij} \right) \right)$$

when first pass is complete the number of the products in the batch is reduced by one.

Therefore,

$$I_2 = I - 1$$

Accordingly the total number of the grouping alternatives for the second pass is:

$$N_2 = \sum_{i=1}^{I-1} (S_{1j})$$

and for Pass Number 'p' we have

$$N_p = \sum_{i=1}^{I-(p-1)} (S_{1j})$$

The total number of the passes is equal to the number of the products in the batch less one. Therefore, by expanding the calculations to all the passes the total number of alternatives to be searched by the method for a given batch (N) is the sum of N_1, N_2, ...N_p, N_{I-2}.

That is:

$$N = \sum_{p=1}^{I-2} \sum_{i=1}^{I-(p-1)} (S_{1j})$$

by substituting (S_{1j}) then we have

$$N = \sum_{i=1}^{I-2} \sum_{i=1}^{I-(p-1)} \left(\sum_{j=1}^{J} \left(\sum_{i=1}^{I} \sum_{j=1}^{J} S_{ij} - \sum_{j=1}^{J} S_{ij} \right) \right)$$

It can be understood from these equations that the number of alternatives to be evaluated becomes extremely large, which can create problems such as longer clustering time and shortage of computer memory. In order to reduce this type of problem, a rough cutting method has been incorporated into the method. By a simple calculation this rejects inefficient alternatives before completely processing them. In the given example of "Batch 1" for Stage 5 the total number of the alternatives attempted is 2680; from these only 550 alternative has been evaluated on the cost measurements. As another example for a batch of about 20 products the total alternatives attempted were roughly 100000 from which only around 4000 were evaluated.

8.3 Concluding Summary

Previous sections outlined Method II for order grouping. This method is mainly based on the linkage technique of cluster analysis, but uses a particular definition for the distance (or the similarity) between the objects. It also uses a special updating procedure. Orders in the batch are considered as the objects for clustering which produce various grouping options using their alternative routes.

The distance between any order with another order or a previously produced group is defined in such a way that it considers various factors for the two objects. The main components are the weight of the objects, their original route cost and the extra material required as the result of grouping.

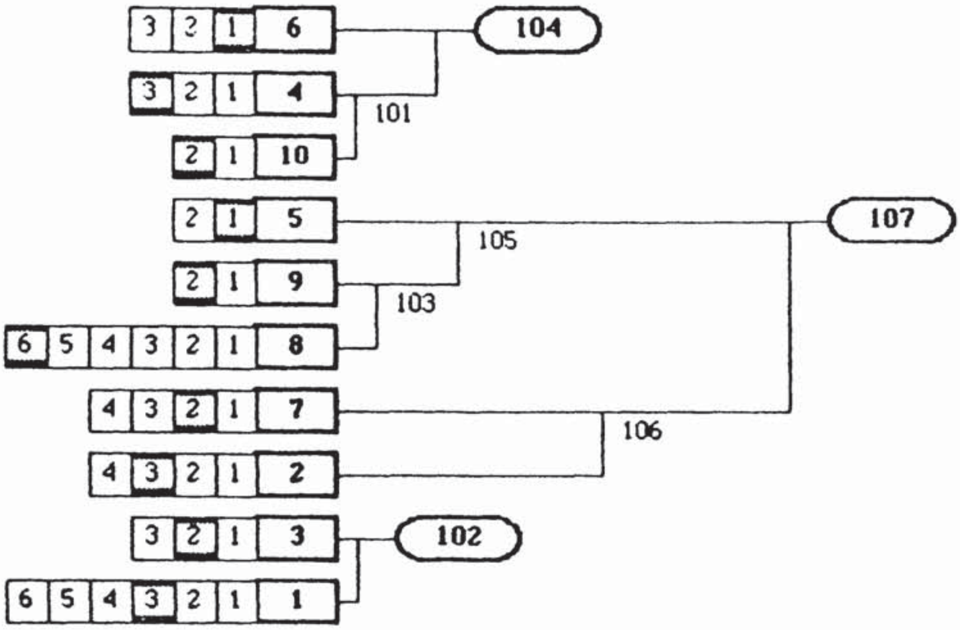
Chaining is a known problem for linkage methods. This problem has been considerably reduced in our clustering method. This is because of the introduction of the relative yield cost and relative route-cost which becomes zero for the groups produced previously. This therefore, increases the chance for the groups to take part in the later groupings.

As the result of the introduction of the weight factor in the calculation for the gauge distance (Dwg), there is more chance for less heavy orders to be attracted by other orders than for the heavier ones. This helps with the grouping cost reduction as in fact moving a less heavy order (allocating to a group) produces less cost.

The application of the method was demonstrated for a typical batch of orders. This indicated considerable advantage over the single order process planning situation. For instance the yield has increased from 0.83, to 0.87, overall route cost increase for the batch has shown a difference of (459-117=342) and the number of different gauges required for the batch has reduced from 5 to 3 each with sufficient weight.

Comparing the results of the application of this method with those demonstrated for Method I in the previous chapter; the current method , as discussed in Section 7.2.6, is more advantageous. Therefore Method II is much more suitable for the order grouping problem.

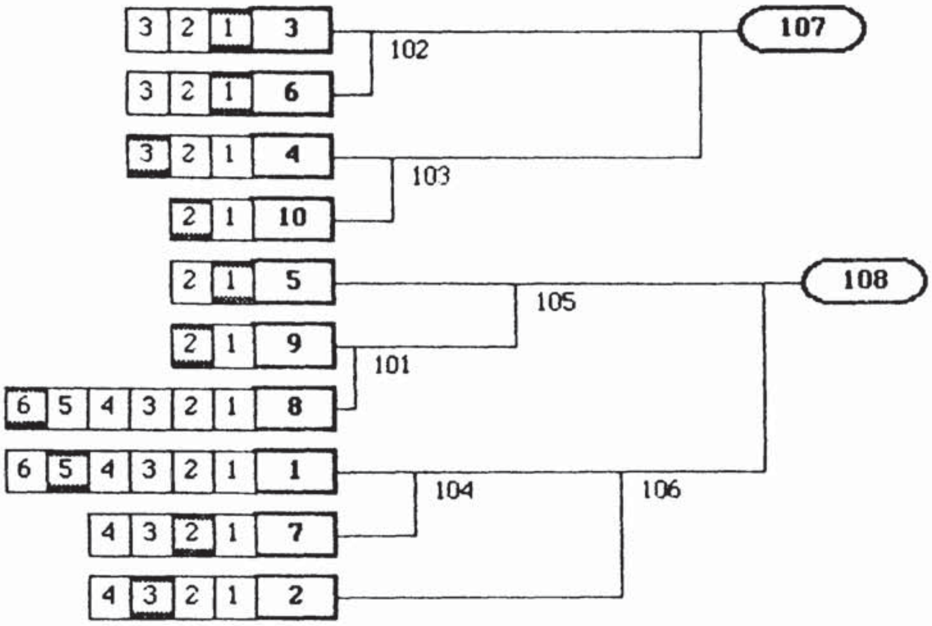
It is important to note that Method II includes provision for considerably reducing the number of routes which need to be examined.



```
-------------------------------
Stage  :        1
Program:        CLUST3.PRO
Datafile:       BT1.DBA
Time used:      1m, 4s, 97hs
Count1 = 2796,   Count2 = 581
-------------------------------
```

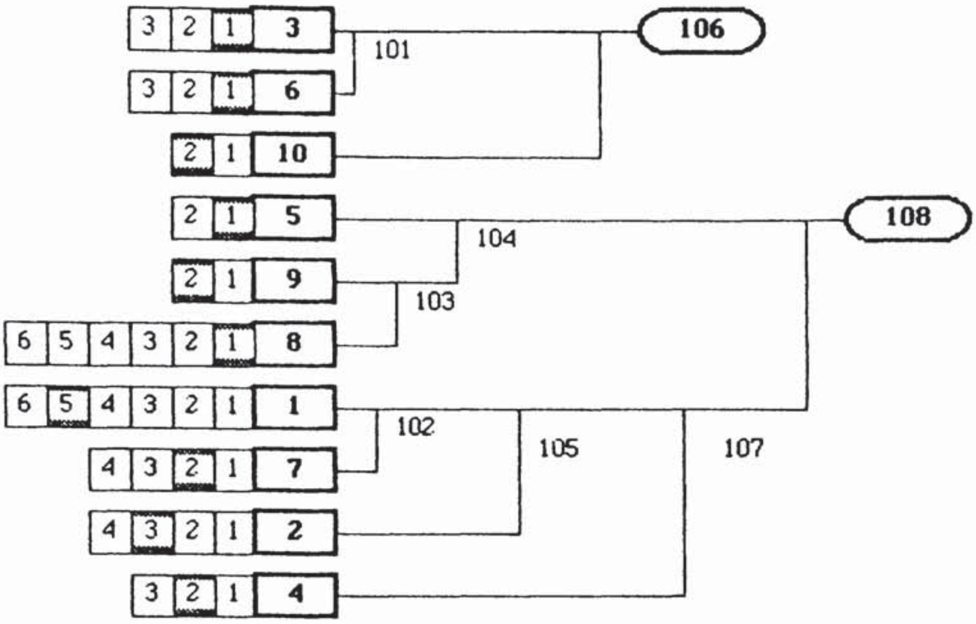
```
   *-*-*-*-*        CLUSTERING RESULTS        *-*-*-*-*

------------------------------------------------------
Stage                    Grouping data
----- ------------------------------------------------
   Gp_no  Head    Member  Weight Gauge Yield       D
------------------------------------------------------
 1  101     4 -3    10 -2  1327   5.81   0.85      0.01
 2  102     3 -2     1 -3  1700   4.80   0.85      0.01
 3  103     9 -2     8 -6   520   5.25   0.86      0.02
 4  104     6 -3   101 -1  1766   5.85   0.83      0.04
 5  105     5 -1   103 -1   740   5.30   0.87      0.05
 6  106     7 -2     2 -3   564   5.10   0.88      0.10
 7  107   105 -1   106 -1  1304   5.30   0.86      0.20
------------------------------------------------------

Products not grouped
--------------------
--------------------


                  D   =Distance calculated for merger
```

Fig. 8.2. Dendrogram and clustering data for Example 8.1



```
-------------------------------
Stage  :       2
Program:       CLUST3.PRO
Datafile:      BT1.DBA
Time used:     0m, 29s, 22hs
Count1 = 2630,  Count2 = 540
-------------------------------


   *-*-*-*-*       CLUSTERING RESULTS       *-*-*-*-*

------------------------------------------------------
Stage                  Grouping data
----- ------------------------------------------------
   Gp_no  Head   Member  Weight Gauge Yield     D
------------------------------------------------------
 1  101     9 -2    8 -6    520   5.25   0.86    1.01
 2  102     3 -1    6 -1    939   5.90   0.87    1.72
 3  103     4 -3   10 -2   1327   5.81   0.85    1.76
 4  104     1 -5    7 -2   1483   5.13   0.90    1.91
 5  105     5 -1  101 -1    740   5.30   0.87    5.78
 6  106   104 -1    2 -3   1764   5.13   0.90    8.03
 7  107   102 -1  103 -1   2266   5.90   0.85   24.24
 8  108   105 -1  106 -1   2504   5.30   0.87   65.04
------------------------------------------------------

Products not grouped
--------------------
--------------------

                  D   =Distance calculated for merger
```

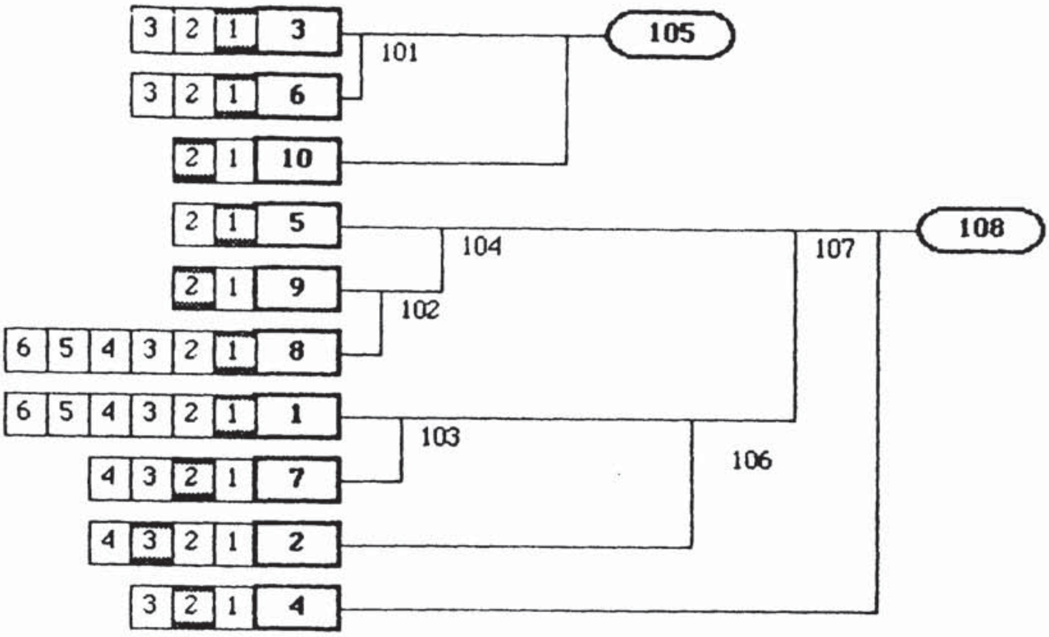
Fig. 8.3. Dendrogram and clustering data for Example 8.2



```
------------------------------
Stage   : .     3
Program:        CLUST3.PRO
Datafile:       BT1.DBA
Time used:      0m, 36s, 85hs
Count1 = 2574,   Count2 = 529
------------------------------
```

```
   *-*-*-*-*        CLUSTERING RESULTS        *-*-*-*-*

-------------------------------------------------------
Stage                  Grouping data
----- -------------------------------------------------
   Gp_no  Head   Member  Weight Gauge Yield     D
-------------------------------------------------------
 1  101     3 -1    6 -1    939   5.90   0.87    1.72
 2  102     1 -5    7 -2   1483   5.13   0.90    1.91
 3  103     9 -2    8 -1    520   5.25   0.89    2.32
 4  104     5 -1  103 -1    740   5.30   0.89    5.57
 5  105   102 -1    2 -3   1764   5.13   0.90    8.03
 6  106   101 -1   10 -2   1839   5.90   0.87   17.63
 7  107   105 -1    4 -2   2191   5.13   0.88   23.04
 8  108   104 -1  107 -1   2931   5.30   0.86   82.07
-------------------------------------------------------

Products not grouped
--------------------
--------------------


                  D    =Distance calculated for merger
```

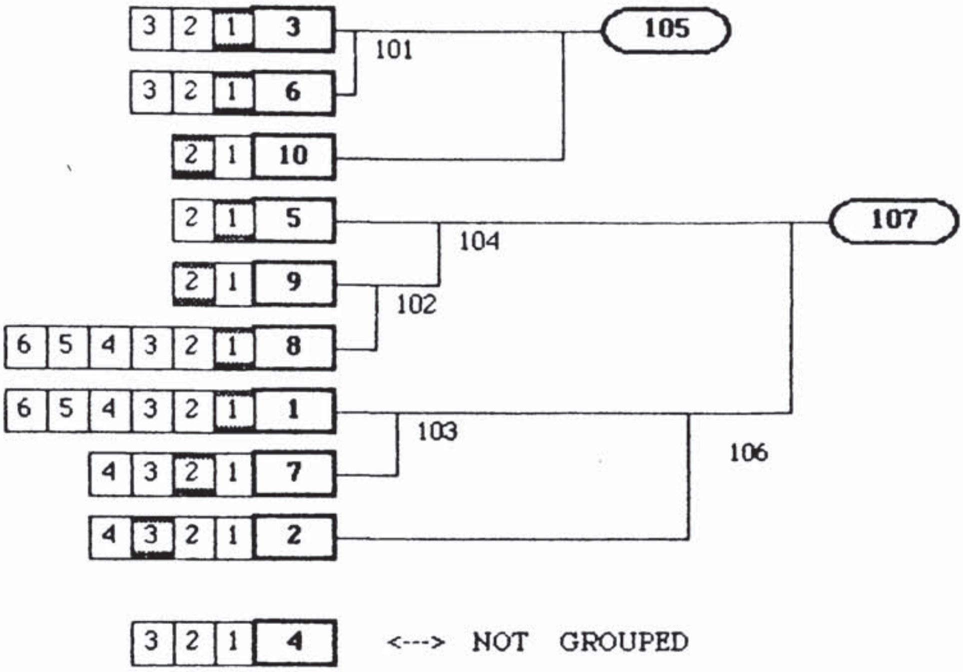
Fig. 8.4. Dendrogram and clustering data for Example 8.3



```
----------------------------
Stage   :      4
Program:       CLUST3.PRO
Datafile:      BT1.DBA
Time used:     0m, 30s, 70hs
Count1 = 2682,   Count2 = 550
----------------------------
```

```
     *-*-*-*-*        CLUSTERING RESULTS        *-*-*-*-*

-----------------------------------------------------------
Stage                      Grouping data
----- -----------------------------------------------------
   Gp_no  Head    Member  Weight Gauge Yield    Cgpr  D
-----------------------------------------------------------
 1  101     3 -1    6 -1    939   5.90   0.87    0     1.72
 2  102     9 -2    8 -1    520   5.25   0.89    0     2.32
 3  103     1 -1    7 -2   1483   5.15   0.90    0     3.19
 4  104     5 -1  102 -1    740   5.30   0.89    1     5.57
 5  105   101 -1   10 -2   1839   5.90   0.87    1    17.63
 6  106   103 -1    2 -3   1764   5.15   0.90    1    29.26
 7  107   104 -1  106 -1   2504   5.30   0.88    3    57.24
 8  108   107 -1    4 -2   3224   5.30   0.86    5    87.56
-----------------------------------------------------------

Products not grouped
--------------------
--------------------


                 Cgpr =Group Cost Rate (cost per unit wt)
                 D    =Distance calculated for merger
                       (cost for moving the member into
                       the group)
```

Fig. 8.5. Dendrogram and clustering data for Example 8.4



```
------------------------------
Stage  :       5
Program:       CLUST3.PRO
Datafile:      BT1.DBA
Time used:     0m, 37s, 62hs
Count1 = 2680,   Count2 = 550
------------------------------
```

```
     *-*-*-*-*       CLUSTERING RESULTS       *-*-*-*-*

-----------------------------------------------------------
Stage                   Grouping data
----- -----------------------------------------------------
   Gp_no  Head   Member  Weight Gauge Yield    Cgpr  D
-----------------------------------------------------------
 1  101     3 -1     6 -1    939    5.90   0.87    0     1.72
 2  102     9 -2     8 -1    520    5.25   0.89    0     2.32
 3  103     1 -1     7 -2   1483    5.15   0.90    0     3.19
 4  104     5 -1   102 -1    740    5.30   0.89    1     5.57
 5  105   101 -1    10 -2   1839    5.90   0.87    1    17.63
 6  106   103 -1     2 -3   1764    5.15   0.90    1    29.26
 7  107   104 -1   106 -1   2504    5.30   0.88    3    57.24
------------------------------------------------------------

Products not grouped
--------------------
1).        4
--------------------
```

```
Cgpr =Group Cost Rate (cost per unit wt)
D    =Distance calculeted for merger
       (cost for moving the memberr into
       the group)
```

Fig. 8.6. Dendrogram and clustering data for Example 8.5

CHAPTER 9

COMPUTER REQUIREMENTS AND THE OVERALL SYSTEM STRUCTURE

9.1 Introduction

This chapter outlines the fundamental planning used for the development of the software and describes the overall structure of the system, which consists of two process planning modules and a database module. The process planning modules provide the options for both "single order" and "batch order" process planning. Details of these modules together with their test run results are given in the following two chapters. The database module is described later in this chapter.

The main objective of this development was to demonstrate the feasibility of the solution methodology and the procedures established earlier in this thesis. Since this application of the Generative CAPP methodology to the rolling mill industry is not based on any previous development for this particular industry, an evolutionary approach was selected.

The system has been improved and expanded through a number of stages. At each stage it was necessary to decide on the planning procedures to be used and how these should be implemented, in terms of decision rules and of programming structure and language. Each stage has also benefited from the feedback of comprehensive test runs for successive developments. This has served to improve the solution procedures and the software itself.

For the successful computerisation of the particular process planning function, a clear understanding of existing practices and the needs in real manufacturing was necessary, as well as an understanding of the theoretical considerations. It was also essential that the knowledge possessed by the planners be captured and incorporated in the planning software. This was achieved through the case studies, previously discussed in Chapter 4, during which frequent and comprehensive discussions had been held with all the relevant personnel in the companies. In addition, some of the rules had to be established through the analysis of a large number of existing plans, as rules of this type are mostly unwritten.

Since the CAPP software is a prototype model at this stage, a relatively simplistic approach has been used for the auxiliary parts of the system, while more emphasis has been put on the main functional modules. For the same reason and considering the time constraints, full documentation of the system (for instance user manual, etc.) has not been prepared, while basic requirements and the logic for the system have been discussed in the various chapters of this thesis.

With regard to more generalised application of the system and enhancement of the quality of the software, further suggestions are also given in Chapter 12.

9.2. Functional Requirements

Major requirements considered in the design of the system are as follows:

1. To work on a microcomputer.
2. To provide the capability for generative type process planning for the production of plates, sheets and circles in a rolling mill.
3. To provide capability for both "single order process planning" and "batch order

process planning" situations.

4. For single order process planning, overall route cost is the determining criterion which has to be minimised.
5. For batch order process planning, the criterion is the optimisation of the total route cost for the orders in the batch.

Other considerations include:

-- Data mainly consists of order data, material data, cost data and data related to manufacturing capabilities. The method of access to these data can be either through disk files or a networking system.

-- The system would require to consult the user at some important stages either for his opinion on the results produced by the system or his preferences for the use of various resources.

-- To provide comprehensive reporting and hard copy facilities.

-- It is important to obtain user's confirmation at a number of major steps of planning.

-- An edit facility is required so that the user can modify final plans or add any comment if needed.

-- Reasonably high speed is required for the planning operation.

9.3. Operating System and Hardware Considerations

Initially, a number of operating systems such as MSDOS, UNIX and OS/2 were considered. Of these, MSDOS was found more suitable because of its cost and availability both in the university and the companies concerned. However, for the future industrial implementation of the system, if greater memory capacity with networking capability is required, then UNIX or OS/2 might be more appropriate.

Since the system is based on extensive search functions and requires a large number of iterations, the processing speed of the system becomes an important factor. The 16-bit microprocessor appears reasonable for the present stage of the development, however, to speed up the computing functions one may move from 16 to 32-bit processor. Ideally, a machine with such a processor and 25 MHz would be most suitable.

Since the CAPP system is of the generative type, the hard disk capacity is not determining factor, however, a minimum of 20 MB hard disk capacity appears to be reasonable.

The hardware configuration used for the test runs of the prototype CAPP system is given in Appendix C.

9.4. Programming Language

Initially, the feasibility of the approach was checked using BASIC as the programming language for some specific and simple situations. Although the objective for this stage was achieved, it was found that the system requires a language with a good capability for:

1. Handling of "condition and action" type statements and the rules,
2. Handling of database operations,
3. Searching facilities,
4. Supporting a modular programming approach,
5. Supporting expert system programming.

BASIC and some of the other languages such as Fortran, Pascal, C, Lisp and Prolog were considered for this application. Of these, Prolog was found to be the most suitable. Turbo Prolog (Version 1.1), which is a micro-computer version of the Prolog language, was used for the entire software development. Relevant features of the Prolog language in general and Turbo Prolog in particular are discussed in the following subsections.

9.4.1 Prolog Language -- Turbo Prolog

The name PROLOG stands for PROgramming in LOGic. It was created in 1973 in France. Since then has seen several expansions and improvements, notably by groups at the University of Edinburgh in Scotland. The popularity of Prolog has increased since it was chosen for the Japanese Fifth Generation Project.

Prolog is a *declarative* language which consists of logical declarations specifying the goal for the program. Other languages such as Fortran, BASIC, Pascal and C are *imperative*; in these a program consists of chunks of instructions that specify the steps taken to achieve the purpose of the program.

Prolog is a high-level programming language. As an AI language, it is specially suited to the development of expert systems, dynamic databases, natural language processing programs and general problem-solving applications. Prolog is also powerful in searching and pattern matching. Its internal unification provides the capability to search through all possible combinations of the program's rules in attempting to satisfy the goal set by the program.

Turbo Prolog, developed by Borland International Inc., is a version of the Prolog which is available on the microcomputers. It is a compiled language with facilities for editing, interactive input/output, debugging and multiple windows.

Some of the fundamental features of the language which are closely related to our work are briefly discussed below, full details about these and other features of the language can be found in: e.g. Borland (1986), Schildt (1986) and Shafer (1987).

Rules, Facts and Databases

In Prolog a predicate called "goal" is used to send the program into action. The language then attempts to match the goal with the rules and facts within the program. Any rule may itself contain other rules (subrules). In general, a rule in Prolog can be represented in the following form.

$$P_0 :- P_1, P_2, \dots , P_n.$$

This means P_0 can be true if $P_1, P_2, \dots , P_n$ are true. This provides an effective means of programming for planning and for the decision making processes. The following example illustrates the use of this format for machine selection. Here, the subrules represent the criteria for the selection of any particular machine.

(P_0) select GR2:-

(P_1) the process is "rolling",

(P_2) the operation stage is a "get ready stage",

(P_3) the operation condition is within a specified range.

The above format can also be effectively used for the planning process. Following is an example for this type of application.

(P_0) plan the current state of the workpiece:-

- (P_1) select the process for this state,
- (P_2) perform the process,
- (P_3) select the appropriate machine,
- (P_4) determine operation condition,
- (P_5) calculate the cost for this process,
- (P_6) update the database,
- (P_7) call for the next stage of the planning (call P_0).

In this example, each subrule itself consists of various levels of other subrules.

Use of the 'facts' is the other way of representing the knowledge in Prolog. The general format of the facts can be represented as:

$$F_p\ (Ob_1,\ Ob_2,\ \ldots.,\ Ob_n).$$

where, F_p is the predicate for the 'fact' and Ob represents the objects described by the 'fact'. The following is an example of the use of the 'facts', which describes the standard gauges of the strip material available for planning.

std_strips($Gauge_1$,$Gauge_2$, ..., $Gauge_n$).

This specifies that there will be n elements in standard strips. Numerical values may be assigned to each element, as below:

```
std_strips(3.0,3.3,4.3,5.0,6.4,7.6).
```

Facts can also be effectively used for the description of the capabilities of the manufacturing equipment. For instance, the following fact describes that the tolerance limit attainable by the specified rolling machine (i.e., GB5) is 0.02 mm.

```
gauge_tol_limit(roll,"GB5",0.02).
```

The data base handling facility provides another important feature of the Prolog Language. The language supports both static (disk-based) and dynamic (memory-based) database handling. The database format is very similar to the format for the facts, which was described above. For more clarity an example is given below.

```
proc_info(product_no,alt_no,route_code,stage_no,current_proc(proc,machine,op_cond,op_cost),dimensions(gauge,width,length),total_reduction)
```

This stores the process information for one particular stage of work in progress. It contains such information as: product number, alternative route number, route code, current process information etc. Here, the current process information is represented in a compound object form which includes such information as: the process number, machine name, operation condition, and the cost for the current operation.

From the above example it can be seen that the database is able to handle the data in a compound and effective way.

When facts or databases are used for a query system, the internal unification routines automatically select facts with the correct values for the known parameters and assign values for the unknown parameters. In addition, the backtracking mechanism can be used to find all the solutions to a given query.

Other Features of the Language

Repetitive tasks

Effective performance of the repetitive tasks is a feature of the Prolog language which is very useful for the programming of the planning functions. This feature of the language was found very effective in the programming in this project. The example given above for the 'rules' represents an application of this feature, where the rule calls itself recursively.

In Turbo Prolog, there are two ways of implementing rules that perform repetitive tasks. These are: *repetition and backtracking* and *recursion.*

Repetition and backtracking -- A goal usually contains one or more subgoals, which can be either facts or rules. If a subgoal cannot be satisfied, the language will backtrack in the search for other possible ways of satisfying the subgoal.

Recursion -- When a rule contains itself as a component, such a rule is said to be *recursive.*

Supporting the operations on lists

This is one other important feature of the language. A list is an ordered set of objects in sequence. The objects in a list are linked internally so that they can be accessed as a group or as individual objects. Major operations on lists supported by Turbo Prolog are: accessing the object in a list, discovering whether an object is a member of a list, splitting one list into two lists, combining two lists into a single list and sorting elements of a list into ascending or descending order.

Search procedures

By default, Turbo Prolog supports the depth-first search technique, however it can also be used for breadth-first and many other search techniques. Depth-first search has been very suitable and effective for the search functions included in the software in this project.

9.5. System Overall Structure

The overall process planning system for the rolling mills, as considered in Chapter 5, is designed to include independent modules for each of the production departments. These modules which are represented in Fig. 9.1. are: (i) CAPP-CR for cold rolling, (ii) CAPP-HR for hot rolling and (iii) CAPP-RC for refinery and casting. The system also requires the incorporation of a CAPP database system (CAPP-DBS) and some other auxiliary systems. As the work for this research concentrates on planning for the cold rolling department, in particular the production of plates and sheets, only this part of the overall system (together with the essential part of the database system) has been developed for the prototype.

Two process planning options have been considered for this system. These options, which constitute two modules of the software are:

1. Single Order Process Planning (SCAPP) -- details in Chapter 10
2. Batch Order Process Planning (BCAPP) -- details in Chapter 11

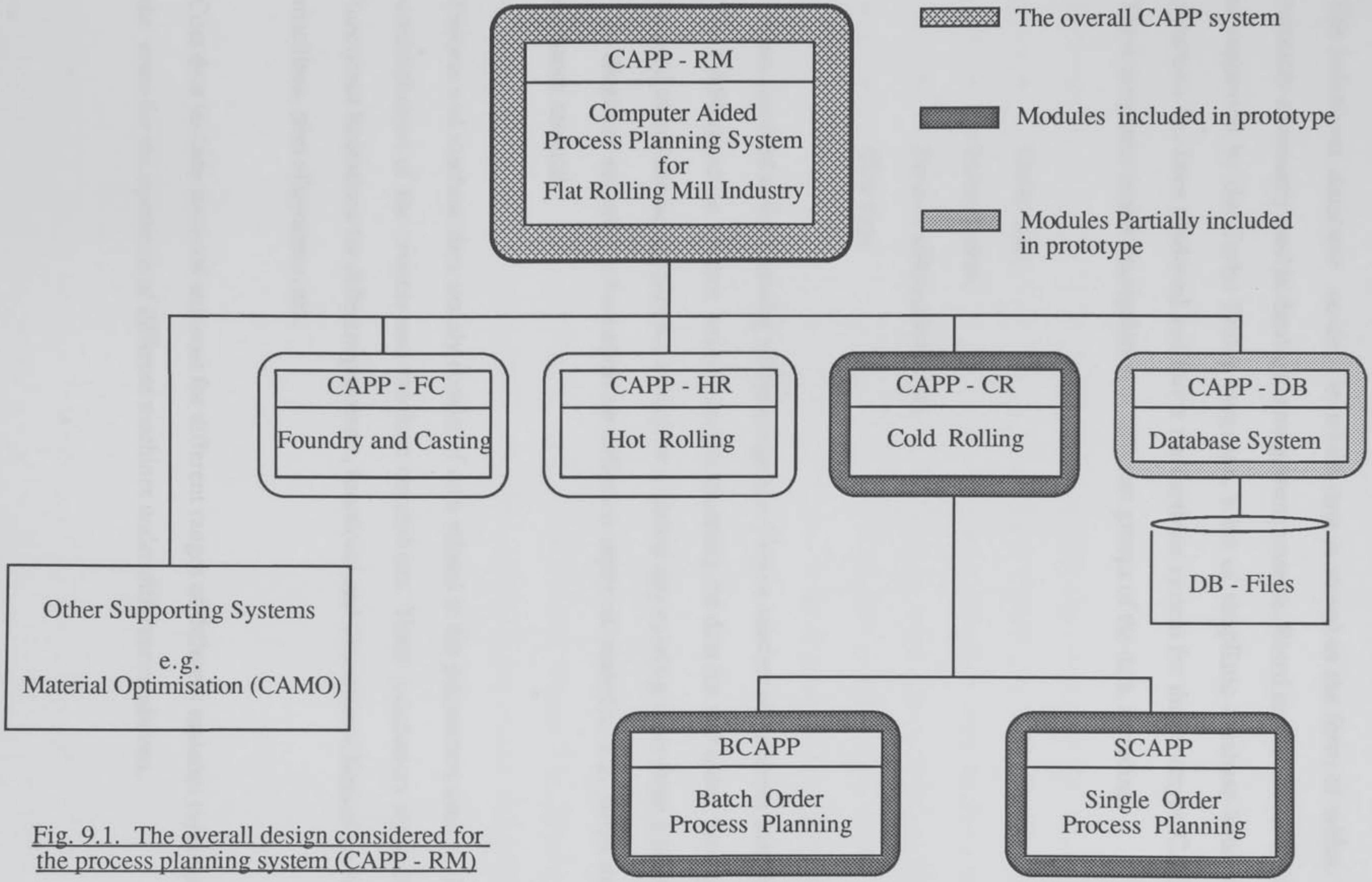


Fig. 9.1. The overall design considered for the process planning system (CAPP - RM)

9. 6. CAPP Database System

The *relational database model*, in which data is stored in the form of tables, is currently commonly used in database management systems. Based on this model which is supported by the Turbo Prolog language, a set of simplistic database handling programs has been produced and forms the database system for the prototype CAPP. These programs enable manipulation of different groups of the data, including:

- Order data,
- Material data,
- Process and machine data,
- Cost data.

Orders received in the planning office are grouped into a number of different batches. The CAPP database handler, apart from manipulating the data for any order, can also be used to include new orders for a batch or to delete any existing order from a batch. The database contains information on different types of material, e.g. strips and millstock material.

Process and machine data mainly consist of data related to the parameters used in the establishment of the process and machine capabilities. These parameters represent functional limitations for different processes, functional and dimensional limitations for machines, trim allowances, etc.

Cost data include material unit cost for different ranges of different material types and the costs for the operation of different machines under different conditions.

9.7. Summary

The overall planning and the structure of the system was discussed in the previous sections. Development of the prototype system indicated some measures which might be useful when, in future, a full-scale system has to be designed to work in the industry.

With regard to the hardware, the specified configuration performed satisfactorily, but of course for a full-scale system this might have to be rethought. For instance, when the system is used in a particular rolling mill, its compatibility with existing hardware is a key factor. Memory capacity could also be critical if the system has to be linked with some other softwares covering functions such as production scheduling, material optimisation, shopfloor monitoring, etc. The overall configuration could also affect the choice of the operating system for the software.

Prolog is found to be appropriate for the programming of process planning function. This language also provides the facility to be linked with some other languages such as FORTRAN, PASCAL C and COBOL, which can be useful in full-scale development of the system in order to communicate with other modules in the overall computing system.

CHAPTER 10

SINGLE ORDER PROCESS PLANNING (SCAPP) SYSTEM -- SYSTEM DESCRIPTION AND TEST RUN RESULTS

10.1. System Description

As mentioned in Chapter 5, the five stages required to plan the processes for any single order are:

Stage 1.

Evaluation of different macro routes for the production of the order specification. This is to *determine feasible macro routes* with the corresponding material yield and the acceptable ranges of material dimensions.

Stage 2.

Searching the available material stock in order to determine alternative choices of material for each route specified in the previous stage. Stock material include millstock, strips and coils.

Stage 3.

Determination of the overall cost (or an indicator of the overall cost) for each route. This requires detailed planning for the routes, including determination of both primary and secondary processes and the selection of machines for the processes.

Stage 4.

Comparing different choices of routes in order to select *the most preferred route* . This final selection is based on the 'least cost' criterion together with the consideration of preferences applied by the planner.

Stage 5.

Production of the *process plan* for final selection of the route.

The SCAPP system which includes the following six modules is designed to perform the above functional stages.

1.	SCAPINIT	to initialise the program
2.	SELECRTS	to select feasible macro routes
3.	ALOCMATL	to allocate material for selected routes
4.	COSTRTS	to determine route cost
5.	PROPLAN	to produce final plan
6.	SCAPTERM	to terminate the program

Each of these modules is, in turn, constructed from submodules and so on, in a descending hierarchy, as shown in Fig. 10.1. In the following subsections a brief description of the above modules is given. A summary of the functions for different modules is included in the software and is also given in Appendix D.

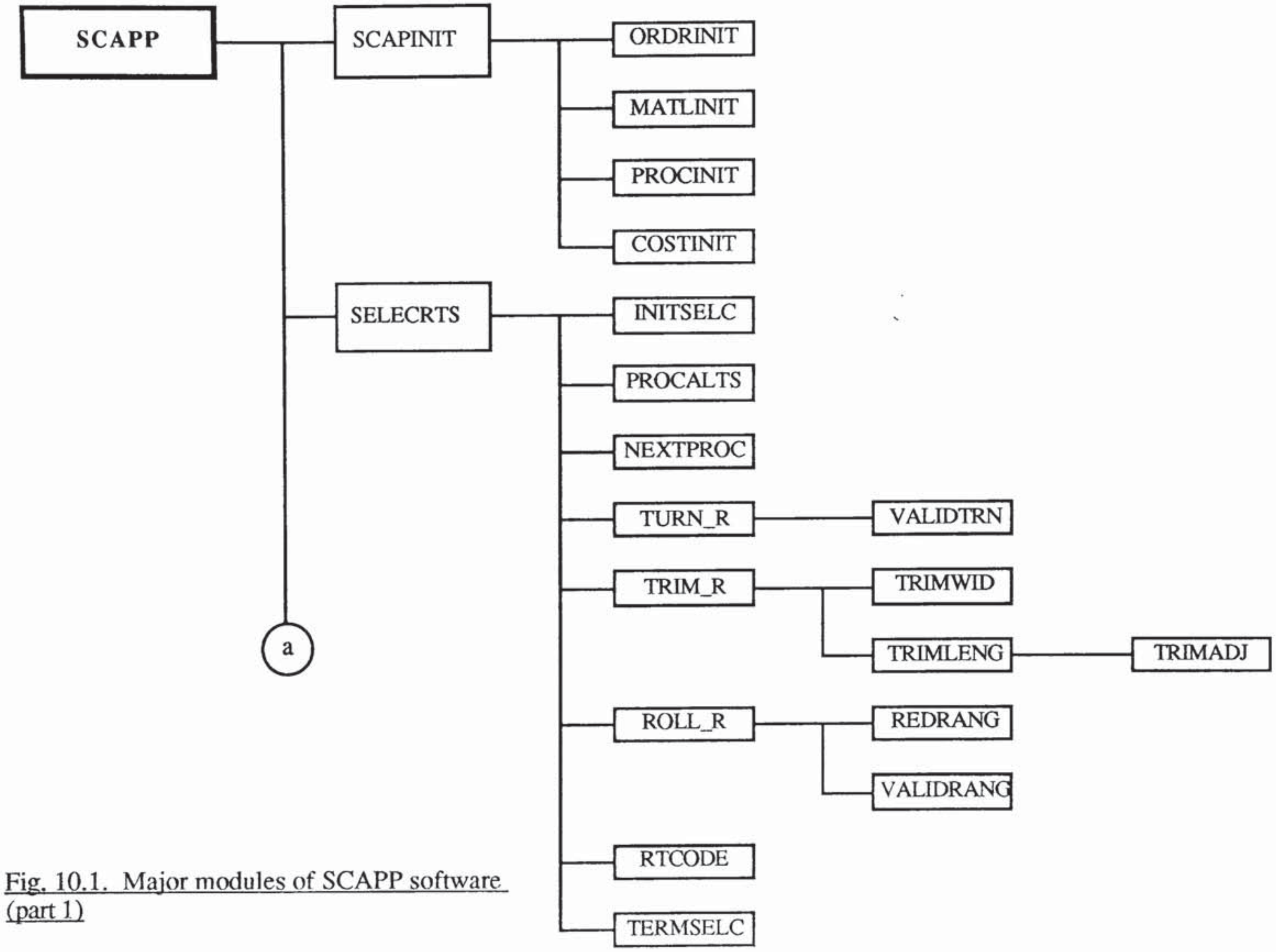


Fig. 10.1. Major modules of SCAPP software (part 1)

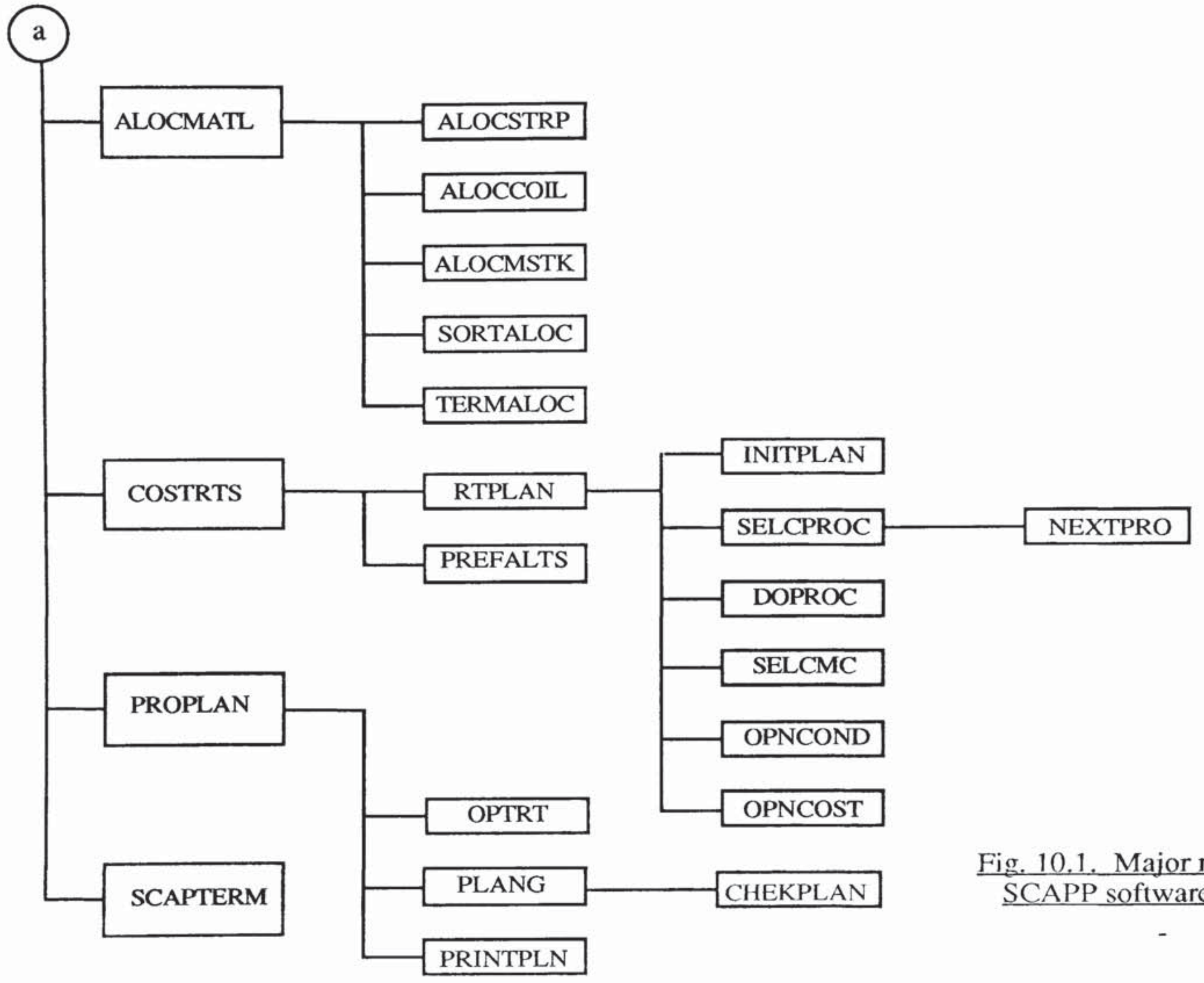


Fig. 10.1. Major modules for SCAPP software (part 2)

10.1.1 "SCAPINIT"

This module is designed to produce the working copy of the relevant CAPP database files. It also enables the user to review and alter the values for any of the planning parameters, or the specifications considered for the product. Such a provision can be effectively used for the purpose of "What - If" analysis, through which the planner can evaluate the effect of different choices of values for the parameters, on the quality and the efficiency of the process plans.

10.1.2. "SELECRTS"

This module is designed to perform the functions included for Stage 1. The combination of macro routes (as discussed in Chapter 5) is considered in the form of a tree, each branch of which representing one macro route. The evaluation of the routes is carried out through a backward depth-first search starting from the finished product state. The search, then applies the reverse form of the processes (i.e. ROLL, TRIM and TURN) to the workpiece at different stages using the procedure discussed in Chapter 5. The search also takes into account major processing limitations. The overall logic employed for this module is represented in the flow chart form in Fig. 10 .2.

In the application of the ROLL process, the feasible range for the reduction ratio is determined by the use of appropriate rules which are based on such considerations as: the required properties for the product, processing limitations, equipment functional limitations and the particular material utilised. The rules help to reduce the feasible range for the rolling reduction, but still in many situations a rather wide range, say a 20 to 70% reduction, has to be considered. Such a wide range of alternative solutions, when produced in different stages of the search, creates a very large number of solutions to be evaluated. If detailed rules which restrict the choice of reduction ratios are not incorporated into the software, this range of alternative solutions may create serious problems in operating the SCAPP system.

Such a problem is conventionally tackled by the use of a method which assigns incremental values for the reduction ratio. However, this method could produce a large number of choices of solutions which not only create computing problems, but the evaluation of which could be a greater problem, particularly when sufficiently detailed cost data is not available.

With regard to the SELECRTS module, because of the difficulties described above, the use of the conventional approach was found to be impractical. An alternative method which we call the "range method" was therefore developed. This method considers the range for the input parameters (gauge, width, length, etc.), then applies the feasible reduction range producing the output ranges for the parameters. Two examples for this method are given below, in which reverse rolling is considered for two situations of the workpiece.

1. Following relations exist when workpiece dimensions (gauge,width and length) are fixed (Fig. 10.3).

$$G2min = G1 / (1-Rmin)$$
$$G2max = G1 / (1-Rmax)$$

$$W2min = W2max = W2$$
$$W2 = W1$$

$$L2min = L1\ (1-Rmax)$$
$$L2max = L1\ (1-Rmin)$$

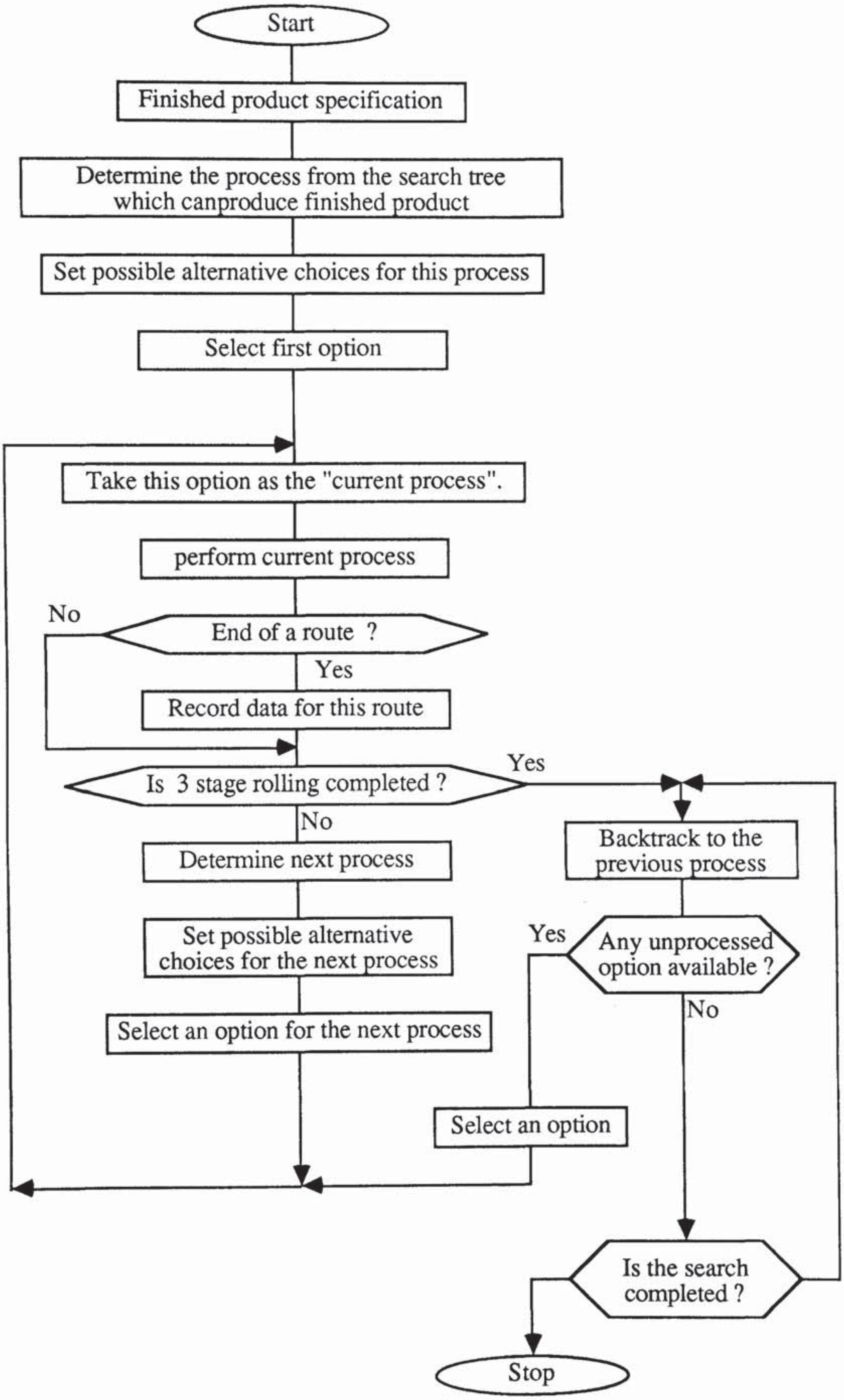


Fig. 10.2. The overall logic used in the SELECRTS module.

2. The ROLL process is reversely applied for a plate specified by a range of gauge, and length (Fig. 10.4.). Relations for the input and output dimensions are:

$$G2min = G1min / (1-Rmin)$$
$$G2max = G1max / (1-Rmax)$$

$$W2min = W2max = W2$$
$$W2 = W1$$

$$L2min = L1min (1-Rmax)$$
$$L2max = L1max (1-Rmin)$$

Using this method, the output dimensional ranges have to be checked and adjusted with regard to the valid range set for each dimension. These adjustments are included for the module.

Different trim allowances have to be considered for different ranges of the width or length. This implies the resulting dimensional ranges to be split into subranges which replace the original range. However, this does not create a serious difficulty because, in practice, only a few (e.g. three) different ranges are considered for these allowances.

10.1.3. "ALOCMATL"

This module is designed to perform the functions included for Stage 2. It considers the material dimensional ranges specified for each choice of the route. It then searches in different types of material stock (strips, coils and mill stock) for a suitable material for each route. The overall method used for this search follows the procedure previously described in the section for "blank preparation" in Chapter 5. If a suitable material is found for a route, then the corresponding data is included for that route. But if no suitable material was found, then the route is deleted from the list of the feasible routes. The result is a list of the feasible routes with different types of material allocated for each route.

The list of the routes produced in this way is then reduced to a shorter list through comparing the choices and eliminating the redundant or less effective ones. An example for the latter case is when both route code and material selected for two routes are identical, but their yields are different, therefore, the route with the lower yield is deleted from the list. Data for this short list is stored in the database for use in later stages.

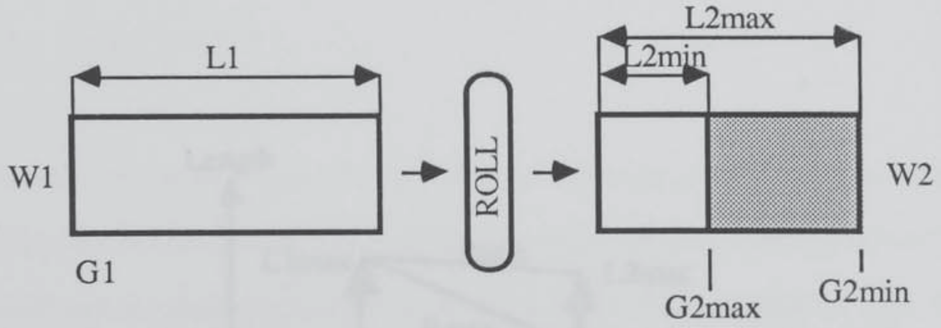


Fig. 10.3.(part1) - A reduction range applied for a plate (sheet) with fixed dimensions

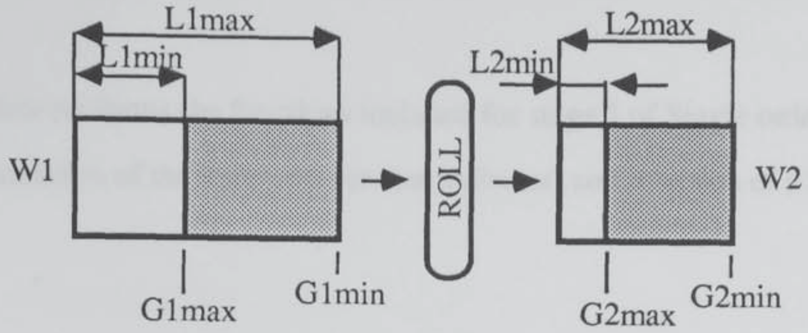


Fig. 10.3 -a

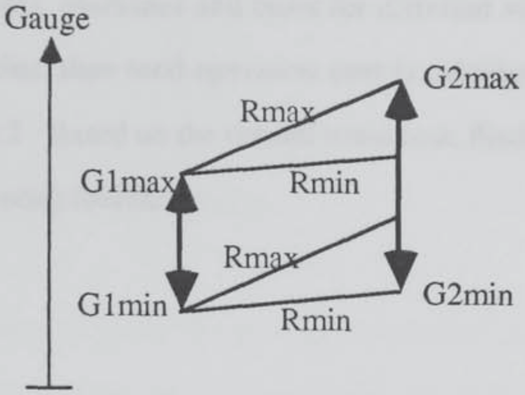


Fig. 10.3 -b.

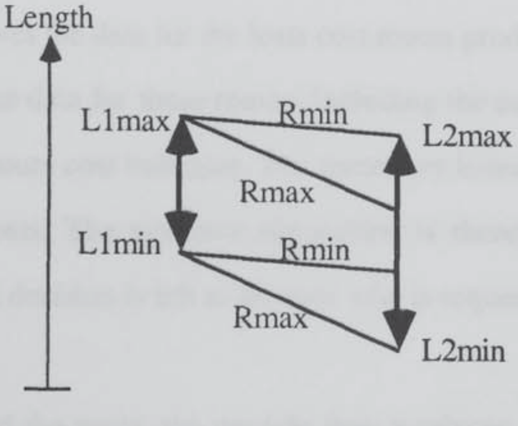


Fig. 10.3 --c

Fig. 10.3. (part2) A 'reduction range' applied for a plate (sheet) with a given range of gauge and length

10.1.4. "COSTRTS"

This module performs the functions included for stage 3 of Single order process planning, i.e. determination of the route cost (or cost indicator) and selection of a number of preferred routes.

Route cost is calculated by taking a weighted average of material cost, scrap cost and total operation cost for the route. The cost for material and scrap are obtained by multiplying their each corresponding weight and unit cost. For the total operation cost, the module firstly, calls upon RTPLAN which is a major submodule for this stage. This module determines processes, machines and costs for different stages of each route for a unit of work load. From this, then total operation cost is calculated detail of which is discussed later in Section 10.2 . Based on the overall route cost, finally, the module selects a number of preferred (least cost) routes.

10.1.5 "PROPLAN"

This module receives the data for the least cost routes produced by the previous module. It then displays major data for these routes, including the code for the utilised macro-route, the yield and the route cost indicator. The routes are listed in a descending sequence with regard to their costs. The system's suggestion is therefore the first route in the list. However, the final decision is left to the user who is requested to enter his selection.

Having determined the route, the module then produces the process plan using the data received from the previous stages (i.e. the RTPLAN module) for different processes and machines selected for this route. The plan is displayed on the screen. An editing facility is provided for the planner to make any alteration or add any comment he might wish. When edit is complete the process plan is saved in a file for reference and a hard copy of the plan is made available.

10.1.6. "SCAPTERM"

This program performs termination functions for the SCAPP software. These include saving some of the data in the appropriate files and clearing the current data from the memory so that the system will be ready to start planning for other orders.

10.2. Route Cost Determination

Route cost which is composed of three cost elements: material cost, scrap cost and total operation cost is used in the SCAPP system as the main criterion for final evaluation of alternative routes. This cost is calculated by taking a weighted average of the above cost elements:

$$\text{Route cost} = (1+V/100)(\text{material cost - scrap cost}) + (1-V/100)(\text{ total operation cost}) \quad (1)$$

The costs for material and scrap are obtained by multiplying their respective weight and unit cost.

To calculate total operation cost, initially a method was used in which it was assumed that a linear relation exists between the operation cost and material weight (i.e. total operation cost is the product of 'operation cost per unit material weight' and 'material weight'). Using this method, satisfactory results were obtained for route selection, but cost differences for different alternative choices of routes were greater than seemed reasonable, bearing in mind the differences between the routes. This, in particular, could be an important problem in the adjustment of the system (discussed below) and for the batch order process planning part of the overall system. Therefore the use of a more realistic costing method was required.

Through the practical study of the problem in the company it was recognised that the operation costs can be more appropriately determined on the workpiece basis rather on unit weight of the work. Therefore cost data were established on the workpiece basis for different operation conditions for different processes. A workpiece of standard weight was considered for the establishment of these data. Then a number of rules were set to obtain the operation cost for any workpiece of different weight from the above calculated cost. The cost so produced for a single workpiece is then multiplied by the number of pieces in the order (count) to produce total operation cost for the route.

In the above relation, 'V' (which is given in percentage) represents a policy factor which can be used to establish different levels of relative importance for each of the two cost types, i.e. material yield related costs and the route total operation cost. For instance, when V is changed from an initial value, say 0, to a new value, say 20, the relation is:

Route cost = (1.2)(material cost - scrap cost) + (0.8)(total operation cost)

This increases the influence of material yield on the route cost and therefore on the selection of preferred route. However, the change reduces the influence of the operation cost. On the other hand when V is reduced this would increase the influence of operation cost on route cost reducing the influence of material related costs.

Another use of the V factor is in situations where sufficiently detailed and accurate cost data is not available for the system, as it is the case in many rolling mills. The SCAPP system represents an example for this situation, in which material and scrap cost data are assumed to be realistic, but the system is using relative cost data for the operations. Since the two cost components, i.e. material related costs and operation costs, are based on two different scales, therefore, the costs have to be adjusted before adding them up to produce the route cost. The value of V for such situations has to be determined through sufficient number of experimental runs of the system and evaluating the results. A sample of such evaluation used for the SCAPP system is represented in Appendix D.2. Through these experiments it was indicated that V in the range between 10 and 20, or more particularly V=15, produces satisfactory results and this value is used in the worked examples described in the following sections.

10.3. Reducing Millstock Level

Accumulation of the millstock increases the overall production cost, therefore this stock should be kept at a minimum level. The SCAPP system facilitates this in two ways:

(i) Accurate planning which helps to produce less millstock. This is mainly through appropriate selection of processes, machines etc. and allocation of accurate trim allowances.

(ii) Providing an adjustable procedure which persuades the use of these material over standard materials (i.e. strips and coils). This is discussed below.

The evaluation of different feasible routes, apart from the preferences set by the user, is mainly based on the overall costs for the routes. With regard to millstock material, as this is partly worked material, it might require less operation cost to satisfy a given order situation. But on the other hand the resulting yield is very often lower than for the other types of material. However, if a lower unit cost is considered for millstock materials this will effectively reduce the cost indicator for the corresponding routes, therefore producing more chance for these routes to be selected. The SCAPP system enables the authorised user to set the unit costs for different materials including millstock materials. Similar facility is also available during the planning session through which the user can evaluate the use of different values for the unit cost of millstock material.

Using this facility, it is very important to establish a reasonable range for the reduction of millstock material unit cost. When a too big reduction is used, some routes with even higher operation cost become selected just because they use a millstock material. On the other hand too little reduction might not effectively persuade the system to use these material. However, a reasonable range of reduction for mill stock material cost can be determined through an experiment and judgement method a sample of which is represented in Appendix D.2. Using this method 5% reduction was indicated as being very satisfactory for the Current setup of the SCAPP system.

10.4. Operation of the System

To demonstrate the operation of the system, we look in detail at just one real order situation and see how this was handled by our system and compare the results with those obtained by using the company's existing system.

The order which we shall concentrate on will be given a code number, say 503. The specification for this order together with the plan produced by the present method in the company is given in Appendix D.3. Briefly, the order is for ten copper plates of general purpose quality having dimensions 1.2x1200x2400 mm and to specified tolerances. The temper is soft and total weight is 281 kg.

The SCAPP system initially, using a menu dialogue, provides the planner with the opportunity to alter the values for any of the planning parameters for the use in the current plan.

The user is then requested to enter the order number for which he wishes to produce the process plan. At this stage, he can also specify any millstock material he might prefer to use for the current order. This means if the specified material can satisfy any of the feasible route for the order, the route will be included for the final list of preferred routes, no matter how efficient it is compared to the other routes.

Having finished the above interactive session, the system goes through main planning process during which; in addition to the final results, some important intermediate results are also displayed to the user, or printed optionally. This is to enable the user to follow up the planning process more effectively, therefore be better prepared for final decision making. The user's better understanding of the planning process can also help him for better setting up the system. It can also promote creative suggestions for further improvement of the system. In addition psychological effects are also expected.

The first result produced is a list of feasible routes, in this case 12 routes, with the corresponding range of the acceptable material dimensional ranges for each route (Fig.10.4). Data for these routes are stored in the database format for the use in the next stage of planning.

The system then makes use of material allocation program to search for suitable material from different types available in the stock (i.e. millstock, strips and coils). This produces a list of routes with alternative materials selected for each route (Fig. 10.5.). Some of the comparatively less efficient options in the list which can be identified at this stage are then eliminated, thus, a short list (called sorted list) is produced (Fig. 10.6.).

For further evaluation of the options in the above sorted list, the system calls upon route costing program, through which total costs for the routes are calculated and finally a number of (say maximum five) comparatively low cost routes are selected. These routes are called preferred routes -- see Fig. 10.7.

Data for these preferred routes are then used by another program in the system for final stage of planning. The program at this stage displays overall information for each alternative selection of the routes and waits for the planner to make the final decision. Since the alternative routes are listed in the order of their overall cost, this indirectly recommends the selection of the first route in the list. However, leaving final decision for the planner seems to be more advantageous than proceeding automatically with the system's selection for various reasons, in particular:

(i) the psychological effects of letting the planner feel in control of the system,

(ii) the planner can consider current overall preferences for the use of different resources such as material types, equipment etc.

Note although Choice Number 4, for this example is not an effective route but because it utilises a material which was specified by the user, therefore this choice has not been eliminated during the intermediate evaluations. However the system provides the user with the cost and yield information for this route together with other routes in the list. So he can easily make final selection of the route.

When the planner selects a particular route the system displays the corresponding process plan and invites the planner to edit the plan or add any instruction he might wish. When the editing is complete the hard copy of the process plan is produced. For the given order situation, plan produced by the system which is based on the first route in the list (i.e. the route with a "2-1" code) is illustrated in Fig. 10.8. The user can also try different selection of the routes given in the menu (Fig. 10.8-a to 10.8-e).

The three first routes recommended in the list are using millstock material. If millstock materials were not considered for this run then the fourth route in the present list which uses strip material would be the first choice recommended by the system. The plan produced by the system for this route is shown in Fig. 10.8-d. This compares favourably with the plan given by the process planner in the company, however, the reason for some minor differences are considered below.

1. Machine selected by the system for first rolling is G3, while using the existing system the planner has selected G3/G4, meaning either of these machines. Therefore system's selection is correct.

2. For the TRIM operation, our system has specified "trim ends" whereas the plan used in the company is specifying "trim 1230 x 1450". The SCAPP system's selection is a result of one of our basic rules: "if material is not turned between the two successive rolling processes then only triming the ends is sufficient". That is, only the deformed part of the ends have to be trimmed, leaving the extra material on the workpiece. However, with the existing retrieval method as the plans are made by different people at different period of times this kind of inconsistency is very common.

3. In the plan produced by the existing system, some of the machines are not specified (e.g. for trim, flatten, etc.), whereas the new system specifies machine for every processes. It is common practice in the industry to leave selection of some of the machines to the foremen at the shopfloor level or the schedulers. The system's selection of the machines for these cases is only for demonstration purposes. However, to cover this fully would take us into the area of machine scheduling which is outside the immediate scope of this project.

10.5. Evaluation of the System

Although this is a university based project, since its early stages there have, fortunately, been opportunities to test the results in a real manufacturing environment. As mentioned in the previous chapter, an evolutionary approach was used for the development of both the methodology and the software. Therefore results obtained at each stage of the development were checked in the industry, then necessary modifications were made. For the single order process planning, the results proved to be satisfactory, even in the early stages of the project. However, the later modification enhanced the generality of the software, details of the plans and the compatibility of the programs with the batch order process planning part of the overall system.

For the evaluation of the performance of the SCAPP system several plans produced by the system were compared with those plans made using the existing system in the company. Results from such a comparison is summarised in Table 10.1. As indicated in this table plans produced by the SCAPP system compare favourably with those produced in the company.

The evaluation of the system indicated overall cost and yield improvements together with some other benefits as listed in Table 10.2. below.

On the other hand, it is also indicated that 2% of the plans were not as good as the manually produced ones this, however, this is because some rules for exceptional situations which are being used by the manual method are not yet incorporated into the proposed system.

The above comparison of the two methods also indicated other potential advantages for the SCAPP system. These are listed in Table 10.2.

Table 10.1 Summary of the comparison of 50 routes produced by the SCAPP system with those planned by the present method.

route recommended by SCAPP matching with the route selected by the company	80%
= = = = better than = = = = = =	8 %
= = = = not as good as = = = = = =	* 2 %
= = = = different from = = = = = =	** 12 %

* This is due to some exceptional rules not yet incorporated in SCAPP.

** Plans are different but they produce similar efficiency.

Table 10.2. Potential benefits indicated by the use of SCAPP system

-- Average yield increase of 2 to 3%.

-- Some reduction in the operations required by the routes.

-- Significant improvement in process planning efficiency.

-- Much less dependency on the planner's experience.

-- Consistency of the plans.

-- Improved planning accuracy.

-- Capability to evaluate the use of different values for planning parameters.

-- Capability to be linked to with other computerised planning activities.
Such as material optimisation, scheduling, cost estimation etc.

-- Reduction of millstock level.

-- Savings as the result of not using the mainframe computing services.

10.6. Summary of Major Features of the SCAPP System

1. It is a generative type of CAPP system designed to produce process plans for the production of plates and sheets and circles in copper alloy rolling mills. Present stage of the system considers cold rolling operations only. It is a microcomputer based system.

2. In order to plan the processes for any order situation the system evaluates all possible routes considering different types of material available in stock. The system then produces a short list of preferred routes with some important information for the route including route cost indicator. While system recommending first option in the list, the user is given the right to make the final selection. The user can also try different options to evaluate alternatives. He can also edit or add comments to final plans.

3. Database setup facilities are provided to allow the authorised user to alter different planning parameters including trim allowances and the corresponding dimensional ranges. This facility is useful when different equipment or technology which requires different allowance is included in the production system.

4. It provides a facility to set relative importance for the two determinant criteria for route selection (i.e. material yield and operation) by using a "policy factor". This feature is described in more detail in Section 10.1.4.

5. It tends to produce a reduction of the millstock level. This is discussed in Section 10.3.

6. Extensive comparisons with an existing manual system shows that the prototype version of SCAPP performs at least as well as the manual system in 80% of cases considered and performs better in 8%.

```
----------------
order no: 503
--------------------------------------------------------------
 Feasible routes & corresponding material dimensional ranges
--------------------------------------------------------------
no. route  volume       gauge          width         length
-- ------- ------  -------------- ------------- ------------
1   0 - 1    311   1.08 -   1.08  1200 - 1200   2400 - 2400
2   1 - 3    354   1.14 -   1.54  1230 - 1230   1867 - 2533
3   2 - 5    354   1.26 -   6.71  1230 - 1230   429  - 2280
4   3 - 9    354   1.40 -  15.00  1230 - 1230   200  - 2052
5   3 - 1    354   1.86 -  15.00  200  - 1550   1230 - 1230
6   2 - 1    354   1.86 -   6.71  429  - 1550   1230 - 1230
7   3 - 13   385   2.67 -  15.00  429  - 1200   400  - 1203
8   3 - 5    385   2.67 -  15.00  400  - 1203   429  - 1200
9   3 - 13   394   2.29 -   8.20  1200 - 1400   400  - 1230
10  3 - 5    394   2.29 -   8.20  400  - 1230   1200 - 1400
11  3 - 13   403   2.06 -   7.19  1400 - 1550   400  - 1258
12  3 - 5    403   2.06 -   7.19  400  - 1258   1400 - 1550
--------------------------------------------------------------
```

Fig. 10.4. First stage of search: Search for macro routes

```
----------------
order no. 503    -
--------------------------------------------------------------------
      Alternative routes with corresponding choices of material
--------------------------------------------------------------------
no.    route code    yield     material   (gauge, width, length)
----   ----------    ------    --------   --------------------
1        2 - 5        0.69       ms1       2.60    1230    1400
2        2 - 5        0.75       ms5       4.50    1230     750
3        3 - 9        0.69       ms1       2.60    1230    1400
4        3 - 9        0.75       ms5       4.50    1230     750
5        3 - 13       0.77       ms2       4.20     800    1200
6        3 - 5        0.77       ms2       4.20     800    1200
7        3 - 13       0.75       ms5       4.50    1230     750
8        3 - 5        0.69       ms1       2.60    1230    1400
9        3 - 5        0.77       ms2       4.20     800    1200
10       3 - 5        0.69       ms1       2.60    1230    1400
--------------------------------------------------------------------
```

Fig. 10.5-a Second stage of search: Search for millstock material

```
----------------
order no. 503    -
-----------------------------------------------------------------
      Alternative routes with corresponding choices of material
-----------------------------------------------------------------
no.   route code   yield    material   (gauge, width, length)
----  ----------   ------   --------   --------------------
1       3 - 1       0.80     stp4       5.00    635    1230
2       2 - 1       0.80     stp4       5.00    635    1230
3       3 - 13      0.81     stp5       6.40    635     947
4       3 - 5       0.81     stp5       6.40    635     947
5       3 - 5       0.79     stp4       5.00    635    1240
6       3 - 5       0.77     stp3       4.30    635    1474
-----------------------------------------------------------------
```

Fig. 10.5-b Second stage of search: Search for strip material

```
order no. 503   (sorted list)
-----------------------------------------------------------------
      Alternative routes with corresponding choices of material
-----------------------------------------------------------------
no.   route code   yield    material   (gauge, width, length)
----  ----------   ------   --------   --------------------
1       2 - 5       0.69     ms1        2.60    1230   1400
2       2 - 5       0.75     ms5        4.50    1230    750
3       3 - 5       0.77     ms2        4.20    800    1200
4       2 - 1       0.80     stp4       5.00    635    1230
5       3 - 5       0.81     stp5       6.40    635     947
-----------------------------------------------------------------
```

Fig. 10.6. Second stage of search: Selection of more effective routes

```
Preferred routes -- listed in ascending order of route cost
--------------------------------------------------------------
no.  rt code  material(G      W      L )     yield     rt cost
---  -------  -------------------------     ------    ------
1.   2 - 5    ms5   ( 4.50  1230  750  )    0.75      524
2.   2 - 5    ms1   ( 2.60  1230  1400 )    0.69      527
3.   3 - 5    ms2   ( 4.20  800   1200 )    0.77      530
4.   2 - 1    stp4  ( 5.00  635   1230 )    0.80      554
5.   3 - 5    stp5  ( 6.40  635   947  )    0.81      565
--------------------------------------------------------------
```

Fig. 10.7. Preferred routes

```
------------------------------------------------------------
order no: 503    customer: A3    due date: 01FEB86
metal:    126    qly:     5    weight:   281     count:  10
rect   dims: 1.20X1200X2400   tols:(0 -0.17),(3.5 -3.5),(5 -5)
hardness: 10 - 55  fdirectional    application  -
remarks:   -
------------------------------------------------------------
material:  ms5   4.5   1230   750
------------------------------------------------------------
route yield: 0.75   route cost indicator: 524      ( 1 )
------------------------------------------------------------
    F44            TRIM ENDS ONLY
    E10/20         ANNEAL TO SHEDULE
    G3             G.R.   1.91 x 1230
    F44            TRIM ENDS ONLY
    E10/20         ANNEAL TO SHEDULE
    G3             F.R.   1.08 ( +/- 0.05) x 1230
    FLT1           FLATTEN
    F18            F.S.
    E10/20         ANNEAL TO SHEDULE
    -              INSPECTION
------------------------------------------------------------
```

Fig. 10.8-a Process plan for the 1st choice of routes

```
------------------------------------------------------------
order no: 503    customer: A3    due date: 01FEB86
metal:    126    qly:     5    weight:   281     count:  10
rect   dims: 1.20X1200X2400   tols:(0 -0.17),(3.5 -3.5),(5 -5)
hardness:  10 - 55  fdirectional    application  -
remarks:   -
------------------------------------------------------------
material:  ms1   2.6   1230   1400
------------------------------------------------------------
route yield: 0.69   route cost indicator: 527      ( 2 )
------------------------------------------------------------
    F44            TRIM ENDS ONLY
    E10/20         ANNEAL TO SHEDULE
    G3             G.R.   1.55 x 1230
    F44            TRIM ENDS ONLY
    G3             F.R.   1.08 ( +/- 0.05) x 1230
    FLT1           FLATTEN
    F18            F.S.
    E10/20         ANNEAL TO SHEDULE
    -              INSPECTION
------------------------------------------------------------
```

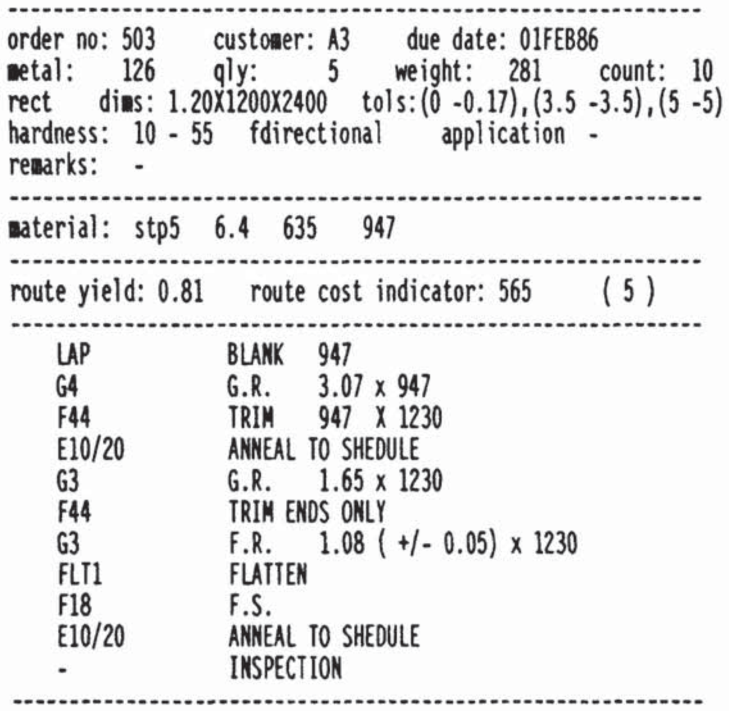
Fig. 10.8-b Process plan for the 2nd choice of routes

```
------------------------------------------------------------
order no: 503     customer: A3     due date: 01FEB86
metal:    126     qly:      5     weight:   281     count:  10
rect   dims: 1.20X1200X2400   tols:(0 -0.17),(3.5 -3.5),(5 -5)
hardness:  10 - 55   fdirectional     application  -
remarks:   -
------------------------------------------------------------
material:  ms2   4.2   800    1200
------------------------------------------------------------
route yield: 0.77    route cost indicator: 530       ( 3 )
------------------------------------------------------------
    F44            TRIM ENDS ONLY
    G3             G.R.    2.54 x 1200
    F44            TRIM    1200 X 1230
    E10/20         ANNEAL TO SHEDULE
    G3             G.R.    1.53 x 1230
    F44            TRIM ENDS ONLY
    G3             F.R.    1.08 ( +/- 0.05) x 1230
    FLT1           FLATTEN
    F18            F.S.
    E10/20         ANNEAL TO SHEDULE.
     -             INSPECTION
------------------------------------------------------------
```

Fig. 10.8-c Process plan for the 3rd choice of routes

```
------------------------------------------------------------
order no: 503     customer: A3     due date: 01FEB86
metal:    126     qly:      5     weight:   281     count:  10
rect   dims: 1.20X1200X2400   tols:(0 -0.17),(3.5 -3.5),(5 -5)
hardness:  10 - 55   fdirectional     application  -
remarks:   -
------------------------------------------------------------
material:  stp4   5.0   635    1230
------------------------------------------------------------
route yield: 0.80    route cost indicator: 554       ( 4 )
------------------------------------------------------------
    LAP            BLANK   1230
    E10/20         ANNEAL TO SHEDULE
    G3             G.R.    1.98 x 1230
    F44            TRIM ENDS ONLY
    E10/20         ANNEAL TO SHEDULE
    G3             F.R.    1.08 ( +/- 0.05) x 1230
    FLT1           FLATTEN
    F18            F.S.
    E10/20         ANNEAL TO SHEDULE
     -             INSPECTION
------------------------------------------------------------
```

Fig. 10.8-d Process plan for the 4th choice of routes



```
------------------------------------------------------------
order no: 503    customer: A3    due date: 01FEB86
metal:    126    qly:      5    weight:   281    count:  10
rect   dims: 1.20X1200X2400   tols:(0 -0.17),(3.5 -3.5),(5 -5)
hardness:  10 - 55   fdirectional     application  -
remarks:   -
------------------------------------------------------------
material:  stp5   6.4   635    947
------------------------------------------------------------
route yield: 0.81    route cost indicator: 565      ( 5 )
------------------------------------------------------------
    LAP            BLANK  947
    G4             G.R.    3.07 x 947
    F44            TRIM    947  X 1230
    E10/20         ANNEAL TO SHEDULE
    G3             G.R.    1.65 x 1230
    F44            TRIM ENDS ONLY
    G3             F.R.    1.08 ( +/- 0.05) x 1230
    FLT1           FLATTEN
    F18            F.S.
    E10/20         ANNEAL TO SHEDULE
    -              INSPECTION
------------------------------------------------------------
```

Fig. 10.8-e Process plan for the 5th choice of routes

CHAPTER 11

BATCH ORDER PROCESS PLANNING (BCAPP) -- SYSTEM DESCRIPTION TEST RUN RESULTS AND VERIFICATION OF THE SYSTEM

11.1. Introduction

The previous chapter discussed the SCAPP system and its capability to plan the processes for single orders. This system, for a given order specification, initially produces a list of preferred routes, from which it finally selects the optimum one (i.e.the least cost route). Study of the list of preferred routes for different orders indicated that in some cases, apart from the optimal route, a few other routes can also be found which are very close to the optimal situation. The study also showed some similarity between the routes for different orders, mainly similarity of their material gauge.

The idea of batch order process planning as discussed in Chapter 6, derives from the concept of overall optimisation rather than local or partial optimisation. Briefly, the idea is to group the orders in a given batch in such a way that each group can make use of the similarity between the routes for that group, more specifically between their material gauges, in order to increase material yield, while optimising the overall route costs for the batch.

BCAPP is designed for carrying out this kind of batch order process planning. It can be considered as an extension of the SCAPP system. It also shares with the SCAPP system some of the major modules described in the previous chapter, such as route selection module, costing module, route detail planning module, etc.

The following sections outline the structure of the BCAPP system, describing features of some major modules specifically designed for the batch processing (and hence not previously considered in our description of SCAPP). It also illustrates the operation of the system through the use of one actual batch of orders which was processed by one of the companies which we studied. Plans produced for this batch by the system are then compared with those plans produced using the existing manual-retrieval method in the company. This chapter finally summarises the features of the BCAPP system.

11.2 Functional Stages

The following functional stages have been designed for the BCAPP system based on the requirements for batch order process planning described in Chapter 6.

Stage 1.

Consider one order from the batch of orders. Determine feasible macro routes for this order.

Stage 2.

Search stock (strip material) to allocate appropriate material for each route situation.

Stage 3.

Divide the gauge range given in the routes into subranges. This is to allow more accurate costing in the next stage.

Stage 4.

Calculate route cost for each choice of the route. Save data for the routes in a file using a format compatible with the grouping program (Stage 6).

Stage 5.

repeat stages 1 to 4 for all the products in the batch.

Stage 6.

Apply grouping procedure for the routes produced for different orders in the batch. Determine the groups.

Stage 7.

Consult the user on the results of the grouping. Edit or modify if required. Obtain the user's confirmation.

Stage 8.

Consider one group. Produce the process plan for each order in the group based on the selected route for that order. Edit or modify the plan if required. Obtain the user's confirmation.

Stage 9.

Repeat Stage 8. for all products in the group.

Stage 10.

Repeat Stages 8 and 9 for all the groups determined for the batch.

11.3. Overall Description of the System

The BCAPP system is designed to carry out the above functional stages. Overall flow of the control and data for this system is represented in Fig. 11.1 and its major modules are listed below.

Batch Order Process Planning (BCAPP) -- Main modules

1. BCAPINIT - Initialisation module,
2. BSELCRTS - Route selection module,
3. BALOCMAT - Material allocation module,
4. BCOSTRTS - Route costing module,
5. BOPTIM - Optimisation (grouping) module,
6. BPROPLAN - Process plan production,
7. BCAPTERM - BCAPP termination module.

Each of these modules is, in turn, constructed from submodules and so on, in a descending hierarchy, as shown in Fig. 11.2. In the following subsections a brief description of the above modules is given. BCAPP System shares common submodules with the SCAPP system. Since these submodules have already been discussed in the previous chapter, they will not be repeated here.

11.3.1. "BCAPPINIT"

This module produces the working copy of the relevant database files. It also enables the user to review or alter the values for the planning parameters and the specifications for the orders. This is similar to the module discussed for the SCAPP system.

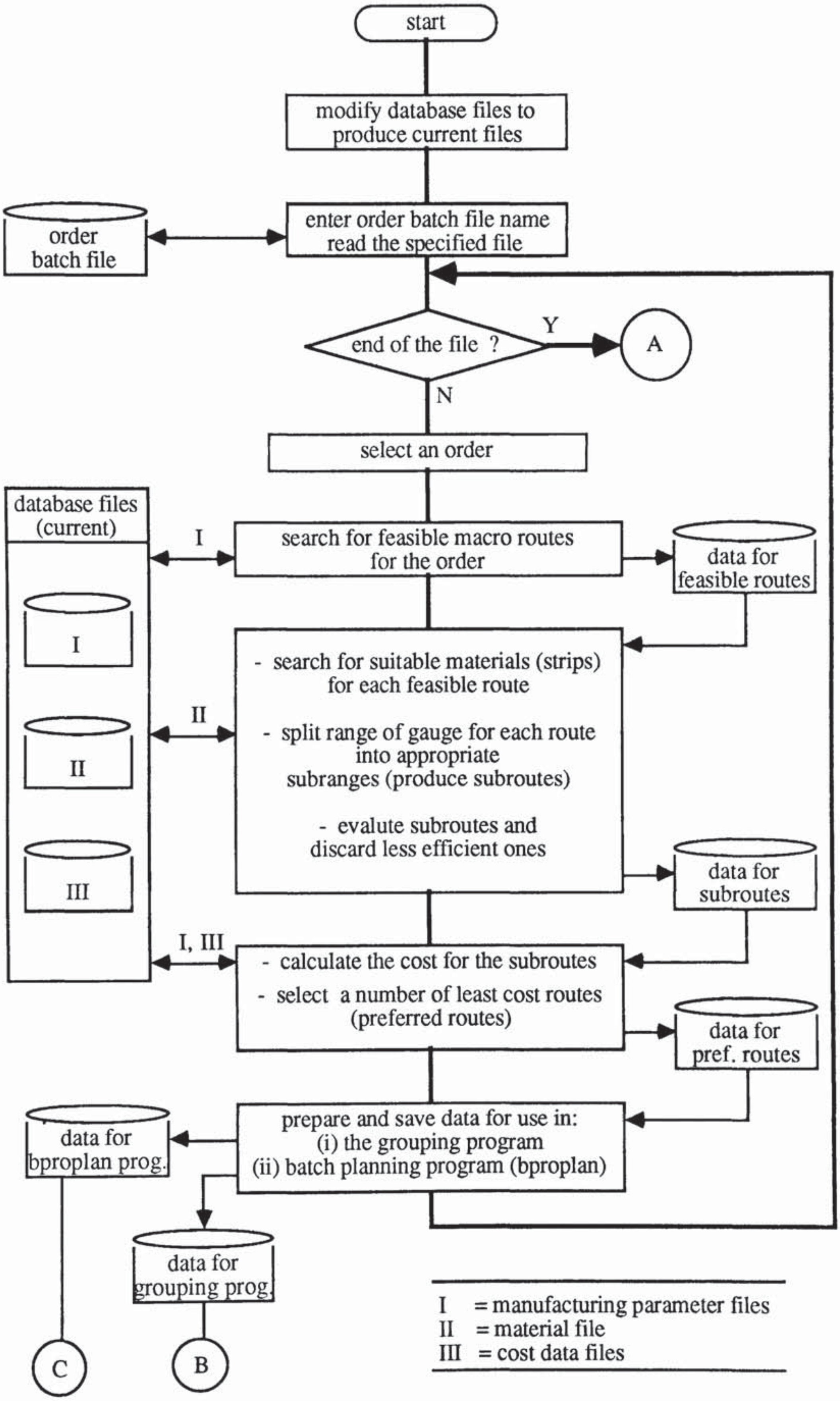


Fig. 11.1 Schematic representation of the flow of control and data in the BCAPP system -- (Part 1)

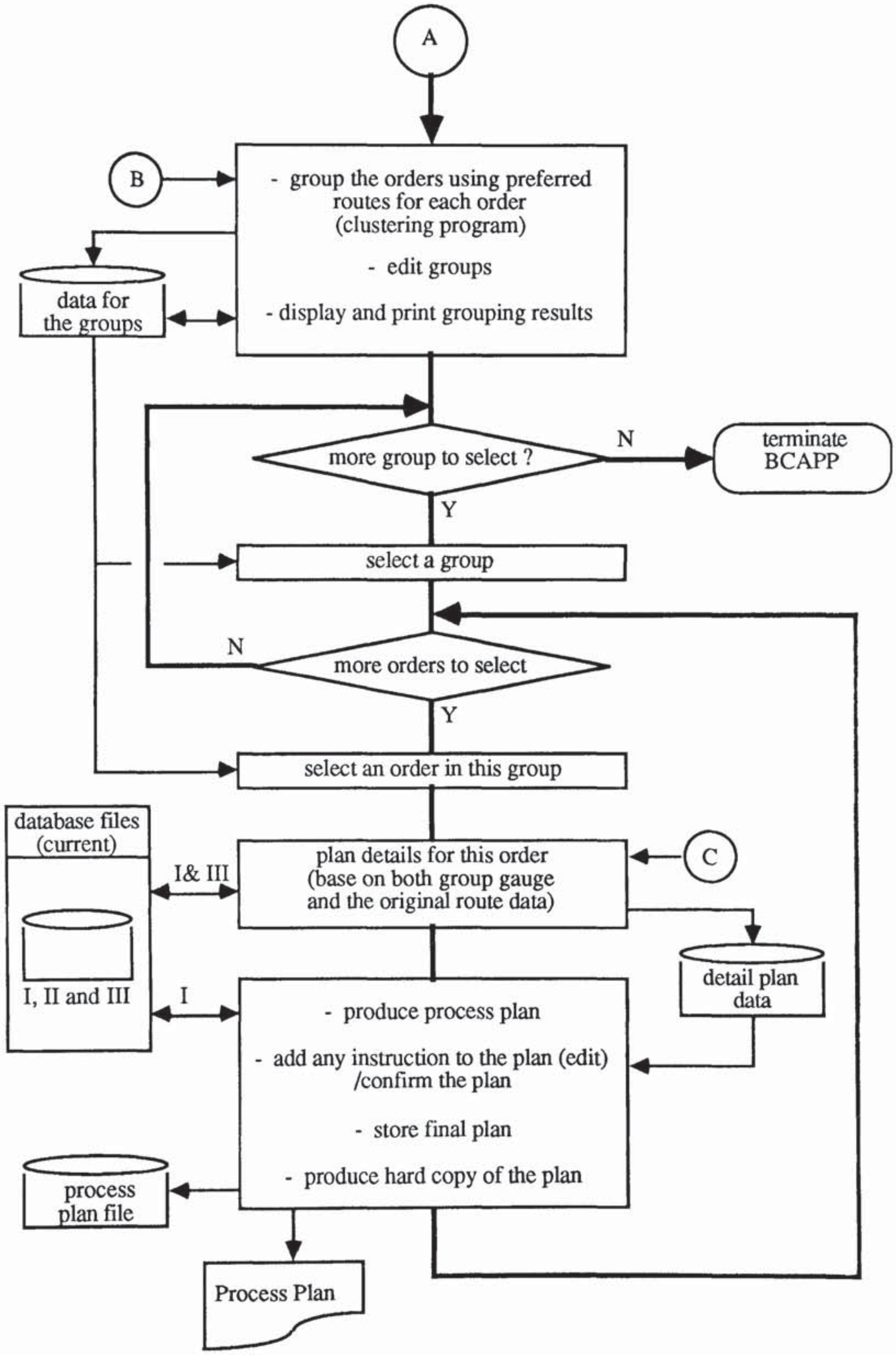


Fig. 11.1 Schematic representation of the flow of control and data in the BCAPP system -- (Part 2)

11.3.2. "BSELCRTS"

Considers orders one at a time, then calling upon the "selecrts" module for each order , as discussed for the SCAPP system, determines feasible macro routes and their corresponding acceptable dimensional ranges.

11.3.3. "BALOCMAT"

Considers each feasible route, then searches for the acceptable range of strip gauge for that situation. If the search is successful then the relevant data is stored in the database for that route. If the search fails the route is discarded.

Successful routes are then compared on the basis of their corresponding yield and the number of rolling stages. This a rough comparison, but helps to reduce the number of routes before comparing them on the cost basis.

Acceptable gauge range for the route is sometimes very wide, say 4 - 10 mm. This makes accurate calculation of the route cost very difficult. To avoid this problem , the program divides the gauge range into smaller ranges producing subroutes for which other data are adjusted accordingly. Data for the subroutes are stored in the database for use in further stages.

11.3.4. "BCOSTRTS"

This module reads the file for the subroutes data which was created by the previous program. It then calls upon the "costrts" module to calculate the cost for the subroutes for each order. The "costrts" program which is shared with the SCAPP system has already been described in the previous chapter. Result of this costing is a list of preferred (least cost) routes for each order.

11.3.5. "CLUSTPRP"

This is an interface subroutine which reads data for the routes (subroutes) created during the previous stages. It then converts these data into a format usable by the clustering program. It also calculates cost differences for each route compared with the least cost route for that order. This cost difference, as discussed in Chapter 7, represents part of the decision making cost associated with each choice of the route for any grouping.

11.3.6. "BOPT"

This module is to perform the optimisation function for the batch of the orders. The module uses the clustering program which has been discussed in Chapter 8.

Results produced by this program are arranged into two forms: one form illustrating the clustering sequences with important data for each sequence and the other representing the groups, the orders collected into each group together with some other information about the groups. Samples for these results are shown later in this chapter.

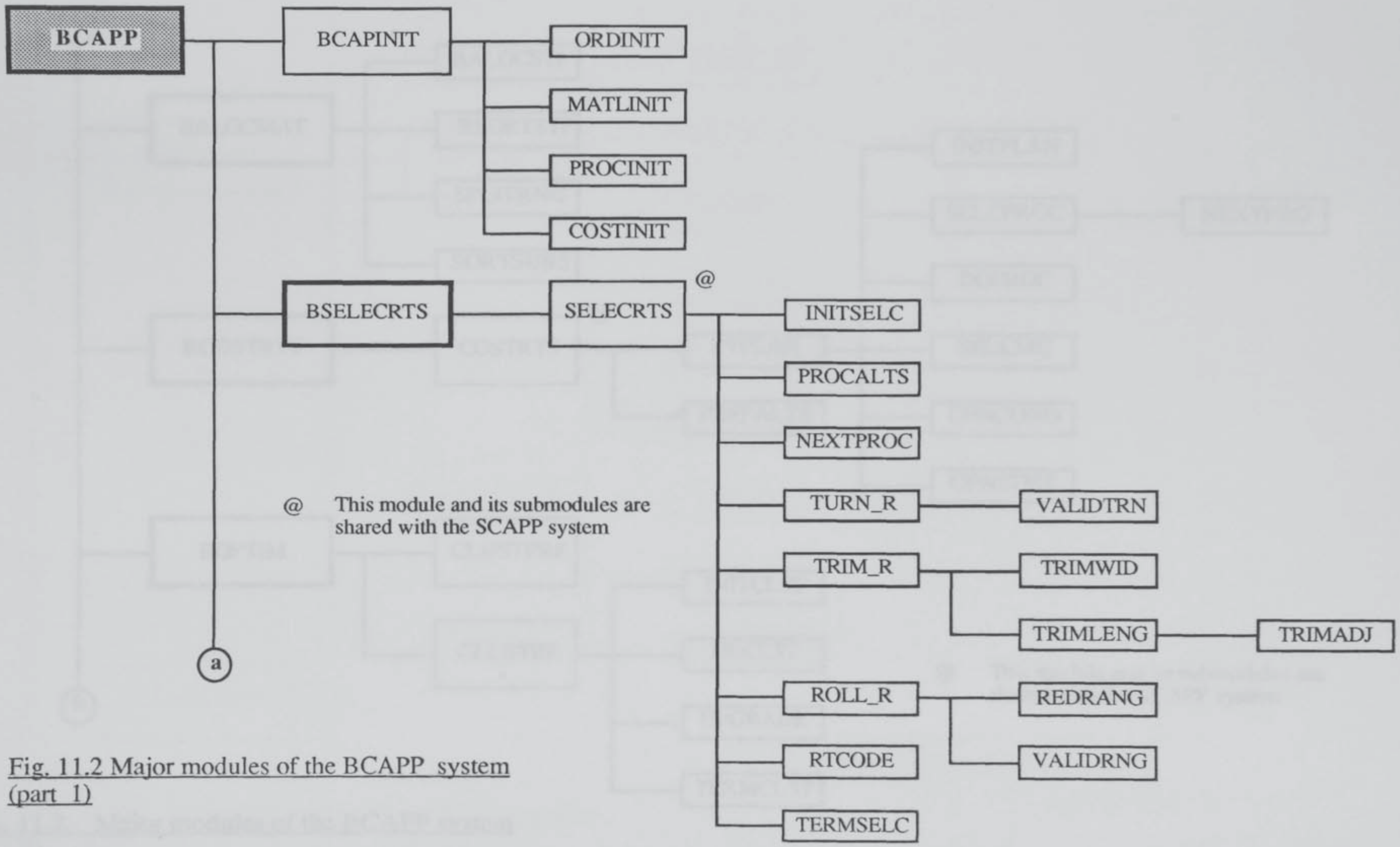
Grouping results are then stored in the database file for use in the next stage of batch order planning.

11.3.7. "BPROPLAN"

This module reads the database files produced by the clustering and other programs in the previous stages. It selects groups in turn, then selects the orders in each group one by one. For each order it considers the group gauge and other relevant data obtained from the database, then calls upon two of its submodules, "costrts" and "proplan", which are shared with the SCAPP system. The first submodule plans the details of the routes, selects machines for the processes, it also calculates accurate cost for the route. The second submodule uses the route information produced by the first module, then it generates the process plan for that order. As was described for the SCAPP system, at this stage the plans are displayed and the user is given the option to add any instruction or edit the plan.

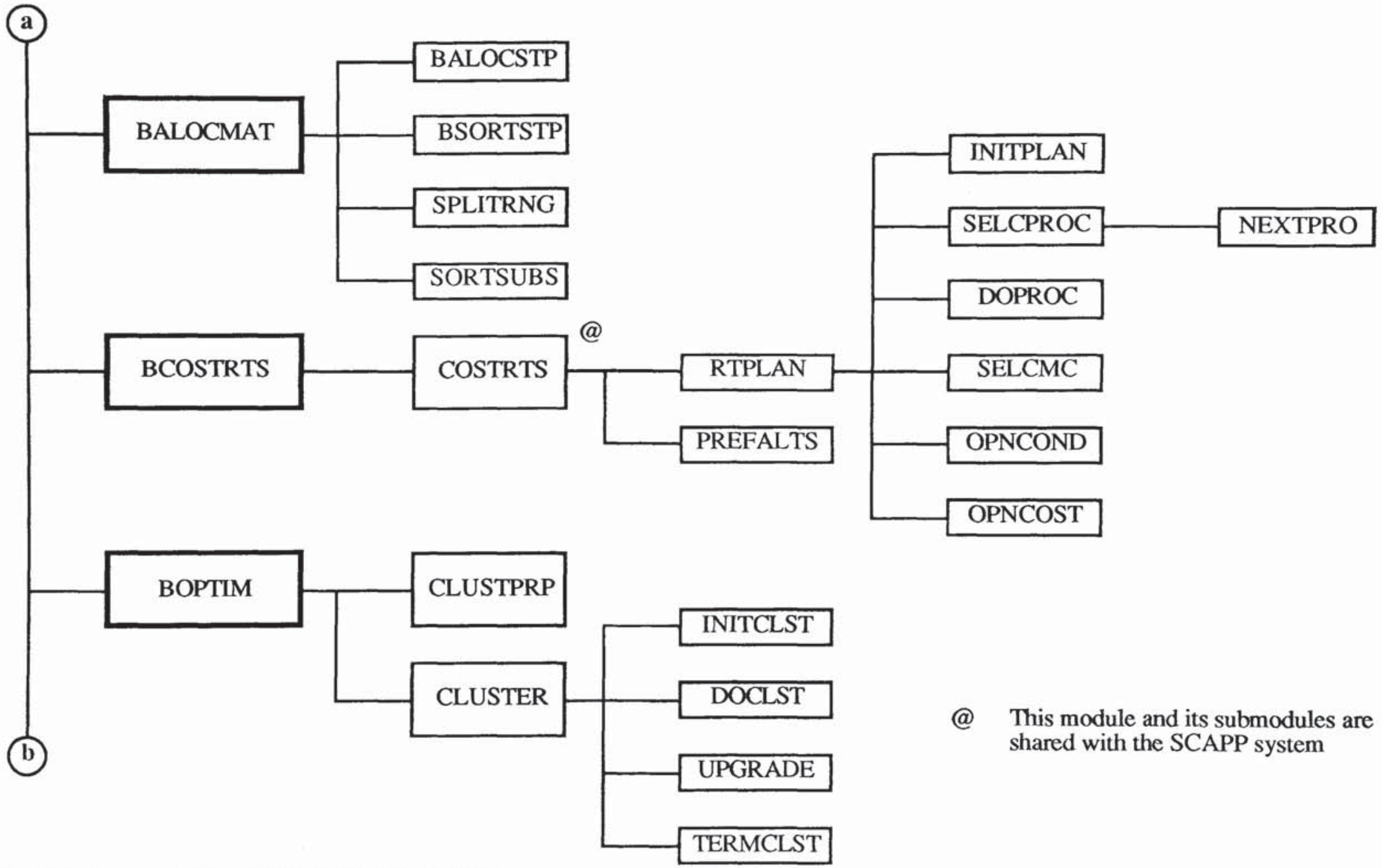
11.3.8. "BTERM"

This module is designed to terminate the batch order process planning. It performs some file preparations such as saving process plans for the reference purpose, clearing memory and producing backup files.



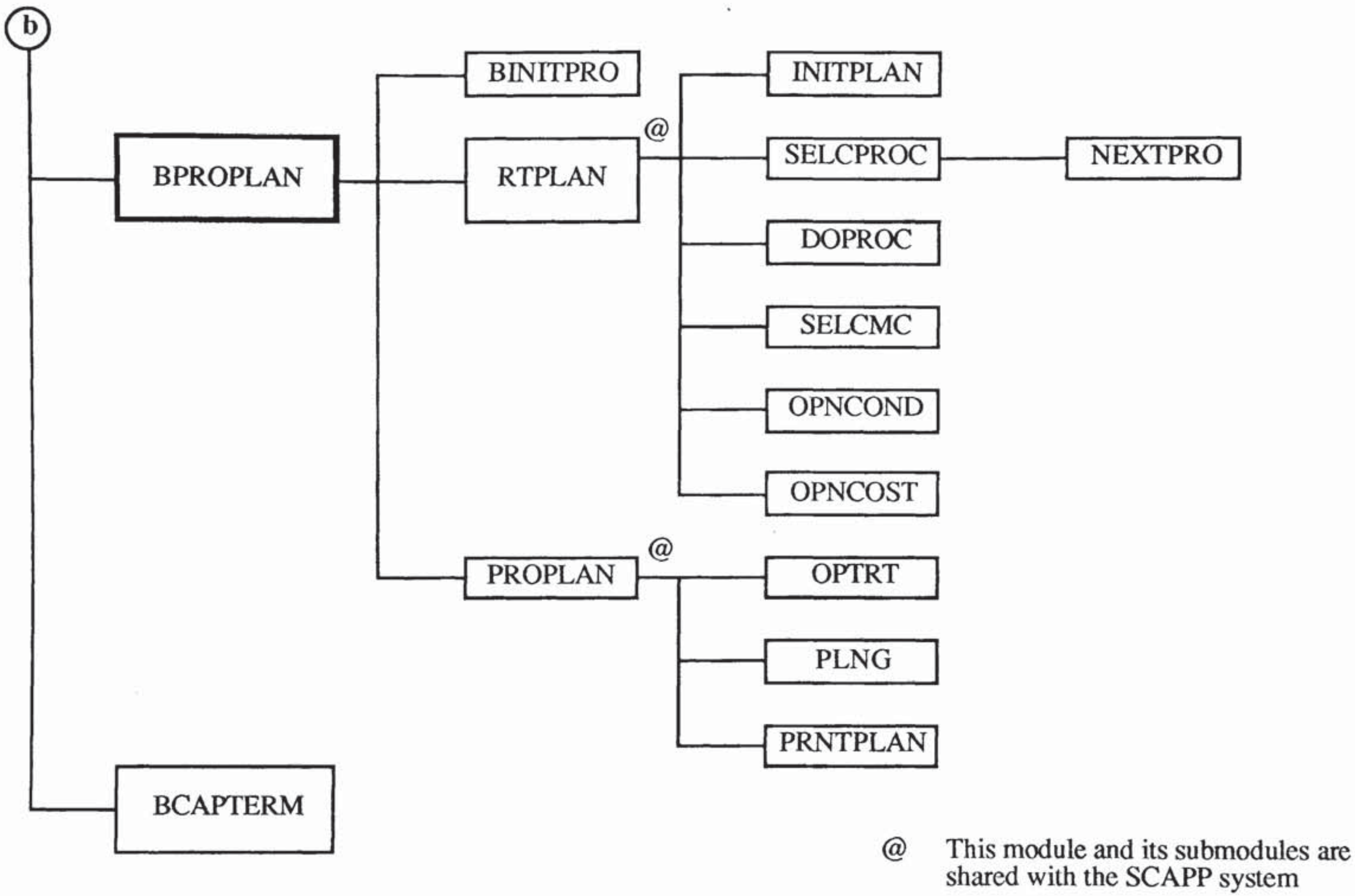
@ This module and its submodules are shared with the SCAPP system

Fig. 11.2 Major modules of the BCAPP system (part 1)



@ This module and its submodules are shared with the SCAPP system

FIG. 11.2. Major modules of the BCAPP system (part 2)



@ This module and its submodules are shared with the SCAPP system

FIG. 11.2. Major modules of the BCAPP system (part 3)

11.4. Operation of the system

This section illustrates the operation of the system through its use for one real batch of orders in the company. The batch considered for this purpose is given a code number, say Batch Number 29 (this stands for the due date week number). This batch consists of 20 orders numbered 501 to 520. A summary of the specifications for these orders is given in Table 11.1.

The BCAPP system, initially using a menu dialogue, allows the user to modify the database set up for the current use of the system. This is similar to the procedure described in the previous chapter for the SCAPP system.

Having completed the above session, the user is asked to enter the batch name for which he wishes to plan the processes. The system reads the data for these orders from the specified data file, then goes through the planning process for which it carries out the functional stages described earlier in Section 11.1. That is, in short, it selects one order, determines preferred routes for that order, then repeats this for all the orders in the batch, producing the list of preferred routes for the batch (Table 11.2.). This list includes such information as: route number, relevant macro route code, acceptable material dimensions, yield and the cost for the routes.

These data for the preferred routes are then transferred to the clustering program which, using the procedure described in Chapter 7, groups the orders through selecting one alternative route for each in such a way that each group can use a material (strip) gauge common for the orders in that group. The major criterion for this grouping is the optimisation of the total route cost for the batch. The grouping program stores data about groups in a file for use by the program in a next stage. It also produces two listings of this information for the user which are displayed on screen and copied on the printer. These are shown in Tables 11.3-a and 11.3-b. The first table shows clustering steps with the information for each step and the second table gives a summary of the information for the final groups. This table indicates the orders collected into each group together with: the gauge, yield and cost for that group. The tables also indicate the orders which are not joined with any group, and hence have to be planned individually, using the SCAPP system (alternatively these orders can be included in some other batches). At this stage the user is also given the right to include any single order in one of the groups already constructed.

Having completed the above grouping stage, the system then considers these groups, each in turn, for the planning of the processes for each order in the group based on the given group gauge and the specified route for each order. This stage produces a final plan for each order, determining both primary and secondary processes and the machine for each process. Plans are displayed on the screen for the user to confirm or to do some editing such as adding instructions. Finally a hardcopy of the plan is issued and the plan is saved in the "process plan file". Plans produced by the BCAPP system for the above orders are given in Appendix E.1. In the following section we look at some interesting features of these plans at each stage and also compare final plans with the actual plans in the company (constructed by the manual-retrieval method).

11.5. Test Run Results and Verification of the System

The BCAPP system has been tested over different batch order situations in the company, indicating satisfactory results. Below we consider one of these applications in detail, then we discuss other applications in more general terms.

The same batch considered in the previous section (Batch Number 29) is selected in this section for detailed study of the planning results. Therefore some of the results already shown in the previous section (i.e. Table11.2., Table 11.4.) and the plans given in Appendix E.1) are also included here.

It can be seen from Table 11.2 that a number of alternative routes are given for some of the orders, but for some other orders only one route exists in the list. This means that for the latter type of orders either other options were too expensive, and therefore discarded, or no other feasible alternative was found.

Table 11.3-a illustrates grouping stages, giving major information about the groups at any stage. This indicates that the grouping procedure has almost selected the cheapest alternative route available for each order. The column titled "C_dist" in this table represents the "distance" which is given in cost terms and represents the decision making cost for each grouping stage. The table shows that grouping starts with the least expensive options then gradually the cost is increased until an exit condition for clustering is satisfied. Exit condition (as described in Chapter 7) is controlled by two limits set for: (i) the distance and (ii) the ratio of total decision cost for the grouping stage to the total weight of the group. In the current clustering program the distance exit limit is set to "70", that is any grouping which exceeds this limit cannot be accepted.

As shown in Table 11.3-b, Grouping, results in four appreciably heavy groups (group weight ranging from 1541 to 0222 kg.) and a single order. Order number 510 which is left single is a heavy order weighting 820 kg. for which two options of preferred routes are shown in Table 11.2. The two gauge ranges specified by these two routes are: (i) 3.36 to 3.56 and (ii) 2.96 to 3.14. However it can be seen that none of the group gauges come close to satisfying this order.

Results produced by the BCAPP system for the given batch are summarised in section 'I' of Table 11.4. Plans produced for the same batch using the present manual-retrieval method in the company were also analysed. The yield and route cost for these plans were calculated manually using the same procedures applied in the BCAPP system. The results together with the comparison of the two methods are also given in Table 11.4. This table shows that: plans produced by the BCAPP system are all of one or two stage rolling routes except for two of the orders (Numbers 501 and 505) for which three stage rolling routes are selected. When compared to the six cases of three rolling stage routes given by the existing method this indicates a considerable advantage for the BCAPP system with regard to the operation cost. More important indications from this table are: (i) the overall saving of input material by 5.8 % and (ii) overall route cost reduction by nearly 4 %. It can also be seen from this table that for those orders which require a gauge of 10 mm the grouping method shows very little advantage. This is because of the particular range of strip material considered for this planning. That is, no material is available in the gauge range between 7.6mm and 10mm (except the 10 mm itself). If this group (Group Number 1) were excluded the comparison of the two methods then the results would be 7.5% material yield improvement and 4.8% overall route cost reduction.

Apart from the above results, the details of the individual plans produced by the BCAPP system were also compared with the actual plans in the company. This showed nearly all the plans are either as good as the plans produced by the other method or even slightly better if we consider such criteria as accurate allocation of the allowances, machine selection, etc.

Additional benefits from BCAPP

More efficient use of strip coils is another advantage of the BCAPP system as this system tends to use the full length of the coils while, in the present method, when part of a coil is used for one order the rest of the coil is stocked for some future use. Total time spent on the planning for the batch indicates another important advantage for the BCAPP system. This time for the planning of the above 20 orders using the prototype

BCAPP system is less than an hour, which is much less than the time for an experienced planner to produce the plans or to retrieve and check the plans for their efficiency before issuing them for production.

Apart from the above results, the application of the BCAPP system to different batches of orders indicated following general results.

Benefits expected from batch order process planning approach over planning the orders individually are related to different factors such as: the number of orders in the batch, existence of alternative preferred (less expensive) routes for each order and the similarity of the routes, i.e. similarity of the theoretical gauges required by these preferred routes. Therefore different levels of benefits can be achieved with different order batch situations.

With regard to the batch size, although some applications for batches with a small number of orders (say 5) indicated good results, there were also cases in which effective grouping were not possible, therefore it would be more beneficial to plan the orders individually using the SCAPP system. In practice therefore, it is recommended that batches with small numbers of orders are processed first by BCAPP. If little or no grouping take place, the batch should then be processed by SCAPP.

However, in general, the test runs indicated considerable advantage for the use of batch order process planning for batches of 10 or more orders. There were also indications that some of the products requiring soft to half hard finish (55 max Hv) allow more flexibility in the routes and therefore are more suitable for batch order process planning.

In the companies which were studied, it was found that batches of orders were usually made up of orders sharing the same due date or those due in the same week. A batch defined in this way may consist of say 5 to 30 orders for the same metal, while 20 orders in a batch is the most common situation. In the light of our tests it is clear that BCAPP system can be effectively used for most of the practical cases.

11.5. Summary of Major Features of the BCAPP System

The BCAPP system is designed to perform batch order process planning based on the functional stages discussed in Section 11.2.

The overall planning process for this system can be considered in three parts. In the first part the system goes through different search functions in order to determine preferred routes for each order in the batch.

In the second part, the system groups the orders by using a cluster analysis procedure based on the similarity of their routes with regard to the material gauge selected by each route. The major criterion for this grouping is the optimisation of total route cost for the batch.

Finally, in the third part the system uses both the grouping results and results from previous stages to plan the details and produce the process plan for each order in the batch.

The BCAPP system was tested over different actual batch of orders in the company. Results have indicated considerable advantage for this system compared with the present manual-retrieval method used in the industry. The advantages include nearly 5 to 6 percent material yield improvement and a reduction of 3 to 4 percent in overall route cost.

Other important advantages for the BCAPP system are:

- ease of the planning task with considerable reduction of planning time,
- much less dependency on the planner's skill and experience,
- more consistency of the plans
- more accurate planning and the allocation of allowance.

It was also indicated that the system is more applicable for batches with 10 or more orders. For smaller batches however it is advisable to try the BCAPP system first. If the grouping is then found to be unsatisfactory the SCAPP system could be used to plan the orders individually.

However, in the light of our tests it is clear that the combination of BCAPP and SCAPP system can be effectively used for most cases likely to arise in practice.

Table 11.1. Summary of major data for the orders in Batch Number 29. (Metal 126, Quality grade 5, Due week 29)

No	Order No.	Weight	Count	Shape	Gauge	Width	Length	------ Tols (gauge width length) -------			Hardness H.V.
1	501	400	8	rectangle	2.0	1200	2400	(+0.11, -0.11)	(0.6, -0)	(+10, -0)	70 - 90
2	502	320	10	rectangle	2.5	1160	1345	(0, - 0.3)	(5.0, 0)	(0, -7)	60 - 90
3	503	281	10	rectangle	1.2	1200	2400	(0, - 0.17)	(3.5, -3.5)	(5, -5)	55max
4	504	1000	22	rectangle	2.0	1500	1800	(0, - 0.24)	(3.5, -3.5)	(3.5, -3.5)	60 - 90
5	505	531	10	rectangle	2.0	1219	2438	(0.14, - 0.14)	(6.0, 0)	(10, 0)	70 - 90
6	506	1000	20	rectangle	2.0	1524	1905	(0, - 0.24)	(3.5, -3.5)	(3.5, -3.5)	60 - 90
7	507	500	11	rectangle	2.0	1435	1880	(0, - 0.24)	(3.5, -3.5)	(3.5, -3.5)	60 - 90
8	508	296	10	rectangle	1.8	1235	1568	(0, - 0.22)	(5.0, 0)	(0, -7)	60 - 90
9	509	427	10	rectangle	1.6	1510	2083	(0, - 0.19)	(0, -7)	(5.0, 0)	60 - 90
10	510	820	40	rectangle	1.6	1160	1345	(0, - 0.19)	(5.0, 0)	(0, -7)	60 - 90
11	511	320	40	rectangle	2.5	1160	1345	(0, - 0.30)	(5.0, 0)	(0, -7)	60 - 90
12	512	664	20	rectangle	2.0	1304	1500	(0, - 0.24)	(5.0, 0)	(0, -7)	60 - 90
13	513	439	10	rectangle	2.0	1395	1855	(0, - 0.26)	(5.0, 0)	(0, -7)	60 - 90
14	514	283	6	rectangle	2.0	1470	1888	(0, - 0.24)	(3.5, -3.5)	(3.5, -3.5)	60 - 90
15	515	686	15	circle	4.5	1290	1290	(0, - 0.2)	(8.0, 0)	(0, 0)	55 max
16	516	182	4	circle	5.0	1150	1150	(0, - 0.3)	(8.0, 0)	-	55max
17	517	112	3	rectangle	1.6	1500	1800	(0, - 0.19)	(3.5, -3.5)	(3.5, -3.5)	60 - 90
18	518	257	5	rectangle	1.6	1510	2088	(0, - 0.19)	(3.5, -3.5)	(5, -5)	60 - 90
19	519	217	7	rectangle	2.5	1087	1380	(0, - 0.3)	(5.0, 0)	(0, -7)	60 - 90
20	520	246	4.5	circle	4.5	630	630	(0, - 0.25)	(3.0, -3.0)	-	55max

Table 11. 2. Major data about the preferred routes used by the clustering program

order number	route code	alt. route number	- gauge min.	range - max.	yield	cost	relative cost *
501	3 - 5	2	10.0	10.0	0.81	677	0
	3 - 5	4	7.57	7.6	0.77	690	13.5
	3 - 5	3	10.0	10.0	0.76	701	24.3
	2 - 1	1	10.0	10.0	0.74	707	30.02
502	2 - 1	1	5.18	5.69	0.90	514	0
	2 - 2	3	4.56	5.02	0.89	517	3.12
503	2 - 1	1	4.53	4.98	0.88	522	0
504	2 - 1	1	5.83	6.18	0.87	1572	0
505	3 - 5	2	10.0	10.0	0.81	885	0
	2 - 1	1	10.0	10.0	0.75	917	32
	3 - 5	3	10.0	10.0	0.78	919	34
506	2 - 1	1	6.17	6.54	0.87	1623	0
507	2 - 1	1	6.08	6.70	0.86	833	0
508	2 - 1	1	4.47	4.92	0.88	492	0
509	2 - 1	1	5.44	5.98	0.86	725	0
510	2 - 1	1	3.36	3.56	0.90	1440	0
	2 - 2	3	2.96	3.14	0.89	1480	40
511	2 - 1	1	5.18	5.69	0.90	514	0
	2 - 2	3	4.56	5.02	0.89	517	3
512	2 - 1	1	4.75	5.13	0.88	1077	0
	2 - 2	3	4.22	4.56	0.87	1086	9
513	2 - 1	1	6.00	6.60	0.86	696	0
514	2 - 1	1	6.11	6.72	0.87	467	0
515	1 - 1	1	10.0	10.0	0.77	1112	0
	2 - 7	2	10.0	10.0	0.82	1153	41
	3 - 3	3	10.0	10.01	0.80	1169	57
516	1 - 1	1	10.0	10.0	0.85	280	0
517	2 - 1	1	4.7	5.26	0.87	181	0
518	2 - 1	1	5.45	6.0	0.86	436	0
519	2 - 1	1	5.31	5.84	0.90	347	0
520	1 - 1	1	4.68	5.15	0.89	491	0

* relative cost represents the difference between the cost for any route and the cost of the best route for the order.

Table 11.3-a Clustering steps

```
---------------------------------
Program:  CLUST3.PRO
Datafile: clustprp.29m
Time used for computing: 0m, 42s,  78hs
Count1 =  393.0 x 10 , Count2 =   42.0 x 10

---------------------------------



          *_*_*_*_*       CLUSTERING RESULTS       *_*_*_*_*

       ------------------------------------------------------------
       Stage                    Grouping data
       ----- ------------------------------------------------------
          Gp_no  Head    Member  Weight Gauge Yield  Cgp Cgp  C_dist.
       ------------------------------------------------------------
        1  101   501 -2  505 -2   931  10.00   0.81    0  0     0.00
        2  102   502 -1  511 -1   640   5.18   0.90    0  0     0.00
        3  103   515 -1  516 -1   868  10.00   0.79    0  0     0.00
        4  104   101 -1  103 -1  1799  10.00   0.80    0  0     0.00
        5  105   518 -1  509 -1   684   5.46   0.86    1  0     1.19
        6  106   517 -1  520 -1   358   4.70   0.88    1  0     1.28
        7  107   514 -1  507 -1   783   6.12   0.86    2  0     2.46
        8  108   512 -1  106 -1  1022   4.75   0.88    5  1     4.12
        9  109   503 -1  508 -1   577   4.54   0.87    5  1     4.75
       10  110   105 -1  519 -1   901   5.46   0.87    8  1     6.35
       11  111   506 -1  107 -1  1783   6.17   0.86   11  1     8.17
       12  112   111 -1  513 -1  2222   6.17   0.86   24  1    13.69
       13  113   108 -1  109 -1  1599   4.75   0.86   41  3    31.33
       14  114   110 -1  102 -1  1541   5.46   0.86   45  3    37.60
       ------------------------------------------------------------

       Products not grouped
       -------------------
       1).      504
       2).      510
       -------------------
```

Table 11.3-b Data for the groups of orders

```
            *_*_*_*_*               GROUPS               *_*_*_*_*

  ----------------------------------------------------------------------
                        DATA  FOR  THE  FINAL  GROUPS
  ----------------------------------------------------------------------
  No (code)  Gauge  Weight Yield Cost ------------- Members -------------
  ----------------------------------------------------------------------
   1  (104)  10.00   1799  0.80   0 - [501,505,515,516,]
   2  (112)   6.17   2222  0.86   1 - [506,507,513,514,]
   3  (113)   4.75   1599  0.86   3 - [503,508,512,517,520,]
   4  (114)   5.46   1541  0.86   3 - [502,509,511,518,519,]
  ----------------------------------------------------------------------

  Products not grouped
  -------------------
       1).      504
       2).      510
  -------------------
```

Table 11.4. Summary of the comparison of the results of the BCAPP system and the present method on Batch Number 29. Part1

Order No.	(I) Results for the BCAPP system				(II) Results for the present (retrieval) system				**Gains:** for (I) compared to (II)		
	Route Code	Gauge	Yield	Route Cost	Route Code	Gauge	Yield	Route Cost	**Route Cost**	Material Cost	Oper'n Cost
502	2 - 1	5.5	0.86	528	2 - 3	5	0.82	656	28	18	10
509	2 - 1	5.5	0.86	725	3 - 5	7.6	0.74	837	107	80	27
511	2 - 1	5.5	0.86	528	2 - 3	5.0	0.82	561	33	18	15
518	2 - 1	5.5	0.86	436	3 - 5	7.6	0.79	505	69	24	45
519	2 - 1	5.5	0.88	356	2 - 2	4.3	0.88	356	--	--	--
503	2 - 1	4.8	0.84	532	2 - 1	5	0.79	553	21	21	--
508	2 - 1	4.8	0.83	507	2 - 1	5	0.79	525	18	18	--
512	2 - 1	4.8	0.88	1077	2 - 1	5.0	0.83	1117	40	40	--
517	2 - 1	4.8	0.86	182	3 - 5	5	0.81	208	26	8	18
520	1 - 1	4.8	0.88	494	1 - 1	5.0	0.83	509	15	15	--
506	2 - 1	6.2	0.87	1623	2 - 1	6.4	0.83	1670	47	47	--
507	2 - 1	6.2	0.85	838	2 - 1	6.4	0.83	852	14	14	--
513	2 -1	6.2	0.84	748	3 - 5	7.6	0.80	780	32	20	12
514	2 - 1	6.2	0.86	469	2 - 1	6.4	0.81	489	20	20	--

Table 11.4. Summary of the comparison of the results of the BCAPP system and the present method on Batch Number 29. Part 2

Order No.	(I) Results for the BCAPP system				(II) Results for the present (retrieval) system				Gains for (I) compared to (II)		
	Route Code	Gauge	Yield	Route Cost	Route Code	Gauge	Yield	Route Cost	**Route Cost**	Material Cost	Oper'n Cost
501	3 - 5	10	0.81	677	3 - 5	10	0.79	685	8	8	--
505	3 - 5	10	0.81	885	3 - 5	10	0.78	910	25	25	--
515	1 - 1	10	0.77	1112	1 - 1	10	0.76	1112	--	--	--
516	1 - 1	10	0.85	280	1 - 1	10	0.84	280	--	--	--
504	Not Grouped				2 - 1	6.4	0.78	--	--	--	--
510	Not Grouped				3 - 5	5.0	0.80	1774	--	--	--
								14367	495	368	127

Total route cost reduction = 495 or
= 495/14367 = 3.5 %

saving on material cost = 368 which is approx. 3/4 of total saving on the route cost
overall material yield improvement = material saved / total order weight = 368/7165 = 5.14 %
saving on the operation cost = 127 which is approx. 1/4 of the total saving on the route cost

CHAPTER 12

DISCUSSION AND CONCLUSION

12.1. An Overview of the Problem

The operations used in the manufacture of flat-rolled copper-alloy products naturally fall into three main functions: foundry and casting, hot rolling and cold rolling. This is recognised in the industry by organising these functions into separate production departments. Such a classification implies that the overall process planning system for a rolling mill company should be designed to include three distinct modules, each corresponding to one of the production departments.

In this project, through a practical study of general characteristics of the overall process planning function for flat rolled products, a number of primary problems were identified in relation to the planning for cold rolling department, in particular for the production of plates and sheets. Therefore, research was concentrated on the process planning for these products in the cold rolling department.

Planning for these, involves the selection of appropriate materials, and determination of an economically viable route for the transformation of any selected material into the end product. This process obviously requires evaluation of various possible options for the selection of both material and the process route. It also incorporates machine selection and the determination of some related operation parameters. *Material yield* and *route cost* are the two most important criteria for the evaluation of the plan. Whilst a higher material yield is generally aimed at, we have chosen the optimisation of the route cost as the ultimate objective for the planning of any single order.

Practical observation in a number of rolling mills has established the type of *manual process planning* traditionally used in this industry. The manual approach, however, has inherent drawbacks, being particularly dependent on the individual planners who gain their knowledge over a long span of experience. The task is time consuming and offers no guarantee of producing plans which are optimal in any obvious sense.

The introduction of the *variant CAPP* approach to this industry was a first step to reduce these problems. But this could not provide a long-term answer because an experienced planner is still needed to supervise the generation of any new plan and major modifications which are frequently required. This approach also fails to take account of the dynamic nature of the parameters involved in planning, such as the varying availability of resources, operation conditions and variations in costs.

After a study of the literature of process planning approaches, the *generative CAPP* approach was found to be potentially a better option in relation to our particular planning problem.

The generative approach to CAPP systems is based on the application of *manufacturing decision logic* and *manufacturing information* on the required order specifications for the production of the process plans. This approach significantly reduces the dependency on the planner. It also has the capability for truly optimal planning, since it is entirely logical and it works on real manufacturing information.

The study of the literature also showed that no particular CAPP system or a solution methodology had been developed for tackling the particular process planning problem which we are facing in this project. Therefore a decision had to be made on how to develop an appropriate solution methodology. It was decided that this methodology should be implemented in a computerised planning system in order to evaluate its practical applicability in the industry.

12.2. Development of the Planning Methodology

The overall production of plates, sheets and circles was considered in two phases. The first phase, which consists of such operations as blanking, shearing, annealing, cleaning is for preparing the required blank specification from the selected type of material.

The second phase, which is for the main processing, includes a number of rolling operations, each accompanied by other operations such as annealing, cleaning, trimming, blanking, flattening etc. Process routes for this phase are categorised into one-, two- and three-stage rolling types. We have divided these into subcategories, which we have called *macro-routes*. A macro-route describes major operations, but not details, for a route. These major operations have been considered as process blocks and their sequence has been determined for the construction of different macro-routes. The main use of the macro-routes is in the initial stages of planning, where they work as a guiding structure in searching the overall solution space. They also provide appropriate coding for the overall structure of the routes.

The overall methodology proposed for the planning of any single order consists of five main steps. The first step consists of a backward search over possible macro-routes against the requirements of the end product. The result of this is a list of feasible macro-routes with their corresponding range of material requirements.

The second step is designed to examine available material types against the requirements for each route. Successful routes are then compared for their efficiency, using a rough evaluation method to produce a short list of *preferred routes*. They require costing for further evaluation.

The purpose of the third step is to calculate the overall cost for the list of preferred routes. This step makes use of a costing method which considers both material and operation costs.

The fourth step is designed to optimise the choice of route. The optimisation objective for single order process planning is simply the selection of the least cost route.

The final step is designed to produce the complete process plan. For this, the system makes use of the details of the optimal route produced through the previous steps. The plan at this stage requires confirmation by the planner before it can be issued to the production department. Editing provisions are also included in this final stage.

12.3. The SCAPP systen

The planning methodology described above has been implemented into a process planning system which is named the SCAPP (*Single-order Computer Aided Process Planning*) system . The system consists of a number of independent program modules particularly designed to perform the functional stages described above.

The system produces the short list of preferred routes. These are then listed in ascending order of cost on the computer terminal together with their yield and cost information and the type of material utilised. Whilst the first route in the list represents the system's choice of the route for the current order, the user is given the right to evaluate the alternative options, using the information provided by the system, and make the final selection. This is important both for ensuring the consideration of the current preferences in the system and to give the planner the feeling that he is ultimately in control. When the route is selected, the system displays the process plan, which requires the planner's confirmation before it can be issued for the production. The editing facility provided at this stage is generally to be used for the purpose of including any comments in the plan or adding further instructions. Facilities are also provided for the user to try different alternative routes in order to view their corresponding process plans.

The database included for the process planning system stores the values for the planning parameters, as well as such information as manufacturing capabilities and cost data. Database setup facilities are provided to allow the authorised user to modify the database if this is required.

The user can also try various alterations in the planning parameters (e.g. trim allowances) in order to evaluate their effects on particular planning situations.

Route cost, which is composed of material related costs and operation costs, is used in the SCAPP system as the main criterion for final evaluation of alternative routes. This cost is calculated by taking a weighted average of the above cost elements. Here, a factor called the *policy factor* is used to relate the 'material related costs' to the 'operation related costs' in the route cost calculation. Although the factor is set initially to a default value, facilities are also provided to allow the user to alter the value for the particular planning situation.

The SCAPP system tends to reduce millstock level as it facilitates the selection of millstock material in two ways. The user can specify any millstock material to use for the current order. In this case the route corresponding to the choice of material would be included in the final list of preferred material with relevant yield and cost information, so that the user can select this or any other route.

In addition the planner is provided with facilities to apply cost reduction for mill stock material. This would pursue the system to select these materials rather than standard types of material such as strips.

Extensive test runs of the SCAPP system indicated that the system performs very well with regard to the objectives discussed in Chapter 1 of this thesis. The system was extensively tested with real data from industry and the results compared very favourably with those from the existing manual and retrieval process planning method in the company. The result of the comparisons indicated that in 80% of the order situations studied, the plans produced by the two methods matched very closely. In 8% of the order situations the plans produced by the SCAPP system were much better than those of the other method. In 12%, slightly different plans were produced by the two methods but their qualities were similar. In 2% of the cases the SCAPP system did not perform as well as the existing method. However, this is mainly because some of the rules for exceptional situations which are used by the manual method have not yet been incorporated into the computerised system.

The comparison of the results also indicated other potential advantages for the SCAPP system. These are: slight increase in the yield (2%) and some reduction in the route cost. However, in addition to the above quantifiable advantages, the main merit of the SCAPP system over the existing methods, is that the system is much less dependent on a human planner. Moreover, the system which is a generative type CAPP system, also carries the general advantages for this type, which we discussed earlier in Chapter 3.

12.4. Batch Order Process Planning

Study of the results produced by single order process planning (the SCAPP system) revealed the existence of considerable scope for flexibility in the planning of processes concerned in this project. We discussed this at some length in Chapter 6. More specifically, the SCAPP results indicated that for the majority of customer order situations more than one route can be found to produce the required specifications, i.e. the short list of preferred routes discussed above. Although here only one route represents the least cost, but very often there exist one or more routes for which the costs are very close to the least cost.

Through this study we found that selecting the routes merely on the optimisation criteria for each individual order does not necessarily lead to the optimisation of the batch as a whole. The consequence of such a local optimisation could be an increase in the costs for the batch or an increase in bottlenecks and unbalanced production in the system. In addition, further detailed study of the alternative routes for various batches of orders led to the recognition of similarities, in particular the similarity of theoretical gauges among the routes for the orders in the batch. in the existing manual system, this is recognised by forcing orders with similar gauges into routes based on standard gauges -- but these are not necessarily optimal.

The batch order process planning concept used in this project is based on the above recognition of the flexibility inherent in this process planning situation and the particular features of the routes. The particular objective for this planning option is the optimisation of the costs for the batch through collecting the orders in a number of groups in such a way that each group could utilise a material gauge common to its members -- but this need not to be a standard gauge in the old sense. This option of process planning has shown considerable improvement in both material yield and the costs for the batch. This will be further discussed below.

12.5. Order Grouping Methods

Bearing in mind the above grouping objective, two grouping methods were developed. *Method I* was used in the initial stages of the project; it consists of a search procedure to produce possible grouping options and a method for the evaluation of these options in order to determine the optimal grouping situation at each stage of the search. This method, which is detailed in Chapter 7, was tested on real manufacturing data and the results, in general, were satisfactory. It indicated significant improvements in both material yield and the cost for the batch compared with the single order process planning situation. However, the trials revealed that there were a number of practical problems.

Method II is based on the *simple linkage technique of cluster analysis* . However, in this method, the *distance* of the grouping objects has been particularly defined to include various dominant factors such as material yield, route cost and the weight of the orders. The application of this method to real manufacturing data not only indicated significant advantages over the single order process planning situation, but the results were also better than those for Method I. This second method was then incorporated into the batch order process planning option of the overall CAPP system, the results of which are discussed below.

Having recognised the merits of batch order process planning, a procedure consisting of ten stages was developed for this planning option; this procedure was detailed in Section 11.2. The stages can be considered as forming three planning phases.

In the first phase of planning, the system selects each individual order in turn. Feasible macro-routes (called 'feasible routes' in short) are determined for the selected order in a manner similar to that discussed for single order process planning. Then, considering the available standard strips for each feasible route, the theoretical gauge, yield and other relevant data are determined for that route. Finally, the short list of preferred routes is produced for each route.

In Phase 2 of the batch order process planning, orders are grouped using Method II of grouping, based on the similarity of their routes with regard to their theoretical gauges, and the optimisation criteria.

Finally in Phase 3, the grouping results, together with route data produced in the previous phases, are used to produce the plan for each order in a group and then for the groups in the batch.

The implementation of this planning procedure, together with the results obtained from batch order process planning are considered below.

12.6. BCAPP System

The BCAPP system was designed to perform the three planning phases described above for batch order process planning. It shares a number of programs with the SCAPP system. The operation of the system, like the SCAPP system, starts with database setting (or confirmation of the default set up). The system then goes through various planning stages in order to automatically plan the processes for the orders in the batch. As with the SCAPP system, final plans have to be confirmed by the user before they are issued for the production. Editing facilities are also available at this stage.

The BCAPP system was tested on different batches of order situations in the company. Results indicated considerable advantages compared with their existing manual and retrieval planning methods. It showed over 5% increase in material yield and reduction of nearly 4% in the route cost for the batch. These figures also indicate the advantage of the batch order process planning option over the single order planning situation.

The BCAPP system, in addition to the yield and cost improvements, has also shown other advantages expected from any generative CAPP systems.

The effectiveness of batch order process planning is a function of the number of the orders in the batch and the nature of the alternative routes for the orders. That is, the larger the batch the more benefits can be expected from our batch order planning option. Extensive test runs of the system indicated that reasonably good results can be obtained for any batch with ten or more orders.

However, in the light of the test runs of the system, it is clear that the combination of the prototype BCAPP and SCAPP systems can be effectively used for most of the cases likely to arise in practice. We shall return later to the question of how such a system can pay for itself.

12.7. Future Work

Development of a CAPP system for the rolling mill industry is a large-scale project which requires a long-term collaboration between the academic and industrial sectors. The overall process planning system would include planning modules for each production department, i.e. foundry and casting, hot rolling and cold rolling. A general database system and other supporting modules would also be required. Having concentrated on planning for the cold rolling department in this project, it is clear that attention would need to be focussed on a number of other areas before our type of system could be fully operational.

1) The most obvious extension of the current work would be the development of process planning modules for the two other departments and their integration with the system developed in this project to produce a complete system for the industry. The system for the hot rolling department, however, would mainly be dealing with the selection of the materials (castings or millstock materials) and determination of the roll pass and the operation conditions which are very important for both the economy of operation and the production to required specifications. Planning for the foundry operations would mainly involve determination of the charge composition, processing conditions and selection of the castings. Some relevant research work has already been published, e.g. Adjmal and Dale (1985). These studies might form the basis for any future development. In relation to the cold rolling department, a module for the planning of strips (coils) -- which is lacking in the present development -- would also be required. Planning for strips would mainly consist of the selecting suitable strip material and determination of a sequence of unidirectional rolling and annealing operations until the required gauge is obtained; then finishing operations would have to be planned.

2) Operation details are not usually determined in the process planning for the cold rolling department at the present state of the art. However, with more automation of the production in future, the inclusion of detailed planning instructions such as the details of roll pass and the reduction for each pass (rationalisation of rolling operation), annealing schedules, press tool selection, etc. could be beneficial. Although this appears to take away some of the authority of the shopfloor supervisors, it represents a desirable step towards standardisation and quality improvement.

3) Application of expert system methodology appears be a most advanced approach to the process planning in manufacturing industries. This can produce further capabilities in the system, such as ease of modification of the rules and the knowledge incorporated into the system, reasoning explanation, a self-learning capability for the

system and the use of fuzzy logic in the decision mechanism. The expert system approach is, however, mostly at the experimental stage at present. Therefore, its use in the CAPP development for the rolling mill industry, which has to be a practical system, would require a great deal of research work. Knowledge acquisition , e.g. obtaining the details of the current practice and their analysis in order to produce general form of the rules, could be a major undertaking.

With regard to the programming language, Prolog, which has been used in the present development, is a very suitable language for the expert systems. The use of this language in future developments would considerably reduce the programming tasks as most of the programs developed in the present prototype system can also be used in the enhanced version of the system.

4) Computerisation of the other planning and control activities, such as production scheduling and control, shopfloor monitoring, and sales order processing and their integration to the CAPP system is of particular importance in this industry. The above developments in particular would require a considerable amount of research effort to ensure their effective integration with the CAPP system.

5) Another major area of research in conjunction with the present CAPP system is the development of a "material optimisation" system. Such a system can make use of the flexibility inherent in the CAPP system through using the alternative routes and their corresponding blank materials to determine the most economic production of the blanks from the hot rolled source blanks.

This area has already been studied in a project carried out in parallel with the one described in this thesis -- see Yazdianpour (1989). Throughout the development of these, Yazdianpour and the present writer have checked to ensure the compatibility of the various modules.

12.8. Prospects for Industrial Use of the System

The number of companies producing copper-alloy flat rolled products is quite considerable. Although coppers and brasses were the types of metals primarily considered in the development of the current system, nevertheless it is clear that with minor modifications it can also be useful for other alloys of copper. In addition, although the system is customised to a copper alloy rolling environment, there is also the possibility of its adaptation to the flat rolling of aluminum or to some other nonferrous metals. Therefore it can be concluded that there is a considerable demand for such a system.

The proposed CAPP system is microcomputer based, and requires very low hardware investment. With regard to the software cost, of course the system is at the prototype level at present. Therefore, any practical application would require investment in the software engineering aspects, as well as some enhancements of the technical side of the system. This initial investment, however, appears to be in a range affordable by majority of the rolling mill companies and the system would clearly payback the cost in a reasonably short time. Some of the ideas, how the system would payback for itself are discussed below.

Major advantages of the system were discussed earlier in this chapter. Cost reduction of approximately 4% in the batch order processing situation is a clear and quantitative advantage. This, when calculated on a monthly or a yearly basis, represents a significant saving of capital. Such a saving would itself justify the use of the system in a medium to high production situation.

Considerable reduction of planning time is another advantage which is easily quantifiable in terms of reduction in personnel cost. Saving the process planner's time would leave him free to spend more time on other productive tasks. The fact that the system would not rely on a planner with long-term experience in manufacturing would represent another saving in personnel cost. However, the planner must still be thoroughly familiar with the implications of this work since he remains ultimately responsible for the day-to-day operation of the system.

Material yield increase, in particular more than 5% in batch order process planning situation, also represents a significant advantage for the proposed system. This would reduce the redundant circulation of material in the system. It would therefore, reduce the capital locked up in the system and the cost absorbed by this material going through unnecessary processing. Reduction in the mill stock level would be another saving.

The implementation of a generative CAPP system, like the one proposed in this thesis, could not only be beneficial in well-established rolling mills. Newly established companies would benefit even more from such investment, as it would relieve them from looking for experienced planners.

In conclusion, this project has shown that it is feasible to develop a generative CAPP system for rolling mills which can be operated from a desk-top computer. The system can take full account of the complexity of the practical needs of plannning for such an environment and yet can be operated by a planner who can be trained much quicker than his counterpart in existing planning systems in the industry. The logic of the system and the optimisation rules built into it ensures that material yield is increased and manufacturing cost is decreased so that the system is economically attractive from many points of view.

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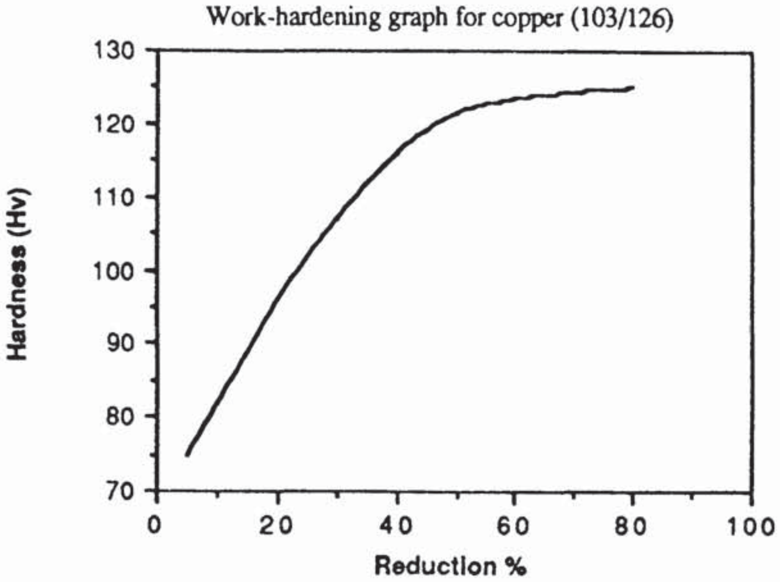
APPENDICES

Appendix A : Work hardening and Annealing Schedule



ANNEALING SCHEDULE
FURNACE (E10/20)
METAL CODES 105/ 126

TEMPERATURE 700 (C)

GAUGE (INCLUSIVE) MM	NO. OF SHEETS OR CIRCLES IN THE PACK	BELT SPEED (FEET PER MIN.)
6.15 - 6.65	1	0.60
5.64 - 6.12	1	0.65
6.11 - 5.61	1	0.75
.	.	.
.	.	.
0.74 - 0.81	7	0.70
0.64 - 0.71	7	0.70
0.55 - 0.61	8	0.70

Appendix B   A sample of machine capability data:

Equipment code: G3

Process: rolling
Operation range: medium breaking down
Max. Gauge: 12.0 mm
Min. finish gauge: 0.35, but preferred not to go below 0.50 mm
Max. width: 1550 mm
Min. width of the workpiece: preferred not below 400 mm
Max. length of the workpiece: 4000 mm
Max. weight per workpiece: 150 kg.

Other notes: Basically can be used to break down previously rolled material within appropriate range of hardness.

equipment code: G5

Process: rolling
Operation range: finishing rolling or any small reductions
Max. start Gauge: 10.0 mm
Min. finish gauge: 0.35, but preferred not to go below 0.50 mm
Max. width: 1550 mm
Min. width of the workpiece: preferred not below 400 mm
Max. length of the workpiece: 3500 mm
Max. weight per workpiece: 100 kg.

Max. reduction 30% coppers and 25 % brasses. Normally planned in the range 5 - 15%. Appropriate for temper rolling.

Equipment code: E10/20

Process: Annealing
Operation range: plates, sheets and circles
max. workpiece gauge: 10 mm
Max workpiece width: 1350 mm
Max. workpiece length: 3500 mm

When used for brasses the metal should be cleaned afterwards but for the copper cleaning is not normally required.

Appendix C: computer hardware

The hardware configuration considered for the test runs of the prototype CAPP system.

Microcomputer:	IBM AT (or Compatibles).
Hard disk:	20 MB.
RAM:	640 K .
Clock Speed:	10 MHz.
Monitor:	Mono or colour monitor.
Printer:	Dot matrix up to 132 column, preferably high speed.

APPENDIX D.1. MODULES AND SUBMODULESFOR THE SCAPP SOFTWARE (PART 1 TO PART 5)

Part 1

MODULE	LEVEL	DESCRIPTION OF THE FUNCTION
SCAPP	2	Performs the Single Order Process Planning task. For thisit calls upon its subordinate modules in order to evaluate the application of of different macro routes and different choices of material. Then selects the most suitable route through the comparision of the costs and consulting the user. Finally produces the process plan for the selected route.
SCAPINT	3	Initialises the software and prepares working data files for the use throughout the program modules for the current order.
SELECRTS	3	Controls a tree structure depth-first search in order to determine the choices of feasible macro routes together with the suitable material dimensional ranges for each route. The module calls upon different submodules to apply the appropriate sequence of reverse processes on the workpiece data.
ALOCMATL	3	Searches the stock for different types of material, allocating more appropriate choices for each selection of the route.
COSTRTS	3	Calls upon its subordinate modules in order to determine operations for each route based on which the operation costs are estimated. The module then produces an overall cost indicator for each route.
PROPLAN	3	Displays preferred routes for any order on hand, indicating the selection of the system and asking for the user's decision. Then generates the process plan based on this decision. It also provides editing facility and produces hard copy of the plan.
SCAPTERM	3	Clears memory from the current data, making the system ready to perform a new planning job.

Part 2

MODULE	LEVEL	DESCRIPTION OF THE FUNCTION
ORDERINT	4	Provides the options for the user to review and modify order data before the data is saved for the working file (or the working memory).
MATLINIT	4	Enables the user to review, alter or include any material available for the stocks of each type of material.
PROCINIT	4	Enables the user to review or alter process and machine capability information for the use in the current plan.
MODIFORD	4	Enables the planner to alter any cost data before storing the data for the working memory.
INITSELC	4	Initialises for the SELCRTS module through loading required data and performing preparatory calculations.
PROCALTS	4	Establishes the alternative situations required to be evaluated for each of the reverse processes (roll, trim and turn).
NEXTPROC	4	Determines the following process at the end of each operation. This is through the consultation of the facts established for the sequences of the processes for different stages in the routes.
TURN	4	Performs the two alternatives of the turn process and calls upon the module which produces the valid dimensional range.
TRIM-R	4	Determines the allowances and reverse trimming for both width and length through the control relevant submodules. It also calls upon themodule which performs required dimensional adjustments.
ROLL-R	4	Controls its subordinate module to determine feasible reduction range. Then applies reverse rolling operation on the workpiece data.

Part 3

MODULE	LEVEL	DESCRIPTION OF THE FUNCTION
RTCODE	4	Assigns corresponding macro route code for each feasible route selected by the SELECRTS module.
TERMSELC	4	Produces a hard copy of the list for feasible routes and terminates the SELECRTS module.
ALOCSTRIP	4	Evaluates the available range of standard strips in order to determine an apprporiately matching material. Appart from the metal specifications, material yield is also considered for this evaluation.
ALOCCOIL	4	Evaluates the available range of standard coils in order to determine an apprporiately matching material. Apart from the metal specifications, material yield is also considered for this evaluation.
ALOCMSTK	4	Evaluates the available range of mill stock material in order to determine an apprporiate matching material.
SORTALOC	4	Evaluates materials allocated for the routes for the purpose of eliminating redundant or comparatively less efficient choices.
TERMALOC	4	Prints out a list which indicates the selected routes and the material for each route, then it terminates the module.
RTPLAN	4	Determines route details together with the corresponding operation costs. This is based on the final product requirements, the specification for the allocated material and the particular macro route specified for that option.
PREFALTS	4	Calculates material cost, then finds out the route total cost by considering the route operation cost. Then, based on this cost, selects a number of preferred (least cost) routes.

Part 4

MODULE	LEVEL	DESCRIPTION OF THE FUNCTION
OPTRT	4	Displays information for the list of the preferred routes in the order of their costs. Then waits for the user to enter his selection.
PLANG	4	Generates the process plan for the route which was finally selected by the user. For this it uses the detailed information for this route prepared by previous modules.
PRINTPLN	4	Produces a hard copy of the plan when the editing is completed.
VALIDTRN	5	Evaluates the validity o the dimensional ranges produced during the TURN operation. Determines the valid range whenever required
TRIMWID	5	Applies the rules set for "width trimming".
TRIMLENG	5	Applies the rules set for "length trimming".
REDRANG	5	Determines the range for rolling reduction ratio, taking into account the metal type, required properties for the product and process capabilities.
VALIDRNG	5	Determines the valid range common for any two specified ranges.
INITPLAN	5	Determines initial information required for the RTPLAN module. These include rolling reduction for different stages which is determined based on the product and material dimensions and the use of the relations for for the particular macro route.
SELCPROC	5	Calls upon its subordinate modules to determine the appropriate process which could proceed the current process.
DOPROC	5	Applies the selected process for the workpiece data.
SELCMC	5	Determines the most appropriate machine for the workpiece based on the selected process and the operation condition.

Part 5

MODULE	LEVEL	DESCRIPTION OF THE FUNCTION
OPCOND	5	Applies established rules to determine the operation condition for each process selected.
OPCOST	5	Determines unit cost for each specified process based on the given operation condition and the machine selected for this process.
TRIMADJ	6	Adjusts the dimensional range when a range is to be split into subranges during the application of the trim allowances.
NEXTPRO	6	Determines the sequence of the processes.

Appendix D.2 : A sample of the method for the evaluation of 'V' factor

Order number = 513

route		a	b	c	d	
route code		2-3	2-2	2-1	3-5	
yield		0.81	0.81	0.73	0.83	
operation cost (for single piece of std weight)		14.5	15.9	14.6	18.9	
V = - 20	sequence of preferred routes	a	b	c	d	
	total route cost	477	495	501	528	
	cost difference with next selection %	3.8	1.2	3.8	--	
	Is the sequence reasonable ?	*Y*	*Y*	*Y*	*Y*	*
	Is the cost difference reasonable ?	*N*	*N*	*N*	--	
V = 0	sequence of preferred routes	a	b	c	d	
	total route cost	520	536	549	560	
	cost difference with next selection %	3	2.4	2	--	
	Is the sequence reasonable ?	Y	Y	Y	Y	
	Is the cost difference reasonable ?	N	N	N	--	
V = 10	sequence of preferred routes	a	b	c	d	
	total route cost	541	556	574	577	
	cost difference with next selection %	2.7	3.2	0.5	--	
	Is the sequence reasonable ?	*Y*	*Y*	*Y*	*Y*	**
	Is the cost difference reasonable ?	*Y*	*Y*	*Y*	--	
V = 20	sequence of preferred routes	a	b	d	c	
	total route cost	563	576	593	598	
	cost difference with next selection %	2.3	3.9	0.8	--	
	Is the sequence reasonable ?	Y	Y	N	N	
	Is the cost difference reasonable ?	Y	Y	Y	Y	

* Position 1: route selection is correct as yield and operation cost for this route (route a)is better than those for other routes. Cost difference with is exaturated as in real terms this route represents only little advantage over route b (see yield and operation costs).

Position 2: route selection is correct as the combination of yield and operation cost for this route is better than the other two. Cost difference is less than its real difference with route c (note their yield difference).

Position 3: route selection is correct because although yield for this route is very low but its operation cost is much better than route d. Cost difference between is more than real difference (note yield and cost difference).

** Position 1: route selection is correcr and cost difference is more reasonable.

Position 2: route selection is correct and cost difference (3.2) better represents the advantage for route b over route c.

Position 3: route selection is correct and cost difference between this route and route d is reasonable.

Appendix D.3: Process Card

PROCESS CARD

Customer Name	Delivery Date	Due Week	Order No..

Metal Code 126	Quality Card 5	Count 10	Thickness 1.2	Width 1200	Length 2400	Grain Size	H.V 55 max

Specification	Weight 281	Tols +NIL -.17	Tols +3.5 -3.5	Tols +5.0 -5.0	

Specification	Special Instructions

Gauge : 5.0	Width : 635	Length : 1230

PROCESS INSTRUCTIONS

LAP	BLANK 1230
E10/20	ANNEAL TO SCH
G3/G4	G.R. 2.0 X 1230
	TRIM 1230 X 1450
E10/E20	ANNEAL
G3	G.R. 1.08 +/-.05 X 1230
	FLATTEN
	F.S
E10/20	ANNEAL TO SCH
	INSPECTION

Appendix E : Process routes produced by the BCAPP system
for Batch Number 29

```
-----------------------------------------------------------
order no: 501     customer: A1     due date: 01FEB86
metal:    126     qly:       5     weight:   400      count: 8
rect    dims: 2.00X1200X2400   tols:(0.11 -0.11),(6 0),(10 0)
hardness:  70 - 90   fdirectional      application  cylinder
remarks:   -
-----------------------------------------------------------
material:  stp   10.0   635    1123
-----------------------------------------------------------
route yield: 0.81    route cost indicator: 677       ( 1 )
-----------------------------------------------------------
    LAP            BLANK   1123
    G4             G.R.    4.80 x 1123
    F44            TRIM    1123 X 1230
    E10/20         ANNEAL TO SHEDULE
    G3             G.R.    2.13 x 1230
    F44            TRIM ENDS ONLY
    GB5/6          F.R.    2.00 ( +/- 0.05) x 1230
    FLT1           FLATTEN
    F18            F.S.
    -              INSPECTION
-----------------------------------------------------------
```

```
-----------------------------------------------------------
order no: 505     customer: A5     due date: 01FEB86
metal:    126     qly:       5     weight:   531      count: 10
rect    dims: 2.00X1219X2438   tols:(0.14 -0.14),(6 0),(10 0)
hardness:  70 - 90   fdirectional      application  -
remarks:   -
-----------------------------------------------------------
material:  stp   10.0   635    1158
-----------------------------------------------------------
route yield: 0.81    route cost indicator: 885       ( 1 )
-----------------------------------------------------------
    LAP            BLANK   1158
    G4             G.R.    4.73 x 1158
    F44            TRIM    1158 X 1249
    E10/20         ANNEAL TO SHEDULE
    G3             G.R.    2.13 x 1249
    F44            TRIM ENDS ONLY
    GB5/6          F.R.    2.00 ( +/- 0.05) x 1249
    FLT1           FLATTEN
    F18            F.S.
    -              INSPECTION
-----------------------------------------------------------
```

```
-----------------------------------------------------------
order no: 515    customer: A15    due date: 01FEB86
metal:    126    qly:      5    weight:   686    count:  15
circ   dims: 4.00X1290X1290   tols:(0 -0.2),(8 0),(0 0)
hardness:  10 - 55   fdirectional     application  cylinder & boiler
remarks:   -
-----------------------------------------------------------
material:  stp   10.0   635    1316
-----------------------------------------------------------
route yield: 0.77    route cost indicator: 1112      ( 1 )
-----------------------------------------------------------
    LAP             BLANK   1316
    G4              F.R.    3.85 ( +/- 0.05) x 1316
    FLT1            FLATTEN
    F44             BLANK   1296 x 1296
    E30/31          CIRCLE
    E10/20          ANNEAL TO SHEDULE
    -               INSPECTION
-----------------------------------------------------------
```

```
-----------------------------------------------------------
order no: 516    customer: A16    due date: 01FEB86
metal:    126    qly:      5    weight:   182    count:  4
circ   dims: 5.00X1150X1150   tols:(0 -0.3),(8 0),(0 0)
hardness:  10 - 55   fdirectional     application  cylinder & boiler
remarks:   -
-----------------------------------------------------------
material:  stp   10.0   635    1176
-----------------------------------------------------------
route yield: 0.85    route cost indicator: 280      ( 1 )
-----------------------------------------------------------
    LAP             BLANK   1176
    G4              F.R.    4.75 ( +/- 0.05) x 1176
    FLT1            FLATTEN
    F44             BLANK   1156 x 1156
    E30/31          CIRCLE
    E10/20          ANNEAL TO SHEDULE
    -               INSPECTION
-----------------------------------------------------------
```

```
-------------------------------------------------------------
order no: 506     customer: A6     due date: 01FEB86
metal:    126     qly:       5     weight:   1000     count:  20
rect    dims: 2.00X1524X1905   tols:(0 -0.24),(3.5 -3.5),(3.5 -3.5)
hardness:  60 - 90   fdirectional      application  cylinder & boiler
remarks:   -
-------------------------------------------------------------
material:  stp   6.2   635    1549
-------------------------------------------------------------
route yield: 0.87    route cost indicator: 1623      ( 1 )
-------------------------------------------------------------
    LAP             BLANK   1549
    E10/20          ANNEAL TO SHEDULE
    G3/G4           G.R.    1.93 x 1549
    F44             TRIM ENDS ONLY
    H1-3-7          ANNEAL TO SHEDULE
    H11             CLEAN
    GB5/6           F.R.    1.81 ( +/- 0.05) x 1549
    FLT1            FLATTEN
    F18             F.S.
    -               INSPECTION
-------------------------------------------------------------
```

```
-------------------------------------------------------------
order no: 507     customer: A7     due date: 01FEB86
metal:    126     qly:       5     weight:   500     count:  11
rect    dims: 2.00X1435X1880   tols:(0 -0.24),(3.5 -3.5),(3.5 -3.5)
hardness:  60 - 90   fdirectional      application  cylinder & boiler
remarks:   -
-------------------------------------------------------------
material:  stp   6.2   635    1460
-------------------------------------------------------------
route yield: 0.85    route cost indicator: 838      ( 1 )
-------------------------------------------------------------
    LAP             BLANK   1460
    E10/20          ANNEAL TO SHEDULE
    G3/G4           G.R.    1.93 x 1460
    F44             TRIM ENDS ONLY
    H1-3-7          ANNEAL TO SHEDULE
    H11             CLEAN
    GB5/6           F.R.    1.81 ( +/- 0.05) x 1460
    FLT1            FLATTEN
    F18             F.S.
    -               INSPECTION
-------------------------------------------------------------
```

```
------------------------------------------------------------
order no: 513     customer: A13     due date: 01FEB86
metal:    126     qly:       5    weight:   439     count:  10
rect   dims: 2.00X1395X1855   tols:(0 -0.24),(5 0),(0 -7)
hardness:  60 - 90   fdirectional     application  cylinder

remarks:   watch tols on width and length
------------------------------------------------------------
material:  stp   6.2   635    1420
------------------------------------------------------------
route yield: 0.84    route cost indicator: 748       ( 1 )
------------------------------------------------------------
    LAP              BLANK   1420
    E10/20           ANNEAL TO SHEDULE
    G3/G4            G.R.    1.93 x 1420
    F44              TRIM ENDS ONLY
    H1-3-7           ANNEAL TO SHEDULE
    H11              CLEAN
    GB5/6            F.R.    1.81 ( +/- 0.05) x 1420
    FLT1             FLATTEN
    F18              F.S.
    -                INSPECTION
------------------------------------------------------------
```

```
------------------------------------------------------------
order no: 514     customer: A14     due date: 01FEB86
metal:    126     qly:       5     weight:   283     count:  6
rect   dims: 2.00X1470X1888   tols:(0 -0.24),(3.5 -3.5),(3.5 -3.5)
hardness:  60 - 90   fdirectional     application  cylinder & boiler
remarks:   -
------------------------------------------------------------
material:  stp    6.2    635    1495
------------------------------------------------------------
route yield: 0.86    route cost indicator: 469       ( 1 )
------------------------------------------------------------
    LAP              BLANK   1495
    E10/20           ANNEAL TO SHEDULE
    G3/G4            G.R.    1.93 x 1495
    F44              TRIM ENDS ONLY
    H1-3-7           ANNEAL TO SHEDULE
    H11              CLEAN
    GB5/6            F.R.    1.81 ( +/- 0.05) x 1495
    FLT1             FLATTEN
    F18              F.S.
    -                INSPECTION
------------------------------------------------------------
```

```
-----------------------------------------------------------------
order no: 503     customer: A3     due date: 01FEB86
metal:    126     qly:       5     weight:   281     count:  10
rect   dims: 1.20X1200X2400   tols:(0 -0.17),(3.5 -3.5),(5 -5)
hardness:  10 - 55   fdirectional      application  -
remarks:   -
-----------------------------------------------------------------
material:  stp   4.8   635    1230
-----------------------------------------------------------------

route yield: 0.84    route cost indicator: 532       ( 1 )
-----------------------------------------------------------------
    LAP             BLANK   1230
    E10/20          ANNEAL TO SHEDULE
    G3              G.R.    1.94 x 1230
    F44             TRIM ENDS ONLY
    E10/20          ANNEAL TO SHEDULE
    G3              F.R.    1.08 ( +/- 0.05) x 1230
    FLT1            FLATTEN
    F18             F.S.
    E10/20          ANNEAL TO SHEDULE
    -               INSPECTION
-----------------------------------------------------------------
```

```
-----------------------------------------------------------------
order no: 508     customer: A8     due date: 01FEB86
metal:    126     qly:       5     weight:   296     count:  10
rect   dims: 1.80X1235X1568   tols:(0 -0.22),(5 0),(0 -7)
hardness:  60 - 90   fdirectional      application  cylinder & boiler
remarks:   watch width and length tols
-----------------------------------------------------------------
material:  stp   4.8   635    1260
-----------------------------------------------------------------
route yield: 0.83    route cost indicator: 507       ( 1 )
-----------------------------------------------------------------
    LAP             BLANK   1260
    E10/20          ANNEAL TO SHEDULE
    G3              G.R.    1.73 x 1260
    F44             TRIM ENDS ONLY
    GB5/6           F.R.    1.63 ( +/- 0.05) x 1260
    FLT1            FLATTEN
    F18             F.S.
    -               INSPECTION
-----------------------------------------------------------------
```

```
-----------------------------------------------------------
order no: 512     customer: A12     due date: 01FEB86
metal:    126     qly:       5     weight:   664     count:  20
rect    dims: 2.00X1304X1500   tols:(0 -0.24),(5 0),(0 -7)
hardness:  60 - 90   fdirectional     application  cylinder
remarks:   watch tols on width and length
-----------------------------------------------------------
material:  stp   4.8   635    1329
-----------------------------------------------------------
route yield: 0.88    route cost indicator: 1077      ( 1 )
-----------------------------------------------------------
    LAP             BLANK   1329
    E10/20          ANNEAL TO SHEDULE
    G3              G.R.    1.93 x 1329
    F44             TRIM ENDS ONLY

    GB5/6           F.R.    1.81 ( +/- 0.05) x 1329
    FLT1            FLATTEN
    F18             F.S.
    -               INSPECTION
-----------------------------------------------------------
```

```
-----------------------------------------------------------
order no: 517     customer: A17     due date: 01FEB86
metal:    126     qly:       5     weight:   112     count:  3
rect    dims: 1.60X1500X1800   tols:(0 -0.19),(3.5 -3.5),(3.5 -3.5)
hardness:  60 - 90   fdirectional     application  cylinder & boiler
remarks:   -
-----------------------------------------------------------
material:  stp   4.8   635    1525
-----------------------------------------------------------
route yield: 0.86    route cost indicator: 182       ( 1 )
-----------------------------------------------------------
    LAP             BLANK   1525
    E10/20          ANNEAL TO SHEDULE
    G3              G.R.    1.55 x 1525
    F44             TRIM ENDS ONLY
    GB5/6           F.R.    1.46 ( +/- 0.05) x 1525
    FLT1            FLATTEN
    F18             F.S.
    -               INSPECTION
-----------------------------------------------------------
```

```
-------------------------------------------------------------
order no: 520    customer: A20    due date: 01FEB86
metal:   126    qly:     5    weight:  246     count:  20
circ    dims: 4.50X630 X630    tols:(0 -0.25),(3 -3),(0 0)
hardness:  10 - 55   fdirectional     application  cylinder & boiler
remarks:   priority one
-------------------------------------------------------------
material:  stp   4.8   635    656
-------------------------------------------------------------
route yield: 0.88    route cost indicator: 494       ( 1 )
-------------------------------------------------------------
    LAP            BLANK   656
    G3             F.R.    4.30 ( +/- 0.05) x 656
    FLT1           FLATTEN
    F44            BLANK   636  x 636
    E30/31         CIRCLE
    E10/20         ANNEAL TO SHEDULE
    -              INSPECTION
-------------------------------------------------------------
```

```
-------------------------------------------------------------
order no: 502    customer: A2    due date: 01FEB86
metal:   126    qly:     5    weight:  320     count:  10
rect    dims: 2.50X1160X1345   tols:(0 -0.3),(5 0),(0 -7)
hardness:  60 - 90   fdirectional     application  cylinder
remarks:   -
-------------------------------------------------------------
material:  stp   5.5   635    1180
-------------------------------------------------------------
route yield: 0.86    route cost indicator: 528       ( 1 )
-------------------------------------------------------------
    LAP            BLANK   1180
    G4             G.R.    2.39 x 1180
    F44            TRIM ENDS ONLY
    E10/20         ANNEAL TO SHEDULE
    GB5/6          F.R.    2.25 ( +/- 0.05) x 1180
    FLT1           FLATTEN
    F18            F.S.
    -              INSPECTION
-------------------------------------------------------------
```

```
-------------------------------------------------------------
order no: 509     customer: A9     due date: 01FEB86
metal:    126     qly:       5     weight:   427     count:  10
rect   dims: 1.60X1510X2083   tols:(0 -0.19),(0 -7),(5 0)
hardness:  60 - 90   fdirectional     application  cylinder & boiler
remarks:   watch width and length tols
-------------------------------------------------------------
material:  stp   5.5   635    1540
-------------------------------------------------------------
route yield: 0.86    route cost indicator: 725      ( 1 )
-------------------------------------------------------------
    LAP            BLANK   1540
    E10/20         ANNEAL TO SHEDULE
    G3/G4          G.R.    1.55 x 1540
    F44            TRIM ENDS ONLY
    H1-3-7         ANNEAL TO SHEDULE
    H11            CLEAN
    GB5/6          F.R.    1.46 ( +/- 0.05) x 1540
    FLT1           FLATTEN
    F18            F.S.
    -              INSPECTION
-------------------------------------------------------------
```

```
-------------------------------------------------------------
order no: 511     customer: A11     due date: 01FEB86
metal:    126     qly:       5     weight:   320     count:  10
rect   dims: 2.50X1160X1345   tols:(0 -0.3),(5 0),(0 -7)
hardness:  60 - 90   fdirectional     application  cylinder & boiler
remarks:   watch width and length tols
-------------------------------------------------------------
material:  stp   5.5   635    1180
-------------------------------------------------------------
route yield: 0.86    route cost indicator: 528      ( 1 )
-------------------------------------------------------------
    LAP            BLANK   1180
    G4             G.R.    2.39 x 1180
    F44            TRIM ENDS ONLY
    E10/20         ANNEAL TO SHEDULE
    GB5/6          F.R.    2.25 ( +/- 0.05) x 1180
    FLT1           FLATTEN
    F18            F.S.
    -              INSPECTION
-------------------------------------------------------------
```

```
-----------------------------------------------------------
order no: 518    customer: A18    due date: 01FEB86
metal:    126    qly:      5    weight:   257    count:  6
rect   dims: 1.60X1510X2088  tols:(0 -0.19),(3.5 -3.5),(5 -5)
hardness:  60 - 90   fdirectional     application  cylinder & boiler
remarks:   -
-----------------------------------------------------------
material:  stp   5.5   635    1540
-----------------------------------------------------------
route yield: 0.86    route cost indicator: 436      ( 1 )
-----------------------------------------------------------
     LAP             BLANK   1540
     E10/20          ANNEAL TO SHEDULE
     G3/G4           G.R.    1.55 x 1540
     F44             TRIM ENDS ONLY
     H1-3-7          ANNEAL TO SHEDULE
     H11             CLEAN
     GB5/6           F.R.    1.46 ( +/- 0.05) x 1540
     FLT1            FLATTEN
     F18             F.S.
     -               INSPECTION
-----------------------------------------------------------
```

```
-----------------------------------------------------------
order no: 519    customer: A19    due date: 01FEB86
metal:    126    qly:      5    weight:   217    count:  7
rect   dims: 2.50X1087X1380  tols:(0 -0.3),(5 0),(0 -7)
hardness:  60 - 90   fdirectional     application  cylinder & boiler
remarks:   watch width and length tols
-----------------------------------------------------------
material:  stp   5.5   635    1107
-----------------------------------------------------------
route yield: 0.88    route cost indicator: 356      ( 1 )
-----------------------------------------------------------
     LAP             BLANK   1107
     G4              G.R.    2.39 x 1107
     F44             TRIM ENDS ONLY
     E10/20          ANNEAL TO SHEDULE
     GB5/6           F.R.    2.25 ( +/- 0.05) x 1107
     FLT1            FLATTEN
     F18             F.S.
     -               INSPECTION
-----------------------------------------------------------
```