Application of Expert Systems in Heavy Capital Plant

Nick Bate

A thesis submitted in partial fulfilment of the requirements of
Sheffield Hallam University
for the degree of Doctor of Philosophy

April 1996

Collaborating Organisation: Davy International (Sheffield)

Abstract

This thesis addresses the design of large bespoke pieces of equipment for the oil, steel and chemical process industries, the Heavy Capital Plant Industry (H.C.P.I.). The production of bespoke equipment relies heavily on experience, which makes it a prime candidate for the application of expert systems. A company operating in this area, producing equipment for the steel industry, is Davy International (Sheffield), a company with a world-wide reputation.

The company had instigated a programme to capture selected areas of their expertise, using design manuals. Each manual focused on the design of one mill component. During this programme, they identified that there might be potential for the use of expert systems. This resulted in a collaborative research programme, with the aim of identifying the benefits of using expert systems in this application.

Two distinct design activities, namely that of the individual components and that of the mill layout, were identified and prototype expert systems were built in these areas.

As a source of component design knowledge the roller table design manual was selected, and this was used to build a rule based expert system prototype. Part of the purpose of this prototype was to gain experience using expert systems and to gain an appreciation of the company's approach to design. These lessons were used to help in the production of the second prototype.

Knowledge of the design of steel mill layouts was built into the second prototype expert system. This used both object oriented and rule based representations.

This thesis, through the use of prototype expert systems, demonstrates the effectiveness of expert systems in the H.C.P.I.. A major advantage of these systems is their ability to cope with the many different layout situations encountered, which are often exacerbated by the size of the plant. The suitability of a combined object oriented and rule based toolkit is highlighted for this area, with the benefits of explanation for layout design systems being elucidated.

Preface

This thesis is submitted to the School of Engineering of Sheffield Hallam University for the degree of Doctor of Philosophy. This study was conducted in collaboration with Davy International (Sheffield).

I would like to express my gratitude to my supervisors **Dr D.T.S. Perera** and **Mr I. Tranter**, for their guidance and constructive criticism throughout the course of this study.

From Davy International (Sheffield), I would like to thank **Mr G. Wilson** for providing me the opportunity and **Mr E.C. Hewitt** for his help and invaluable time, without which it would have been impossible to create the layout design expert system. I would like to thank the engineers at the company, for any help and guidance they provided.

On a personal note, I would like to thank **Mr G. Cockerham** for his continued help, criticism and support throughout the whole of my research.

The results obtained during the course of this research are to the best of my knowledge original, except where reference is made to the work of others.

N.D.Bate
April 1996

Contents

1

Introduction

1.1 OVERVIEW

This thesis focuses on the use of expert systems for design in the heavy capital plant industry. This industry relies heavily on past experience to be able to produce cost effective one off designs within demanding time limits. As an industry which relies heavily on experience it appears an ideal area to use Expert Systems (E.S.). These can automate selected tasks which rely on experience, releasing a human experts time. This research investigates the type of design work carried out by typical industries and how expert systems may be used to meet their specific needs. In the Heavy Capital Plant Industry (H.C.P.I) pieces of plant co-operate as part of a large machine or system to fulfil a function. Examples occur in the oil, steel & chemical processing industries and also in a more limited fashion in the ship building and construction industries. Engineering design in the area is characterised by one off projects; the designs relying on experience, together with calculations, to help reduce the problems that are encountered when the machines are installed. Quite often the systems are serial and any failure in one of the machines on the plant has a plant wide effect on all other equipment. This means that the reliability and performance of any plant supplied is critical.

The area selected for study was that of engineering design in the steel industry. This was achieved by collaborating with Davy International (Sheffield). They were selected because they are an example of one of the U.K.'s leading firms in the design of plant needed by the steel industry. They have a turnover of approximately 80 million pounds and employ around 150 engineering designers.

1.2 ENGINEERING DESIGN IN HEAVY CAPITAL PLANT INDUSTRY

The H.C.P.I supplies large pieces of equipment/plant to their customer. A constituent part of this work is commissioning (building and installing) of this equipment on the customers' site. Examples of this type of industry are companies supplying equipment to the Steel industry. Their business area is to design, manufacture, install and commission any equipment sold to the steel mills.

The equipment is manufactured in single units or small batches. It is then assembled in a form for transportation / shipping. The equipment will be fully assembled for proving trials before shipping, if possible. On arrival at the site the equipment is assembled and commissioned. The timing of each aspect of this process is critical and errors can have heavy cost penalties associated with them, any delay could contribute to more downtime. The cost of downtime can be measured in thousands of pounds per minute. The equipment used in a steel mill combines to form an essentially continuous single machine, which means that if one part of the machine is not working the whole process is effectively stopped.

For this reason the customer steel companies demand that most equipment supplied to them has references from other steel mills, i.e. it has been proven to work. This means that most engineering design is incremental, being based on equipment previously supplied to other mills, with relevant modifications to adapt them to the current situation.

There is limited time to develop designs, which leads to conservative designs based on previous contracts. This makes the equipment more expensive than it needs to be. Computer support can be valuable by helping to streamline this process. The extra time created could give the design engineer more time to refine designs and reduce cost.

The following section introduces typical equipment used, outlining the some of the potential reasons for this conservative engineering design approach. There are two types of design activities carried out when supplying equipment to the steel producing companies. These are the layout of the steel mill (especially for a greenfield site) and the design of the individual items of equipment used.

1.3 STEEL MILL EQUIPMENT DESIGN

Each piece of equipment used on a steel plant is an expensive, engineering design, which needs to fit into the plant, possibly requiring customisation. This section describes how this equipment is used to produce steel for hot strip production.

1.3.1 The Hot Strip Mill

Hot strip mills are used in the metal processing industry to transform billets or slabs of 150-200mm thick steel down to coils of 1-10mm thickness and upwards of 80m in length. This needs to be cold rolled before it is in the form required by the majority of its applications. The mill consists of a core set of equipment that includes Furnaces, Roughing mill(s), Finishers and Coilers. Transport between the equipment is achieved by powered roller tables. Additional equipment contributes to improvement of quality, yield or mill throughput. For instance the addition of axially moveable work rolls allows the opportunity to equalise the effects of roll wear between changes leading to improved product quality. Typical capital costs of mill equipment range from £1 million to £50 million. An example of a typical layout is shown in figure 1.1, which could meet the requirements for most plants. Slabs are heated in the furnaces and then proceed through the mill from the Rougher to the Finishers and is finally coiled in the Downcoilers. After leaving the Furnaces, scale is removed from the slab by the Horizontal Scale Breakers. The slab is reduced in thickness from about 300mm down to approximately 50mm by 5 - 7 reversing passes through the Roughing mill. The Enco Panels are used to reduce the heat loss of the slab, now called a transfer bar, between leaving the Rougher and entering the Finishers. The Head and Tail of the slab are removed by the Crop Shear, important for later processing of the strip. The Finishers reduce the thickness down to the final thickness required, which can be down to 2mm. The least effective piece of core equipment limits the whole mill.

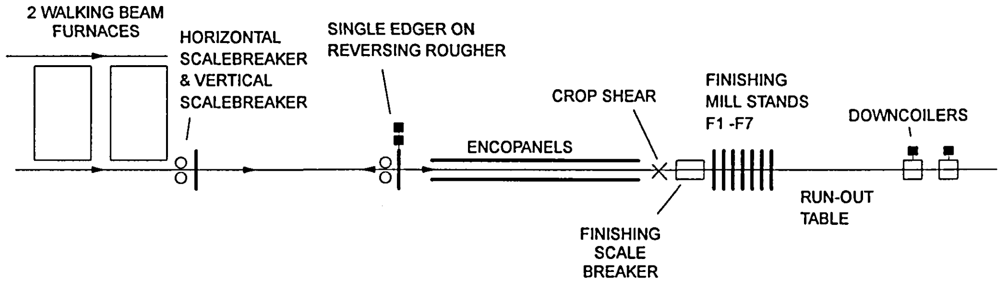


Figure 1.1

Any loss of production on a mill costs thousands of pounds per minute and so improvement in the mill availability is welcome, as is yield improvement which also has the potential to generate large financial benefits. Equally, by improving the products quality it may be possible to sell material to new and higher value markets, although improved quality might also be vital to maintain market share.

The thesis investigates the expert process in each of these areas and identifies the benefits of the use of expert systems in these areas. The following sections introduce these areas.

1.3.2 Equipment Design

Applications for engineering design expert systems need to be carefully selected in the steel industry. This type of industry does not have the opportunity in most of its products for volume production to generate the payback necessary to offset the time and money investment needed to produce an expert system. Only equipment which is common to most contracts should be represented on expert systems. This ensures the maximum return on the time invested to create an expert system, as discussed by Thomas et al (1991).

One such example is a roller table which is used to transport materials to and between processes. A roller table is made up of banks of rollers fitted onto a bed. Roller tables are used on all mills, which provides the opportunity for the expert system to be used sufficiently to repay the time invested. One application of roller tables is to transport hot strip between the different equipment on a mill. The roller tables are different at each part of the mill, because of the different local environmental conditions and load requirements. For example around the reversing rougher stand, on a hot strip mill, the tables needed to be able to stop the transfer bar (the term for the strip as it passes from the roughing to the finishing mills) and accelerate it up to speed in the reverse direction.

To provide a standard approach to the design of this and other equipment the company have produced design manuals, written by young graduate engineers, incorporating knowledge used by experienced engineers to design each piece of equipment. The design manuals are the repository of the company's knowledge for the approach to design for individual pieces of equipment. This makes them an ideal source for knowledge for incorporation into expert systems.

1.3.3 Techno-economic Feasibility Studies

Another good generic application is the development of plant wide feasibility studies. Producing a feasibility study is a central part of any bid for the construction of a re-configured layout of any Hot Strip Mill, a activity which is occurring increasingly and contributes significantly to the turnover of Davy International (Sheffield). Producing a feasibility study can take anything up to 6 - 8 weeks for the company expert and can be a bottleneck in the tendering process. This is mainly due to the time required to operate technical computer programs and then interpreting and incorporating results into spreadsheet models. Anything that can be done to free up the expert's time will give potential for the expert to perform additional or further studies.

The process starts when the company receives a request from a customer for a technical feasibility study which requires them to propose and evaluate general or specific alterations to a plant layout. A typical request might be to consider the feasibility of adding heat retention panels, called Enco Panels, positioned over the transfer table to prevent heat loss. These panels offer a range of benefits: reducing the fuel required in the furnace to obtain the correct temperature of strip coming out of the finishing mill; thus allowing larger thickness reductions in the rougher whilst avoiding the excessive cooling of the thinner transfer bars; or jointly with the use of water curtains increase the acceleration possible at the finishers which allows increased throughput. Other options are also available during the feasibility study process an expert reviews the current mill layout in the context of the customers request. The expert receives a query from a customer and then makes a decision on how to alter the mill. To justify the changes the expert uses two main technical programs which simulate what happens in the mill.

The figures from the technical programs are used in a spreadsheet to generate a cost justification for the possible changes the expert recommends (e.g. see appendix A).

To do this the expert needs to understand the benefits that a piece of plant can offer to a given layout. The expert uses his knowledge based upon experience to provide figures for establishing capital costs, cost of foundations, installation cost, learning curves for operators, etc. The financial case is built up using a spreadsheet as the expert evaluates different plant layout options. The expert uses technical programs (mathematical models), developed by Davy International (Sheffield), to model the rolling process and generate financially significant parameters such as mill motor power, throughput for each new or existing piece of equipment included in the plant layout. Each alternative layout requires a unique spreadsheet to be developed, which in itself is very time consuming.

A variety of approaches have been used to date to help automate parts of the process of creating feasibility studies. Examples of these are in the use of spreadsheets to model different strategies for Hot Strip Mill reconstruction (Hewitt, 1989, 1991) and in the use of mathematical models which optimise the combined technical and economical parameters of a mill (Hewitt et al, 1987). Even with the aid of these approaches, the creation of a feasibility study takes from 6 - 8 weeks. This process is currently very labour intensive.

In creating this particular expert system the key source of expertise was Mr E.C. Hewitt, a company director with 30+ years of experience. He is currently the only person capable of generating both feasibility studies, and be able to generate a financial arguments to back up the results of the studies (i.e. a spreadsheet).

1.4 EXPERT SYSTEMS

One of the initial expert systems was developed to help doctors select therapy for bacterial infection (Jackson, 1986). Work on this system began in 1972 and emulated how doctors diagnose patients illness' and was called MYCIN. Expert systems are a computer based representation of the techniques and knowledge an expert employs when solving a problem. Initially these systems existed in powerful computers, created each time using low level computer languages (e.g. LISP, PROLOG, etc.), however now they can be created using sophisticated toolkits on workstations or PC's using off the shelf expert system shells.

Most of the original systems created were using similar strategies to MYCIN, i.e. diagnosis systems, discussed in section 2.5. The application areas which are covered by expert systems have expanded from system analysis to include system modification and system synthesis. The areas of system analysis and system modification are well researched. Research into system synthesis is still in the early stages, especially in the area of Engineering Design.

Initial systems employed pattern matching techniques when representing knowledge, called rules. Generally these are IF... THEN... statements whose order of execution is dynamically controlled by an Inference Engine. In large systems the management of the rules becomes increasingly difficult. This gave rise to the development of frames (which are the same as schemas). A frame is an object, either conceptual or physical, defined by its attributes (also called slots); e.g. a frame for a chair has attributes number of legs, colour, etc.. Other techniques which are now being employed in knowledge representation include Object Oriented Systems, frames with procedural code (called methods), and Case Based Reasoning, which has a database of previous cases and selects the nearest case to the current situation.

1.5 RESEARCH OBJECTIVES

The aims / objectives of the research program are:

- To asses the benefits which expert systems within engineering design can offer to the Heavy Capital Plant Industry, using Davy International (Sheffield) as an example.
- To review how expert systems have already been used in other areas and use these to identify approaches which can be transferred to our engineering design system.
- To build prototype expert systems from both the component and the layout design areas.
- To review the strengths and weakness' of current expert system methodologies and approaches used for the engineering design process.
- To identify an appropriate methodology and approach, including suitable software representations, for this problem area.

The result of the research will be to identify the benefits, limitations, appropriate representation structure and transferability of engineering design knowledge in the Heavy Capital Plant Industry.

2

Literature Survey

2.1 INTRODUCTION

The literature review examines how Expert Systems (E.S.) can be used to represent design knowledge in the Heavy Capital Plant Industry (H.C.P.I.). This is achieved by reviewing any similar systems, to determine if any commonality exists. The knowledge gained can then be used to help determine the approach to use when creating the two prototype systems.

There are no reported E.S. applications that relate specifically to the H.C.P.I.. As a result it was necessary to look at the more general use of E.S., applications in areas with similar features / characteristics and the approaches used when representing knowledge in mechanical design.

Part of the reason for this is that the uses of E.S. for engineering design is not as well developed as some other areas. This is shown in an industrial survey by the DTI (1989), were diagnosis systems have the largest number of applications, 54 out of 194 entries. This distribution is also reflected in initial commercial A.I. applications in manufacturing E.S. (Rauch-Hindin, 1988).

This chapter contains a general review of expert system techniques to determine approaches for use in knowledge elicitation and subsequent representation.

2.2 KNOWLEDGE ELICITATION / ACQUISITION

This section reviews knowledge elicitation and acquisition techniques used by the knowledge engineer when gathering knowledge. There are a wide range of techniques which can be used when collecting knowledge for an expert system (A.I.A.I., 1991). These include

- Document Analysis
- Interviews
    - Structured
    - Unstructured
- Protocol Analysis
- Concept Sorting
    - Card Sort
    - Repertory Grids

Document Analysis - reviewing any documentation relevant to the knowledge domain. Engineering design in the H.C.P.I. produces documents which contain specifications, calculations and drawings (both for assembly and components). Calculations are a sensible point to start any initial evaluation of how a product is designed. They hint at the procedures and processes considered during the design process. Drawings provide a useful tool for evaluating any special criteria which had to be considered for the product represented. This evaluation needs to be done with an engineer who is involved with the design of the products.

Interviews - These can either be unstructured, used more in initial stages of knowledge elicitation, or structured, used to firm up on principles. Hart (1986) discusses the different types of interviews which can be used and highlights the situations in which they should be considered. For example using unstructured interviews initially appears to be useful for establishing the extent of the application area. After this the use of structured interviews can be used to gather details from selected areas, making efficient use of the expert and knowledge engineers time.

Protocol analysis - This involves the shadowing of an expert, watching how they do their job. This can reveal any sources of information the experts use on a regular basis. Videos are a useful tool for recording this for later analysis

Concept sorting - These are techniques used to identify the concepts the expert uses when reasoning about problems and the importance of their relationships. Card sorting and repertory grids are different techniques which can be used to elicit these personal constructs. Repertory grids provide a tool for analysing these constructs. These approaches take their roots from the psychology field and are useful for identifying relationships the expert has not thought about before.

Both protocol analysis and concept sorting appear to be techniques which are more appropriate for skilled operators, who are able to apply appropriate heuristics, but are unable to conceptualise them. They appear to be inappropriate for engineers who need to be able to justify any design decisions that they make. Interviewing the expert in their working surroundings can provide clues to key sources of knowledge the expert refers to.

2.2.1 Human Issues

The expert needs to be committed to the project, with enough time to provide the time required to gather any knowledge needed. Support from the top makes it easier to gain time with the expert, any work with the knowledge engineer is then one of their legitimate tasks (Thomas et al, 1991).

It is recommended that the knowledge engineer should make sure that they are properly prepared to ensure that they gain the maximum from any session with the expert.

When gathering knowledge it is essential to choose a knowledge representation with which the expert is happy (Hart, 1986). For example, mechanical design engineers produce drawings to describe the final shape of the product they have designed. As a result they are an appropriate knowledge representation to use for any discussion about mechanical design with engineers.

2.2.2 Intermediate Representation

After finishing interviews the knowledge has to be described using an appropriate paradigm. Common approaches include Decision trees (Ignizio, 1991), Semantic networks and Frames. Decision trees provide a useful intermediate representation because they are easy to translate into rules. Decision trees show the links between criteria used to arrive at a decision (

see figure 5.6 for an example, on page 84). This makes them a useful tool for "teaching back" the knowledge gathered to date. "Teaching back" is when the knowledge gathered is translated into a different representation which is shown to the expert to confirm mutual understanding of the knowledge.

2.3 KNOWLEDGE REPRESENTATIONS

The common forms of knowledge representation used in engineering design E.S., include rule based and object oriented (discussed in detail later). Booch (1991) provides guidelines for the construction of objects. The purpose of using guidelines when creating objects is to avoid falling into the trap of placing an instance, a unique object which cannot be specialised anymore , in an inappropriate class (Brachman, 1985). Rich et al (1991) has some useful thoughts to the degree in which knowledge needs to be broken down into primitives. For example a designer specifying a motor may not need to understand in detail why it is constructed in a specific fashion, but just its performance characteristics.

The methodology used for recording parts of the object code that was proposed by Martin (1993) and was selected because it represents a large portion of the current position of the object management group (which is investigating how to diagram object oriented programs). Other more standard methodologies have drawbacks when working with objects, each having strengths and weakness' in different areas (Sutcliffe, 1991). For instance only two out of the eight methodologies reviewed by Sutcliffe (1991) support the principle of Encapsulation (the hiding of all but important concepts in an object), only one supports the design of Classes.

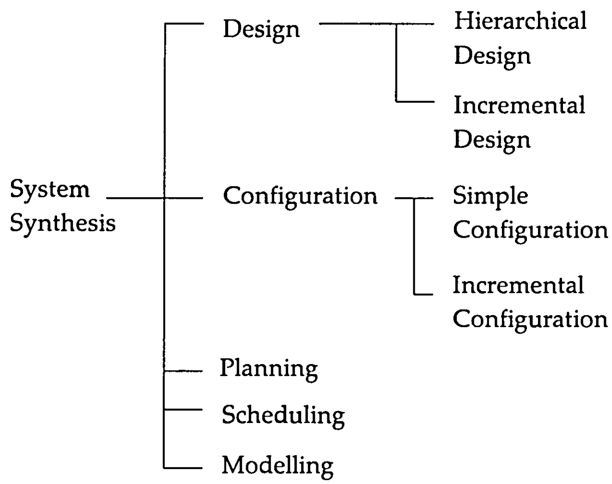
2.4 KNOWLEDGE REPRESENTATION FOR ENGINEERING DESIGN

This section reviews the approaches used to describe the stages of the design process. The aim is to determine the likely types of thought process we can expect to encounter and capture when creating a mechanical design Expert System. This was done by reviewing design theory and methodologies used to describe the design process; these have been used to help guide the creation of E.S..

Brown et al (1988) defined design knowledge in three distinct classes. Classes 1 & 2 deal with the aspects of design which involve creating novel solutions to problems. Class 3 is defined as the area where all aspects of a design have been explored, i.e. there is known expertise.

In the KADS (KBS Analysis and Design Support) hierarchy, types of design have been identified which exhibit similar attributes to those defined by Class 3.

When analysing how knowledge is used in system synthesis there are several basic areas identified by the KADS methodology. System synthesis is "the process of building up separate elements into a coherent single structure" (Tansley et al, 1993). The KADS methodology aims to provide generic models which describe the component aspects of the knowledge required to perform a task (e.g. design). The aim is for these models to create a description identifying the key aspects of knowledge needed to complete the designated task. The pre-prepared tasks are not intended to be definitive statements on the knowledge needed for a particular task, rather initial guidelines which can be adapted to suit the task in hand.



(Tansley et al, 1993)

Figure 2.1

The knowledge models are part of larger models which identify all of the tools and data that is needed for the completion of the task. These are used to guide the creation of the expert system in a coherent fashion, i.e. they clearly identify how all aspects inter-relate to produce the desired result. The knowledge models are categorised into different areas, one of the main branches, dealt with here, is system synthesis which encompasses the areas shown in figure 2.1.

Within the general area of the system synthesis branch there are several different groups, or specific tasks, see figure 2.1. The following section reviews selected design task models.

The "Design" task model is the basic task upon which all other design tasks are built. This model is similar to models described in knowledge representation for design (Smithers et al, 1990) or in more traditional design methodologies (Shaughnessy et al, 1992). The knowledge components are shown in figure 2.2 where a Domain roles is a description of the current knowledge stage and an Inference types is a process needed to transform the knowledge to the next knowledge stage.

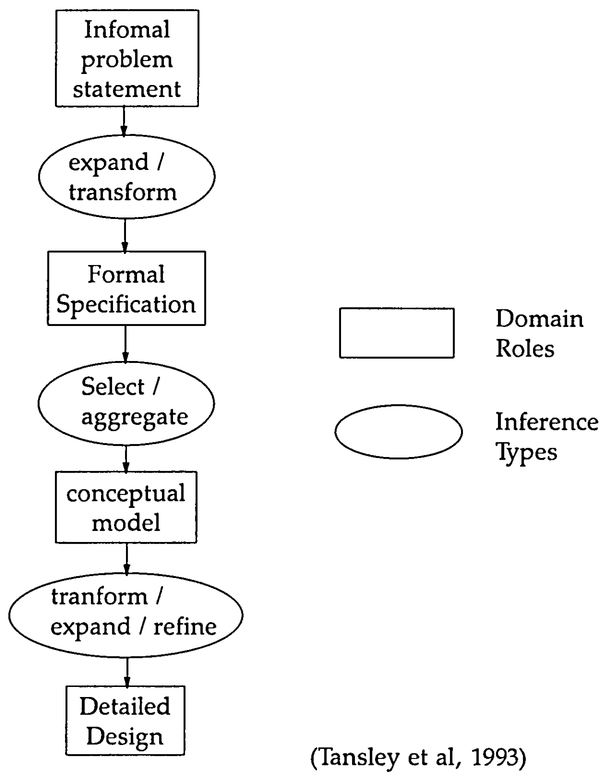


Figure 2.2

The relevance of all of the parts of this model will depend upon the problem that is being addressed. It could be assumed for component design that the expert system / engineer is provided with a formal specification before they begin designing.

Traditional design methodologies do not focus on the different knowledge activities which an expert would use when designing a product, they focus on the stages of the design process.

When capturing the knowledge of mechanical design this would be the initial task model used, with adaptations added as and when necessary.

The above example describes the generalised case for simple design. There are several specialised generic models which can be applied, or adapted to special cases. One such example is the KADS Hierarchical Design, General Design model. Because most of the design work in the steel industry is based on previous work a good generic model to start with is the KADS Hierarchical design model. The representation for this generic model is shown in figure 2.3. When bidding for a contract, one of the jobs necessary to compile the bid is to estimate the cost of producing the design. To do this the estimator must know what previous contract the current design is being based upon. These are effectively the models which are used in the 'select' inference type. The estimator uses the information from this contract to generate weights (used to generate costs for equipment) and the number of hours needed to design the component.

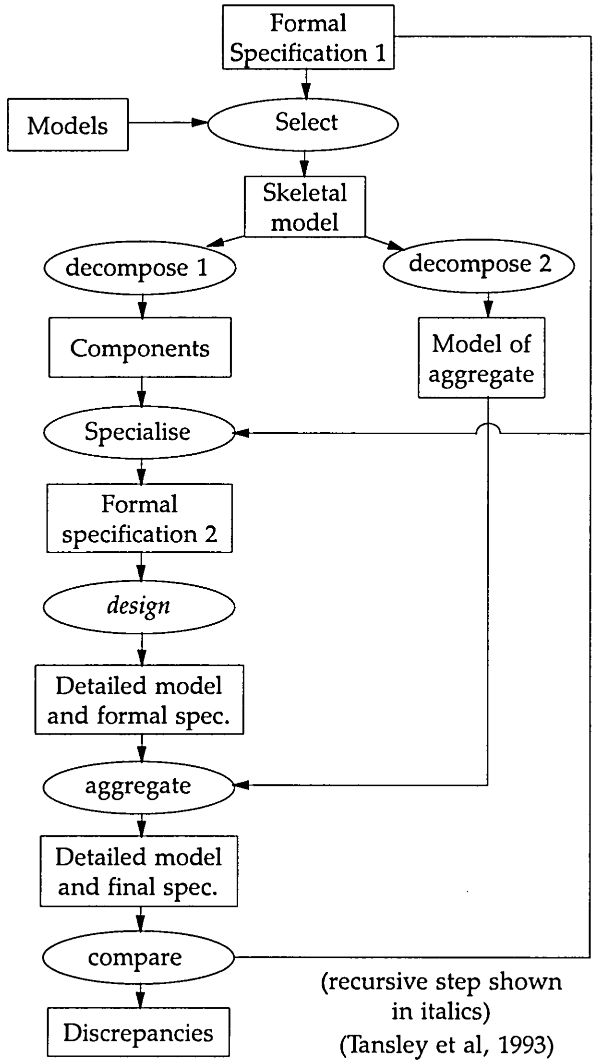


Figure 2.3

The KADS diagrams are used as a guide for knowledge acquisition, indicating the type of knowledge which needs to be covered when representing the design of a component.

The following example identifies a possible way to integrate geometric representation with design knowledge. To aid attaching knowledge to geometric descriptions the knowledge engineer needs to identify the different domains of knowledge in design. The knowledge is categorised as follows (Balachandran et al, 1988):

- Domain knowledge - knowledge of structural entities and concepts. This can be represented with the use of frames (which are basically objects minus methods).
- Procedural knowledge - knowledge of graphic operations, graphic interpretations. This deals with tasks such as graphic display, graphic interpretations and evaluation of properties of graphic entities. This provide the framework to describe geometric features in an appropriate syntax, for example joint could be of type pin and be joined to X, Y, Z in location A.
- Classification knowledge - knowledge involved in classification strategy. This is used to match the described object against an object which already exists in the system. This is done, for example, to determine if a beam is stable when compared with the systems internal description of a stable beam. To do this the system uses the properties of inheritance where properties and descriptions are inherited from parent objects.

By identifying the different areas of expertise, they can be used to aid the creation of the system. One of these is to aid the collection of the knowledge necessary for the system to work. Another reason is to help in system maintenance, one area of expertise might need to be updated more often than another.

When selecting the type of design to represent and the results which can be achieved the knowledge engineer has to understand which category the design falls into. Designs can be described as being either routine or non-routine (Gero, unpublished paper). He describes routine design as the process which occurs when the design takes place as soon as all the variables are known and the mechanisms needed for the design are already established. This does not however imply that "routine design is not complex or easy". Non-routine design describes the design which can produce an unexpected result. Non-routine design can be split into two further groups "innovative design" and "creative design". Innovative design produces "new" designs, where creative design is a vehicle / tool to aid in the production of new designs. Creative design is described as the "design activity which occurs when a new variable is introduced in the design", by either combination, mutation, analogy or design from first principles. Most expert systems for component design knowledge appear to represent the routine design type. This is because they represent existing expertise which encapsulate the knowledge necessary to design an existing product. The way in which they aid "creativity" is to allow the designer to experiment by adjusting input values to produce a better design. This together with an analysis of the financial and business benefits of representing the knowledge (Thomas, 1991) will aid the knowledge engineer to decide if a knowledge area can or should be represented.

2.5 EXPERT SYSTEMS FOR MECHANICAL DESIGN

The more popular approaches which are used for expert systems development are object oriented systems and rule based systems. There are however, many other approaches which can be used to represent knowledge for design, for instance constraint based reasoning or case based reasoning. There are examples of systems which integrate other approaches for use in problem solving, for example uncertainty (Mills et al, 1987). Expert systems for design however tend to be either rule based or object oriented. These should perhaps be considered before looking at other representation approaches.

The first Expert Systems were written using rule based systems, e.g. MYCIN, these however have problems associated with them. For example in the control of the rules, as the number of rules increases. This is a problem because as the number of rules increases, the number of combinations for these rules increases which can lead to the system either slowing or ultimately halting altogether. For this reason meta-rules (rules which select which set of rules of rules to apply) are used to manage the knowledge base. The design of these meta-rules needs to be done carefully because otherwise the benefit of the use of E.S. will be lost (Wilson, ICAD). The use of meta-rule is slightly alien to the way in which engineers would work if they were managing the design process themselves. Engineers tend to decompose the problem into either manageable functional chunks or into different designs of each sub-component. Meta-rules, unless they are well thought out, will not work in this fashion.

2.6 EXAMPLE APPLICATIONS OF EXPERT SYSTEMS

There are many areas of E.S. use which include medicine, process control, simulation, e.t.c.. This section reviews a subset of Expert System applications in other areas of the H.C.P.I.. The aim is to identify the representation techniques used in similar problem areas.

2.6.1 Design expert systems in the construction industry

The building / construction industry have to design and build one-off designs at the customers site, which is similar to H.C.P.I..

Experience in the building industry is encapsulated in building codes, which can be "complex and ill-structured". Rosenman et al (1986), describe how the building codes were initially used in an expert system called PREDIKIT (PREliminary Design of KITchens). This was developed into a expert system, using rules, called CODE, using the knowledge gathered from Part 49 of the Australian Model Uniform Building Code (AMUBC) (Rosenman, 1990). These building codes cover aspects such as material selection, construction regulations (e.g. recommended room sizes for habitation), Transportation (type required for certain materials), control on site, workmanship, etc. It may be necessary to consider the type of knowledge described above when designing how the heavy plant equipment should be fixed to the ground. There are similar design standards, e.g. British Standards, which are used in mechanical design which could make this a suitable representation technique.

FABEL (1993) uses case based reasoning to allow the system to learn as the number of cases increases. FABEL is designed as an addition to product called A4, which helps in the planning process used in the construction of large buildings with a complex infrastructure. The A4 system was modelled using an object oriented approach. When designing the layout of a plant it may be necessary to consider the staging of the construction of the plant.

Shen et al (1991), describe a system which captures value management in the building industry, used as a tool to aid reduction in overall cost. A frame based representation was chosen because of the similarity of determining the functional worth with cost estimation used in other systems (e.g. ELSIE). They identified that the creative and environmental aspect of the job could not be incorporated in the proposed system.

Both rules and objects have been used to represent knowledge in the building industry, with the use of case based reason now being used as tools to augment the capabilities of some of these systems.

2.6.2 Ship Design Expert Systems

Ship design has to balance all of the sub-components of the ship with its expected duties, which is then built into one machine.

Chou et al (1992), describe a system which co-ordinates the use of different tools and functional requirements used in naval ship design. The system controls the questions asked whilst building a design specification, carries out some preliminary design tasks and does initial evaluation of the designs. The evaluation of the designs is done using combination of heuristics and empirical mathematical formula. A rule base, in its final form, was used for efficient handling of heuristics. Example rules show how the system establishes the baseline ship data and how the use of weighting criteria is used to report the best recommendation. The tool used provides an explanation system which uses the rules to show how a decision was reached. This approach highlights that an expert system interacting with existing decision support tools aids in creating a more encompassing design tool.

2.6.3 Design Expert Systems in the Chemical Industry

Goring et al (1993), describe a system which analyses a chemical plant design and identifies any potential hazards that the designer may not have thought about. The software integrates with existing CAD flowsheet models, which it then uses to generate a written report of the hazards. The system generates an object representation of the plant which is interrogated by rules to generate the hazard report.

Tan et al (1993), describe a rule and schema (frame) based system which provides a chemical plant designer with a starting point for a new plant. The system can specify either single or parallel processing of chemicals. The system is an amalgamation of different evaluation mechanisms combined with analysis tools which provide performance indices. The under-lying consideration the system has is to minimise the total equipment cost. The choice of how to alter the plant is left to the user. The user selects which layout to pursue by comparing the performance indices of the different options. This approach requires that the user must understand the implications of the relative importance of the indices.

Novak et al (1994), describes an expert system for bottle plant design. The system uses a rule based approach, written in Prolog, to select the equipment needed to produce bottles containing a specified liquid. The basic specification details appear limited, with detailed equipment data stored internally. The design process is separated into sub-tasks, always performed in the same order. Financial costs produced at the end are calculated by adding each of the equipment costs.

2.6.4 Examples of the use of E.S. for Mechanical Design

Early expert systems tended to use rules to encapsulate any knowledge. Two examples of systems which use rules are outlined below.

One of the earliest examples of the use of expert systems in mechanical design was for computer configurations in the 'R1' system by D.E.C. (Rychener, 1985).

Wang et al (1988) deals with the design of a standard roller chain-drive. In this system the knowledge is represented using rules. The knowledge base is split into groups which are based on their working environment. They describe how their expert system is linked with a CAD system. The main difficulty encountered was that their expert system was written in Lisp and they stated that CAD was mainly written in languages such as Fortran, Pascal or Basic. Their link was achieved with the use of data file transfer.

The last example linked an expert system to a CAD system. One successful system which is marketed which achieves this is ICAD. The following are three examples of the areas in which ICAD has been used.

ICAD literature , reference (ICAD - Tooling), describes an example which creates automatic tooling geometry for glass tubes of televisions. This system imports CAD data which is used by the knowledge base to automatically determine the design of the punch and die components. This echoes the traditional methods where a tool designer receives drawings and specifications and uses these to design the tooling required.

A European manufacturer of industrial cleaning equipment uses ICAD to help in the preparation of bids, proposals and design, reference (ICAD -Sales). A design to meet a customers specific requirements is a "reconfiguration of previous designs and standard parts". The design / proposal knowledge is entered into ICAD's object oriented language to produce smart models. These are then used in both the conceptual and detailed design stages to help in the quick response to design changes and to aid in evaluation of design alternatives. When the method of calculation has been used before then these simple models can be built up into complex groups of co-ordinating objects, which represent the design.

The language uses an object oriented format to store the knowledge. The use of an object oriented format allows any new design to exploit pre-defined primitives (features needed to create a CAD drawing) which are able to generate drawings of the component. The use of the term rules, by ICAD, seems to approximate what would be termed methods in object oriented programming.

The following two examples use a frame based representation when they are dealing with problems that require feature recognition. Frames by their nature create families of like representations, creating default definitions (see section 2.3).

Woodward et al (1990) use a rule and feature based approach for the design of die cast components. A feature based approach, using pre-defined geometric primitives to describe the component, was chosen in preference over feature recognition, which in turn determined the features from a geometric model. A feature based approach ensures that the system can recognise all of the design elements. The system uses the features to assess the die design and if there are any problems the user will receive a message to this effect. The system will inform the user of the implications of leaving this problem unchanged and on possible ways to rectify the fault. It is the users responsibility to make any changes required.

Cunningham et al (1993) describe an object based expert system which is used to provide a cost estimate of automotive parts, working without the use of any rules. The system relies on its ability to relate features to different manufacturing cost models. Because some parts can be manufactured by more than one process the system needs to decide which process to include in alternative manufacturing plans.

Rules appear to be predominately used in the earlier examples of design knowledge bases. The more recent approaches appear to favour an object oriented format(see section 4 for further discussion).

2.6.5 Summary of Example Expert System Applications

The important features which can be extracted from the applications described previously include:

- The expert systems which require feature recognition use a frame based representation.
- The two expert systems which dealt with costing are feature based.
- The rule-based approaches have used existing mathematical tools, represented in procedural programs, to handle certain aspects of the design.
- In plant design both rules and objects have been used, rules being used to select equipment, with objects used to capture a representation of the plant.
- Both rule based and object oriented approaches have been used for design systems in this area. The type of system chosen appears to depend on the particular type of problem, not a particular design problem area.

2.7 TOOLS USED IN PLANT LAYOUT DESIGN

The design of more complicated machines that affect how a plant performs tends to use more heuristic knowledge to help in arriving at a solution. To design the layout of plant requires not only knowledge about the machines but the way in which the plant needs to perform as a whole. This occurs across a range of industries which supply equipment that forms part of an automated plant, e.g. steel industry, construction industry, chemical industry, etc.

When looking at the Steel Industry there are a range of techniques and approaches which could be integrated or incorporated to provide a comprehensive toolkit for a human expert or E.S. to help when designing a plant. These include techniques such as planning, product scheduling, layout configuration, mathematical modelling and simulation.

Modelling of the rolling process was originally carried out with the use of mathematical models (Bratus, 1985; Beagles et al, 1992). The models are theoretical simulations of reality. The rolling process is difficult to model because of the complex nature of the process. There are various approaches to modelling the process. The pure mathematical models, which simulate the technical process, aid the engineer to determine a possible reduction strategy. The amount of reduction in thickness of the strip for each pass is termed the pass schedule. Initial passes reduce the majority of thickness, with the later passes focusing the accuracy of the required strip profile. More sophisticated models amalgamate all of the approaches to enable evaluation of the optimal pass reduction sequence (Czlapinski et al, 1989; Kopp et al, 1991; Vorontsov et al, 1985; Kopp et al, 1990; Shilov et al, 1984). To truly optimise a mill it is also necessary to minimise the energy wastage of the in the mill. Most model do not address the problem of inefficient energy usage.

To incorporate energy usage into the problem is synonymous with incorporating cost (Koinov et al, 1985; Koinov et al, 1986; Koinov et al, 1987). This allows the expert to arrive at a optimised solution, which can be justified by building a financial case for its decisions. The problem with this technique is that it assumes that the current mill layout is perfect. Other configurations can be evaluated using the models in an iterative fashion.

Other techniques use a combination of the mathematical models to determine a schedule for a steel plant:

- The coffin schedule - The optimisation of the flow of steel has to account for roll wear, hence the coffin schedule. The coffin shape represents the widths of material being rolled, i.e. narrow at first then widest to narrow at the end. This approach has been modelled both using mathematical models and E.S..
- Mathematical models and plant simulations work in a set order which derive the optimal solution. The information represented in these programs is shallow knowledge. The systems specify the minimum information needed to solve the problems. They do not detail the reasons for taking an approach or have the ability to justify a particular choice.

Expert Systems, however represent a model of an expert's problem solving strategy (Arizono et al, 1991; Alvey IKONMAN Project, 1989; V Remeika et al, 1991). By representing the expert's strategy unexpected or unknown problems can be tackled. Mathematical models only represent solutions for known or defined problems.

Traditional scheduling systems are concerned with the flow of a product batch through a plant. The scheduling system aims to maximise the output possible (Arizono et al, 1991; Alvey IKONMAN Project, 1989; V Remeika et al, 1991). More sophisticated systems should allow more complex strategies which incorporate the relative values of the product and specific customer rating. To justify the choice of a particular layout chosen, the Plant Layout Design Program (P.L.D.P.) must contain elements of the knowledge needed to schedule a mill.

Mills et al (1987) discuss the integration of cost knowledge for the design of industrial combustion systems that are used to identify which of the solutions gives the best return on customers money, depending on different design philosophies. This is the kind of approach for the use of cost knowledge when a designer is either trying to pick the best option or justify a choice to a customer.

2.8 E.S. IN THE STEEL INDUSTRY

This thesis concentrates on how the design of equipment used by process industries can benefit from the use of expert systems. This part of the literature survey focuses on how expert systems have been used in the process industry, with particular emphasis on the steel industry. The aim is to see if any of the techniques used could be adapted for plant layout design.

Industry has been using mathematical models to help in the control of equipment for a number of years. However some areas were insufficiently understood to generate accurate models (Takekoshi et al, 1989) and other pieces of equipment have relied on operator skill and experience. The areas which rely on operator skill could not be represented using mathematical models and are potential areas for the use of E.S.. Consequently there are a high proportion of control type E.S. applications (Sumida et al, 1993).

E.S. have been used to improve performance of all aspects in steel plant which include equipment control and set-up, scheduling, diagnosis, planning and design (Noderer et al, 1990). Examples of each of these areas of E.S. include:

2.8.1 Equipment Control

Both Kawasaki Steel and Sumitomo metals have developed systems for the control of blast furnaces. The Sumitomo system is described as a hybrid expert system, which uses numerical models and experimental rules to achieve stable furnace operation (Otsuka et al, 1992). The Kawasaki system uses fuzzy theory together with expert systems to diagnose, plan and control different aspects of the furnace (Iida et al, 1992). Both use previous operator experience to help provide the knowledge for the expert systems.

2.8.2 Partial Plant Monitoring and Control

Expert systems have been used to monitor or diagnose how a piece of plant is performing. Examples of passive diagnosis and active control are given in the following text. Sumitomo metals linked an expert system to its facility monitoring system. The data generated by this system is interpreted and used in the expert system to diagnose the plant during operation. This system was used to help inexperienced operators with plant diagnosis and to plan any repair needed (Nakamura et al, 1992), helping to reduce maintenance time.

Kawasaki Steel has used expert systems to assist in the control of a fully automated steel finishing line. The system forms optimum schedules for transferring slit coils using all 24 carriers, which works in real time (Anabuki et al, 1992). This system was developed using simulation models which were then used as a basis for developing the rules used in the system. This approach was required because Mizushima Works was a new plant and consequently had no existing operator knowledge. A system was written at the Kashima Steel works, also for scheduling coils, but this uses existing operator knowledge (Kuribayashi et al, 1992).

The previous examples were both concerned with scheduling operations on a localised part of a steel mill. E.S. have also been used to schedule plant wide activities, e.g. determining the order in which slabs are rolled (Arizono et al, 1991). Different strip sizes require different mill set-ups, for instance the rolling of wide strip immediately after thin strip could result in marking of the strip, resulting from roll wear. The scheduling of the mill is done using an object oriented approach, with objects modelling the roll of a set of slabs. This knowledge is represented using rules and methods which operate by using a blackboard model for management of the knowledge. To be able to schedule the mill the system must be able to model how it performs. The system will need to have varying depths of knowledge for different equipment, to be able to arrive at an answer. The use of objects allows the knowledge to be segmented into coherent modules each dealing with a particular piece of equipment.

The rule based systems used by Kawaski Steel and Sumitomo Metals both use a frame based approach when representing knowledge (Fukumura et al, 1992; Takenaka et al, 1992). Suggesting the use of frames might be required when creating a rule-based system in the steel industry. Rules are used in the majority of the approaches surveyed. Rules are used for diagnosis and control problems, with scheduling represented using object orientation.

2.9 JUSTIFICATION OF PROGRAMME OF WORK

Ship design of Chou et al (1992), falls into both component design and plant layout design but is limited in both. For component design there is no detailed design to determine a components make-up and precise dimensions needed for design. This thesis aims to determine how expert systems can help in this area. For the layout of the ship the layout design programs do not need to account for specific plant conditions, for instance the location of cranes, reducing the complexity of the problem.

Part of design is to create the object, be it component or plant, in the most cost efficient manner. Tan et al (1993) use performance indices to help in this process which were developed from work like that of Yeh et al (1987). Not all areas of plant layout design are as well modelled as chemical plant design. This thesis aims to determine the benefits which expert systems can bring to plant design where existing plant layout design relies on an expert's knowledge.

Mechanical design of equipment used on steel plant provides examples of both component design and plant layout design. As a result of problems highlighted above it is necessary to investigate the use of Expert Systems in both of these areas. Component design is a logical choice as the first area to investigate. Components of the mill are combined to create the mill layout. Consequently any lessons learnt could impact on the approaches used for plant layout design.

A rule based approach for component design was chosen because of the similarities between this and the ship design E.S. (Chou et al, 1992). The mill knowledge used when designing a component is un-structured, similar to approaches used in construction, which is more suited to a rule based representation. Objects have been used in problems demanding feature classification, examples include CAD, cost, etc. This is not the case in roller table design (see section 1.2.2).

For the plant layout design the primary tasks performed are the scheduling of the product through the mill, diagnosis of the present mills performance and the generation of a cost justification for the choice of a particular layout. Diagnosis is traditionally represented using a rule based approach (Goring et al, 1993). Scheduling, in the examples examined, employs an object oriented approach. Consequently it seemed appropriate to use an hybrid expert system, which has both of these types of representation. Rules would be needed for the knowledge the expert uses to determine the most appropriate piece of plant to use, which appears to be similar to the CODE expert system (Rosenman, 1990). The objects would be useful for the incorporation of the cost knowledge (Cunningham et al, 1993; ICAD - Sales), ensuring all pieces of equipment could be evaluated using a standard cost approach.

Each of the layout design systems discussed leaves the choice of which layout to proceed with under the users control. They are all unable to represent the full scope of the experts knowledge in their systems, at least partially due to the difficulty in anticipating every conceivable layout restriction. It is expected that this will also occur for layout design in the H.C.P.I..

Both systems need to use a system which has interfaces with other software. Successful examples use other systems to handle the standard parts of the design process (Chou et al, 1992; Goring et al, 1993).

2.10 SUMMARY

- Engineering design in the H.C.P.I is a knowledge intensive area, requiring understanding of a complex process which has high costs penalties for any mistakes. As a result, the potential benefits which can be gained with the use of Expert Systems appear high. The aim of the thesis is to evaluate the best approach when using E.S. in this area, to maximise their potential benefit.
- There are two application areas, component and plant layout design, which both need to be investigated. Component design will be investigated first; looking in detail at the approach to specific design, some of which may contribute toward plant layout design. The aim is to incorporate the lessons learnt in this in the plant layout area.

3

Roller Table Design Program

3.1 INTRODUCTION

This section looks at how expert systems can be used for engineering design of components. The application selected, discussed in the introduction (see section 1.2.2) is the design of roller tables. These are used to transport material between the different parts of a mill. The approach to their design is affected by their location in the mill. This chapter describes and reviews the approach used to create an expert system used for their engineering design.

3.2 DESIGN MANUALS

In order to create a design manual, the manual writer worked closely with an appointed expert engineer. Between them they create a written document which recorded the best practice used to design the piece of equipment in question.

The engineer would specify which contracts should be reviewed as a basis for creating the manual. The basis would normally be the most recent contract that the equipment had been used on. The next step would entail finding all drawings and calculations that were associated with the component. The calculations would be used with the engineer to create a flow diagram of the stages involved in creating the design. Any missing parts of the design process would be filled in by the engineer. The flow diagram, drawings and calculations would then be used to create a manual which is checked by another expert engineer.

The roller table manual was one of the initial manuals to be completed. A complete manual was used as the basis for the creation of the roller table expert system. This product was selected because it links each section of a mill, i.e. a core piece of equipment, which maximises the potential financial / time returns of the expert system.

3.3 ROLLER TABLE PROGRAM

This section outlines the format / type of knowledge contained in the manual and describes stages of the roller table expert system's creation.

3.3.1 Roller Table Design Manual

Figure 3.1 shows the drive side half of the roller used on a roller table. The diagram shows the important dimensions needed to describe a completed roller design.

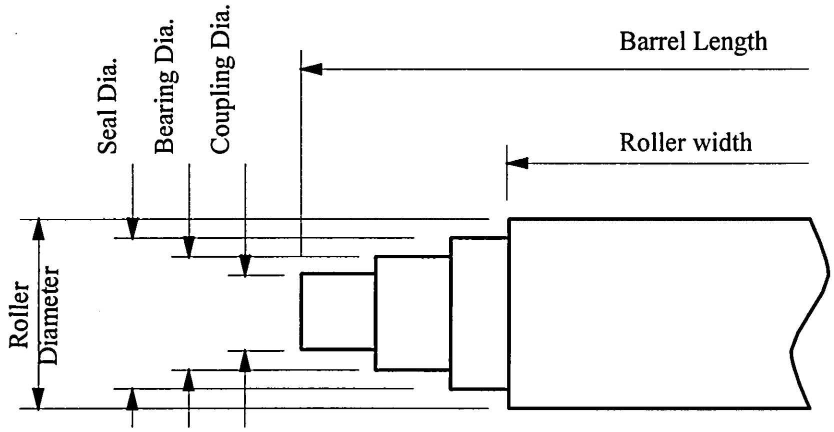


Figure 3.1

The design manual describes the systematic approach needed to design a roller. The manual also provides brief guidelines about how to select the accessories needed by the roller; i.e. motors to drive the rollers, couplings to transmit the motor power to the rollers, bearings to support the rollers, seals to protect the end of the rollers from scale or debris from the plant.

An example of the heuristics used to design roller tables is in the selection of the roller. The type of roller selected depends upon the position of the roller table in the mill, together with the width.

Table 3.1 is an extract of the knowledge used in the procedure which selects the roller diameter and pitch for a Hot Strip mill 1420mm (56") wide. Where:

- D is the outer diameter of the roller
- d is the inner diameter of the roller if it is hollow
- Pitch1 is the pitch between the rollers. When both Pitch1 and Pitch2 exist they represent the length the pitch needs to fall within

- Turndown is the front end drop below the top of the last roller, see figure 3.2. The greater the turndown the greater the impact force on the following roller.

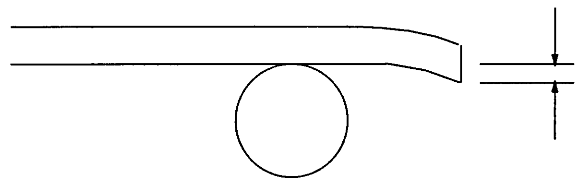


Figure 3.2

Location in the Mill	D (mm)	d (mm)	Pitch1 (mm)	Pitch2 (mm)	Roller Type	Mass Distr'b	Turndown (mm)
Furnace entry table	400	0	950	0	solid	2	10
Furnace delivery table	400	0	870	950	solid	2	20
Approach table to reversing rougher	400	0	950	0	solid	0.5	50
Ingoing main table	400	0	750	0	solid	2	50
Outgoing main table	400	0	750	0	solid	2	50
Outgoing extension table	350	0	850	0	solid	0.5	50
Entry table to crop shear/coil box	350	0	950	0	solid	0.5	-1
Runout table to downcoiler(min thk 1.5mm)	305	255	460	0	hollow	0.5	-1
Runout table to downcoiler(min thk 1.2mm)	305	255	420	0	hollow	0.5	-1

Table 3.1

In the mass distribution column, figures less than or equal to 1.0 represent the PERCENTAGE (e.g., 0.5=50%) of rollers that the product rests on; figures greater than 1 represent the NUMBER of rollers that the product rests on. For example on the approach table to reversing rougher, the product rests on two rollers (See figure 3.3). The turndown value will be 20 if the product is travelling at transport speed. The value of 50 is for product travelling at mill speed. -1 in the turndown column means the turndown value is not given in the Roller Table Design Manual.

The values for the diameter of the roller have been specified using the engineers experience. The rollers have to withstand impact loads, retain heat (to reduce cooling of the strip as it passes) and accelerate the strip to the desired velocity.

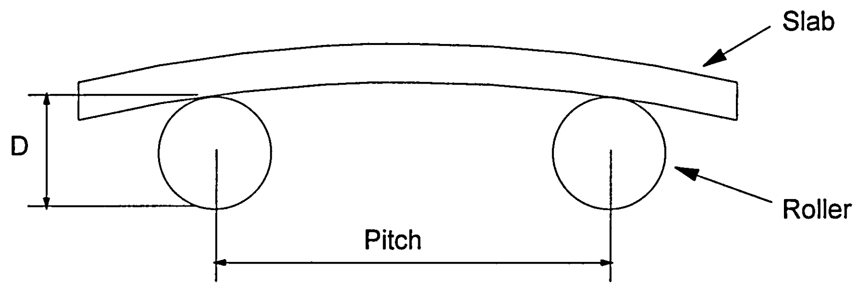


Figure 3.3

The program uses the knowledge in the Design Manual to design the complete roller and selects components need for its installation. It does not design the table beds or any housings needed.

The main area of contention with the current design is how the impact loads on the roller are modelled. There is no accurate data to which can be used to validate the mathematical models used. It is suspected that the impact loads are to high and as consequence the roller is being over engineered.

3.3.2 Expert System Software Selection

The design manual was written in a form similar to a rule based approach. Each section contained conditional if... then... statements which reference the next section. Each section represented a stage in the design of a roller table. Because of the use of the if... then... statements the use of rule based system is desirable.

It was decided to use a PC based piece of software to generate this program, to maximise its availability. The extracts from independent reviews of Xi Plus (Lydiard, 1989; Brown, 1990), Art-Im (Lydiard) and Kappa-Pc (Lydiard, 1990) were used to construct table 3.2. This table aims to highlight the features considered when selecting which piece of E.S. software to use.

Product	**Features**				
	Rule Capabilities	Similarity of Rule syntax with Knowledge syntax	External Links		Ease of Interface Generation
			Supplied	'C' Interface	
Xi Plus	Yes	Good	Good	Yes	Good
Kappa-Pc	Limited	Average	Good	Yes	Good
Art-Im	Yes	Average	Good / Difficult in practice	Yes	Average

Table 3.2

Having fulfilled the basic criteria of having a rule base capability and being able to link with external programs, the main selection criterion was the similarity of the rule and knowledge syntax. This ensures that no unnecessary translation is done, which reduces the chance of the meaning being corrupted. As a result Xi Plus seemed the most suitable software to use.

3.3.3 System Development

Initial attempts used the default Xi Plus approach for prompting the user by asking for values when they were needed. The approach mirrors how the design is recorded in the design manual. This is annoying to an engineering designer, because the questions appeared to be asked in a random fashion. This made it hard for an engineer to gather together the minimum amount of data needed for the program to specify a roller.

The second stage of the program's development was to improve the interface, making it more acceptable to the engineers. All the questions which the system needed answers to, in order to design the roller, were asked in the initial stages of running the program. The questions which the engineers were asked are the same as the questions needed to create an engineering design specification. Procedures for automatic selection of the accessories (i.e. the bearings, couplings, seals, motors) for the roller were added. Using automatic selection of accessories was felt to provide a coherent approach to the design. This allow the system to select only approved components. A model representing the stages of the program are shown in figure 3.4.

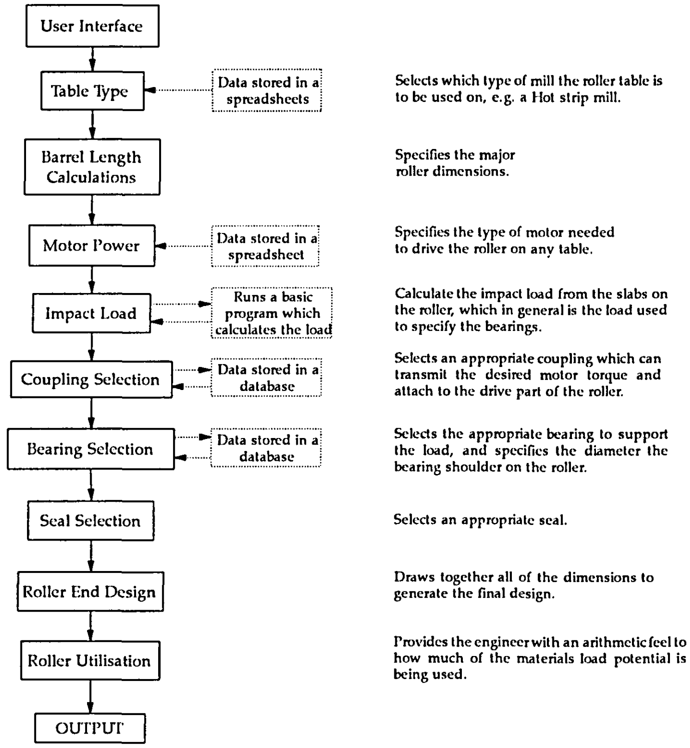


Figure 3.4

The program was ordered in this fashion to design the roller from the coupling shoulder to the centre of the roller. This is for ease of assembly as each shoulder from the centre outwards needs to be at least the same size or a little smaller.

The design manual required the engineer to refer to additional sources during the design process, for example when calculating the impact load and selecting components needed to house the roller (i.e. the bearings, couplings, seals, motors). This was an appropriate method when using a paper based system, however using a computer system means that the data needs to be automatically pulled into the program. This maximises the performance benefits of using an expert system.

This is also true when selecting accessories to add to the mill, e.g. bearings, some of which already exist in their own component databases. The integration of component databases into the system means that the engineer will be able to investigate multiple configurations in the time it would have taken to determine one configuration. Integration of component selection gives the opportunity for the company to only allow preferred suppliers and or sizes.

During the development of the program it was also decided to investigate linking the system to a pre-defined parametric which could generate a drawing for the final design. The production a file with the dimensions required by the parametric, meant that when the parametrics exist the production of drawings would then be possible. Without the integration of known component databases it would be difficult to ensure that the component could be drawn by the program.

Representing the motor selection process proved difficult, with the expert only willing to commit himself for the selection of standard DC motors. The development of the program took approximately 3 months.

3.4 OUTLINE OF PROGRAM

This section gives a more detailed description of the parts of the program. The following sections describe the calculation procedures and design methodologies that each knowledge base incorporates.

3.4.1 User Interface

The flow of the program is shown in figure 3.5. Most of the knowledge bases used to specify the engineering specification are similar to knowledge bases used later in the design process. The knowledge base with the major difference is the "input motor power". This is the final knowledge base which requires input from the engineer later in the program.

The program was written using sequential knowledge bases, with each knowledge base containing the knowledge needed for the design of one aspect of the roller, each knowledge base acting as a pseudo frame.

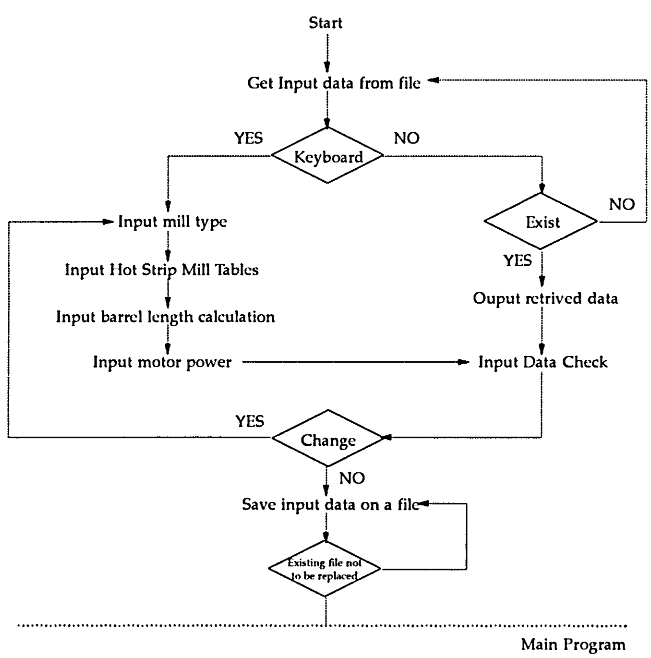


Figure 3.5

3.4.2 Mill Type

This provides a menu to select the type of mill on which the roller table is to be used. The types of mill includes Hot Strip, Plate, Beam and

Billet mills. At this stage of development the only working option is for Hot Strip Mills, the major area of the companies work.

3.4.3 Hot Strip Mill tables

This knowledge base asks the user where the roller table is to be used on the mill;

- Furnace entry
- Furnace delivery
- Approach to the Reversing Rougher
- Ingoing main table
- Outgoing main table
- Outgoing extension table
- Entry table to crop shear
- Runout table to downcoiler min. strip thickness 1.5mm
- Runout table to downcoiler min. strip thickness 1.2mm

Heuristics are used to determine the roller diameter in relation to its position in the mill. The position of the roller table determines the duty that the tables will receive. The tables before the roughers are likely to receive the largest impact load; the tables before the roughers are furnace entry, furnace delivery, approach to the Reversing Rougher and the ingoing main table. The reason for this is that this is where the weight of the product per roller is at its greatest. This means that the roller barrel diameter will be the greatest here.

3.4.4 Barrel Length

This is calculated using simple rules of thumb knowing;

- maximum product width.
- maximum deviation from centre.
- maximum product length - if the product needs to be turned whilst on the table.
- number of billets - if the mill is a billet mill.

An example for the calculation of the barrel length is:

If products are placed within 50mm of the centre of the table

Then max. barrel length = product width + 150

fact barrel length = max. barrel length + 30

3.4.5 Motor Power

This knowledge base calculates the full load torque which is used to specify a motor plus additional information which is reported to the user (e.g. total acceleration power, skid power, rms torque, etc.). The full load torque is calculated using the following equations:

product torque = mass product per roller x acceleration rate x roller diameter / 2

total torque = product torque + torque required to overcome roller inertia

full load torque = total torque / 2

3.4.6 Motor Selection

This uses the value of full load torque calculated in the previous knowledge base to select a motor. The details of approved motors are stored in a spreadsheet file. The knowledge base starts at the top and pulls the first record at the top of the spreadsheet. If the current motor torque is greater than the value of the full load torque then the motor is selected, otherwise the program retrieves the next motor. This process is repeated either till a motor is selected or until there are no more motors to retrieve.

3.4.7 Impact Load

This knowledge base uses an adapted basic program to calculated the effect of the impact load seen at the bearings. The manual specified the use of either multiplying the bearing specific load capacity by 25 or the use of PGRN or RPIMP (existing mathematical programs used currently by the designers). Each program uses different assumptions about how the strip reacts after hitting the rollers. For thicker slabs it is assumed the energy of impact is absorbed by plastic deformation of the end of the slab, whilst for thinner slabs the impact produces a vertical deflection in the strip. Historically these programs have been used by designers when assessing the impact loads on the roller table.

3.4.8 Coupling Selection

At this stage of the development of the program, it has been assumed, as a demonstration example, that the only coupling used on roller tables are Welman Bibby Gear couplings. The program calculates the diameter of the shaft necessary to transmit the torque supplied by the motor to the roller. This value together with the torque required is used to select an appropriate coupling from the selection stored in the coupling database.

3.4.9 Bearing selection

The program has to make some initial assumptions to be able to select a bearing, these include:

- the distance between bearing centres
- the impact load is split evenly between the two bearings
- the bearings used are spherical roller bearings

The knowledge base uses the minimum diameter specified by the coupling knowledge base, together with data calculated to select a bearing. The search criterion used to obtain a bearing from the bearing database is coupling diameter > minimum roller diameter, outside bearing diameter < roller diameter and satisfactory static and dynamic load capacities. The bearing data is stored in a database and retrieved through the use of a database program which incorporates the search criterion. This is written to a ASCII file from which the knowledge base selects the first line of data, which describes the bearing.

3.4.10 Roller End Design

This brings together the values calculated throughout the rest of the program and calculates the remaining dimensions of the roller.

e.g. coupling seat width = coupling:b + fillet radius between d3 and d4 - coupling:gap / 2

The variables d3 & d4 are shown on figure 3.6. The "coupling:gap" is the gap between the input and output shafts which the coupling joins and "coubling:b" is the width of the coupling.

Ideally these values would be calculated in the relevant knowledge base. However since this version of the program is a prototype, it not important.

3.4.11 Reporting of results

This was done using a combination of forms and reports in Xi Plus. The dimensions of the roller, together with the utilisation factors were reported using forms. Forms allow the use of a scanned Autocad picture of a roller end, specifying the nomenclature of dimensions / sections used, to be called up by the user when required. Results of the rest of the consultation were generated using an Xi-Plus 'report'. Details include the type of motor, coupling, bearing, seals, together with key figures used during the consultation process used to design the roller. An extract of the report of the results produced includes major dimensions of the final roller design, figure 3.6 defines the variables referred to below.

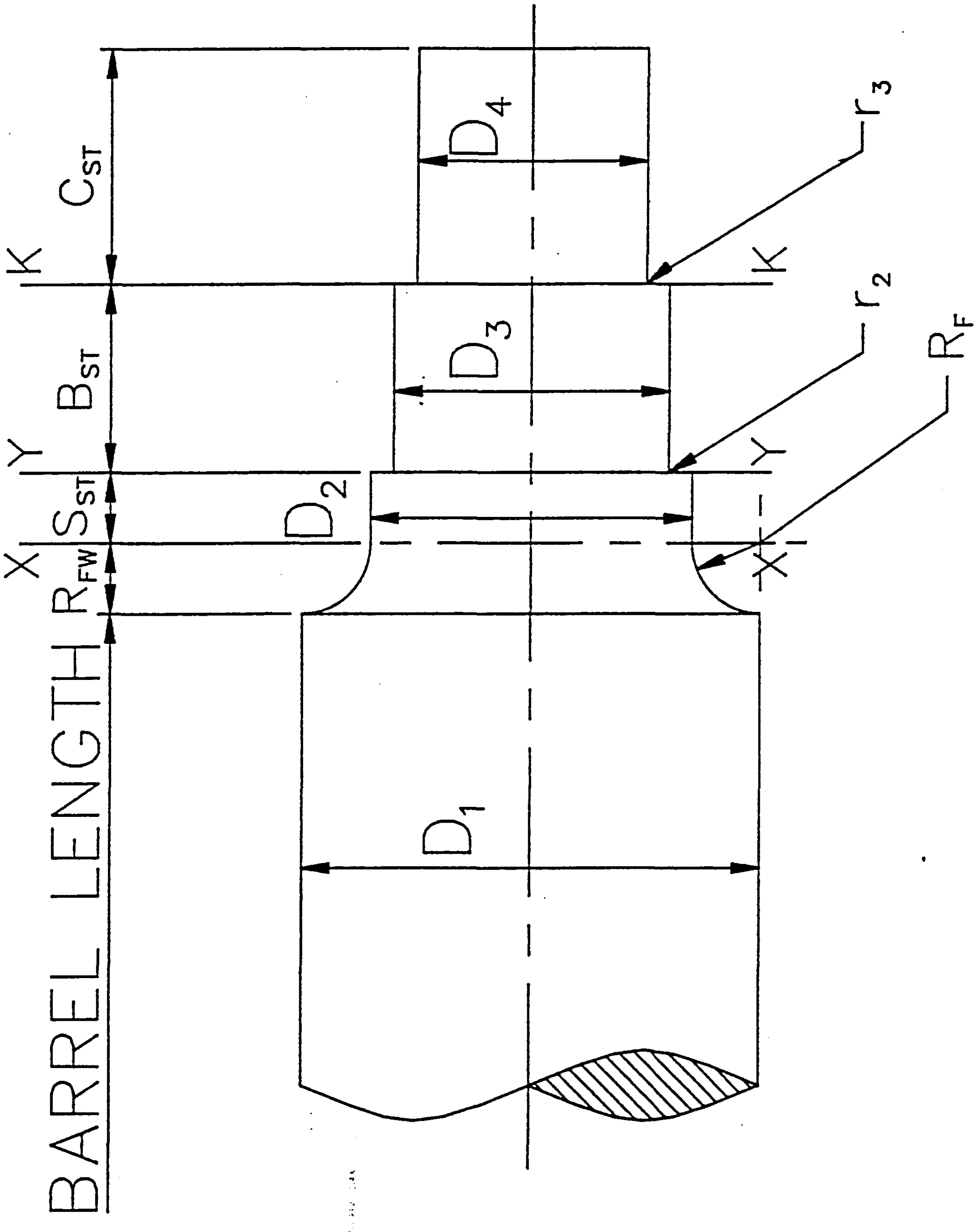


Figure 3.6

ROLLER DIMENSIONS

The barrel length of the roller = 1200
The width of the coupling seat = 183
The width of the bearing seat = 124
The width of the seal seat = 218
The width of the turn down = 148
between D1 and D2

Diameters:	D1	= 400
	D2	= 104
	D3	= 90
	D4	= 87
Fillet radii:	between D1 and D2	= 148
	r2	= 2.5
	r3	= 2.5

(see appendix B for full report).

3.5 PROGRAM VALIDATION

This was carried out in an informal fashion by demonstrating the program to engineers, appendix B shows an example of the typical output of the program. The program was used, in parallel with designers, on a contract to generate a roller table design. The results the program produced made the company re-evaluate how impact loads were accounted for in the roller design. The designers did not like the size of the bearings selected. It is difficult to accurately determine exactly what occurs during impact. The basic results the program produced were acceptable, with the exception of the problems with the impact load. These were resolved through discussions with SKF (bearing manufacturers). These generated a different approach to determining the value of the impact load .

The program takes 5 minutes to produce its results, the same process would take an engineer approximately between 30 minutes to an hour.

3.6 DISCUSSION

The knowledge representation used in this program was rules. This was adopted because of the similarities of the demands of the system used for naval ship design (Chou et al, 1992). There are however problems with using this as the major representation technique when dealing with component design which requires mechanical calculations. When designing it is not always possible to know all the inputs for a calculation, some can only be determined from the result of the current calculation. This results in design being an iterative process, with current stages feeding back and modifying previous stages (Cross, 1989). Rules, however do not easily represent iteration; Xi Plus has an in-built debugging tool which will not allow loops to be written. This became apparent during preliminary development of the bearing selection routines. This was solved by adding an additional criteria that the minimum inner diameter of the bearing could not be less than the coupling diameter (D4 on figure 3.6). On more complicated designs a similar approach may not be possible.

The knowledge incorporated in the roller table design manuals was of a simple procedural nature which does not need the pattern matching facilities of rules. The use of rules, however, does make the translation of expertise from the design manuals to the expert system easy because they are both expressed in the same fashion. It can be argued that using rules also eliminates the need to determine the exact order in which the rules fire, which makes later modification easier. The order in which the rules fire is determined by the inference engine at consultation time, which means that there is the opportunity to add a new rule anywhere in the relevant knowledge base. However, in this program the rules have been written in a form which does not really benefit from this flexibility.

Links to a CAD system could be through the use of a single simple parametric which converts the dimensions output by the system into a drawing. In this situation the geometric description is fixed, the shape of the component does not alter, i.e. the size of the dimensions alter but the shape remains constant, as in figure 3.7. This design does not require the system to deal with different shape relationships under changing conditions. Consequently representing the roller table program by using a rule based approach is acceptable. If the spatial build up changed then other representations could be more appropriate (see section 2.6.4).

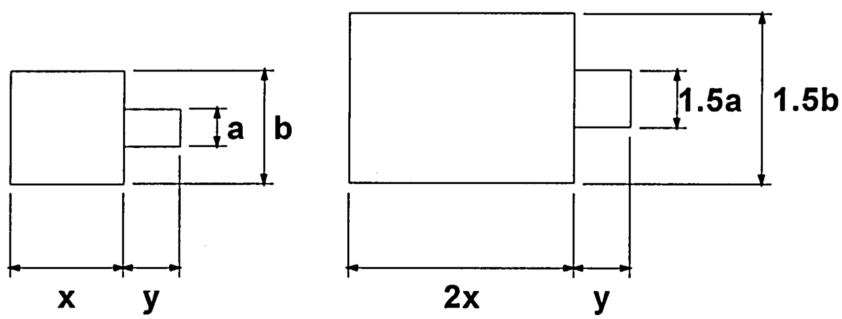


Figure 3.7

The program would have been easier to write using a toolkit which allowed the knowledge engineer to write the program interface as desired and use the rules to deal with any knowledge as required. The use of rules when writing the user interface required the programmer to twist the rules into an alien form, to ensure that the user was asked questions about the specification at the start, rather than as desired by the engineers.

The knowledge which determines the diameter of the roller uses knowledge about the environment of the plant. The size of the roller diameter has been determined through experience. This information exists in a structured format for different parts of the mill, i.e. it can be tabulated. These heuristics, if any less structured, should suit a rule based representation.

The plant knowledge, which handles the different load criteria on the rollers could have easily been represented in either rules or a more structured language. There is no strong reason to use either, they could fit into either type of representation.

Details about the plant layout are not needed for the design of the rollers, however in the design of other components it is necessary. In the design of the mill stand, contingencies for un-jamming the mill after a cobble need to be considered. In this situation cranes are sometimes needed, consequently access needs to be considered.

3.7 SUMMARY

This system is an example of E.S. used for component design. This forms the main part of the company's business, namely the design of mill equipment. At this point knowledge of customer practice has been highly distilled to provide the essential knowledge for the designer. The knowledge has been collected through experience of supplying equipment to their customers. An example of this is the format of the knowledge used to specify the main roller diameter. This heuristic knowledge, if less structured, appears to fit the use of rules. As a consequence any expert system used, for engineering design in the H.C.P.I., will ideally have rule based capabilities.

This knowledge is used together with product knowledge to design the roller. This is organised into subtasks areas, where each area is represented in one or more knowledge bases. The knowledge in this system has been totally represented with the use of rules, together with some data and calculation procedures that are handled externally (usually using adapted existing facilities). In these elements there is no explicit distinction between types of knowledge (Maher, 1990), the basic description of the component and the knowledge and functions necessary to design the component are inter-mixed.

4

Discussion of the use of E.S. in Component Design

4.1 INTRODUCTION

The previous section dealt with an expert system which represented the design of a mechanical component. This area has natural links with traditional Computer Aided Design (CAD) and parametric programs. Component design needs to deal with geometrical data to be able to generate engineering drawings. Engineering drawings can be recorded electronically with the use of CAD systems. To gain the most benefit from E.S. they should be linked to CAD. This allows the system to create drawings as either product or to aid the process of its design.

There are two existing tools available which have direct links to CAD and are able to represent design knowledge, these are ICAD and Wisdom's systems. They are used in large companies like Rolls Royce, British Aerospace, Lucas, etc. to store their design knowledge.

ICAD has a two way link between a CAD system and its own internal knowledge representation language IDL (ICAD Design Language). This gives the opportunity for the system to import CAD geometry for standard parts, as well as being able to produce a drawing as an end product from a consultation. This facility is useful in situations when the system is modelling the knowledge required to design moulds which uses existing CAD drawings of tool geometry, references (ICAD - Sales; ICAD -Tooling).

The ability for a system to deal with CAD geometry gives it a distinct advantage over other E.S. software, when dealing with component design. For other E.S., links with CAD will be through a selection of parametric programs. This link is sufficient if the design of the component only requires scaling for different sizes. It could be possible to select the appropriate parametric from a selection. This will become increasingly complex as the components design increases in complexity.

A more complicated design will change its shape as it's specification alters. To do this the E.S. must have both geometric knowledge and knowledge of how the component is to be assembled. This is because the system will need to have the spatial knowledge required to redesign the components shape as the design specification alters. For example ICAD in their product information cite an example where the assembly of standard size of pipes and pumps alters for different situations, references (ICAD - Sales; ICAD -Tooling).

4.2 KNOWLEDGE REPRESENTATION

One of the key issues when integrating expert systems with CAD is the representation of geometric knowledge. CAD systems represent the component using a combination of lines or in more sophisticated systems with the use of 3D models. These however have no structured meaning, their interpretation has been part of the skill of an engineer. The difficulty is representing / interpreting the relevant features, which require different manufacturing processes, or have other specific considerations. Smithers (1989) discusses the weakness' that current CAD systems have when dealing with engineering knowledge. CAD systems can be used to represent features, but in their current state the engineer is very restricted. This ignores the issue of a standardised approach for representing and naming of the features. This could be handled with the use of a system which forces the designer to design using pre-specified features (Colton et al., 1991). The inability of current CAD systems to represent features is highlighted by the amount of work which has to be done when a CAD drawing is sent to a Computer Aided Manufacturing (CAM) program; another engineer has to select and translate parts of the engineering drawing into crude drawings which are used to create tool paths for NC machines, for instance.

However as discussed by Smithers (1989) this geometric knowledge only records the final stages of the design process, ignoring the knowledge intensive area of conceptual design. Any system which is to represent the whole design process must therefore be able to handle more than just geometric details. The system needs to be able to represent the knowledge that the designer used to arrive at the geometric shape.

4.3 EXPERT SYSTEMS SOFTWARE

Mechanical design deals with the design of components, each component of a design could be described as an object. When designers design a component they will design large parts of it in isolation. The more complicated a design becomes the more it is decomposed into manageable sub-components. This process of decomposition is present in most design with the exception of the simplest design, as shown by the approach to generic models in KADS (Hickman, 1989). The process of decomposition of the problem into small parts is similar to the principle of modularity described in the principles of object oriented programming (Booch, 1991).

When a designer is given the job of designing a sub-component he / she will be given a description of the environment in which the component will function and details of the functions it will have to perform, i.e. a specification. This specification has parallels to the principles of abstraction and encapsulation in object oriented programming. Objects theoretically only interface with other objects through specific channels, with all other processes being hidden. The process of encapsulation can be applied so that the knowledge required to design a component is hidden, and any communication with the component is through the design specification or through the description of final design. This means that changes in the way the product is designed will only need to be altered in the object, which should then automatically integrate with the rest of the system. The abstraction, the way the object is viewed by the outside world, is that the object represents the knowledge required to design the component, or co-ordinates the process, i.e. it performs a specified design process.

One of the strengths of object oriented programming is in its ability to create program interfaces, i.e. its ability to deal with symbolic representations. This ability can also be used for representing geometric descriptions, which demonstrates suitability for the use of object structures when using E.S. for mechanical design, e.g. ICAD.

Only a small part of the roller table expert system needed the use of rules, e.g. the selection of the roller diameter. However this can be represented by using an inheritance framework. This could be done with a class having the basic characteristics of rollers and instances storing the specific details dealing with a roller table mill location. For other situations which depend upon the layout of the specific mill being dealt with, rules are an ideal tool for representation. For example dealing with the alteration of the configuration screw gear to allow for access for cranes, which is needed to help clear cobbles in the mill. On balance, the majority of the roller table program would have better suited a more structured programming language. In the light of the discussion above an object oriented toolkit with rule base capability would appear ideal.

4.4 FLEXIBILITY OF APPROACH

One of the difficulties encountered when design knowledge is incorporated in an Expert System is that the stages of the design process are fixed by the knowledge base. This removes the flexibility that the designer has when designing. A designer can eliminate possible design solutions quickly by evaluating certain critical areas. If standardised parts are used, the design has to integrate around them. If non standard parts are used, determining their sizes may affect the order of the design procedures.

If a part of the design needs to be altered and the flow of design procedures is fixed then the rest the design knowledge contained in the system would also be unusable. If a designer was able to incorporate the results determined externally into the system, then they could use their creativity to improve designs.

For example when designing the roller table one of the critical areas is the sizing of the roller body diameter. The size chosen has evolved to a fixed set of sizes, for different areas on a mill. Incorporating the facility to vary the roller size was achieved by adding an option to increase or decrease the roller size by a specified amount, then the roller would be totally redesigned. This was an easy change to implement but as the amount of information needed increases, the question of how to manage this process becomes more important. How can the user be made aware of all values they need to specify, or will there be simply a long list of questions, what is appropriate?

4.4.1 Representation

If objects were used then altering the order or allowing the input of manually calculated values can be handled easily. The abstraction of the object would need to be carefully considered during initial stages, with values only being part of the public representation of the object.

Changing the order using rules is difficult, especially if the rules are part of a large unstructured knowledge base. If the rules were partitioned into frames or packages of rules to be fired at the same time, then it would be possible to alter the order the rules fired using an equivalent approach as used by objects.

Volunteering values manually calculated could not be handled unless the rules were partitioned into areas dealing with a specific part of the calculation. Handling of unknown values when using backward chaining, in both Kappa-Pc and Xi Plus, is done by prompting the user for values as the rules are fired. With forward chaining any values which need to be volunteered would need to be known before the knowledge base was fired.

4.4.2 Transparency of knowledge

If an expert system needs to be flexible in its approach, then knowledge needs to be in a format so that anybody editing the knowledge base can easily grasp how the knowledge is represented. If it is easy to understand how the knowledge is structured then it is apparent how new design approaches should be incorporated into the knowledge base. This would mean that as the components design lifecycle progresses then any developments can be readily incorporated.

Knowledge represented in rules tends to be more transparent than when represented using objects and methods. The rules provide an intuitively understandable format for knowledge, however it can be difficult to track all of the rules links. Using an appropriate structure for knowledge or the partitioning of the rules will aid the process of understanding / maintenance.

4.4.3 Incorporation of design specific parameters

This section looks at how results generated from alternative design processes can be incorporated into the design process represented in the expert system.

When volunteering information the designer needs access to the current information generated by the knowledge base. Values generated from part of the process may be needed by the designer when considering alternative designs. The knowledge base will need to be able to carry out partial designs in a user / system defined order, to generate values needed by the designer.

For the designer to access this information the user interface would either need to be carefully designed or the information would need to have the potential to be represented in a drawing. A drawing provides information in a format which gives an engineer an instant picture of the current state of the products design. Because the user interface needs to be able to supply more information, it will take longer to construct.

The system will need to keep a record of the order in which major calculations were done. This will allow the user to change values in the specification and see how this alters the design. Initial assumptions which are used to help generate the rest of the design may turn out to be incorrect, which will result in parts of the design needing to be redesigned. By using the recorded order the next iteration can be recalculated in the same fashion as the first. It would, however, be essential that the system knows where the first reference for a variable occurs in the design process.

Where recommended values exist the user should be informed what they are, together with any extra information which explains their applicability. This will provide the user with access to low level knowledge contained in the system.

When the systems are partially completed, flexibility allows the users to work with the system at an early stage. With flexibility, use of the knowledge contained in the system is not limited to one design approach. The knowledge can be used to help the designer experiment with new approaches to a design, guiding in the selected area and automating other areas of the design. This allows the designers to see how their changes affect the overall design of the component.

4.5 DISCUSSION

Generally most expert systems used in design tend to use an object type framework for the representation of knowledge. This is because of their ability to deal with geometric features, with the use of a hierarchy of objects. The hierarchy of objects provides the framework which provides the syntax for the semantics of the knowledge the system incorporates; i.e. provides the language needed to describe the knowledge.

Objects provide a mechanism for the decomposition of the design knowledge into modules or objects, which is similar to the way in which the design of complex parts are managed. They are also good at handling graphical details, which is why they are being used for the creation of program interfaces. This points towards their suitability as an integrating technology when linking design knowledge to engineering drawings done on CAD.

The use of rules is appropriate when the system has to be able to make qualitative decisions about different options, using a more heuristic approach to problem solving. This is less significant in component design, especially a pre-designed product, which is more concerned with the representation of the mechanisms which translate the product specification to a final product design.

There are examples of work which demonstrate the capabilities of the use of expert systems for component design (See section 2.6.4). The difference between these and the roller table program is that the roller table program has to incorporate knowledge about the hot strip mill to be able to design a suitable roller. The knowledge boundaries between one component and the next are more blurred than they would be in other product areas, i.e. knowledge which just applies to that design alone. However the knowledge segment of 'hot strip mill knowledge' needed to design a component is relatively small. For this reason the next part of the thesis looks at an area where a larger segment of knowledge of mill knowledge is needed for the design of the mill layout to produce a specified product mix of a total annual tonnage per year.

Component design has very little environmental knowledge, and from the experiences with the roller table this appears to be better suited to rules. Design is generally suited to a more structured paradigm. The next section investigates whether dealing with an area of greater environmental knowledge, when designing the layout of the whole plant, the similar conclusions about representation paradigms apply.

5

Plant Layout Design Program

System Design

5.1 INTRODUCTION

This chapter investigates how an expert approaches the design of a Hot Strip Mill layout, introduced in section 1.2.3. The results of this investigation are used to select an appropriate expert system shell and identify suitable representations for each aspect of the knowledge needed.

5.2 REPRESENTATION OF KNOWLEDGE

The starting point of the process of knowledge acquisition is to review existing material. This enables the knowledge engineer to start building up a dictionary of important terms which he / she needs to understand to be able to communicate with the expert. For this reason the first source of knowledge which was looked at was the spreadsheets produced as the result of a feasibility study.

As the expert has carried out feasibility studies over a period of years it seemed sensible to examine a reasonably current study and use this to develop a generic approach. During the initial stage of acquiring the knowledge, the expert was part of the way through producing a feasibility study for Case One. He had produced a spreadsheet which reported some preliminary findings about the benefits of adding Enco Panels to their plant. The spreadsheet is of a relatively simple nature making it an ideal vehicle to gain initial insight into how the expert worked and where he used his knowledge. The different calculation procedures and data used in the spreadsheet were identified. This is recorded in appendix A which also holds a copy of a print of the spreadsheet with cell references. The spreadsheet is set-up to focus on the key figures of the return in investment and the time it takes to payback the investment needed (Figures 5.1-5.4 present a diagrammatic description of the stages of the process, showing how the spreadsheets are used).

There was a possibility that the format of the spreadsheets was the same for all studies, for this reason the expert was asked how the spreadsheets were constructed. The expert stated that he built the spreadsheets as he went through the process of doing a feasibility study. He felt that each spreadsheet differed from previous ones because the way they developed depended upon the information / data he had and the case he was trying to justify. He was able to identify some pieces of data that were common to all of the spreadsheets. These tables of data were:

- A strategically selected range of strip gauges for selected types of material produced, for each of these he needed some indicative tonnage's that the plant produced currently.

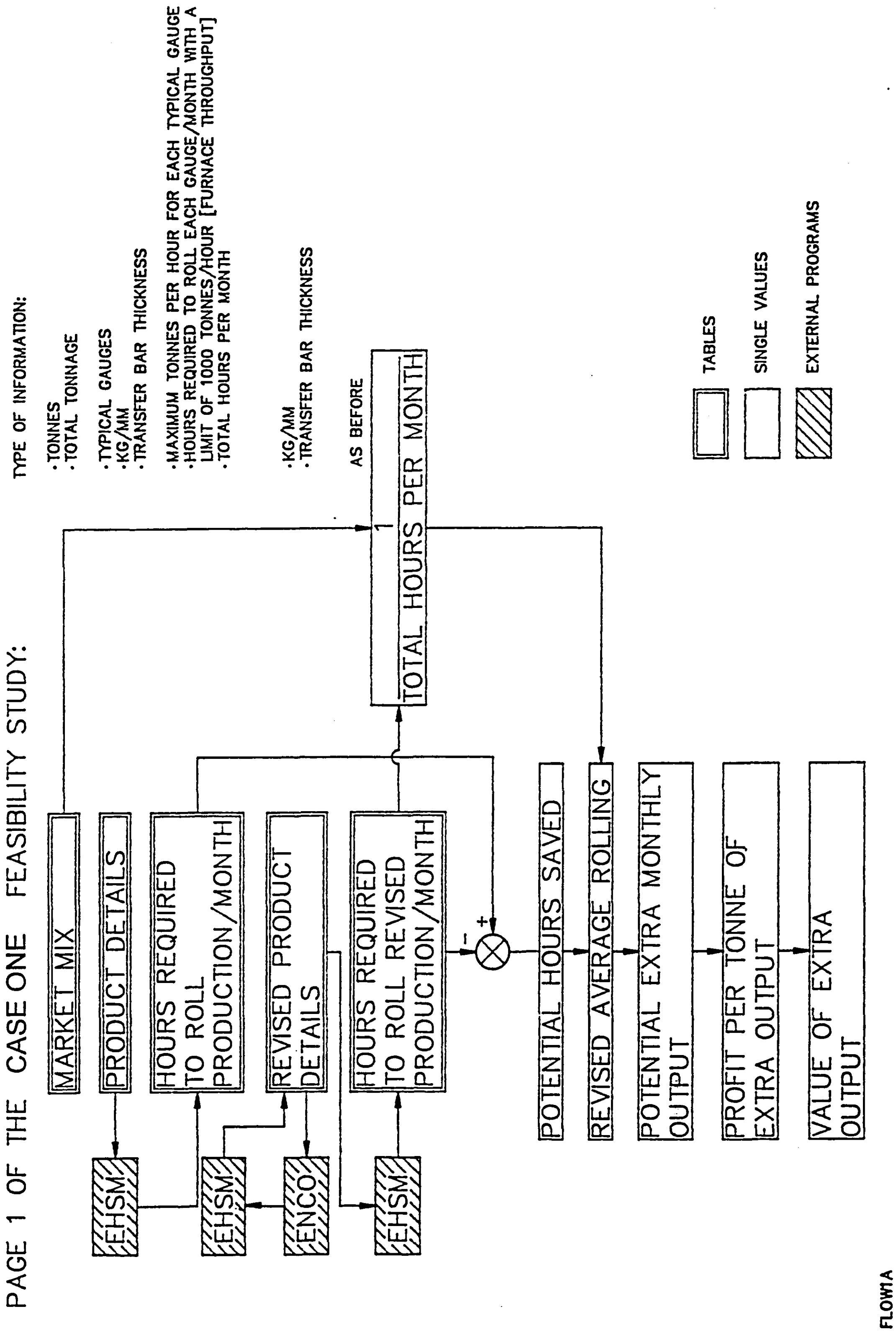

PAGE 1 OF THE CASE ONE FEASIBILITY STUDY:
TYPE OF INFORMATION:
MARKET MIX
·TONNES
·TOTAL TONNAGE
PRODUCT DETAILS
·TYPICAL GAUGES
·KG/MM
·TRANSFER BAR THICKNESS
HOURS REQUIRED TO ROLL PRODUCTION/MONTH
·MAXIMUM TONNES PER HOUR FOR EACH TYPICAL GAUGE
·HOURS REQUIRED TO ROLL EACH GAUGE/MONTH WITH A LIMIT OF 1000 TONNES/HOUR [FURNACE THROUGHPUT]
·TOTAL HOURS PER MONTH
REVISED PRODUCT DETAILS
·KG/MM
·TRANSFER BAR THICKNESS
HOURS REQUIRED TO ROLL REVISED PRODUCTION/MONTH
AS BEFORE
TOTAL HOURS PER MONTH
1
EHSM
EHSM
ENCO
EHSM
-
+
POTENTIAL HOURS SAVED
REVISED AVERAGE ROLLING
POTENTIAL EXTRA MONTHLY OUTPUT
PROFIT PER TONNE OF EXTRA OUTPUT
VALUE OF EXTRA OUTPUT
TABLES
SINGLE VALUES
EXTERNAL PROGRAMS
FLOW1A

Figure 5.1

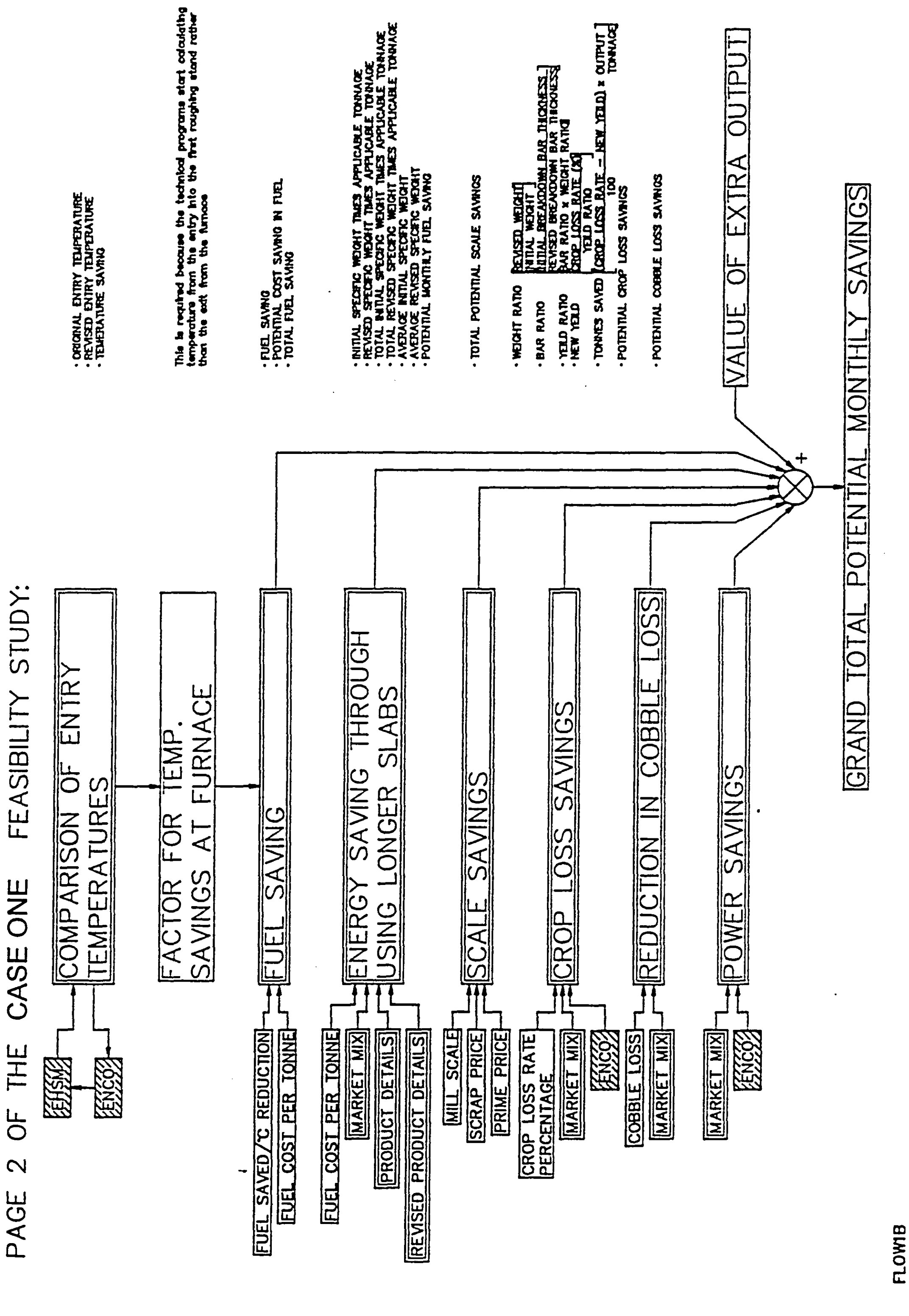
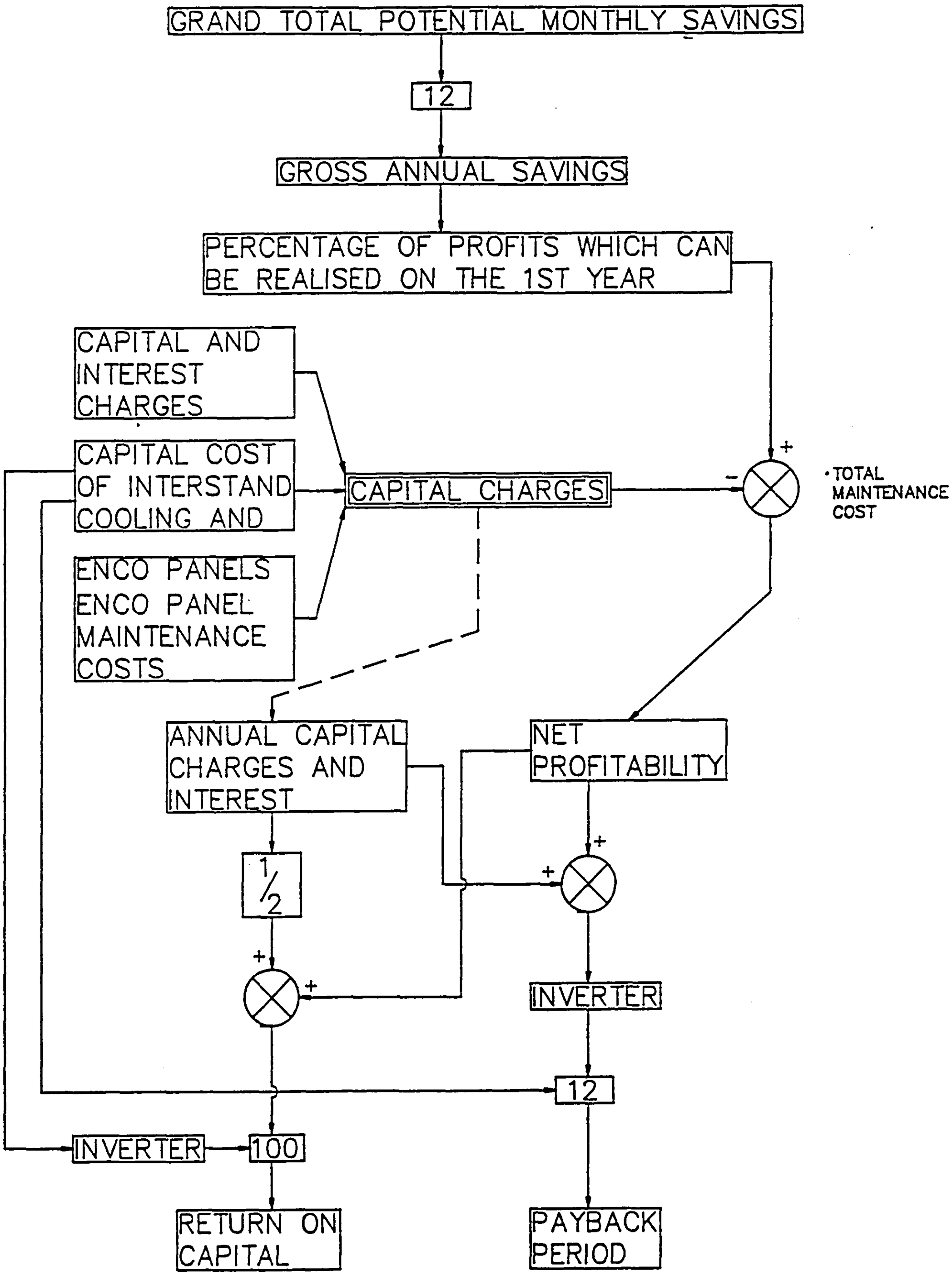
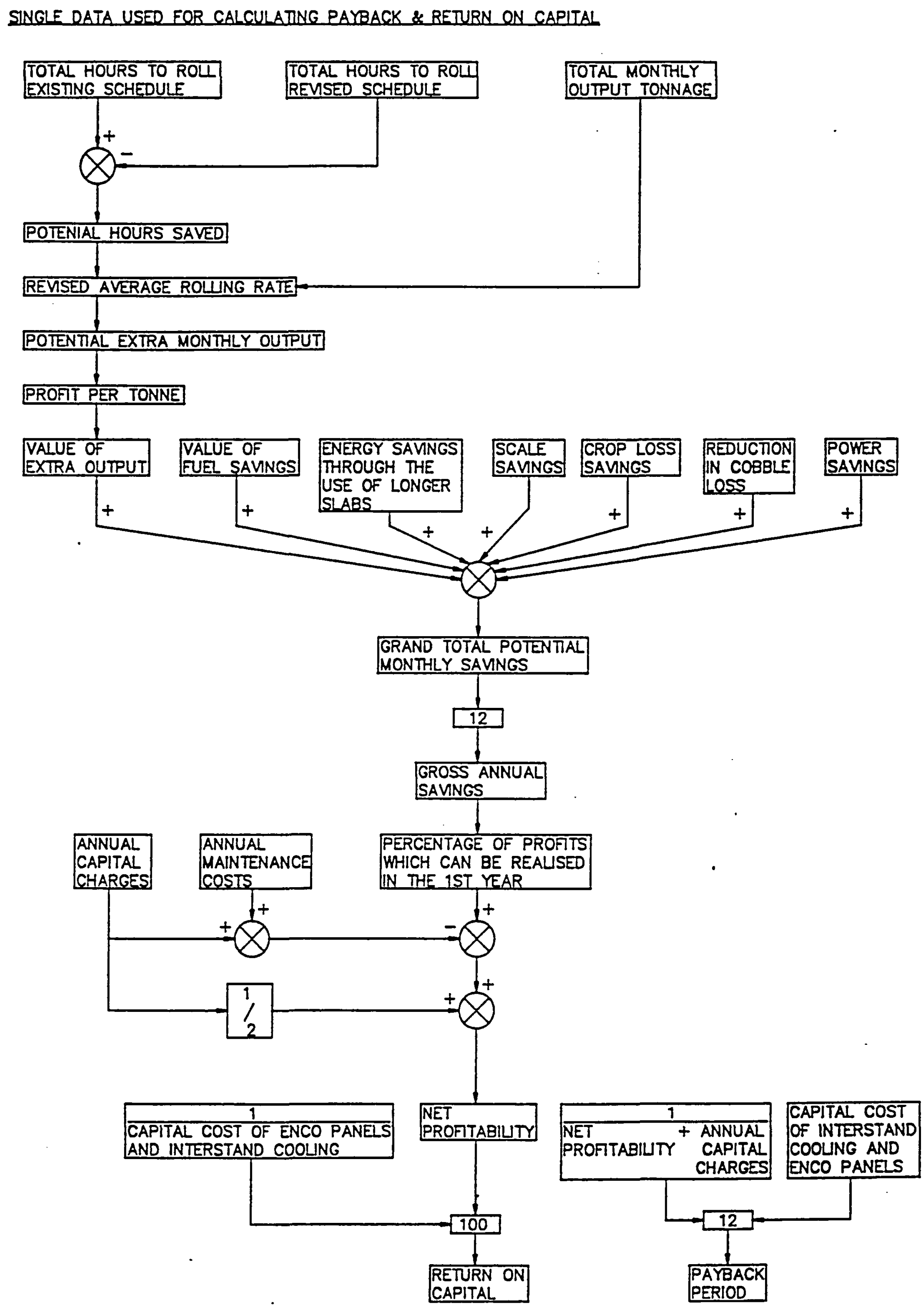

PAGE 2 OF THE CASE ONE FEASIBILITY STUDY:
COMPARISON OF ENTRY TEMPERATURES
EHSM
ENCO2
FACTOR FOR TEMP. SAVINGS AT FURNACE
FUEL SAVING
FUEL SAVED/°C REDUCTION
FUEL COST PER TONNE
ENERGY SAVING THROUGH USING LONGER SLABS
FUEL COST PER TONNE
MARKET MIX
PRODUCT DETAILS
REVISED PRODUCT DETAILS
SCALE SAVINGS
MILL SCALE
SCRAP PRICE
PRIME PRICE
CROP LOSS SAVINGS
CROP LOSS RATE PERCENTAGE
MARKET MIX
ENCO
REDUCTION IN COBBLE LOSS
COBBLE LOSS
MARKET MIX
POWER SAVINGS
MARKET MIX
ENCO
VALUE OF EXTRA OUTPUT
GRAND TOTAL POTENTIAL MONTHLY SAVINGS
· ORIGINAL ENTRY TEMPERATURE
· REVISED ENTRY TEMPERATURE
· TEMPERATURE SAVING
This is required because the technical programs start calculating temperature from the entry into the first roughing stand rather than the exit from the furnace
· FUEL SAVING
· POTENTIAL COST SAVING IN FUEL
· TOTAL FUEL SAVING
· INITIAL SPECIFIC WEIGHT TIMES APPLICABLE TONNAGE
· REVISED SPECIFIC WEIGHT TIMES APPLICABLE TONNAGE
· TOTAL INITIAL SPECIFIC WEIGHT TIMES APPLICABLE TONNAGE
· TOTAL REVISED SPECIFIC WEIGHT TIMES APPLICABLE TONNAGE
· AVERAGE INITIAL SPECIFIC WEIGHT
· AVERAGE REVISED SPECIFIC WEIGHT
· POTENTIAL MONTHLY FUEL SAVING
· TOTAL POTENTIAL SCALE SAVINGS
· WEIGHT RATIO
· BAR RATIO
· YIELD RATIO
· NEW YIELD
· TONNES SAVED
· POTENTIAL CROP LOSS SAVINGS
· POTENTIAL COBBLE LOSS SAVINGS
FLOW1B

Figure 5.2



FLOW1C

Figure 5.3



FLOW2

Figure 5.4

- The number of slabs produced of a particular gauge for the group of materials selected.
- The thread speeds of the each piece of strip when it entered the finishing stands
- The amount of acceleration that occurs in the finishing train once the material has started to be coiled in the coilers.
- The top speed that the strip reaches whilst it is inside the finishers.
- The cycle time of the different sections of mill. This includes the time it takes for the furnace to heat a slab and supply it to the roughers, the total time of the roughing operation and the total time of the finishing operation.
- Slab details, which include the current transfer bar thickness (the thickness of the strip when it has been through the roughers and is just about to enter the finishers) and current specific weights (the weight of strip produced for a given width of product).

The spreadsheets were the final output for the feasibility study; they do not record the thought process the expert went through to create them, in a similar fashion to the way an engineering drawing only records the final design. For this reason it was necessary to identify the stages the expert goes though when doing a feasibility study, this show in figure 5.5. This identifies that the knowledge the expert uses when doing his job can be split into distinct parts

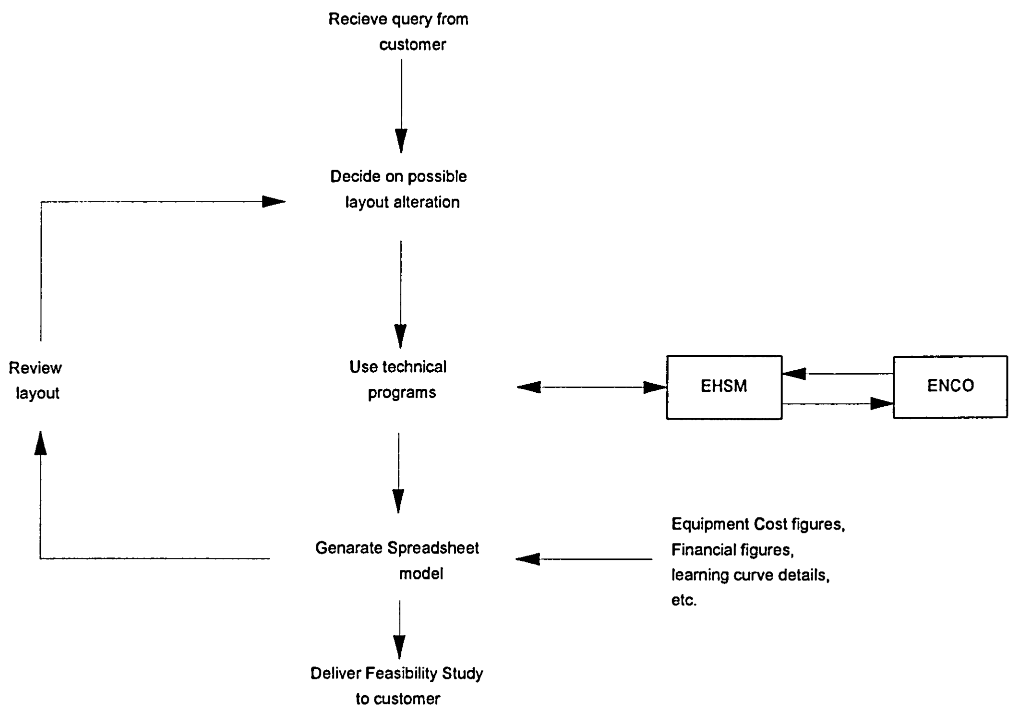


Figure 5.5

- knowledge of how to use the technical programs, for the optimisation of a particular layout. EHSM is used to model how the hot strip mill performs, with ENCO used to simulate heat loss of the strip, with or without Enco Panels, on the transfer table.
- Integration of results of the technical programs into decisions of how to alter the plant.
- Assessment of options for the alteration of a layout.
- Cost and payback implications for the addition of a particular piece of equipment.

5.2.1 Problem Definition

Because each spreadsheet seemed to alter for each study that the expert did it seemed inappropriate to try to form a spreadsheet as part of the result of the system. The spreadsheets, when necessary, also contain a risk assessment of the sources of the capital for building the plant. Steel mills are sometimes able to get capital from governments or international bodies. The reason for assessing the sources is because the modification of a mill can take place over a series of years, during which time a decision might be taken to stop the funding for the mill refurbishment. If this is considered at the planning stage of the work then the refurbishment could be staged to make the best use of the funding. This information would be very difficult if not impossible to represent in a system.

Aside from the production of the spreadsheet it was felt that it would be possible to create a system which did the other aspects of the expert's job, namely to produce different mill layouts. This meant that the system would have to be able to identify what piece of equipment to add to the mill and also to optimise the layout after its addition.

5.2.2 Preliminary Knowledge Elicitation

Because the current work that the expert was doing involved the addition of Enco panels to a mill it seemed appropriate to concentrate on the addition of equipment which perform a similar function. There are two other pieces of equipment which can do a similar job, which are an MStand or a

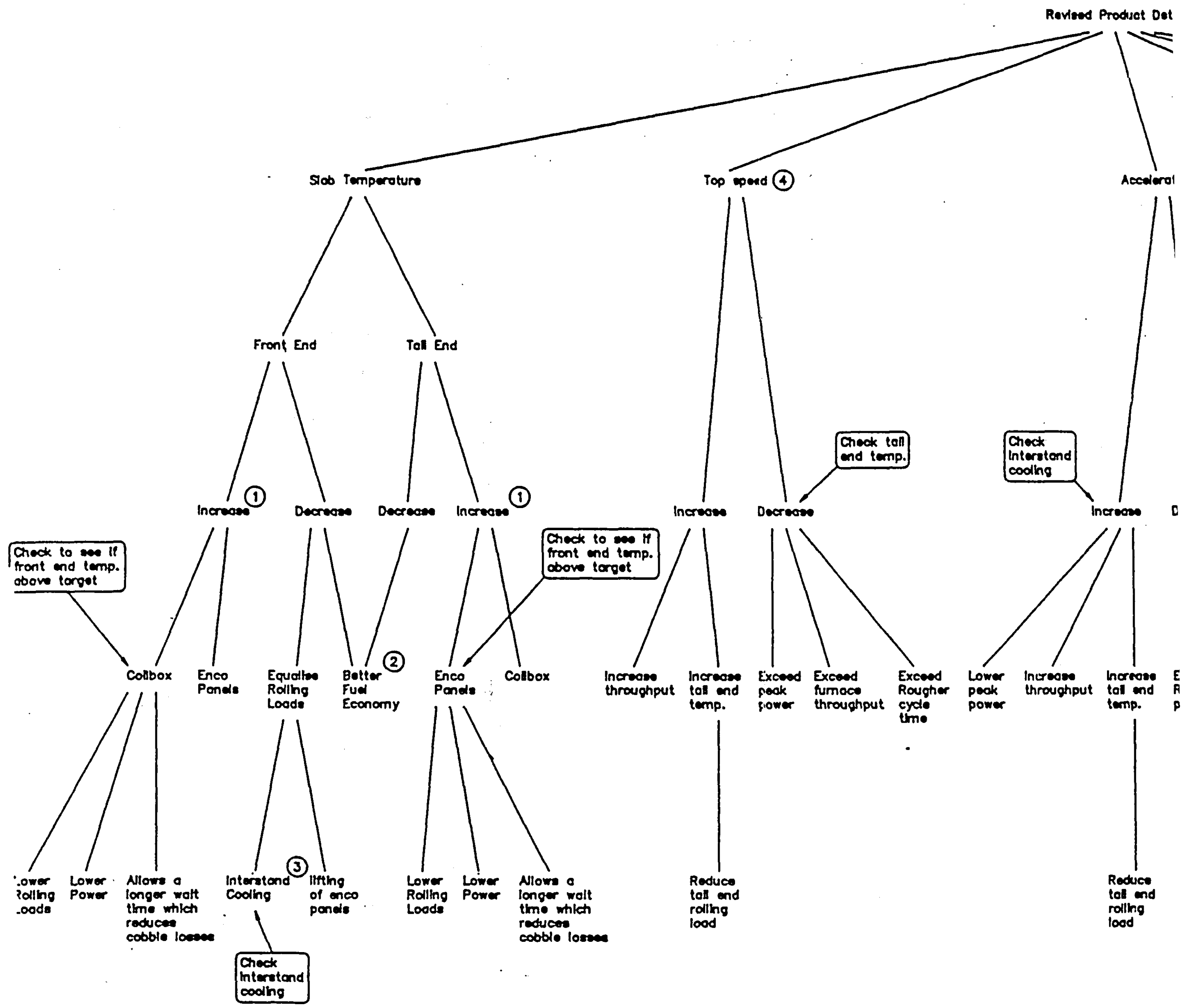
Stelco Coilbox. These pieces of equipment are all used to reduce the amount of heat lost between the roughing and finishing stands, figure 1.1 shows the layout of a Hot Strip Mill. The Enco Panels achieve this using heat retention panels positioned along the length of the transfer table. A Stelco Coilbox coils the strip when it comes out of the roughers and then un-coils it before feeding it into the finishers. This in turn provides the opportunity to produce a transfer bar which is longer than the transfer table between the roughers and finishers. Giving the opportunity to increase the slab length, which increases throughput, when revamping a mill without having to re-site all the equipment after the roughers. An MStand is positioned just before the finishing stands making a 50-55% reduction of the transfer bar (the strip when its between the roughers and the finishers). As a result the transfer bar is shorter and thicker, the reduced surface area of the transfer bar results in reduced heat loss.

The reason for initial focus on the knowledge for these three pieces of equipment was because it gave the opportunity to observe the expert as he did the job, i.e. protocol analysis. This meant that the process the expert went through was recorded, instead of a simplified description given in hindsight months after the event.

This knowledge was acquired in a series of interviews with the expert. The elicitation started with unstructured interviews to help in the process of generating an understanding of the expert's thought processes when doing the job. The initial area looked at was the knowledge required to optimise the layout. The result of this are shown in figure 5.6 which records the initial attempt to record the knowledge the expert uses when optimising a layout. This was shown to the expert to 'teach back' the knowledge which had been elicited.

The problem with this decision tree was that it mixed up different domains of knowledge; i.e. optimisation knowledge with knowledge about which piece of equipment should be added next to the mill, together with a smattering of other knowledge. An example of the mixing of the knowledge can be seen on the extreme left branch which deals with the slab temperature. One of the branches describes that if the front end temperature is increased in conjunction with the use of a Stelco Coilbox then the powers of the finishing stands would be expected to drop. In the same branch, dealing with slab temperature, the tree describes that if the front and tail end temperatures of the slab are reduced this will result in fuel savings at the furnaces. The first example deals with knowledge which will be used to optimise throughput, the second example deals with knowledge which helps to create a financial case for the alterations made to the plant. These examples deal with different parts of the of the experts job, one being the financial case and the other the optimisation of any alterations to the plant. As a result, this decision tree could not form a basis from which the system could be developed. The decision tree needed to be rewritten in a form which segmented the knowledge into focused domains.

DECISION TREE – to determine which of the six control variables should be altered next, in the technical program EHSM.



NOTES

1. The question of available space determines whether to use either Enco or Stelco coilbox. If a stelco coilbox is used on a new mill it will result in the mill being shorter (60m of extra length required for a Enco panel).
2. Optimum if minimum finisher tail exit temperature is achieved.
3. If there is not enough interstand cooling then reduce the breakdown bar thickness.
4. The top speed only needs to be big enough to ensure that it is not the process bottleneck.
5. The acceleration only needs to be big enough to ensure that it is not the process bottleneck.
6. If the strip runs out of interstand cooling at its fastest point then reduce the transfer bar thickness.
7. The slab length can be increased until the maximum furnace output/length is reached.
8. If the temperature of the tail end of the slab is lower than the target then the slab length should be reduced (used as a last resort, try reducing the breakdown bar thickness).

From the initial results of the knowledge gathered it became clear that the strategy that the expert used for adding equipment to the mill depended upon what he was trying to achieve. Namely whether the main purpose of the study was to improve either throughput, quality or yield. This also depended upon the type of strip he was currently investigating. This in turn depends upon what market the strip was being aimed at, each having different requirements for the strip the mill has to produce. For example if the strip had to be sold as tin plate then it was important that the edges of the strip were the same thickness as the centre, i.e. the mill had to reduce the edge drop which is naturally present on the strip. Thin pieces of strip are much more problematic to roll because they lose more heat than thick strip, which results in problems for the tail end of the strip. These problems can result in reduced quality or ultimately cause the tail of the strip to jam, leading to reduced yield. These process problems do not tend to affect the thicker strip. The current 'study aim' will affect the solution chosen to address the particular problem.

Using the study to partition the areas of knowledge works fine for the problem of optimising a layout once a piece of equipment has been selected, but is inappropriate for use in selecting a piece of equipment. The knowledge for selecting a piece of equipment is inter-related. Segmentation would either require knowledge duplication or ignoring it altogether.

Before the knowledge can be translated into a form that can be used by a system it is necessary that the type of knowledge is loosely fitted to the type of systems which could be used. For this reason it was necessary to select a piece of software to build the system.

5.2.3 Approach to optimisation

One clear area of expertise identified was the experts' ability to use the technical programs to generate figures which he used in the spreadsheet. A knowledge of the programs he used and how they were used was obviously necessary. After talking to the expert it became clear that the two main technical programs he relied upon were EHSM and ENCO (see appendix C for input sheets).

An initial layout is run through the technical programs and the results compared to reality. If they differ, the technical programs can be tuned so that the figures generated from the technical programs have good agreement with reality.

The expert used these programs in an iterative fashion, shown in figures 5.8 and 5.9 where he monitored key figures to assess the impact of each change that he made. It is necessary to use the programs which simulate the mill because each time a piece of equipment is added to the mill it alters how the mill works. It is important that the mill operates in a similar fashion to the mill owners' current best practice to ensure that the quality of the metal produced remains constant (or improves if specified). The major factor which affects this is the temperature of the strip when it leaves the finishers. This is important because to get the desired metal properties it is important that the strip is heat treated in the correct fashion.

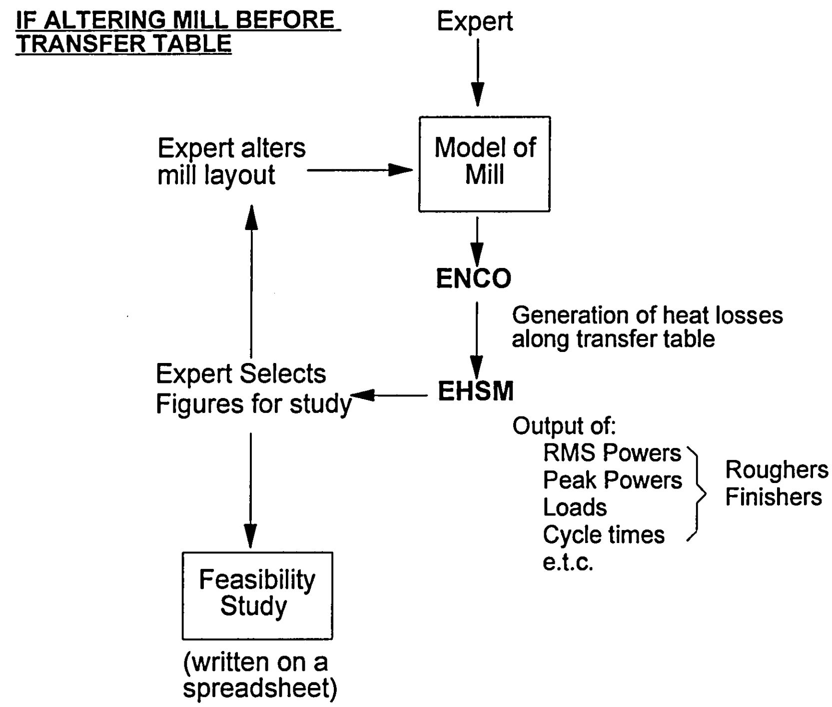


Figure 5.8

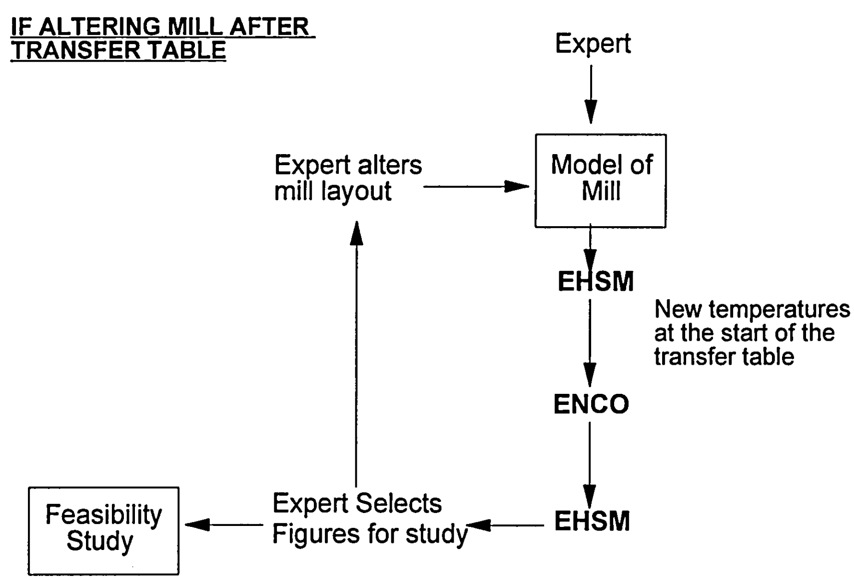


Figure 5.9

The expert has to be aware of how the current mill performs together with details of the types of equipment and performance specifications they have. These are compared with figures that he monitors after each program iteration;

- Equipment performance - Finishing stand motor powers and RMS powers; Roughing stand motor powers and RMS powers. The expert bases his work on the current maximum powers, before alteration, at the motors. This approach allows for wear in the power transmission mechanisms in the mill to be incorporated.
- Current maximum loads - Loads on each of the finishing stands; Loads on each of the roughing stands.
- The temperatures of the metal do not go above certain temperatures which would cause excessive scale build up or affect the properties of the metal being rolled.
- The amount of water used on the interstand curtains, essentially to check that the demand does not exceed the maximum capacity of the system.

To bring the plant's performance in line with its performance before the new piece of equipment was added; the expert uses 6 factors to optimise the layout. These factors are used in conjunction with the EHSM technical program . The 6 factors, referred to as control variables, are:

- Acceleration of the strip in the finishers

- Top speed of the strip in the finishers
- Thread speed of the strip when entering the finishing stands
- Slab temperature entering the roughers
- Transfer bar thickness which is the thickness of the slab when it is transferred from the roughing stands to the finishing stands
- Slab length, which is the length of the slab before it enters the mill

The importance of each of the control variables alters depending on the aim of the optimisation. These optimisation aims were broken down into three different study aims which are increased throughput, increased quality or increased yield. The user selects the desired approach for optimisation before starting the optimisation process.

5.2.4 Automatic optimisation

By knowing the aim of the optimisation and the equipment selected, within the customers financial constraints, each control variables is altered until the outputs of the mill reach a point on a predetermined maximum performance envelope or can not be altered any more. The order of importance of the control variables varies with each piece of equipment which could be added to the mill. The order also changes depending upon the approach of the alteration of the layout. Knowing the order in which to use the control variable is a major part of the optimisation expertise. The expert must also know whether they should be increased or decreased and the magnitude of the alteration.

The order is set-up in descending importance, so that the control variable which can give the most benefit is considered first. This control variable will be used until it reaches a point when any further changes will cause the mill to exceed the performance envelope or the variable itself can not be altered any more.

5.2.5 Plant Assessment

The knowledge incorporated into figure 5.6 had to be re-evaluated to remove any knowledge that was not used to select a way to alter the layout. Knowledge was represented in the form of decision trees, each tree dealing with separate pieces of equipment which affect the mill. Each decision tree had two root decision nodes, i.e. whether the equipment can be used or whether the equipment can't be used.

The knowledge represented in figure 5.6 does not cover everything needed to select which, if any, piece of heat retention equipment to use. As a result further knowledge had to be elicited from the expert. This was done using semi-structured interviews.

As the interview proceeded, notes were made of key points in the interview, which were used to guide the interview as well as being partial sources of the knowledge which form decision trees. The interviews were taped which provided a complete record of all that was discussed throughout the interviews. The notes and diagrams together with the tapes were compiled into a complete transcript of the interviews.

After eliciting the knowledge for the heat retention equipment, the next stage was to sort the transcripts of the information into coherent areas. An example of the headings which were used include;

- Heat retention equipment specific - which holds any knowledge relating to the selection of Enco Panels, Stelco Coilbox or MStand.
- General information which applies to all heat retention equipment.
- Information which must be part of the User Interface.
- Product Mix - knowledge relating to the type of applications the steel is sold for use on.
- Steel qualities.
- Plant layout Information - knowledge relating to selection of any equipment other that heat retention equipment.
- Case information - Any examples used to illustrate why a specific piece of equipment was selected in the conditions being discussed.

These headings were an initial identification of a structure for areas where knowledge fitted. This highlights some of the problems of interpreting the knowledge gathered into a form in which it can be used by the system:

- The difficulty in seeing how the various bits of knowledge fitted together to identify opportunities for the addition of a piece of equipment to a layout.

- The information was still written in an English language format; i.e. reducing the conversation about a given point down into a format which represented the knowledge in enough detail but no more.
- Some of the information is data that the expert uses when assessing the layout. Examples of this are the costs associated with the addition of a piece of equipment, calculation procedures for analysing the cost benefits for the addition of a piece of equipment, etc..
- Some of the information is not applicable for use in assessing how to alter the layout. When the expert justifies any information he often backs it up with an anecdotal reference.

The knowledge was sorted by creating decision trees using sentences from the transcript of the interviews. The sentences were then translated into rules and then entered into the system. Creating the decision trees using the sentences helped in the process of sorting which knowledge could actually be used. The decision tree split the knowledge up using meta-rules, which manage the knowledge needed to select heat retention equipment.

5.3 SOFTWARE SELECTION

The system has to be written to work on a stand alone PC, specifically a 486 PC. This maximises the opportunity for the systems use. The use of more powerful sophisticated machines would immediately limit it's use to a few machines in the company. The choice of PC limits the choice of software to languages e.g. Lisp, shells e.g. Xi Plus, or Toolkits e.g. Kappa Pc. This section describes the types of knowledge and how they could be represented, resulting in the choice of a software package.

The processes which are needed in plant layout design have a mixture of decision making and a requirement to perform technical calculations. The use of a rule based system would have been inappropriate because the system was required to perform technical calculations. These are a stepped sequence of events with a fixed order. To do this the rules have to be forced to work in a procedural manner. This adds to the difficulty of representing the system, because the programmer has to restrict the flexibility of the rules rather than simply using a procedural approach. Consequently the system selected should not be a pure rule based system. However rules are needed to represent the knowledge for selecting what equipment to add to the mill.

More than one representation is needed to cover the different aspects of the expert's job. These need to be split up into coherent and manageable areas. The segmentation of the knowledge simplifies program management during development and in maintenance, if required. Each of these segments can be represented using a frame based approach, for example details about different layouts. By using a framework the details which are associated with each mill layout are stored together.

Segmentation of the problem can also be used for managing the procedures for running the technical programs. This process can be incorporated into a frame based approach by using object oriented programming. Procedures can be written in methods, with objects segmenting the knowledge required to run the various technical programs.

An additional issue touched upon by Dym et al (1991) is that any tool chosen should be flexible in its knowledge representation approach. The knowledge engineer is not committed to only one representation technique for the whole system, which allows different representation approaches for different knowledge processes.

The extracts from independent reviews of Xi Plus (Lydiard, 1989; Brown, 1990), Art-Im (Lydiard) and Kappa-Pc (Lydiard, 1990) were used to construct table 5.1. which highlights the features considered when selecting the E.S. software.

Product	**Features**					
	Rule Capabilities	Handling of procedural calculation	External Links		Multiple representation paradigms	Ease of Interface Generation
			Supplied	'C' Interface		
Xi Plus	Yes	Average	Good	Yes	No	Good
Kappa-Pc	Limited	Good	Good	Yes	Yes	Good
Art-Im	Yes	Good	Good / Difficult in practice	Yes	Yes	Average

Table 5.1

In summary the system needs to incorporate the ability to reason about how to alter the mill, to represent the approach for use of the technical programs, incorporate details about the mill and have the facility to manipulate the technical programs which the expert uses. Both Kappa Pc and Art-Im offer the required facilities, but the ability to link to external programs and perform technical calculations are especially important. As a result the Kappa Pc, with its object oriented strength, was chosen.

5.4 METHOD OF REPRESENTATION

To identify how to alter the mill the expert uses existing data about the mill, facts, together with his knowledge. The knowledge process is similar for different pieces of equipment. This indicates linking patterns which are common to more than one piece of equipment. Pattern matching is one of the fundamental abilities that rules have. The common patterns can be represented, using a structured approach, by using methods, objects and inheritance. However the knowledge used for assessing the layout of the plant is not of a highly structured form.

One of the weakness' of Kappa-Pc is that the rules need pre-specified slots, in an object, to develop new knowledge. This limits the linking ability of the knowledge represented in the system.

The use of an object structure for representing the links of this knowledge would require the system to have a mechanism to manage the links, decide upon the knowledge that should be evaluated next and what knowledge still needs to be evaluated. The inference engine needed to control the firing of the rules inherently deals with this. The question is then, why bother to recreate this using methods? One possible reason would be to increase the speed of response of the system, this is however not an issue at present. The use of the inference engine provides a strong reason for the use of rules when representing knowledge which requires the linking of several conditions. The majority of knowledge which is used for selecting the next piece of equipment uses the linking knowledge, consequently it is represented in rules.

The knowledge which could possibly be needed as part of that for assessing the layout was highlighted in the interview transcripts. This knowledge was then cut up into small sections which could exist as a coherent sentence or group of sentences. It was then a matter of sorting these sentences into a tree-like structure which captures the links between each grouping. This was done by cutting the transcripts into the groups and moving them round to determine the best representation. For example the expert stated that;

> "It is worth saying that both the enco panels and the coilbox can relive the rougher a little bit by being able to roll a breakdown up to 30% bigger. Because of eliminating the heavy tail end rolling loads"

This created rules which related roughers being a bottleneck to either selecting Enco Panels or a Stelco Coilbox.

The two roots of each tree are for representing situations when a piece of equipment can or can't be added to a layout. When the trees, which represent the knowledge acquired to date for the heat retention equipment, were finished they were shown to the expert. This provided a means of validation by 'teaching back' the knowledge to the expert; i.e. where a knowledge obtained in one form is taught back in a different form, to verify the knowledge engineer's understanding.

The decision tree for Enco Panels contained approximately 15 reasons why Enco Panels could possibly be added to a layout. Situations could occur when more than one reason could apply for the addition of Enco Panels. The importance of the reasons differed, but the decision tree did not reflect this.

Similar numbers of reasons why Stelco coilbox or MStand could be added to a layout also exist. If each piece of equipment had a number of reasons why they could be added to the current layout, then the system needs to be able to choose the best piece of equipment to add to the layout. This means that the system needed to have a form of ranking to help limit the number of choices for the system, or expert, to consider.

The method used to rank the rules was a crude set of four meta-rules which were;

- Equipment can be used - Reasons why a piece of equipment could be used, but not imperative reasons.
- Equipment can't be used - This reports any reasons why a piece of equipment can't be used, including a lack of money.
- Equipment should be used - This identifies important reasons why a piece of equipment should be used

- Equipment cost reasons - This checks if there is enough money to use the equipment in question.

This crude ranking was felt to be sufficient to manage the number of possible choices. A wider range of options was not employed because the ranking depends on the current situation.

These rankings were then applied to the decision trees and their new configurations approved by the expert.

The use of the meta-rules on their own usually was not sufficient to identify how the layout should be altered. Having identified that there was a possibility to add a piece of equipment to a plant, one of the most important criterion for selecting which option to choose, was the return that a given piece of equipment could give on the investment necessary for its installation. Some pieces of equipment can not be justified this way, they can only be justified on quality grounds. For this reason it was necessary to obtain any knowledge which was used to justify the addition of a piece of equipment.

5.5 SUMMARY

The expert combines the use of existing technical programs with his knowledge of how to alter a plant to generate feasibility studies, which calculate the benefits of the changes identified. Kappa Pc, an object and rule toolkit, has been chosen to create an expert system to emulate his approach for this task. An object oriented approach is utilised whilst running the technical programs. Rules will handle the knowledge used to select the plant alteration need. The use of meta-rules provides a crude ranking of the importance of each alteration.

6

P.L.D.P. Development

6.1 DEVELOPMENT OF SYSTEM

As outlined in the knowledge elicitation in chapter 5 the first stage of the system development was to represent the knowledge for the three pieces of equipment, each achieving the same results from different means, together with the knowledge needed to optimise a layout. This chapter describes how this knowledge was implemented in Kappa-Pc. The first stage was to integrate the technical programs and then control them so that the current layout could be optimised.

6.1.1 Technical Programs

When the expert is analysing a plant he uses mathematical models which simulate how different aspects of a Hot Strip Mill work. The two main programs which are used both run in DOS;

<u>EHSM</u>

This models the requirements of the mill to roll a specific piece / batch of strip (see appendix C for input forms). The program gives figures for loads, powers and temperatures for key parts of the mill. These figures can be reported to the system in two formats. These are as a file created by the system, in a form specified by the expert, which can be imported into a spreadsheet; or as the screen output redirected to a file.

The system uses both formats to retrieve data from the results. The Lotus format is read into the database which stores scenario data, using array facilities within the database. The file with the screen output is read into Kappa-Pc using its ability to read lines of text from a file. The program looks for a line which locates the results within the file. It then looks for the desired result in a specific position a predetermined number of lines after the locating line.

ENCO

This models the temperature drop between the Roughing stand and the first Finishing stand (see appendix C for input forms). The program is able to calculate the strip's temperature drop when 'Free Air' and 'Enco Panels' are used. The results of the temperature drop can be fed into EHSM allowing the use of Enco Panels to be evaluated. This is done by retrieving the information from the screen output in similar fashion as for EHSM.

It was decided to use the ENCO program to calculate the temperature drop with no heat shields even when Enco Panels were not being used. This means that if only one scenario used Enco Panels, the comparison of different layouts will use the same calculation approach.

The inputs for the technical programs were written to an ASCII formatted file, with values positioned in a form similar to the original program written for a Prime minicomputer based system. The technical programs were written to read these inputs from a file, containing the values which model the mill, before it ran. The name of the file was entered by the user during program execution. This meant that the DOS version of the programs could not be executed remotely in their present form. They were modified by the Davy International (Sheffield) IT department so that the programs ran without asking for a filename by using pre-specified input files.

One of the first stages of creating the automatic optimisation program was to be able to interface the technical programs with Kappa-Pc. This involved creating an object that would be responsible for this task for each technical program. Each object requires slots for the inputs of the technical programs. A method needed to be created to write this information to a file, using a template, to produce the input files to the program.

To run the programs in DOS it was necessary to write a batch file which started the programs in the correct fashion and also displayed a message to inform the user of progress. The batch files were linked to a windows PIF file which allows the programs to run in a windowed format. This provides a better user interface than if the programs had been run in full screen, where the whole screen would change from Windows to DOS and back again.

When the program has been run under the control of the E.S. then the results have to be read back into the system, before the E.S. can proceed any further. Two approaches were needed because some of the results were printed to the screen and other selected results were written to file. The results which were written to file allow the expert to read results he used frequently into the spreadsheet he was using for the current feasibility study.

The results were written in vertical column format which meant that the information would have to be read one line at a time if retrieved by Kappa-Pc. This could be achieved more efficiently with the use of the array facilities which are present in the database program Foxpro. This was chosen because it was the company's standard for PC databases. However the indices which this database produces are not compatible with Kappa-Pc. This does not cause a particular problem because for this application the database will only be required to hold a limited number of records, which are referenced via a unique title (consequently indexing is not needed). Each record holds the results of the corresponding output from the technical programs together with other selected inputs. These are inputs which are not part of the description of the equipment makeup or physical layout of the plan, for example the slab temperature leaving the furnace.

The plant description and equipment makeup are handled by the class 'PlantLayout'. The original description of the layout of the plant is stored in the class 'ControlScenario'. All other scenarios exist as instances beneath this class. The instances can then be modified as the expert explores the advantages and disadvantages of different approaches to altering the plant layout. Each of these different approaches or scenarios, will be evaluated using the technical programs and their results stored in the Foxpro database, see figure 6.1. The 'PlantLayout' object uses the title of the scenario, in the database, to link the layout knowledge with the performance data generated.

The use of a database means that the data for more than one scenario can be stored and retrieved as needed (This process is described in Appendix D). This minimises the number of instances that have to be used for storing data produced from the technical programs. The E.S. renames the old record and marks it for deletion for each technical program iteration. After the current layout has been optimised all marked records are deleted, ensuring the database only has one record per scenario. A separate database records the details of how the water curtains are used for each scenario, and is updated in parallel to the main scenario database.

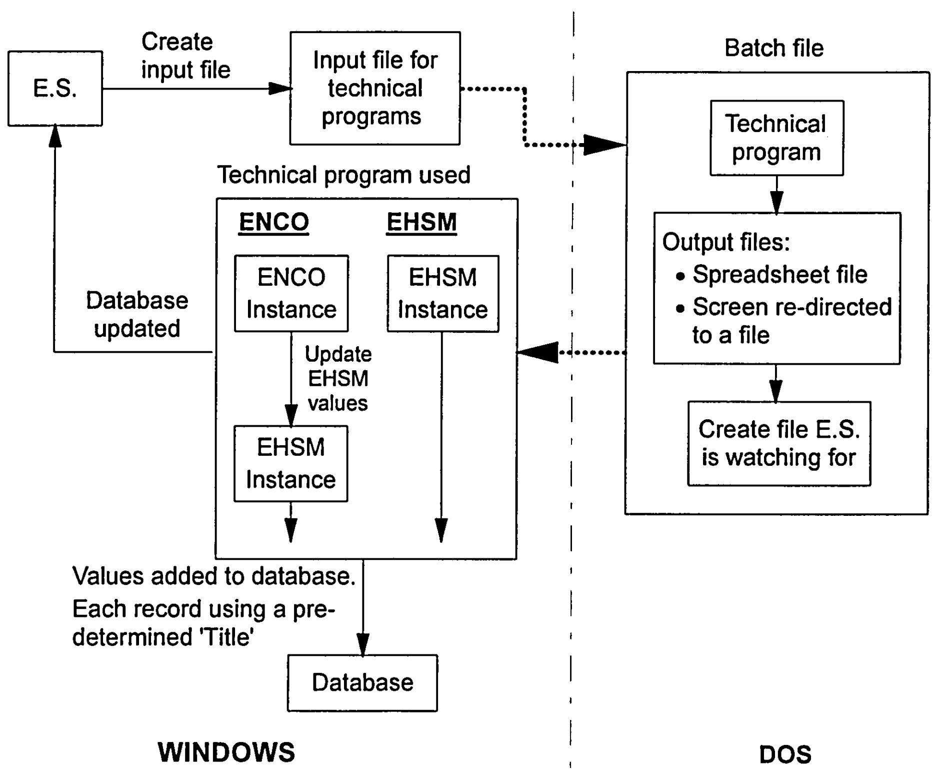


Figure 6.1

An example of the comparisons the expert might make is comparing a Stelco coilbox and Enco Panels which perform similar functions but each require the mill to work in a different fashion. The expert may need to present cases for both possibilities to the customer and allow the customer to decide which approach to take. For this reason it is necessary for the system to be able to evaluate more than one scheme. The other reason is that for each scheme the layout has to be evaluated for different strip dimensions selected to represent the product / market mix for the mill.

The data stored in the database can be retrieved using a facility in Kappa-Pc which is able to read a row of data into a specified object; this object can also co-ordinate the functions for running a technical program.

The approach needed for obtaining the rest of the information is to retrieve the data which is reported to the screen. The screen output is re-directed to a file which is then interrogated by the system to obtain specific values. Routines have been written which uniquely identify the positions of the data desired in the file and then retrieve the data from those lines. The file is searched from the beginning each time for the data, once the data has been retrieved the file is then closed. By opening and closing the file each time a piece of data is needed it ensures that the data in question can be found. If the file was only opened once then the program would need to know the order in which the variable occurred in the file. This would cause a problem each time it was necessary to add to the list of variables the program had to retrieve.

This data is stored in a slot in the instance which deals with the technical program which is currently being used. It is then updated by writing to the relevant scenario row of the database.

Because Kappa-Pc is run in Windows and the technical programs run in DOS the interface between them caused complications. Windows multitasking means that once Kappa-PC has started to run the technical programs it carries on with its program execution without waiting for the technical program to finish. The results of the technical programs are needed before the next step of the Kappa-Pc should execute. To ensures that this happened, it meant a way had to be found which would disable windows multi-tasking whilst running the technical programs.

The way this was achieved was by running the technical programs through the use of batch files. The last command in the batch file was to create a dummy file which acted as a flag, see figure 6.1. A loop was written within Kappa-Pc which stalled further execution until this file existed (which is then immediately deleted).

EHSM has to be run before the ENCO program because two of its inputs are the temperature of the head, and the tail temperatures of the strip at the exit of the roughing stands. These are fed into the ENCO program input file together with detailed information about the slab details. The results of this program are the temperatures of the strip, in one metre intervals when they reach the end of the transfer table, for heat loss in free air or with Enco panels. Depending on the current layout either the results for free air or the Enco Panels are needed. The system then reads the temperature of the strip at specific points which are used in the EHSM program to model what happens to the strip in the finishing mill [1].

Each time the technical program EHSM is run the outputs need to be checked to see that the program run was complete. The inputs given to the technical program will sometimes cause a problem for the technical program at which point it will crash giving an error message. The system needs to know that the technical program has crashed because otherwise it will hang when it tries to read some results which have not been generated or when it reads incorrect results (e.g. zero values). Whenever the system receives results from external programs, the system should be able to work out if the external program has not worked properly, to ensure that no incorrect information is read into the system. This ensures that any failure to another program does not result in the system becoming unstable. Both of these problems are handled by checking the program has run satisfactorily by looking for the text "MILL OUTPUT AT 100% UTILISATION", which is one of the last lines in the file which contains the screen output.

[1] The system was written to link these two programs, however after the writing of this part of the system the company IT department wrote a new version which integrated these programs. This was never used in the system because the system version worked in a satisfactory fashion. Incorporating the new program would have been possible as demonstrated by the programs already integrated into the system.

6.1.2 Optimisation of a given Layout

The optimisation should be able to be started in two ways

- User controlled - This means that the programs can still be executed in the current manual fashion with the user making the desired changes. This is necessary because the user may need to do something new to overcome a specific problem.
- Automatic optimisation which occurs after the user has a piece of equipment to add to the plant. When a particular layout is optimised it is done using the six control variables, depending on the approach for plant optimisation (See Appendix D for diagrams which describe this process).

The user specified approach for running the program is to ensure that a specialised problem could still be modelled on the system; for instance the system knowledge currently only models how to alter the mill when using mild steel, not for stainless steel or silicon steels. These are sometimes a large part of a product mix so any layout modification could not be justified without taking them into account. However on the majority of the mills that the expert assesses for improvement, mild steel provides 80-85 % of the total product mix, the rest of the material being effectively ignored when analysing the mill.

The order of the control variables is stored in a 'list', a multiple valued slot, inside the object 'optimise'. This provides the class definition for how to alter each piece of equipment. An instance call 'Add' followed by the equipment name exists for each piece of equipment, e.g. AddEncoPanels, that can be added to the layout. For each study aim (throughput, quality or yield) there is a list in the 'optimise' object which represents the order in which the control variables should be used. The use of inheritance ensures that these are the default orderings unless they are over-written at instance level.

An example of a default ordering would be for the study aim of increasing throughput, written in descending order of importance.

- Acceleration (increase)
- Top Speed (increase)
- Thread Speed (increase)
- Transfer bar thickness (decrease)
- Slab Length (decrease)
- Slab Temperature (decrease)

An example where the default ordering is changed is for adding roughing stands to the layout, where the effect of increasing the transfer bar thickness (top priority) allows the roughers to do less work, consequently increasing throughput.

Using a list is sufficient to cope with most optimisations however it is sometimes necessary to alter the sequence. For instance, with Enco Panels when the approach is to increase throughput for increased slab temperature, after each slab temperature alteration the top speed should be optimised.

This process is implemented using rules, to ensure there is the flexibility to represent a more complex approach. At present the facility is used for one exception, possibly this did not require the flexibility of the rules.

Each control variable has a method associated with it in the 'translation' class which determines the size of the step for increasing the variable. These methods are also responsible for determining when the variable has reached the limit for its alteration.

Whenever the value of the slab length or the transfer bar thickness is changed this automatically affects the value of the transfer bar length. The system is written so that as soon as one of these values changes then the transfer bar length is automatically updated. The affect of changing the width, height or length, for a constant slab volume is currently handled by the expert.

6.1.3 Representation of the basic knowledge description for equipment

This is done by defining the basic elements needed by each piece of equipment in the 'PlantEquipment' object. It also contains the method which is used each time to clear slots used by the rule system. Any slot which is not to be cleared has its name stored in a list in each object, referred to during the clearing process. An example of this are the facts used to calculate the financial benefits for adding each piece of equipment.

The menu for getting the cost information, needed to calculate financial benefits, is automatically created each time the system is started. This ensures that the menu will contain any future equipment objects. The menu uses the same session window to get the cost information for any piece of equipment, the object associated with the image is changed to suit.

6.1.4 User interface

This can form a significant part of an Expert Systems development, e.g. in the Dipmeter Advisor it formed 42% of its lines of code (Dym et al, 1991). Expert systems need to more than a black box which outputs answers, they need to justify their choices. As a result the interface should be intuitive to the user, together with being forgiving any mistakes they make (Microsoft Corporation, 1992). This next section describes how the interface was created for the Plant Layout Design System.

When the user enters information to specify the initial conditions of the mill this is done through a series of input windows. These are accessed through named buttons, shown in figure 6.2 which shows the User Interface before the mill details have been entered. Each button shown on the screen represents a group of associated information needed to describe the mill, mainly needed for the technical programs.

The data entered in the User Interface, via Edit images, is stored in the relevant object and slot pair. For instance, the information for the technical programs is stored in the EHSM instance and saved as a database record.

This is satisfactory if all the values modified for each scenario were stored in a database, which could update the object whenever the user wished to view a different scenario. Some of the information about the scenarios is stored in different objects. This information describes the layout of the mill, equipment present, roll diameters and motor powers. The object called 'ControlSenario' records the initial details of the layout. These are inherited to instances which record the changes to the layout for each scenario. Each time the user changes a scenario the interface needs to update which of the layout objects they are using. To do this a class of image objects were created, e.g. PLEdit. These objects contain the interface tools for editing the scenario data. The object which holds the current scenario data was declared at class level rather than individually defined for each instance. These images then have to update their links to get the object and slot pairs current values. This is handled easily by resetting the links for the instances in this class.

This process is handled by the class 'Display' using the instance PLDisplay. As soon as the scenario is changed the value of slot in this instance, containing the name of the object which represents the new scenario, is updated. By changing the value of this slot, a method fires automatically to update all the links for the edit images, which alter with the change of scenario. This looks at an internal list which contains the names of the 'Edit' classes. The name of the object scenario is altered at the class level for each 'Edit' class which in turn updates its instances.

Initially the buttons are white to signify that no information has been entered in this area. The buttons change colour when the input window has been accessed. This was set-up to try to create a visual way of highlighting the completeness of the information input, without looking at the input screen. If there was a way of identifying the minimum information needed for each section, then their colour would only change when it was present. This has not been done because the amount of information needed by the technical programs varies with the layout, making it a complex problem with limited benefits.

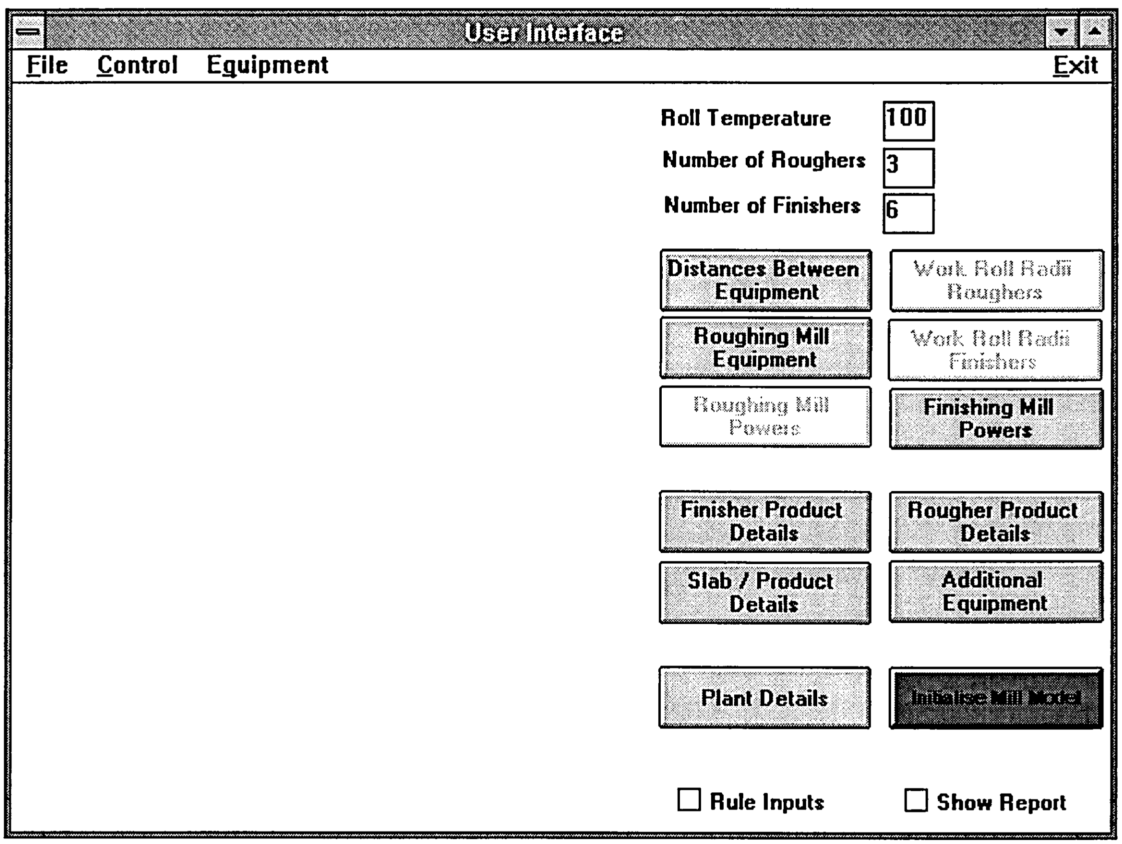


Figure 6.2

Once all of the information needed has been entered the user then initialises the Mill Model. This will only be successful, when EHSM runs without crashing, when all of the information required by the technical programs has been correctly entered. When using external programs there are two ways to ensuring the data received is complete. This is to ensure the input is correct, which requires an intimate knowledge of the system, or by checking that the output received is okay. The system assumes the person using this system will ensure that all of the inputs needed are present before they initialise the mill or optimise a layout. The results are checked before retrieval by Kappa-Pc (see section 6.1.1). If the technical programs have run correctly then the mill model is initialised. The User Interface is then altered to allow the user to experiment with the mill layout. Figure 6.3 shows the interface after the mill model has been initialised.

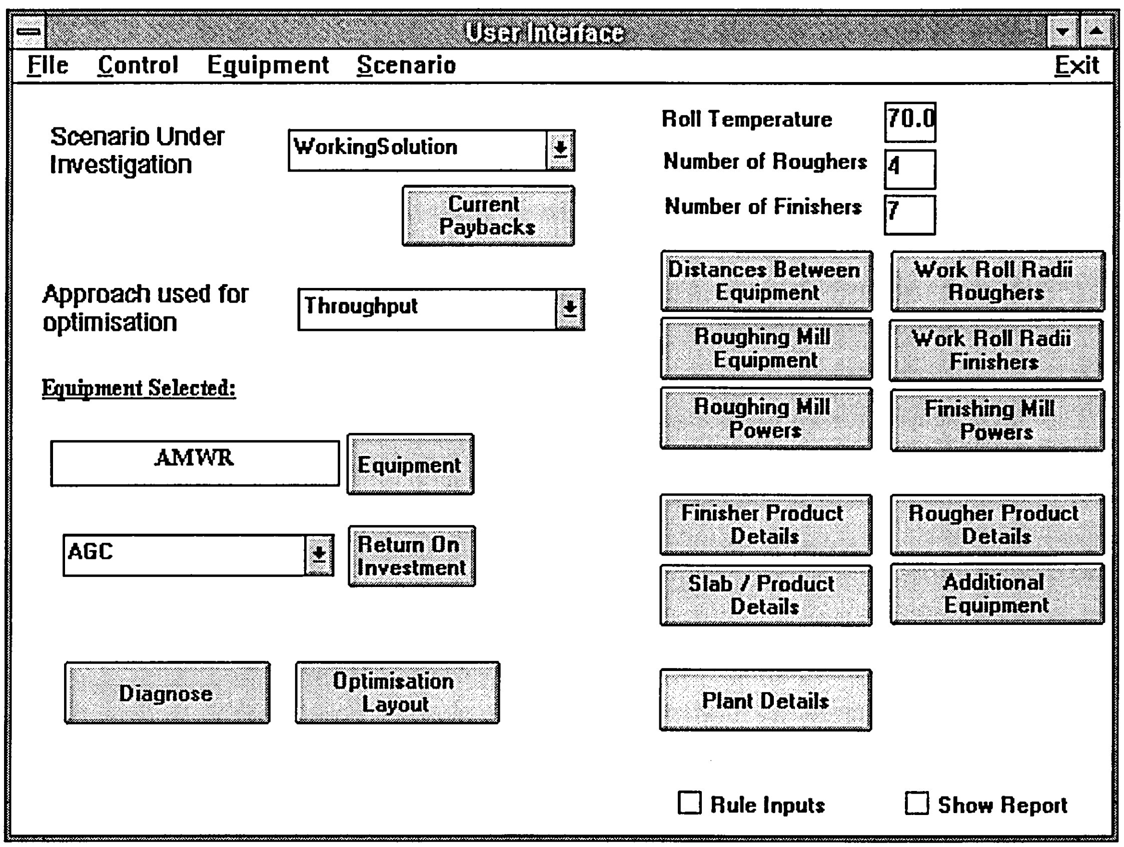


Figure 6.3

A report is constructed as equipment is added to the current scenario, which can be displayed each time a piece of equipment is added, by checking the show report box. The report list all equipment added to the mill, together with the financial benefits which it offers.

After the mill model has been initialised there are other inputs which describe aspects which can change how the mill is altered. These are essentially inputs for parts of mill knowledge which are represented using rules.

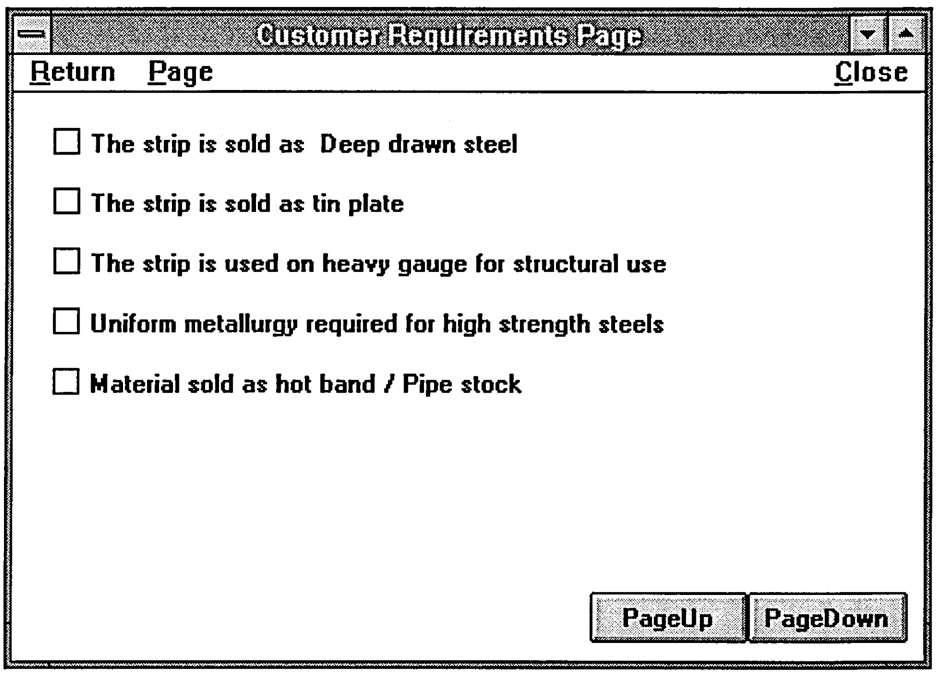


Figure 6.4

Some of the inputs into the rules are by the checking of points listed on pages of special input windows (Figure 6.4). The pages created include "Mill Problems", "Customer Requirements" and "Mill Details / Aims".

The user is prompted for these questions each time the rules are fired. Figure 6.5 shows that when the user presses the diagnose button they are prompted with a menu asking either for additional information or to fire the rules. The use of the menu ensures that the user is prompted in a gentle fashion each time the rules are fired so that they consider entries for the "additional information" window. Many of these questions will only need consideration when initially describing the mill layout.

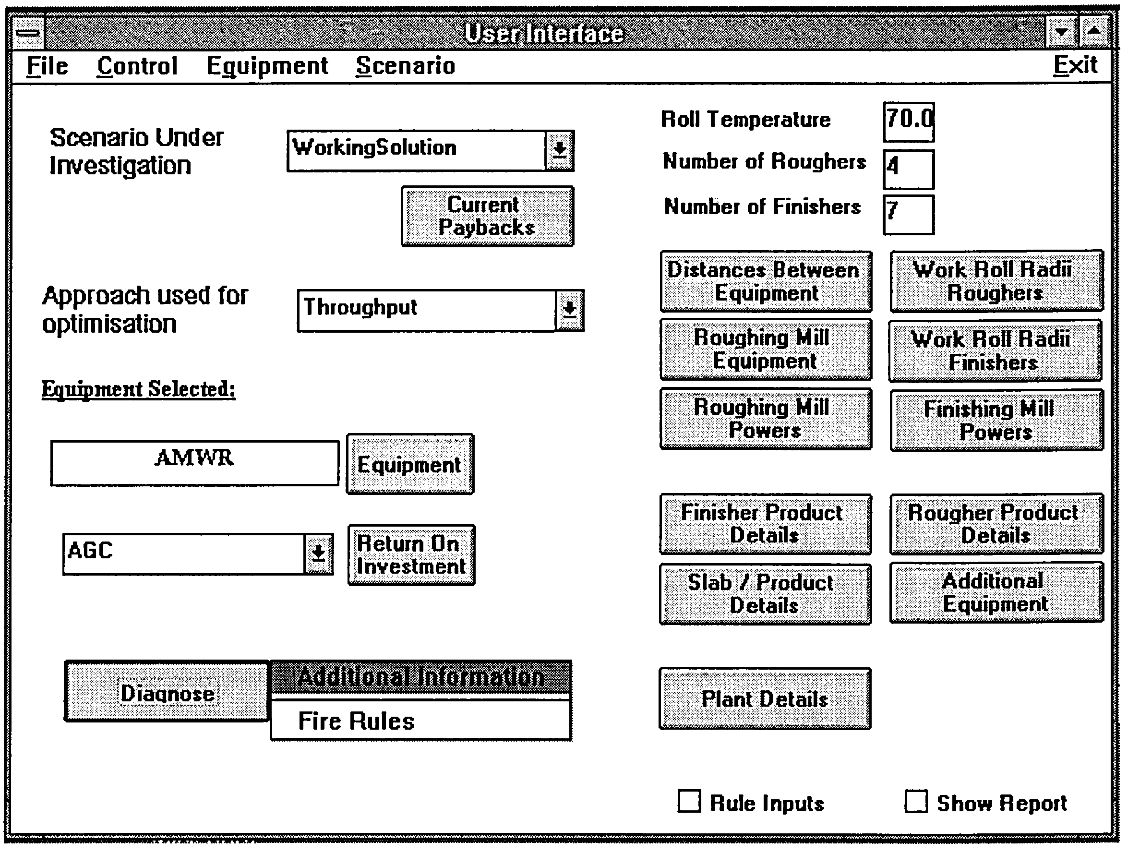


Figure 6.5

Initially routines were written to translate the TRUE / FALSE values generated by the CheckBox into the values used by the rules. The later rules were constructed to use the syntax of the CheckBox.

6.1.5 Integration of optimisation programs with technical programs

The 'Translation' class translates the aim of the optimisation into numeric value change. It changes the textual requirements to increase slab length to a value entered into the technical program. These changes are then relayed to the appropriate technical programs which are used to model the changes. At present this class is only used as an intermediate to the EHSM program. The class has been laid out so appropriate translation procedures can be incorporated for other programs if necessary. This is implemented at present by ensuring any change of the control variable is done via the top level object in the Translation class. This change would then be inherited to any sub-class which needed the information. The process of updating the technical programs is then done by informing the 'Translation' object which control variable should be altered, this name corresponds to a method name which effects the appropriate change.

The object which does the translation between the optimisation object and the technical programs is the instance 'Intermediate'. This instance representation and behaviour is defined in the class 'EHSMLink'. This approach separates the implementation, 'Intermediate', from the functional, 'EHSMLink', which helps during development / maintenance. This ensures that it is clear which slot values have a purpose for the implementation and which are generated during the programs run. The class also deals with the translation of the numeric results into semantic descriptions, e.g. that the finishers peak power has been exceeded. These are communicated to the optimisation class.

As part of the implementation it has been necessary to incorporate limits for plant operation in 'EHSMLink'. These are the boundaries of the plant's performance, used to check whether a change is possible. The limits incorporated are maximum slab temperature, maximum furnace temperature, minimum thread speed and maximum thread speed. They represent values that the expert uses based on his experience. For example the maximum slab temperature is limited by metallurgical properties of the metal being rolled.

This class has access to the internal data contained in EHSM, i.e. inputs and results for the technical programs. The data obtained is used to monitor the value for the finishers peak power, RMS power, tail end loads and the peak power in roughers.

For Peak & R.M.S. motor powers this is done by comparing the name plate power of a motor, multiplied by a factor, against the current power the motor requires. The factor is determined by analysing how the mill currently runs their motors in relation to their name plate powers. These values can be altered by the user if needed.

In the object 'EHSMLink' there are the methods which evaluate whether the plant performance envelope has been exceeded. Some of the methods monitor the changes the optimisation class makes to the control variables. Others monitor the results produced as the result of any changes.

If any of these methods detects that the performance envelope has been exceeded their corresponding slots are updated in the optimisation class. These are used to assess the point at which the layout is optimised.

6.1.6 Integration of the results of the technical programs with the rules

When the system is optimising a layout it has to monitor for key values. Some of these affect the way the mill layout could be altered. At present these values are:

- Peak power in the finishers
- The acceleration rate of the strip in the finishers
- The thread speed of the strip into the finishers

These values link into the rule system though a method called 'LinkToRules', through slots in the optimise class which then update corresponding slots in the RunRulesLink object. The slots in the RunRulesLink object are then asserted by the method 'Assert', each time the knowledge base is fired.

Each time the optimisation routines are run the values of these slots are reset. This ensures that the key values only reflect what has happened during the last optimisation run, i.e. they only apply to the current layout.

6.2 EXPLANATION SYSTEM

Figure 6.6 outlines the stages of the process used to generate an explanation Appendix D gives more detail about the objects involved in this process, together with details of the diagramming convention used below.

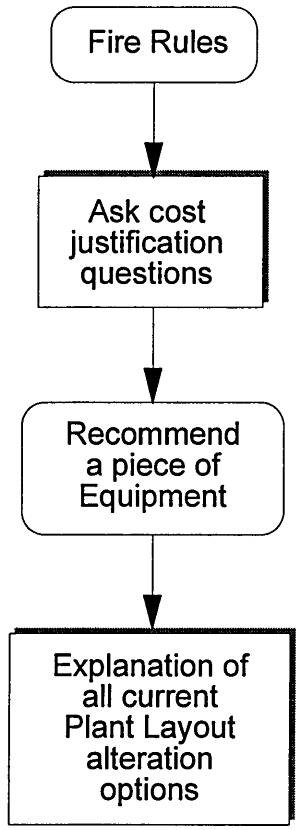


Figure 6.6

6.2.1 Firing the Knowledge Base

To analyse the plant the user presses the button 'Diagnose' and selects 'FireRules' on the main Session window called 'User Interface'. This function which fulfils the following task

- Posts the window which gives the explanation.

- Clears the fact base. Kappa-Pc structures rules and facts by associating them with slots inside a object. This means that slots used internally during inferencing need to be reset each time the knowledge base fires. To write the system so that it only clears the slots used internally would make the system difficult to maintain and will increase the complexity of the use of rules. To reset only the internal facts requires the system to know what fact have just been used internally, which is difficult. For this reason the fact base is totally reset each time the knowledge base is fired. This means that initial values have to be added to the fact base and asserted before each knowledge base firing (see Figure 6.7). The slots used to represent the fact base are written in objects and instances which are part of the PlantEquipment class. Not all of the slots in this class are used in the fact base. These slots are not reset with each inferencing.

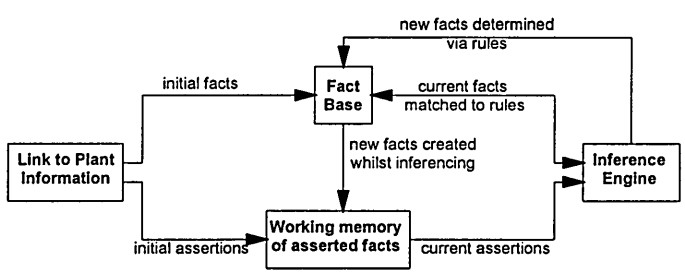


Figure 6.7

- RunRuleLists instance is initialised. This instance is used to generate explanations, discussed in section 6.2.5.
- The value of equipment selected is updated in the 'User Interface' window.

- A message is sent to the object RunRulesLink to fire the method 'Assert'. This provides the link to plant information.
- The explanation system generates an explanation from the results of the rules fired. This is done by sending a message to RunRuleLists to fire the method 'Explain'.

6.2.2 Integration of the rules

Each time the rule base is fired it is necessary to update the slots used in the rules which are contained in the PlantEquipment class. Slots in this class act as a factbase, these are asserted along with slots contained in the 'AssertedRulesLink' class. The slots in the 'AssertedRulesLink' class are stored in a list called 'SelfAssertList'. The instance 'RunRulesLink' controls this process. The other instances in the 'AssertedRulesLink' class exist to store the inputs to rules which require the users' input.

The reason for the use of forward chaining is so that the system identifies all possible alterations and then recommends the equipment which offers the best return on the money invested. If backward chaining were used then the system would only identify one possible solution. For the system to specify a solution it might have to compare more than one possible equipment option, but is unlikely to identify them all.

Because the user of the system controls the specification of what equipment to add to the mill, it is better for the system to inform them of all possible solutions.

Some of the user inputs to the factbase do not come directly from the interface, these are rules associated with checking money and time requirements. The last action of the method 'Assert' is to send a message to each piece of equipment in the PlantEquipment class asking them to check their cost and time links.

For each piece of equipment which can be added to the mill, represented as an object in PlantEquipment class, there exist two slots which enable / disable the use of cost or time links. These are altered by the user with the 'Equipment' menu on the main interface window (see figure 6.3). This menu allows the user to select the equipment and then choose to enable / disable the cost and / or time links, using a check box. Information about the various costs and times from the piece of equipment then need to be entered. If values are not entered then the system informs the user and disables the appropriate link.

The values for costs / times (details which can be modified by the user) used in the links are stored at the equipment level. These are then compared with the values of total money / time allowed for the layout alteration. This is done with the use of methods which either set the value of the 'MoneyAvailable' / 'TimeAvailable' slot to Excessive or NotExcessive.

6.2.3 Creating Explanations

Explanations can be generated in other systems using the text of the rules, e.g. Xi Plus. Explaining the reasons for a choice using the rules, makes the explanations harder to understand. With Xi Plus the system uses the rules to explain **Why** a question is being asked. Because Xi Plus can be written using English type rules this makes it relatively easy for the user to follow why a question is being asked.

The Kappa-Pc inference browser provides a clear diagrammatic explanation of how the rules have fired. As the volume of rules fired increases it becomes more difficult to determine which pieces of knowledge are important in the present situation. Kappa-Pc requires a name for each rule. These are used in the inference browser to inform the user which rules have been fired. The browser can be used to access the rules themselves. These however have to be written using objects and slots which make the rules confusing to a lay person. Figure 6.8 shows the a typical window used for editing a rule.

Rule tracing is provided as part of the system, and is controlled by the system. This does not allow the programmer the scope to control the use of the explanations. Because of this it was necessary to create a custom explanation system, which uses the rules comment text.

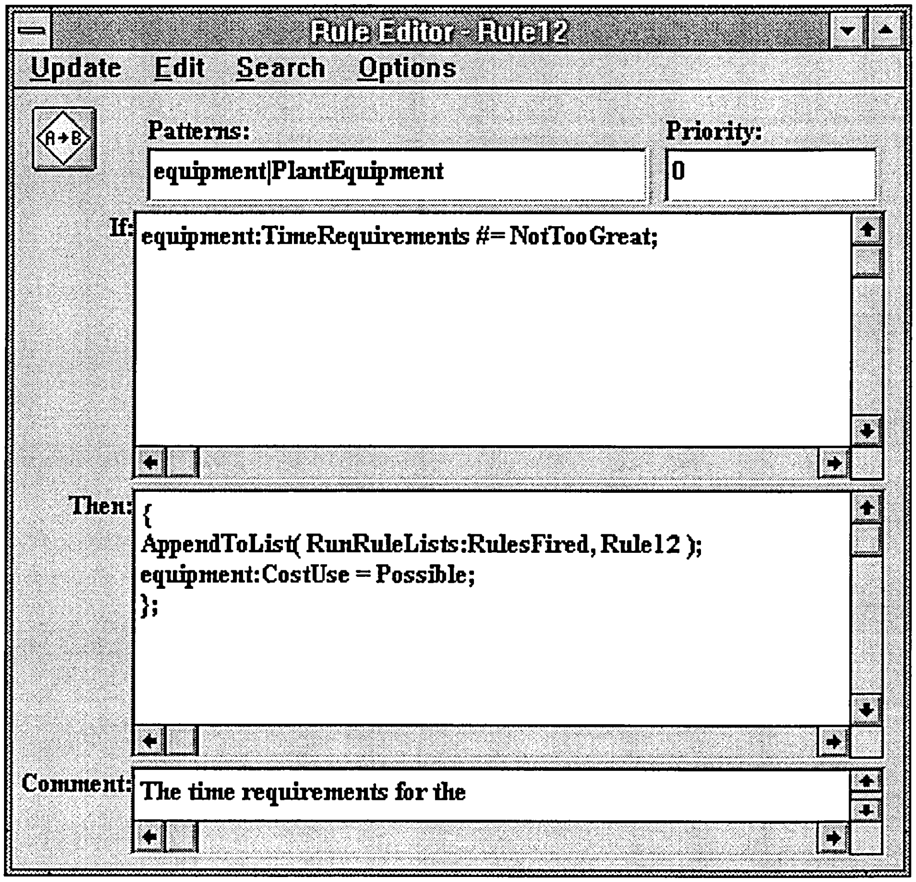


Figure 6.8

6.2.4 Integration of the knowledge base to the user / system

- links to results gained from the optimisation routines
- links to approach (throughput, quality or yield)
- links to additional information and questions (essentially 3 pages of check lists)
- links to equipment costs

Because the system uses forward chaining when using its rules this means that the system must assert key facts to the knowledge base to start the process off. Key facts are mainly those which can not be determined elsewhere by firing the knowledge base; at present they are not referenced elsewhere, but there is no reason for them not to be specified by other rules. This is handled by the method Assert.

The sources for the facts come from inputs from the users or are determined as a result of running the optimisation routines.

As part of the input from the user the system has to consider whether there is enough time and money available for a given layout to be viable (discussed in section 6.2.11). This is handled by sending a message to each piece of equipment which could be added to the plant, asking it to evaluate time and cost implications . Each piece of equipment has information stored which details its capital cost, foundation cost, shutdown time and foundation time. These are compared against the total time and money allowed for altering the plant (discussed in section 6.2.11). If the time or costs of a piece of plant are to be considered the results of the comparisons are asserted to the knowledge base.

The input from the user comes mainly from three windows, grouped into rough topic areas, as discussed from section 6.1.4. The other input from the user is though the selection of an approach for use when optimising a particular layout. Altering this causes different groups of rules to be fired.

The rule inputs which are generated as a result of optimising a particular layout alteration, are values which are updated each time the optimisation routines are run. When running the optimisation routines, discussed in section 6.1.5, the system monitors key values generated by the technical program. One of these key values is the acceleration of the strip in the finishing mill. If during the optimisation this is maximised then a message is sent to the optimise object. This then updates slots in RunRulesLink object (see section 6.1.6). This object is the object which deals with the assertion of new facts to the knowledge base.

The instance intermediate is used as part of the optimisation to control the increase of the 'control variables' (see section 6.1.5 for more details), e.g. the acceleration of the strip in the finishing mill. When the control variable in question can not be increased anymore , the slot containing it's value is changed to 'Exceeded' . When this slot is changed this causes a method to be fired which results in a change to a slot in the RunRulesLink object. This slot is referenced in the list 'SelfAssertList'.

As part of the preparation for analysing a particular plant layout the method 'Assert' is fired. This method checks the value of the slots referenced in the list 'SelfAssertList'. If there is value in any of these slots then the slot is asserted as a new fact. This method handles all of the jobs needed to assert all new facts to knowledge base.

These facts must be asserted each time the knowledge base is fired; forward chaining does not finish till it has explored all new facts. The results of this is that the system needs a mechanism for asserting relevant facts for each firing.

6.2.5 Knowing the order in which the rules fired

As the rules are fired new facts are added to the working memory, some of which are evaluated straight away and some of which are evaluated later. This depends on the inference engine control strategy being used (discussed in section 6.2.7). Knowing this and the order in which the rules are fired, it is possible to understand the steps taken to arrive at the knowledge base's conclusions. Consequently for the explanation system to function it is necessary to know the order in which the rules fired. This was achieved by adding an 'AppendToList' function in the Then portion of all the rules. This function adds the name of the current rule to the RulesFired list in the RunRuleLists object (See Figure 6.9).

This is not an ideal way of creating rules because it means that the rules contain code which is not directly needed for the rule to function. It has been assumed that only a knowledge engineer will have access to the rules at this level. If it were to be decided at a later date that the general users should have access to the rules a custom interface could be written which disguises this problem. Editing the rules must be done with care to ensure none of the present knowledge is lost by the inadvertent loss of a link to other rules

6.2.6 Creating a way of knowing that the rules had reached a specified goal

To be able to breakdown the list of rules fired into branches of possible equipment options it is necessary to know when the end of branch is reached. This is achieved by forward chaining to a goal so that the last rule is known, which will always be called 'Goal'. This allows the system to prune branches which are not attached to the decision tree representing the current plant layout being reviewed. In the decision tree shown below $Rule_{n+1}$, $Rule_{n+2}$ and $Rule_X$ are the rules fired from the facts (slots) asserted. Only branches which are attached to the root GOAL are options which can be applied to the current situation. Updating the related rules class takes between 5 - 10 minutes, depending on the type of computer used.

The rule which provides the root of the current tree is shown in figure 6.9.

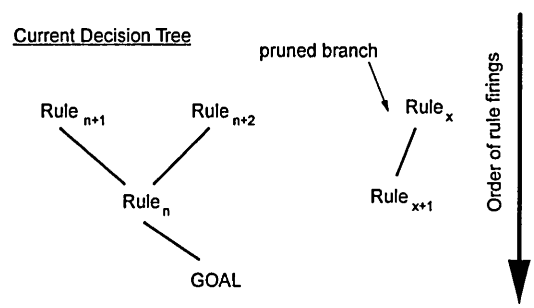


Figure 6.9

Figure 6.10 shows the rule 'Goal' used as a root for the current decision tree.

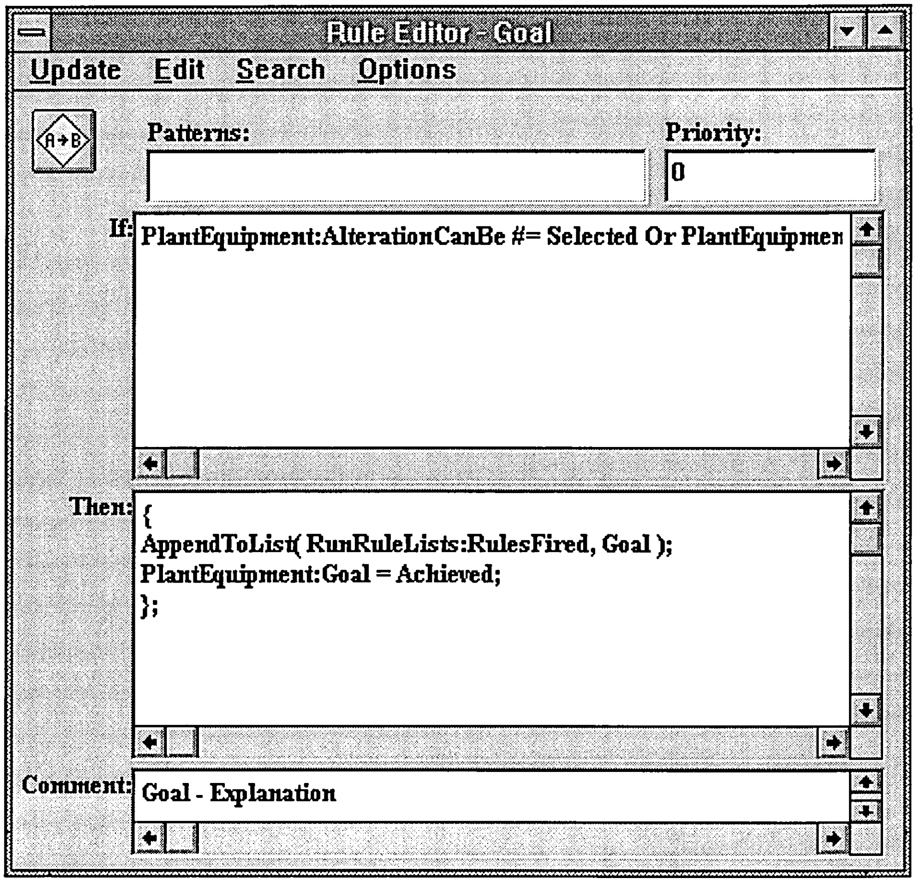


Figure 6.10

6.2.7 Understanding the exact way in which the rules fired

Kappa-Pc has four different modes of Forward Chaining SELECTIVE, DEPTHFIRST, BREADTHFIRST and BESTFIRST. Each mode has different approaches for deciding which rules they evaluate next, explained below:

- SELECTIVE adds newly identified rules to the agenda according to priority. Without knowing this priority it makes it very difficult to determine which rules each rule identified.
- DEPTHFIRST evaluates each new assertion fully, i.e. an exhaustive strategy before backtracking and evaluating the next assertion, all new

assertions are added at the beginning of the agenda. The next rule could then check if it is related to any part of previous branch. If true it can then be grafted onto the appropriate stump and the branch continued.

- BREADTHFIRST is also exhaustive but adds new assertions at the end of the agenda. Without knowing the current rules on the agenda it becomes difficult to unravel why each rule was fired.
- BESTFIRST mixes newly identified rules into the agenda according to their priority. This causes similar problems as already discussed in the SELECTIVE strategy.

Any of the approaches would have achieved the same end using Forward chaining, but DEPTHFIRST was the simplest to decompose. The addition of new slots to the top of the agenda aids the process of identifying exactly where the branches occur, using the list RulesFired, in the decision process. Knowing the position of the branch points allows the system to identify complete linear routes down a branch. Each branch, constituted by rules, is then stored in its own list.

Figure 6.11 shows how a typical part of the list RulesFired can be used to create a current decision tree. With the use of the rule 'Goal' the list is split up.

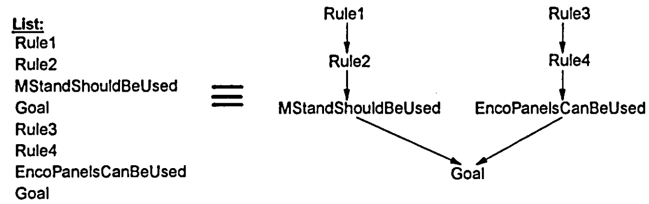


Figure 6.11

Each of these branches will be stored in their own list. These lists would contain

- List1: Rule1, Rule2, MStandShouldBeUsed, Goal
- List2: Rule3, Rule4, EncoPanelsCanBeUsed, Goal

6.2.8 Being able to check that the rules in a specific branch were related to each other

As part of the process of pruning unwanted branches the system has to check that the sequence of rules which represent a branch are related; i.e. the rule in a sequence is related to the preceding and following rules. Kappa-Pc provides this capability as part of its toolkit. The flaw with this tool is that it can only be used by the user and not be integrated programatically. This resulted in the writing of a system which could check the relations of specified rules.

The class RelatedRules was created to deal the process of checking whether two rules were related to each other. This class repeats information stored in the rules. Each instance, in the class, stores the name of the rule it has data on, the pattern of the rule, the object & slots referred in the IF part of the rule and the object & slots referred to in the THEN part of the rule.

The instances of the class RelatedRules are created programatically. This is done by writing all rules to temporary file and then integrating the file to create one instance per rule. The rule name of the current rule in the temporary file is stored in a slot, in the current instance, called RuleName. Similarly the pattern is stored in a slot called Pattern; at present the system makes the assumption that there is only one pattern per rule, which may be incorrect in the future. Then values of the objects and slots, from the IF.. and THEN.. components of the rule, are stored in lists (multi-valued slots). The Pattern is then used to replace each occurrence of the pattern variable with a set of object and slot pairs for all plant options.

Checking the relationship of two rules is then achieved by sending a message to the object RelatedRules, passing arguments detailing the names of the rules to be checked. Argument rule1 is the preceding rule to the current rule2. The process of determining if they are related is shown in Figure 6.12.

After determining if the rules are related, the system is able to determine where one branch finishes and another starts. Without this facility it would be impossible to generate an accurate runtime decision tree.

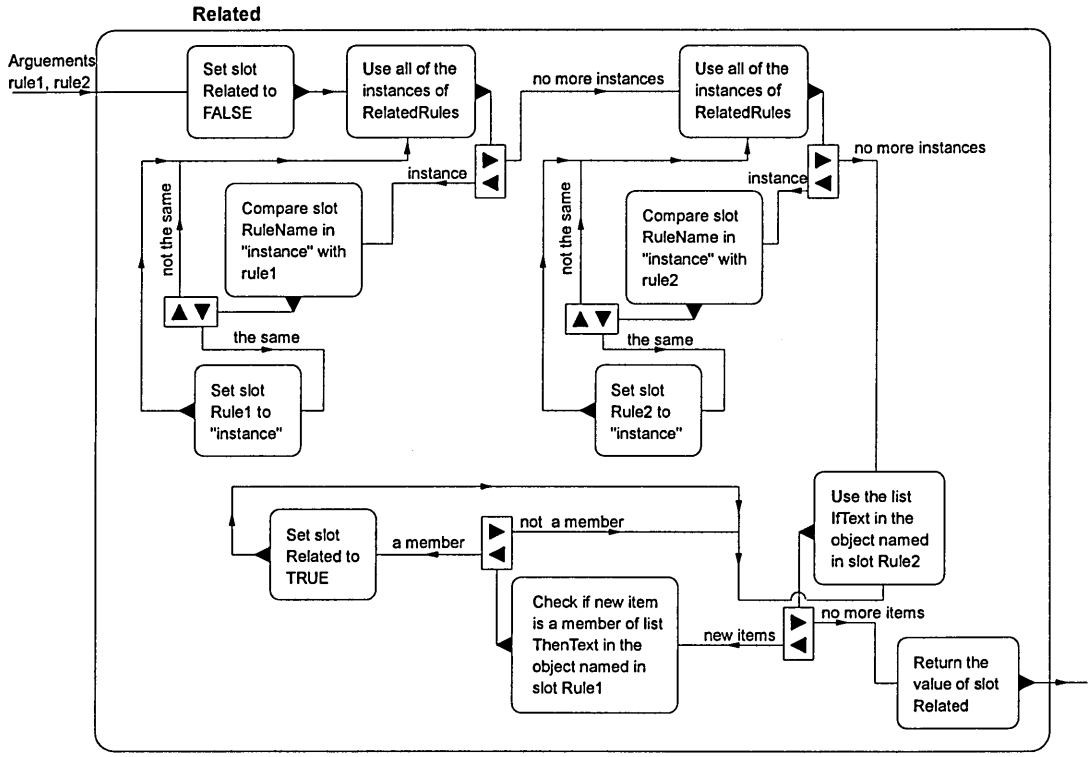


Figure 6.12

6.2.9 Producing an understandable explanation for why the rule has fired

To use the system's presentation of the rules as explanations would be confusing. This is because the rules written in the system are not written using an English type format. This meant that an English interpretation of the rule had to be recorded elsewhere in the system. The logical place for this was in the rule comment facility. It could then be referenced by the system and presented in an appropriate format, with complete branch becoming a text block in the explanation window (See Figure 6.13).

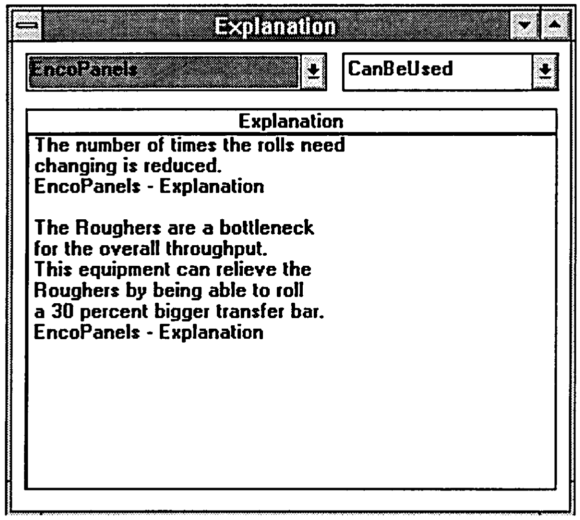


Figure 6.13

6.2.10 Sorting of Explanations

As discussed in the previous section the rules were split initially using meta-rules ("can be used", "should be used", "cost use" and "can't be used"). An additional area for the pruned branches, called "unrelated" was also added. These provide the major divisions when presenting what options there are for altering the plant. On selection of a meta-rule the system looks at the relevant list which contains all equipment that applies to the meta-rule. This then updates the equipment that can be selected through the explanation window, e.g. EncoPanels in Figure 6.13. The meta-rule and equipment selected combine to specify the name of a rule, e.g. EncoPanelsShouldBeUsed.

The rule name is then used to select the lists which should be included as part of the textural explanation. These are the lists which contain for instance EncoPanelsShouldBeUsed, if the meta-rule is 'Should be Used' and the equipment selected is Enco Panels. The lists are used to access the explanations stored in the comment field of the rules. By storing the explanations in the comment field it means that the English version of the rule is stored with the programmatic description, this should allow the experts to validate the rules in the system.

Each list, unless it is an unrelated branch, represents a branch which states the reasons why a piece of equipment was selected. The explanation is built up from the explanation text for each of the rules stored in the list. That is apart from the 'Goal" rule, which is ignored. The meta-rule always precedes the 'Goal' rule. The explanation from this rule is used to confirm that the list reported was for the desired piece of equipment. It clarifies that the explanation was generated to confirm why a piece of equipment was selected.

6.2.11 Integration of cost knowledge

The cost knowledge is stored in the PlantEquipment class in the instance of the equipment concerned. This knowledge is accessed through the slot ExtraIncome. When this is accessed it fires methods which calculate the extra income that a piece of equipment can generate. Some of the values needed to calculate the extra income are gathered by asking the user for data or opinions of the impact of the addition of a piece equipment for time savings. Figure 6.14 shows an example of the type of input which might be asked for. This particular input is being used the help justify the benefits of the addition of Quick Work Roll Change (QWRC). Each of the formulas used are custom created to represent the cost justification the expert uses.

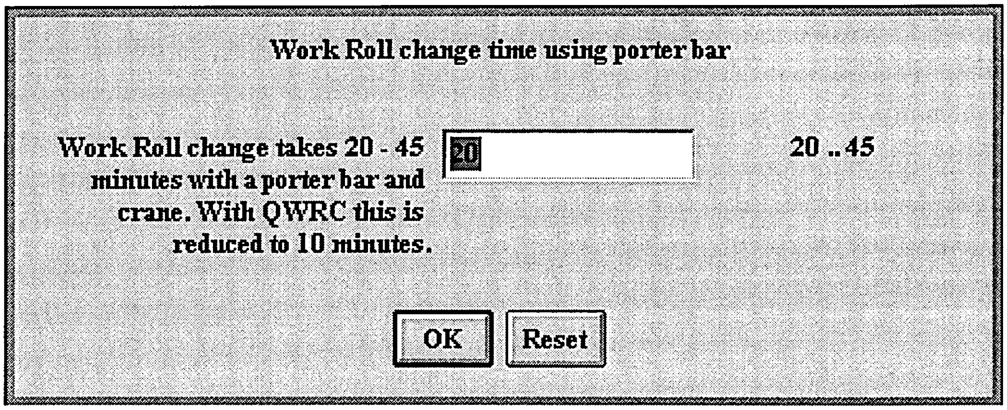


Figure 6.14

Some of the equipment can not be justified using costs. These pieces of equipment can only be justified on quality or other grounds. The quality grounds are reported to the user, if any exist, when the equipment object is asked for the amount of extra income it can generate. Figure 6.15 shows an example of quality or other reasons why water curtains can be used.

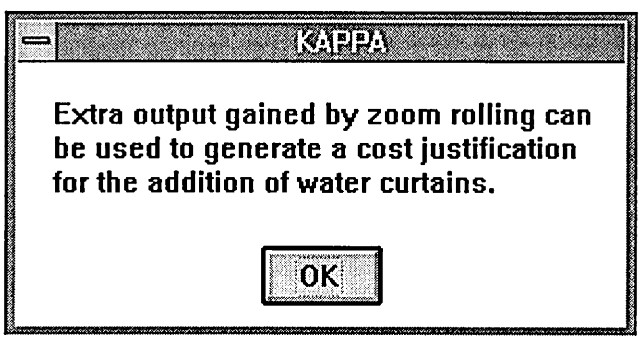


Figure 6.15

This knowledge is only accessed if it is need to help specify which piece of equipment to recommend as the best alteration to the current mill layout.

When deciding whether to add a piece of equipment to the mill, its suitability within the time and money available need to be checked. There is a facility for the user to enter the money and time available for the whole study[1], together with information about time and costs for individual pieces of equipment. Once either cost or time information is entered, checks against study limits can be enabled for individual equipment. This evaluation is carried out each time the rules are fired.

6.2.12 Recommending a piece of equipment

When all of the lists have been sorted, the final part of the process of integrating the knowledge base and creating explanations is to try and recommend a piece of equipment. This is done by choosing the piece of equipment which gives the most extra income, and should ideally take into account the cost of the investment needed. This is done by asking each piece of equipment selected what extra income it can generate. If pieces of equipment give the same return on investment then the user is asked which subset of equipment they want to choose. If no equipment can be recommended the system will inform the user of this.

The system gets the list of possible equipment to recommend from the list of alternatives which should be used. If there are no values in this list then the system looks at the list of equipment which can be used.

---

[1] The system should take the equipment already added to the layout when evaluating this, which not done at present.

If a piece of equipment falls into the list of equipment which is 'Not Used' then it will never be 'Recommended'. It will however be left in either the ShouldBeUsed or CanBeUsed list, when the user accesses them through the explanation window. This gives the expert the opportunity to override the system in special conditions. Potentially these conditions could then be incorporated in the future.

6.2.13 Links with the rest of the system

The explanation system is linked into the rest of the system through the RunRuleLists object, its links are shown in figure 6.16. It is triggered by the user asking for an explanation by pressing the explain button. This fires a function which fires the rules in the knowledge base. It then fires a method in the 'RunRuleLists' object which then compiles the explanation and reports it to the user through a session window.

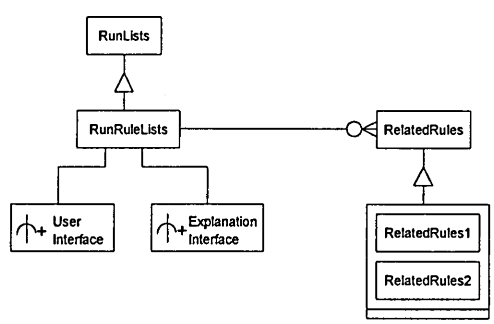


Figure 6.16

6.3 OUTPUTS FROM THE PROGRAM

The last stage of the consultation with the knowledge base is for the system to recommend a piece of equipment if possible. To do this the system checks to see if there is any equipment that 'should be used', or if none exists, what 'can be used'. If there is only one piece of equipment then it is recommended. Otherwise if there is more than one value then the system will evaluate which of the pieces of equipment has the best return on money invested, and recommend it. This is done by posting a message to the user informing them of the recommended value, and if there is one where the explanation of why it has been chosen.

After each consultation of the knowledge base the system produces a list of equipment which might be added to the layout. Each piece of equipment has associated with it reasons why it has been selected as a possible alteration. Figure 6.17 shows an explanation produced as part of a consultation.

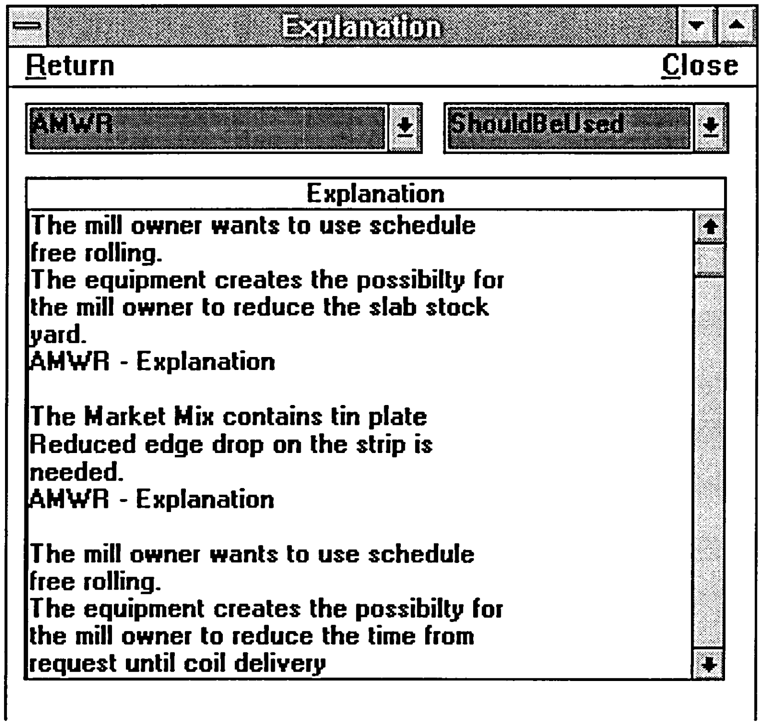


Figure 6.17

The top right hand box is used to select the equipment which has been sorted using the meta-rules (e.g. should be used, can be used, etc.). The top left box contains all of the equipment which should be used to alter the current layout. After selecting a piece of equipment, the explanation is produced in the main window.

The choice of the equipment to add to the layout is left to the user. If the equipment is selected because it either 'should be used' or 'can be used' then the file which records the equipment added to the mill is updated. For each scenario there is a complete record of the figures needed by the technical programs, these provide selected results from the output of the final state of the layout. At present these are stored in the database, but the output can not be seen by the user. A report could be constructed which presents the figures to the user, these would be needed to produce the feasibility study. The system produces a file for each scenario which records the equipment added to the layout in the order it was added, together with any cost benefits and / or quality reasons.

There is the possibility of the system producing a variety of reports which could present some of the information needed to produce the feasibility study. For example a print which records the figures used to arrive at a cost benefit for the addition of a piece of equipment. A spreadsheet file could be produced which presents the information in a standard fashion. The feasibility study could then be written in a similar fashion using this spreadsheet. Because the system demonstrates the capability to produce a text file, it would be only a matter of modifying this format to create a spreadsheet.

7

P.L.D.P. Validation / Review

7.1 PROGRAM VALIDATION

The system was continuously validated using the study Case One, with the experts help, during its construction. A study not used during knowledge elicitation was chosen to validate the program in its completed form. To test the expert system the information used in the Case Two feasibility study was fed into the system and the results were compared with the results that the expert generated by his normal method. The aim of this feasibility study is to reconstruct the a 1700 mm semi-continuous hot strip mill to (Hewitt, 1992):

- Increase output capacity from 2.4 to 3.5 million tonnes per year
- Increase the maximum coilweight from 10/13 to 20 tonnes
- Improve product quality to world standard
- Achieve 100% concast slab input, using four slab widths
- Achieve schedule free rolling
- Achieve optimum fuel economy via hot charging
- Achieve world class yields and minimum operating costs

To enter the data some assumptions were made about the pass reduction schedules used in the roughers and the finishers. The technical program EHSM was unable to handle the two reversing roughers, consequently one of the reversing roughers was modelled as a set of continuous stands, with stands equalling the number of passes.

7.1.1 Approach for setting up the study

The mill wanted to increase their throughput from 2.4 to 3.5 million tonnes per year. This can be done using a combination of improved throughput and by increasing the total volume of the slabs entering the mill. The extra material provided by increasing the maximum slab length from 5.5 to approximately 7.5m. By increasing the slab thickness its surface area is reduced which will in turn reduce the total amount of heat lost between the furnaces and the roughers. As a result the new maximum slab dimensions changed to 7m x 250mm x 1550mm (the same as chosen by the expert). After initialising the layout the E.S. was asked how the mill should be altered.

7.1.2 Evaluation of Plant Knowledge

The furnaces needed to be improved to deliver the throughput required to supply the rest of the mill. The program did not identify this but could be made to check with the user, whether the furnace capacity would be sufficient to meet the new demand, if throughput was increased.

The piece of equipment recommended was AMWR, however one of the options selected was the use of an F0 stand. Using cost to determine which is the best option will always pick a piece of equipment which provides the best return on the capital invested.

It is not possible to generate a figure for the cost benefits of all pieces of equipment. Equipment such as the Roughing or Finishing stands are not able to generate cost benefits until the layout has been re-optimised. This means that they are less likely to be picked using the current recommendation approach.

The reason for picking the F0 stand is because the finishing stands are the mill's bottleneck. This is identified by comparing the throughputs of the three main sections of the mill (the furnaces, roughers and finishers). These are reported to the user by using the analysis menu in the user interface. If required, it would be possible to define an envelope above which the recommendation routine gives priority to address the bottleneck problem. This would mean that only solutions which dealt with improving say, the finishers throughput would be considered.

After adding F0 to the plant and optimising the layout the explanation system could still not identify that the roughers needed revamping. To maximise the throughput of the mill it must be able to process the slab in its maximum size. When the size of the slab was changed to its maximum length the rougher peak powers were exceeded. After this change the explanation system then identified that the roughers might need re-motoring or re-vamping. This was selected as a CanBeUsed option. This option was chosen because the customers wanted to increase their annual tonnage. Without improving the performance of the roughers this would be impossible.

Because the layout of the roughing mill changed, this meant that the length of the Enco Panels needed to be reconsidered. In the study, the expert increased the length of the Enco Panels. The P.L.D.P. assumes that the panels are always as long as the transfer bar.

The above options discussed were all specified by the expert in the feasibility study Case Two. In addition to this the expert also identified the need to add a new crop shear and new down coilers.

The program would also identify that if the mill wanted to improve yield the new coilers should be considered. However if the coil-weight increases then the system should have identified that the user should check the current maximum coil weights the coilers can handle.

The crop shear was also identified as an option to be considered if the customer needed to improve their yield.

Table 7.1 summarises the equipment altered by the expert together with whether the system also identified it as an alteration that was required.

Equipment Altered	Human Expert	Expert System
F0	YES	YES
Repowering Finishers	YES	NO
Revamping Roughers	YES	YES
Revamping Edgers	YES	NO
Lengthening Enco Panels	YES	PARTIAL
New Crop Shear	YES	YES
New Downcoilers	YES	PARTIAL

Table 7.1

7.1.3 Evaluation of optimisation routines

Tables 7.2 - 7.5 show how the mill performance changed from its initial state (Control Scenario) to fully altered, for slightly different conditions. These are the outputs from the technical programs, which are compared against original layout, Control Scenario, to create the cost justifications of the feasibility study. Both the widest (1550mm) and narrowest (950mm) width of strip were modelled on the mill.

Title	Rougher Power Pass 1	Rougher Power Pass 2	Rougher Power Pass 3	Rougher Power Pass 4	Rougher Power Pass 5	Rougher Power Pass 6	Rougher Power Pass 7	Rougher Power Pass 8
Control Scenario	3541	4233	5176	6004	6678	7793	5427	3328
E.S. (1550 x 3)	5651	7743	10628	12833	8240	6758	0	0
Expert (1450 x 3)	5286	7243	9943	12005	7708	6322	0	0
Expert (1550 x 3)	5651	7743	10628	12833	8240	6758	0	0
E.S. (950 x 3)	3463	4746	6514	7865	5050	4142	0	0
E.S. (950 x 3) RR max. pass speed 4.5	3463	5721	8719	11138	7379	5917	0	0
Expert (950 x 3)	3463	4746	6514	7865	5050	4142	0	0

Table 7.2

Title	Peak Power F1	Peak Power F2	Peak Power F3	Peak Power F4	Peak Power F5	Peak Power F6	Peak Power F7
Control Scenario	4150	4162	3990	4100	4592	2107	0
E.S. (1550 x 3)	2498	2961	3275	3717	4265	5186	3039
Expert (1450 x 3)	2925	3581	4022	4602	5309	6503	3857
Expert (1550 x 3)	3127	3828	4299	4919	5675	6951	4123
E.S. (950 x 3)	2793	3213	3510	3929	4499	5450	3177
E.S. (950 x 3) RR max. pass speed 4.5	2702	3135	3446	3864	4426	5352	3122
Expert (950 x 3)	6017	6346	6793	6957	7463	7777	4755

Table 7.3

Title	RMS Power F1	RMS Power F2	RMS Power F3	RMS Power F4	RMS Power F5	RMS Power F6	RMS Power F7
Control Scenario	3684	3777	3667	3786	4245	1952	0
E.S. (1550 x 3)	2133	2618	2963	3400	3923	4774	2808
Expert (1450 x 3)	2132	2683	3080	3554	4109	5033	2985
Expert (1550 x 3)	2279	2868	3293	3799	4392	5380	3191
E.S. (950 x 3)	2360	2783	3103	3500	4005	4827	2817
E.S. (950 x 3) RR max. pass speed 4.5	2296	2724	3055	3456	3951	4756	2772
Expert (950 x 3)	3693	4109	4562	4756	4994	5157	3178

Table 7.4

Title	Tail Load F1	Tail Load F2	Tail Load F3	Tail Load F4	Tail Load F5	Tail Load F6	Tail Load F7
Control Scenario	4522	4025	3506	3242	3242	1845	0
E.S. (1550 x 3)	3651	3643	3461	3235	3217	3398	2285
Expert (1450 x 3)	3415	3408	3238	3027	3009	3179	2137
Expert (1550 x 3)	4047	4011	3805	3555	3527	3703	2465
E.S. (950 x 3)	2266	2184	2052	1898	1889	1988	1323
E.S. (950 x 3) RR max. pass speed 4.5	2193	2132	2016	1869	1861	1957	1304
Expert (950 x 3)	2560	2304	2112	1842	1781	1743	1198

Table 7.5

Title	Rougher Through put	Rougher Cycle Time	Finisher Through put	Finisher Cycle Time
Control Scenario	591	89.9	461	115.4
E.S. (1550 x 3)	682	107.9	472	155.8
Expert (1450 x 3)	638	107.9	500	137.6
Expert (1550 x 3)	682	107.9	534	137.6
E.S. (950 x 3)	418	107.9	544	82.9
E.S. (950 x 3) RR max. pass speed 4.5	473	95.3	544	82.9
Expert (950 x 3)	418	107.9	672	67.1

Table 7.6

"E.S. (1550 x 3)" and "Expert (1550 x 3)" represent what happens to the mill after adding an F0 and revamping the roughers for an initial slab size

1550mm x 250mm x 7.5m producing 3mm strip. The difference between them is in the finisher pass schedule. Both were optimised using the E.S..

The finishers pass schedule used by the expert system was adapted from a database of standardised schedules. The way the expert said he generated new pass schedules. This had to be done outside the program. When the pass schedule was compared with one used by the expert on the feasibility study Case Two they were different. His schedule forced the initial finishing stands to do more of the initial work to enable the finishers to employ acceleration which in turn increased the throughput of the finishers (see table 7.5). This can be seen by comparing E.S (1550 x 3) with Expert (1550 x 3) in table 7.6. When comparing either of these results shown in the study the throughput of the finisher of 500 tonnes / hour (TPH) is substantially less than the 772 TPH achieved for 1450mm wide strip in the study. The rougher produces 638, with some degree of overload of the peak power on the motors. The rougher motors on the old mill were operating at a 30% overload.

"E.S. (950 x 3)", "E.S. (950 x 3) RR max. pass speed 4.5" and "Expert (950 x 3)" represent what happens to the mill after adding an F0 and revamping the roughers for an initial slab size 950mm x 250mm x 7.5m producing 3mm strip. The difference between "E.S. (950 x 3)", and "Expert (950 x 3)" is in the finisher pass schedule. "E.S. (950 x 3) RR max. pass speed 4.5" investigates the affect of increasing the maximum speed out of the roughers, to increase their throughput. All were optimised using the E.S..

These were optimised using the "E.S. (1550 x 3)" as a starting point. Only acceleration rate and thread speed were changed. The Pass schedule used by the expert provides the finishers with the greatest potential throughput (see table 7.6). In this case the limiting factor in throughput is the roughers. The reduction in the work done by the rougher could be exploited by increasing it maximum speed. At present there is no routine in the program which will increase the speed through roughers without first changing either slab length or transfer bar thickness. When the maximum pass speed is increased to 4.5 (which almost exceeds the maximum peak rougher power of 12000 Kw on pass 4, see table 7.2) the throughput of the mill, 473 TPH compares favourably with a figure of 495 TPH quoted by the expert in the study.

7.1.4 Review of results

There are certain areas of knowledge which cannot be represented, these are environmental considerations which are too general to feasibly be dealt with by the knowledge base. The location of any new pieces of plant can only be established with knowledge of this information. An example is the location of the cranes in the mill which are needed to load and unload the rolls used in the mill stands.

When the expert decides on the position of a piece of equipment this is done in collaboration with the mill's personnel and engineers at Davy. This is why the environmental factors fall outside the direct area of the experts knowledge.

Certain pieces of equipment can not be altered by the program, the Finishers and the Roughers both fall into this group, they need to account for customers preferences for their setup. The system allows the user to make changes to the layout and then 'Initialise' the layout in its new state. If the system needs to automatically specify the finishers pass schedule, then the way the expert selects an appropriate pass schedule requires further investigation.

Part of the results of the validation of the expert system, dealing with the plant selection element, identified that there are some areas which are not addressed, these include:

- The program identifies that an F0 stand should be added to the mill to relieve the finishing stands. The program does not however identify that finishers may need re-powering and does not specify appropriate powers to use, or suitable work roll diameters.
- Likewise with roughing stand it was able to identify they were under-powered, but not suggest appropriate changes.
- The program did not identify that the edgers on the roughers were also too weak, the system does not have this knowledge.

Some features which need adding to the system include:

- An ability for the user to disable specific control variables (acceleration, etc.) if required.
- To be able to independently increase the maximum speed in roughers.
- Eliminate existing equipment from the options suggested by the program, this requires modifications of the rules.
- Re-write the way the program alters pass schedules. This might be handled by the user supplying a base set of pass reductions, for the number of passes required. The percentage change for each pass, from the total reduction, would then be used as a basis to calculate new pass schedules as the total reduction changes; i.e. to re-calculate the pass schedule if either the transfer bar thickness or the initial slab thickness alters.

The optimisation part of the program has been demonstrated to work on Case One and on the Case Two feasibility study. On Case Two for wide slabs, the maximum throughput determined by the E.S. is different to the one quoted in the study. This means that for optimising wide slabs more research / knowledge gathering needs to be done. In general, however, it can be seen that the approach taken by the E.S. to optimise a given layout, after automatic alteration, achieves results comparible with the expert.

7.2 DISCUSSION

The explanation system provides a useful feature when describing to the user what has happened to arrive at a conclusion. Explanations could be created as part of running methods but it means that each method which needed to provide an explanation would be required to have extra code, similar to the rules. In this program the explanation system was only used to explain the choice of equipment added to the layout, knowledge used in methods were part of the subject of the explanation. It could be argued that the methods which were used to determine whether there was enough time / cost to enable / disable its addition should have been included in the explanation system. The difficulty in doing this is that the methods are run before the rules are fired. One way of addressing how to integrate the methods and rules needing explanation is for the system to split the explanation process, with one system dealing with rules and the other dealing with methods. The explanations created by these systems would then need to be integrated as the last step before displaying the explanations to the user.

The layout of the rules which produce explanations have to be created in a structured fashion. This could be handled with the use of a custom interface. This could give the user the opportunity to enter or edit the rules. The drawback is that the user will probably not appreciate how the rule links with other rules. Having an English version of the rule enables the user to validate the rule.

The system has to work using a combination of diagnostic and forward reasoning. This would suggest that the system should contain a combination of backward and forward chaining. The reason for only using forward chaining is due to the use of meta-rules, which enables the system to diagnose the plant, the meta-rules providing a partial ranking of the solutions. The system provides a way which for each run of the rule base, re-asserts any the current knowledge description of the mill, i.e. inputs to the rules which apply to the current situation.

The use of meta-rules forces the rules to forward chain where possible to a goal. The goal in this case is the rule 'Goal' which ties together all of the possible alterations to the plant. This is necessary for the system to be able to identify the branches to give a coherent explanation. The use of meta-rules to control explanation was also used on one of the versions of MYCIN, called NEOMYCIN. It removed rules required by the system from the text which the rules generated for explanations (Valley, 1992). The meta-rules in this case were used to group rules of equal importance when presenting the user with alternatives for altering the plant.

The use of frames helped ensure that the slots needed for the meta-rules existed for all equipment which could be altered on the mill. The objects could also be used to store all the financial information appertaining to each piece of equipment. These features combined to form a central knowledge source for the knowledge needed to select a piece of equipment.

The explanation system was used as a focal point when selecting equipment to add to the mill. This means that the knowledge base is continuously being validated. Any new knowledge identified, or errors spotted, can be used to improve the knowledge base.

The translation of user inputs to rules proved to be one of the most difficult areas to solve. This was not helped by the need of the system to use forward chaining. Kappa-Pc has the ability to ask questions when backward chaining if there is no current value in a slot. The use of check boxes as a means of input to the rule system means that the user has to evaluate each check box, at least once. This is not an intuitive way for the user to give the system additional information about the customers needs or the mill. A way which this can be made intuitive is by grouping them, which cuts down on the number of inputs the user has to read. These inputs only need to be entered during the initial stages as they are mostly things which do not change as the layout is altered.

A tool was created to determine if any two rules were related. The assumption is that if the rules were related if the object & slot pairs referred to in the rules body matched. This does not take into account the value stored in the slots. As far as could be determined this is the approach used by the system when it determined if two rules were related. For this reason the custom version was designed to run in a similar fashion. During the use of the explanation system nothing has occurred which indicates that this should be written to include the value referred to in the rule. The objects that holds the relationship details about rules are updated if the developer issues a command programmatically, this is the most efficient approach.

The approach used for identifying a fork part of the way along a branch is faulty at present. This needs to be re-written so that system is able to identify a multiple branching justification. The fault lies in its ability to backtrack multiple divergent branches. The current approach is acceptable for the explanations to date but this needs to be reviewed for the future. In order to do this, the way the method MoreLists works needs to be reviewed.

The use of an expert system toolkit has allowed more than one approach for knowledge representation. The use of Kappa-Pc has meant that the tools were available to create a explanation interface, other software would have proved inflexible. A better approach would be to select a piece of software which has these abilities in-built.

The use of control variables to control the optimisation of a layout, after alteration, has proved successful. Further work is needed to allow greater flexibility in the control of the 'control variables', as discussed in section 7.1.4. Further work is needed to improve how the program optimises wide strip.

When specifying the pass schedules used in the roughers and finishers, the expert may talk to other people before deciding what to use. For this reason it is questionable whether incorporating an automatic pass schedule selection system will be of value. The technique used to determine appropriate pass schedules, used for Case Two, needs to be incorporated into the program.

To specify details like the diameters of work rolls as the layout of the mill is changed, the system could select them from pre-existing data from other mills. An approach which might yield additional benefits would be the use of Case Based Reasoning. Case Based Reasoning could also hold some of the answers as to how to alter the distances between the equipment as the layout changes.

The system is also able to provide partial cost estimations of the total benefit of the changes to initial layout, for each scenario modelled. These combine increases in throughput with other known benefits gained from the addition of a piece of equipment; for example using Computer Controlled Furnaces can make from 5 -13 % improvements in fuel efficiency.

7.3 SUMMARY

The system diagnoses a plant layout in a similar fashion to a human expert, doing about 60-70% of their job (see section 7.1.4), cutting down the time needed to complete the study from 6-8 week to 2-3 weeks. The system represents the information about the mill which the expert uses when conducting a study. The system is able to guide the user in the choice of what equipment should be added to the mill next and in many cases pick the most cost effective alteration. The user is guided by the use of explanations and specific messages which tell the user what the recommended equipment is or give additional information. The system gives the user the flexibility to override the system if required, e.g. when part of the study involves examining the mill for stainless steel production.

After adding in a piece of equipment the system uses the technical programs available to the expert to optimise the layout in a similar fashion to the expert.

The system produces a start to the figures which are necessary to create the justification for the alteration of a layout.

The use of an expert system allows the capture of two distinct and key forms of knowledge: synthesis knowledge used in generating different reconstruction strategies such as layout alterations (Hewitt, 1991; Hewitt, 1989; Koinov et at, 1986) and process optimisation knowledge. These aspects of knowledge are then incorporated into an integrated expert system based feasibility system. The process optimisation knowledge concerns the methodology used by engineers at Davy International (Sheffield) when using technical programs (e.g. EHSM, ENCO). The expert system will represent a central pool for the focus of knowledge that is used when producing feasibility studies. This will create a tool that helps the engineers when producing a feasibility study, improving their productivity.

8

Discussion of the use of E.S. for Plant Layout Design

8.1 E.S. AND PLANT LAYOUT DESIGN

Plant modelling systems need to incorporate more than one approach to solving a problem. The Plant Layout Design Program contains elements of the systems described above. For this reason it will probably be advisable to choose a form of knowledge based toolkit which has the ability and the appropriate facilities to link to any other tools which are needed.

8.1.1 Using Object Oriented Systems and Plant Layout Design

When designing the knowledge base it will be necessary to consider if the knowledge about the various pieces of plant will need modification, or if the addition of knowledge of new equipment might be needed. If this is the case then the use of a modular approach for storing the knowledge is appropriate.

The use of objects or schemas provides an ideal vehicle for this if used properly. One of the principles of objects is encapsulation, this means that the object only interfaces with the outside world through a pre-defined set of channels and the knowledge which provides the responses is represented internally. If any knowledge is accessed through a set of standard channels then any modification to the internal knowledge will only affect what is sent down that channel, which is easier to track when modifying the system. This is demonstrated in the Plant layout design system when each equipment object has methods which calculate the extra income that a given piece of plant is able to generate. If new equipment is added then the basic outline of the object which the knowledge is stored in should have been pre-defined using inheritance. It should then be a relatively simple matter to incorporate the object into the system, because the mechanisms for talking to other equipment objects could be used to interface with the new object.

8.1.2 Using Rules for Equipment Selection Knowledge

The use of meta-rules is needed to help to rank the suitable layout design options. The use of rules can lead to difficulties in maintaining the system, as the number rules in the system increase. In the Plant layout design system, modification of rules will become more difficult as the size of the system increase. This could have been made easier if the general rule names (i.e. non meta-rules) had incorporated a pointer to the type of equipment or to the nature that they represented.

The use of rules also helps give the system the ability to provide explanations for the reasons for a particular choice. In plant layout design it is not possible to always say that one particular option is the most suitable. Forward chaining of the rules provides the system with the ability to generate more than one solution, as is required in plant layout design. Forward chaining produced lots of information which needed sorting, which was done with the help of the meta-rules. The use of explanations is needed to guide the user to the most suitable option. Creating explanations in the Plant Layout Design Program was not helped by the systems' lack of a facility to check if rules were related inside the code of the program. A separate class called Related Rules had to be created which contained information which identified links between rules. This built in redundancy of information which should not be needed if a more flexible piece of software had been chosen.

8.1.3 Re-Use of Knowledge

Generalised knowledge associated with modelling of the mill can be incorporated in its own specialised module. This could allow the knowledge to be re-used in different design problems. The use of objects could promote the consideration of reuse of the knowledge, which could be used as a method for providing a central library of mill operation knowledge. This would mean that as the knowledge was updated all of the systems which used the central mill knowledge would be using current knowledge. This approach would need careful management and planning to ensure that any system which used this type of knowledge did so via the central model. The development of the central module would need to be very carefully planned to avoid improvements or rationalisation which would result in the channels being altered.

A central model gives the company more opportunity to gain the maximum return on the money which they have invested to create the module. If the module can be reused in more than one system then each system can be used to provide a contribution to the return on the money invested. The return which each systems contributes will depend on their needs in the area of the knowledge that the module encapsulates. The knowledge of how the customers' plant performs is needed more when designing a layout, than when designing one piece of equipment. The difficulty as the size of the knowledge grows is to be able to identify the knowledge which is contained in the module, and the channels which should be used to access it. In trying to re-use knowledge there will be a vast amount of redundancy in the systems. This could lead to problems in performance and also in selecting the appropriate piece of knowledge needed.

8.2 SUMMARY

When using an E.S. for designs in the H.C.P.I., rules are needed to handle plant specific knowledge, which tends to be less structured. Objects or frames help to split the knowledge up into coherent modules. The use of methods helps in the control of any external tools which the expert already uses. The use of objects to encapsulate these methods helps separate each of these different aspects of knowledge or tools needed in plant layout design.

The use of explanation should be considered if it is not possible to be certain that only one option exists. The use of forward chaining together with an explanation system provides a mechanism for dealing with the multiple solutions which can occur.

9

Recommendations for the use of E.S. in the Heavy Capital Plant Industry

9.1 INTRODUCTION

Traditional component design focused on the two main design areas of functional design and design for manufacture. In the Heavy Capital Plant Industry they must also consider installation, commissioning, transportation, any special manufacturing required and other pre-determined specifications (e.g. roller diameter on the roller tables).

The supplier needs to understand in detail how the equipment is used by their customer. They must understand how each piece of equipment fits together to build the whole plant and how their performance affects the plant's overall performance. The performance of the plant is not an overall economic measure. The amount of maintenance it requires and the length of the maintenance period (reliability, quality of the machines, etc.), all contribute to its profitability. The equipment location can add to the problems of maintenance and / or make installation problematic.

Manufacture adds additional constraints due to the component's size, which limits the number of suitable techniques available. Manufacture can not be considered in isolation, installation must also be considered, which could include transporting the equipment to a site anywhere in the world.

Because design in the Steel industry needs to incorporate knowledge from a wide range of fields, some equipment specifications have been determined through experience. An example of this is the proven diameter of the rollers used on roller tables. The diameter together with if they are solid or hollow affects the amount of heat lost when the roller is in contact with the strip, the amount of impact that the roller can withstand, how quickly the roller can be accelerated, etc.

The example described above typifies one aspect of the experience of the engineering designer in the Heavy Capital Plant Industry. The knowledge needed to be able to identify and adapt a piece of equipment due to differences in the site layout, the extra "environmental factors", is a key skill needed for this type of engineering design. These "environmental factors" are also found in the building industry, where they are recorded in the building codes used by a Civil Engineer. The engineers in the steel industry have to work with civil engineers when creating foundations for any equipment which is being installed.

9.2 GENERAL RECOMMENDATIONS

1 To determine which parts of the specification have been generated through experience, compare selected contracts chosen by the

engineers. If similar criteria exist check with the engineer if it is constant on all contracts (see section 3.2).

2 Use key selection criteria to filter the list of possible options when selecting which piece of equipment to add to a layout. In the plant layout system the expert's key selection criterion are Quality, Throughput and Yield. Only the last two are quantifiable to some degree, therefore the final choice of criterion should be left to the user (see section 6.3). In the P.L.D.P. expert system, the system will select the piece of equipment which gives the best return on the money invested (see section 6.1.2), but also provides the user with explanations of all other possible solutions that were considered (see section 5.2.2).

3 Forward chaining is more suitable for selecting which piece of equipment to add the plant because of the likelihood of there being to be more than one option (see section 6.2.2).

4 Separate the specialist knowledge from the more general knowledge when eliciting knowledge from the expert. For example in the P.L.D.P. it was only necessary to concentrate on the knowledge used for configuring the plant for Mild Steel, which generally makes up 80% of the product mix and therefore dominates the economic justification of an investment (see section 6.1.2).

5 Ensure that each part of the program has the full support of all people involved in the project. One of the problems when writing the design

manuals was in obtaining time with some of the allocated engineers (see section 2.2.1).

9.3 SOFTWARE SELECTION

1 This type of company already has a large number of existing programs / mathematical models which they use to accomplish their job. An E.S. needs to be able to integrate with existing mathematical models, together with contributing the heuristics used by a human expert when solving a problem (see sections 3.3.2 and 5.3). To communicate with other programs the system needs to incorporate procedures and protocols for this purpose. Consequently the expert systems used is likely to be a toolkit comprising of procedural facilities and facilities for knowledge modelling. This is seen in the approach taken by the steel mills when constructing their own specialised E.S tools (see section 2.8).

2 Use a system which has a mixture of a rule and object / frame based representation approach. A system which supports explanation will help in the process of guiding the user in situations where there is more than one suitable option (see section 5.3).

9.4 REPRESENTATION TECHNIQUES

1 The use of frames allows anyone adding to the knowledge base to intuitively determine where similar knowledge would exist in the

knowledge base. For example in the P.L.D.P. any knowledge associated with the selection and justification of Enco Panels is stored in the EncoPanel object. New slots or methods can be added to the object as required (see section 7.2).

2 Use of meta-rules enables ranking of the selection of equipment, which helps in the recommendation process. Each of these rules require the same slots for each piece of equipment, which suits the use of inheritance in a frame based representation. For this knowledge to be able to select a piece of equipment all of them require the same slots. Determining whether to use rules, methods or another technique will depend on the form of the selection knowledge. In the P.L.D.P., methods were used because the calculated cost knowledge fitted naturally into procedural language used in methods (see section 7.2).

3 The knowledge used to determine when to add a piece of equipment will be in the form of complex, unstructured knowledge, which is best suited to rules. This is similar to the approach adopted with representation of building standards in expert systems in the building industry (see section 5.4).

4 If the same hierarchy of frames is used on all applications it means that knowledge from other design applications can be easily integrated (see section 6.1.3).

5 Use methods from object oriented systems to handle calculations needed when specifying the mechanical design of a component. The allowable communication channels need to be known, so that the internal calculations procedures can be changed without requiring changes to another part of the components design. The control process used to guide the design process needs to be carefully thought out. Some design calculations need to make assumptions for values determined later in the design. In such cases steps required for re-calculation need to be established. For re-calculation the knowledge requirements for the design process have to be more global (i.e. the steps of the design process need to be known) than for the design of part of a component (see section 4.5).

6 Objects provide a suitable vehicle in which to focus the representation of each piece of equipment's design knowledge (see section 7.2). Use of objects as discussed earlier is ideal for representing the geometric knowledge which is generally needed when designing a component (see section 4.3).

7 When representing component design knowledge the piece of software needs to have facilities for handling calculation procedures. The use of an object oriented approach seems to be popular for component design, consequently the preliminary choice of an object oriented piece of software seems sensible (see section 4.5).

9.5 PITFALLS TO AVOID

1 Select software which has facilities which help the process of creating explanations, or at the very least will allow the system to identify during the running of the program that rules are related (see section 6.2.3).

2 Stage the implementation of the program by completing the modelling of how the expert uses any existing tools before investigating the ways the expert redesigns the plant layout. The staged delivery helps provide continued motivation and support for the project, by demonstrating partial benefits of the project as soon as possible.

9.6 BENEFITS OF THE USE OF EXPERT SYSTEMS

This industry has to supply designs which are based on previous designs, due to time pressures, adapted to integrate with the current plant. Varying degrees of plant knowledge are needed to accomplish the various design tasks of this type of company.

E.S. can be used as a vehicle for integrating this knowledge with the component designs, or as a way of representing this knowledge to help better specify how the equipment should be used.

Most designs produced for a steel mill need to be done in conjunction with a reference of an existing piece of equipment. Because of this much of the development work is done on the back of a contract to supply a selection of equipment. The roller table program would free up their time to concentrate on this development. As the knowledge for the design of the roller changes, the E.S. can be altered to reflect the new approach to design.

A developed system can be used as tool a to investigate the opportunities to further improve the product. Different departments, e.g. manufacturing, could review the design and add their knowledge to the process, so the system acts as though it were a team of designers practising concurrent design. For the steel industry the use of E.S. gives them the opportunity to value engineer the component, enhancing the persistence of the knowledge; having the opportunity to apply this knowledge to multiple contracts. This can alter the approach taken to selected designs, from single designs to multiple batches. The choice of the component is critical to obtain the maximum benefit from the money invested.

10

Conclusions

This section contains the conclusions that have resulted from the work described in this thesis.

- Rule based systems are not sufficient to represent engineering design knowledge in the H.C.P.I., the minimum they should have is the ability to link to external programs (see section 3.7). It is better to use an object oriented toolkit which has rule based capabilities (see section 4.3).
- When integrating semantic design knowledge with geometrical design representations the use of object based representation techniques is best (see section 4.5).
- The knowledge of how the customer's plant operates is needed at various levels in both component design and layout design. This amount of knowledge is much greater when designing the plant layout than for the design of individual components (see section 4.5).
- The use of expert systems in the heavy capital plant industry is especially appropriate because of the need for any design to be based on a previous design (see section 2.10). The use of expert systems can capture the

previous component design knowledge to provide a secure base for any future developments (see sections 3.5 and 7.3).

- The use of expert systems enables the heavy capital plant supplier to integrate their knowledge of the plant with their design knowledge to create a system which represents their design practice (see section 8.2).
- The use of explanations can provide a vehicle for the user to validate the knowledge which is represented using rules. The rules in the P.L.D.P. also have an English version of the rule, as well as the system version, which is reported to the user through the explanation system (see section 7.2).
- The use of object oriented systems allows the modularising of knowledge to make it easier to build the system. Each module deals with a different aspect of the job, e.g. plant selection knowledge. These modules can either be an object or groups of objects which should only be accessed through specified channels. This aids development, but reaps the most benefit during any future maintenance of the system (see section 8.1.1).
- The use of a toolkit enables a mixture of approaches for knowledge representation, particularly necessary for layout design. This means that the most appropriate technique can be used (see section 8.1).
- E.S. for layout design give the company the opportunity to bid for more contracts. This is because the use of the layout system helps to reduce the time it takes to produce a feasibility study. As the program is used more and the knowledge refined, the system could allow the opportunity for a

less experienced engineer to do more of the work in producing the feasibility study (see section 7.3).

- The use of an E.S. allowed the use of existing tools, used by the expert, to be integrated with the experts knowledge in their use. This was incorporated in the optimisation routines used when optimising a layout. The knowledge included procedures and the heuristics used by the expert when optimising the layout (see section 6.1.5).

11

Further Work

This section highlights areas of further work, in the area of engineering design in the H.C.P.I., identified as a result of this research.

(A) The use of Case Based Reasoning means that the knowledge base can be continually updated as new approaches to layout design appear. This is achieved by adding a new case to the Case base (a database of case descriptions). Watson (1994) describes how structural or derivational rules can be used to adapt a case to the current situation. CLAVIER is an example of how the case based reasoning has been used to create new layouts for aircraft composite materials requiring curing in an autoclave. In addition to being able to update the knowledge in the system, additional benefits to the H.C.P. area are:

i A Hot Strip mill layout can be split into three main areas Furnace, Roughers and Finishers. The way in which they are constructed is determined by their required throughput together with the physical layout of the mill. The nearest matches to the current layout for each area could be amalgamated to produce an initial configuration. This approach could be adapted to any system which could be split into identifiable sections.

ii To help the system to generate appropriate distances between pieces of equipment from a similar existing layout.

iii The use of Case-Based reason opens up new possibilities of using previous layouts to explain to the user why a particular option might be better than another. This would provide the user with information to help them generate a justification to present to the customer.

(B) The exploration of approaches to structuring H.C.P. environmental knowledge for the use in both component and layout design. In this case, how to represent the plant specific knowledge for use in more than one design system. Can the component design knowledge be structured in such a way as to allow part of it to plug directly into a layout design system, possibly using modules. One approach would be to have different levels of knowledge, aiming at having the environmental knowledge forming part of the higher levels, see figure 11.1. This could be achieved using a frame hierarchy, possibly using some form of multiple inheritance. Because the same environmental knowledge is needed for more than one design process, if this changed it would only be a matter of changing one source of knowledge and updating it's links. This process would be helped by strictly applying encapsulation principles, i.e. only communicating with objects using pre-defined channels.

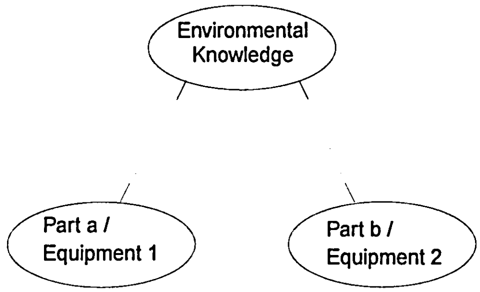


Figure 11.1

(C) Create a more graphic interface for the P.L.D.P., with the aim of making it more intuitive for the user. For example creating a picture of the current layout will help to identify any equipment the user may have missed during setup and aid the reporting of the current mill configuration.

(D) Decide how the knowledge will be modified in the future, considering who will make the changes. If the users are to modify the knowledge base then custom facilities will need creating to guide them through this process.

(E) The following work / modifications are needed to be able to deliver the P.L.D.P.;

- Add the knowledge identified in section 7.1.4.
- Give it the ability to independantly increase the maximum speed of the Roughers.
- To ensure that it eliminated existing equipment from options presented in the explanation window, or have the option to.

- Modify the way the pass schedules are determined for the Roughers and Finishers.
- Thoroughly debug the P.L.D.P. and ensure that its performance is robust. Special care will be required when managing how the technical programs are integrated (section 6.1.1 describes the current approach).
- Re-write / check the method used to establish if rules are related.

References

A.I.A.I.. 1991. *Knowledge Elicitation* (Course). A.I.A.I. Edinburgh.

ALVEY IKONMAN PROJECT. 1989. IKBS Production Control in Manufacturing Industry. *IKBS Directorate.* SERC\DTI.

ANABUKI, Y.; OWAKI, R.; SAKIYAMA, H.; NAKAZI, S.; KATAE, T. 1992. Application of an Expert System to Real-Time Coil Transportation Control of an Electrical Steel Finishing Line. *Kawasaki Steel Technical Report No. 26.* June, p.46 - 51.

ARIZONO, N.; SAEKI, T.; KUSUMOTO, S. 1991. Expert System for Scheduling Rolling Sequence in Plate Mill. *Kobelco Technology Review No.10.* March, p.47 - 49.

BALACHANDRAN, M.; GERO, J.S. 1988. A Model for knowledge-based graphical interfaces. *Artificial Intelligence Developments and Applications.* Elsevier Science Publishers B.V. (North-Holland), p.147-163.

BEAGLES, A.; HEWITT, E.C.; MIZBAN, S. 1992. Thermal Control of Hot Strip Mills Modelling and Efficiency. *Internal Report Davy McKee (Sheffield).*

BOOCH, G. 1991. *Object Oriented Design with applications.* The Benjanmin / Cummings Publishing Company, Inc.. p.1-151.

BRACHMAN, R.J. 1985. "I Lied about the Trees" Or, Defaults and Definitions in Knowledge Representation. *The AI Magazine*, Fall, p.80-93.

BRATUS, S. 1985. Optimization of temperature-speed conditions of Hot Rolling in a continuous wide strip mill. *Stal'.* (11), p.40-43.

BROWN, D.C.; CHANDRASEKARAN, B. 1988. Expert Systems for a Class of Mechanical Design Activity. *Expert Systems in Engineering.* Edited D T Pham. IFS Publications.

BROWN, J. 1990. Product Evaluation: Xi Plus Version 3.0, *Note No.127*, Knowledge Engineering Group, AI Applications Institute, University of Edinburgh.

CHOU, Y.C.; BENJAMIN, C.O. 1992. AI-based decision support system for Naval Ship Design. *Naval Engineers Journal.* May, Vol. 104(3), p.156-165.

CROSS, N. 1989. *Engineering Design Methods.* John Wiley & Sons. p.27.

COLTON, J.S.; PASCANCO II, J.L. 1991. An Integrated, Intelligent Design Enviroment. *Engineering with Computers*. Vol. 7, p.11-22.

CUNNINGHAM, A.; SMART, R. 1993. Computer-Aided Parts Estimation. *A.I. Magazine*. Fall, Vol. 14(3), p.39-49.

CZLAPINSKI, W.; ZIEGENHAGEN, A. 1989. Optimization strategy and model forming for heavy plate rolling. *Metallurical Plant and Technology*. 1, p.44-53.

DTI. 1989. *Market Surveys and Applications*. Manufacturing Intelligence

DYM, C.; LEVITT, R.E. 1991. *Knowledge-based systems in Engineering*. McGraw-Hill International Editions. section 12.7, p.349-360.

FABEL. 1993. Survey of FABEL - The FABEL Consortium. *FABEL-Report No. 2*. Gesellschaft fur Mathematik und Dataverarbeitung mbH (GMD), Samkt Augustin. ISSN 0942-413X

FUKUMURA, S.; SANOU, K. 1992. Establishment of Basic Infrastructure for Expert System Development. *Kawasaki Steel Technical Report No. 26*. June, p.14-21.

GERO, J.S. Unpublished paper. *Developments in Artifial Intelligence in Design with Particular reference to Creative Design*. Design Computing Unit, University of Sydney, NSW 2006, Australia.

GORDON, Y. 1990. ICAD Inc. Report. *Internal Report Davy McKee (Poole) Limited*.

GORING, M.H.; SCHECKER, H.G. 1993. HAZEXPERT an integrated expert system to support hazard analysis in process plant design. *Computers and Chemical Engineering*. Oct., Vol 17, p.429-434.

HART, A. 1986. *Knowledge Acquisition for Expert Systems*. Kogan Page Ltd. p.49-69.

HEWITT, E.C.; EARNSHAW, E. 1987. Technical options for modernising hot strip mills. *Iron and Steel Making*, Vol. 14, No. 3, p.22-28

HEWITT, E.C. 1989. Use of Spreadsheets in feasibility studies and Modelling Steelworks. *Iron and Steel Making*, Vol. 16, No. 3, p.174-182.

HEWITT, E.C. 1991. Use of Spreadsheets for modelling Steelworks: Part 2 Evaluating strategies for enhancement of hot strip mills. *Iron and Steel Making*, Vol. 18, No. 3, p.182-192.

HEWITT, E.C. 1992. *Case Two - Internal Report Davy International (Sheffield).* Feasibility Study Covering the Revamp of the Hot Strip Mill.

HICKMAN, F.R.; KILLIN, J.R.; LAND, L.; MULHALL, T.; PORTER, D.; TALYOR, R.M. 1989. *Analysis for Knowledge-Based Systems - A Practical Guide to the KADS methodology*. Ellis Horwood. p.53.

ICAD - Sales. Using the ICAD System for Sales and Applications Engineering. *ICAD, Inc. D-7.5-292.*

ICAD - Tooling. Automating the Tooling Design Process withe The ICAD System. *ICAD, Inc. KW-75-491.*

IGNIZIO, J.P. 1991. *Introduction to Expert Systems the development and implementation of rule-based Expert Systems.* McGraw-Hill International Editions. p.111-151.

IIDA, O.; TANIYOSHI, S.; UETANI, T.; SAWADA, T.; HASHIMOTO, M.; ONODA, D. 1992. Application of AI Techniques to Blast Furnace Operation. *Kawasaki Steel Technical Report No. 26.* June, p.30 - 37.

JACKSON, P. 1986. *Introduction to Expert Systems.* Addison-Wesley Publishing Company. p.35-60.

KOINOV, T.; GIVKOFF, I.; GEORGIEF, K. 1985. Optimization of Deformation - speed rolling conditions on 2300 mill, *Metalurgia (Sofia).* (6). p.17-20.

KOINOV, T.; KIHARA, J. 1986. Process Optimization for Hot Strip Mills. *Transactions ISIJ.* Vol. 26, p.895-902.

KOINOV, T.; KIHARA, J.; TSANKOV, T. 1987. Optimization of a whole line system for Strip Rolling. *Proceedings of the IMACS/IFAC International Symposium on Modelling and Simulation of Distributed Parameter Systems.* October, Hiroshima, Japan, p.607 - 704.

KOPP, R.; DOHMEN, P.M. 1990. Simulation and Planning of Rolling Processes with the aid of the Finite-Element Method. *Stahl u. Eisen.* 110, No. 7, p.131-136.

KOPP, R.; TWICKLER, M.; BUNTEN, R.; HACHMANN, B. 1991. Simulation and Optimation of Section Rolling Processes. *Der Kalibreur Heft.* 54. p.4-44.

KURIBAYASHI, T.; YAMAMOTO, A.; HOSODA, M.; TAKENAKA, K.; KIMURA, T. 1992. Coil Transfer Control based on an Expert System. *The Sumitomo Search No. 50.* July, p.59-67.

LYDIARD, T.J. *Product Evaluation Art-Im / MS-Dos Version 1.50*, Artificial Intelligence Applications Institute, University of Edinburgh, 80 South Bridge, Edinburgh, EH1 1HN.

LYDIARD, T.J. 1989. PC-Based Expert Systems Shells: A Survey of Their External Interfaces, *Note No.92*, Knowledge Engineering Group, AI Applications Institute, University of Edinburgh.

LYDIARD, T.J. 1990. Product Evaluation KAPPA PC Version 1.0, *AIAI-TR-85*. Artificial Intelligence Applications Institute, University of Edinburgh, 80 South Bridge, Edinburgh, EH1 1HN.

MAHER, M.L. 1990. Process models for Design Synthesis. *AI Magazine*. Winter, p.49-58.

MARTIN, J. 1993. *Principles of Object Oriented Analysis and Design*. P T R Prentice Hall. p.69-155.

MICROSOFT CORPORATION 1992. The Windows Interface: An Application Design Guide. *Windows Help File*.

MILLS, P.; JONES, R.; SUMIGA, J. 1987. The integration of cost knowledge and uncertainty into expert systems for engineering design. *Proc. 4tg European Conf. Automated Manufacturing*. May, p.443-452.

NAKAMURA, N.; NISHIMURA, K.; BEPPU, Y.; YOSHIMINE, T. 1992. An AI system for the Facilities Monitoring On-Line System. *The Sumitomo Search No. 50*. July. p.68-77.

NODERER, K.; HENEIN, H. 1990. A Survey on the Use of Expert Systems in the Iron and Steel Industry. *Iron Making Conference Proceedings*. p.497-501.

NOVAK, M.; JEZERNIK, A. 1994. An Expert System for bottling plant design. *Applications of Artificial Intelligence in Engineering*. p.197-203.

OTSUKA, K.; KOJIMA, M.; YOSHIDA, M.; MATSUOKA, S.; MATOBA, Y. 1992. Expert System for Blast Furnace Operation. *The Sumitomo Search No. 50*. July, p.43-50.

RAUCH-HINDIN, W. 1988. *A Guide to Commercial Artificial Intelligence Fundamental and Real World Applications*. Prentice Hall, p.6.

RICH, E.; KNIGHT, K. 1991. *Artificial Intelligence*. Mc Graw Hill, 2nd Edition, p.115-126.

REMEIKA, V.; EMENEAU, B.; SIMMONS, J.D.; SZTRIMBELY, W.M.; WEYMOUTH, P.J. 1991. Computerised production scheduling at Lasco - An Expert systems approach. *Iron and Steel Engineer*. September, p.16-19.

ROSENMAN, M.A; GERO, J.S.; OXMAN, R. 1986. An Expert Sytems for Design Codes and Design Rules. *Applications of AI in Engineering Problems*. p.745-758.

ROSENMAN, M.A. 1990. Application of Expert Systems to Building Design Analysis and Evaluation. *Building and Enviroment*. Vol 25, No. 3, p.221-233.

RYCHENER, M.D. 1985. Expert Systems for Engineering Design. *Expert Systems*. Jan., Vol 2, No 1, p.30-44.

SHAUGHNESSY, K.; STURGES Jr, R.H. 1992. A systematic approach to conceptual engineering design. *Design Theory and Methodolgy*. D.E.- Vol. 42, ASME, p.283-291.

SHEN, Q.; BRANDON, P.S. 1991. Can Expert Systems improve VM implementation. *S.A.V.E. proceedings*. p.168-176.

SHILOV, V.A.; INATOVICH, Y.V.; SMINOV, V.K.; STAROSTINA, T.S.; MERKUREV, S.E. 1984. Computerised analysis and optimization of processing proceedures for rolling standard sections on tandem mills. *Steel in the USSR*. June, Vol 14, p.279-281.

SMITHERS, T. 1989. AI-based design versus geometry-based design or Why design cannot be supported by geometry alone. *Computer-aided design*. Vol. 21, No. 3, p.141-150, April.

SMITHERS, T.; TROXELL, W. 1990. Design is Intelligent Behavior, But What's the Formalism. *Journal of Artificial Intelligence for Engineering Design, Analysis and Manufacturing*. November, Vol 4, No2.

SUMIDA, N.; WAKISAKA, S; HIRATA, T. 1993. AI Technology in Large-Scale Real-Time Control Systems. *SEAISI Quarterly*. Jan., p.82-96.

SUTCLIFFE, A.G. 1991. Object-oriented systems development: survey of structured methods. *Information and Software technology*. July/August Vol 33, No 6, p.433-442.

TAKEKOSHI, A.; AOKI, T.; TAKAHASHI, I.; TOMISHIMA, H.; YOSHINO, M. 1989. Application of Knowledge Engineering for Iron and Steel Making works. *NKK Technical Review*. No. 56, p.1-9.

TAKENAKA, K.; YOKOI, T. 1992. Development of an Expert System Building Tool : SMI/MARKS-II. *The Sumitomo Search No. 50*. July, p.11-19.

TAN, S.; MAH, R.S.H.; KARIMI, I.A. 1993. Interactive approach to the design of non-continuous plant. *Computers and Chemical Engineering*. Jan., Vol. 17(1), p. 71-93.

TANSLEY, D.S.W.; HAYBALL, C.C. 1993. *Knowledge-based systems analysis and design a KADS developers handbook*. BCS Practioner series. Prentice Hall, p.327-365.

THOMAS, M. 1991. How should Senior Managers react to Expert Systems? *The Enterprise Initiative*, Summer, p.6-8.

VALLEY, K. 1992. Explanation, Exploration, and Learning: The Use of Expert System Shells in Education. *Jl. of Artificial Intelligence in Education*, 3 (3), p.255-273.

VORONTSOV, V.; POLUKHIN, P.I.; BRINZA, V.V.; BOIKO, V.F. 1985. Optimization of reduction sequences for blooming mill rolling. *Steel in the USSR*. May, vol 15, [lz 85-89] UDC 621.771.22.014, p.226-228.

WANG, Q.; ZHOU, J.; YU, J. 1988. A Chain-Drive Design Expert System and CAD System. *Expert Systems in Engineering*. Edited D T Pham. IFS Publications.

WATSON, I. 1994. The Case for Case-Based Reasoning. *EPSRC project number GR/J42496*. University of Salford, Bridgewater Building, Salford, M5 4WT, ENGLAND.

WILSON, J, ICAD. Knowledge-Based Systems in CADCAM. *ICAD Engineering Automation Ltd.*

WOODWARD, J.; CORBETT, J. 1990. An Expert System to Assist the Design for Manufacture of Die Cast Components. *Engineering Designer*. May/June, p.14-17.

YEH, N.C.; REKLAITIS, V. 1987. Synthesis and sizing of batch/semi-continuous processes: Single product plants. *Computers and Chemical Engineering*. Vol. 11, p.639-654.

A | B | C | D | E | F | G | H | I | J | K

CASE ONE

ASSESSMENT OF TECHNICAL & FINANCIAL EFFECT OF FITTING ENCOPANELS & INTERSTAND COOLING	PAGE ONE DATE RUN TIME	28-Apr 15:25:13

The starting point is the monthly output split by gauge and quality:-

MONTHLY PRODUCT MIX BY GAUGE RANGE & QUALITY

GAUGE / QUALITY	<1.80	1.8-2.0	2.0-2.5	2.5-3.0	3-4	4-5	5-6	6-8	>8	TOTAL
SPHC	6841	11467	11702	5558	8921	8595	5201	4353	881	63499
SAE1008/20	0	105	864	128	141	128	0	0	0	1384
MP 1/2/3	918	1377	10190	1850	344	557	248	0	33	15313
SPHT 1/2/3	290	2317	817	1883	1571	593	120	1938	139	9788
1008/45RRC	300	8815	33712	12107	15513	0	15	0	0	70482
COLD	0	3857	11557	38408	32788	6984	380	39	0	93789
TOTAL*	8347	27738	68842	59830	59258	16857	5942	6330	1033	254175
TOTAL REST	2018	1451	9419	1903	10291	5331	7416	6369	10130	54329
SUB-TOTAL	10366	29189	78261	61733	69547	22188	13358	12699	11163	308504

This product has been simulated by the following coils:-

TYPICAL GAUGES	1.57	1.78	2.02 2.33	2.82	2.95	4.54				HOURS AVAILABLE
MODEL REF #	LOG0	LOG3	LOG2 LOG8	LOG5	LOG1	LOG4				669
ORIGINAL KG/MM &	15.4	14.7	14.4 18.8	18.3	15.4	18.2	18.2	18.2	18.2	
TFR BAR MM	38	35	37.5 40.8	40.7	38.1	42.8				

This enables us to calculate the rolling hours per month:-

PART ONE:- CALCULATION OF HOURS TO ROLL MONTH'S PRODUCTION

BASE TPH	526	588	837 905	992	855	1075	1075	1075	1075	TOTAL HOURS PER MONTH
BASE HOURS LIMIT 1000TPH	19.7	49.6	46.8 43.2	62.2	81.3	22.2	13.4	12.7	11.2	
TOTAL	19.7	49.6	90.0	62.2	81.3	22.2	13.4	12.7	11.2	382.3

PRACTICE WITH FULL LENGTH BARS ⇒ LOWER TEMPERATURES

NEW KG/MM &	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3	18.3	
TFR BAR MM	41	38	40.5 43	42.5	40	42				
NEW TPH	546	622	906 970	1003	954	1037	1037	1037	1037	
NEW HOURS	19.0	48.9	43.2 40.3	61.7	72.9	22.2	13.4	12.7	11.2	
TOTAL	19.0	48.9	83.5	61.7	72.9	22.2	13.4	12.7	11.2	343.5

ASSUMED PROFIT PER TONNE ON EXTRA OUTPUT	60 $/TONNE	POTENTIAL HOURS SAVED	18.8
		POTENTIAL EXTRA MONTHLY OUTPUT	16914
		PERCENTAGE OF NORMAL OUTPUT	5.5
NEW AVERAGE ROLLING RATE	898 TPH	VALUE OF EXTRA OUTPUT $	845715

The rest of the potential sources of financial savings are assessed in Part Two, below:-

PART TWO– CALCULATION OF FUEL, SCALE & YIELD SAVINGS

PAGE TWO — TOTAL

1 COMPARISON OF R1 ENTRY TEMPERATURES

										TOTAL
								C/F FROM PAGE ONE		8457.15
GAUGE MM	1.57	1.78	2.02/2.33	2.82	2.95	4.54	5.5	7.5	10	
ORIGINAL	1250.0	1242.0	1228.5	1230.0	1255.0	1244.0	1244.0	1244.0	1244.0	
REVISED	1235.0	1192.0	1183.5	1180.0	1205.0	1184.0	1184.0	1184.0	1184.0	
SAVING	15	50	45	50	50	60	60	60	60	
FACTOR FOR SAVING AT FURNACES				1.05	1					
TEMP SAVING @ FURNACES	15.75	52.5	47.25	52.5	52.5	63	63	63	63	
FUEL SAVING BASED ON 50 DEGREES=10%. PERCENT	3.15	10.5	9.45	10.5	10.5	12.6	12.6	12.6	12.6	
FUEL COST PER TONNE ASSUMED TO BE–				10	$/TONNE					
TOTAL POTENTIAL FUEL SAVING DUE TO TEMPERATURE REDUCTION	3286	30648	73957	84820	73024	27957	18831	18001	14065	320588

2 ENERGY SAVING DUE TO USING LONGER SLABS

INITIAL SPECIFIC WEIGHT TIMES APPLICABLE TONNAGE						AVERAGE	18.5	TOTAL–	5083724	
	159838	429078	1213048	1129714	1071024	403822	243118	231122	203187	
REVISED SPECIFIC WEIGHT TIMES APPLICABLE TONNAGE							18.3	TOTAL–	5845823	
	189698	534158	1432178	1129714	1272710	406040	244451	232392	204283	

AVERAGE HEATING COST IS REDUCED BY RATIO OF OLD OVER NEW AVERAGE SPECIFIC WEIGHTS.

REVISED BASIC HEATING COST $ 8.00 SAVING IS 1.00 DOLLAR PER TONNE

THE POTENTIAL MONTHLY FUEL SAVING AMOUNTS TO– 307049

3 SCALE SAVINGS

SCALE SAVING BASED ON ONE HUNDREDTH PART OF FUEL SAVING PERCENTAGE

SCRAP PRICE ASSUMED TO BE 150 $/TONNE MILL SCALE HAS ZERO VALUE.

PRIME PRICE ASSUMED TO BE 300 $/TONNE

TOTAL POTENTIAL SCALE SAVINGS	980	9195	22187	19448	21907	8387	5049	4800	4220	98171

4 CROP LOSS SAVINGS

CROP LOSS RATE ASSUMED TO BE 1.2 PERCENT

SAVING IN CROP LOSSES BASED ON RATIO OF SPECIFIC WEIGHTS DIVIDED BY RATIO OF TRANSFER BAR THICKNESS.

WT RATIO	1.09	1.25	1.19	1.00	1.19	1.00	1.00	1.00	1.00	
BAR RATIO	0.88	0.83	0.89	0.96	0.95	1.02	1.02	1.02	1.02	
YLD RATIO	0.982	1.040	1.066	0.957	1.133	1.019	1.019	1.019	1.019	
NEW YIELD	1.248	1.154	1.125	1.255	1.059	1.178	1.178	1.178	1.178	
T SAVED	[illegible]	13.6	58.4	-33.7	97.8	5.0	3.0	2.8	2.5	
VALUE $	-743	2023	8758	-5048	14688	747	449	427	378	21655

5 REDUCTION IN COBBLE LOSSES

IT IS ASSUMED THAT THE NUMBER OF PUSHOVER BARS & TAIL END TEAR-OFF WILL REDUCE INCREASING YIELD BY 0.1 PERCENT

VALUE $	1555	4378	11739	9280	10432	3328	2004	1905	1874	48276

6 POWER SAVINGS

THE REDUCTION IN FURNACE TEMPERATURE IS ACCOMPANIED BY AN INCREASE IN BREAKDOWN THICKNESS. WHICH MEANS VIRTUALLY NO CHANGE IN ROUGHING MILL POWER CONSUMPTION.

THE FINISHING TRAIN POWER CONSUMPTION REDUCES BY THE FOLLOWING KWH/TONNE–

KWH/T	1.65	-0.28	-0.11	0.52	-0.30	0.01	0.01	0.01	0.01	
KWH	17089	-7448	-8532	32229	-21098	125	75	71	63	

TAKING POWER COSTS @ 5 US CENTS PER KWH GIVES SAVING OF 829

THE GRAND TOTAL OF POTENTIAL MONTHLY SAVINGS AMOUNTS TO $ 1838062

GROSS ANNUAL POTENTIAL $M 19.7

	A	B	C	D	E	F	G	H	I	J
579										
580		ASSESSMENT OF RETURN ON CAPITAL							PAGE THREE	
								POTENTIAL ANNUAL SAVING $M		
		BEING CONSERVATIVE, LET US ASSUME THAT ONLY SOME								
		35	PERCENT OF SAVINGS CAN BE REALISED. IF SO THE ANNUAL							
			IMPROVEMENT IN PROFIT, PRIOR TO CAPITAL CHARGES AND							
585			RUNNING COST IS				$ 6879862		SAY $M	6.88
	CAPITAL CHARGES		IF TOTAL CAPITAL COST OF ENCOPANELS & ISC IS APPROX $5 MILLION							
			AND IF CAPITAL & INTEREST CHARGES ARE				20 %		$M	
					THE ANNUAL CAPITAL CHARGES ARE				1.00	
590	MAINTENANCE		IF ENCOPANEL MAINTENANCE COSTS ARE				5	US CENTS/TONNE		
	COSTS				THE ANNUAL MAINTENANCE COST WOULD BE				0.19	
										1.19
	PAYBACK		THE PAYBACK PERIOD WOULD BE			9	MONTHS.			
595	RETURN ON CAPITAL		AFTER INTEREST CHARGES OF 10%			124	PERCENT.			
			(EXCLUDING DEPRECIATION).					NET PROFITABILITY $M		5.69
596	====	====	====	====	====	====	====	====	====	====

(1) Comparison of R1 Entry Temperatures

Original

B519 :	D403	SlabTemperatures at R1 ⇒ (Part 1)	Derived from EHSM
C519 :	D145		
D519 :	(D79 + D343) / 2		
E519 :	D277		
F519 :	D14		
G519 :	D211		
H519 :	G519		
I519 :	H519		
J519 :	I519		

Revised

B520 :	T403	SlabTemperatures at R1 ⇒ (Part 2)	Derived from EHSM
C520 :	T145		
D520 :	(T79 + T343) / 2		
E520 :	T277		
F520 :	T14		
G520 :	S211		
H520 :	G520		
I520 :	H520		
J520 :	I520		

Temperature Savings at Furnaces

B525 : B522 x Factor for saving at furnaces
C525 : C522 x Factor for saving at furnaces
D525 : D522 x Factor for saving at furnaces
E525 : E522 x Factor for saving at furnaces
F525 : F522 x Factor for saving at furnaces
G525 : G522 x Factor for saving at furnaces
H525 : H522 x Factor for saving at furnaces
I525 : I522 x Factor for saving at furnaces
J525 : J522 x Factor for saving at furnaces

Fuel Savings based on 50 Degrees = 10%

B527 : B525 / 50 x 10
C525 : C525 / 50 x 10
D525 : D525 / 50 x 10
E525 : E525 / 50 x 10
F525 : F525 / 50 x 10
G525 : G525 / 50 x 10
H525 : H525 / 50 x 10
I525 : I525 / 50 x 10
J525 : J525 / 50 x 10

Total Potential Fuel Savings

B531 : B527 / 100 x [Fuel cost / Tonne] x B475
C531 : C527 / 100 x [Fuel cost / Tonne] x C475
D531 : D527 / 100 x [Fuel cost / Tonne] x D475
E531 : E527 / 100 x [Fuel cost / Tonne] x E475
F531 : F527 / 100 x [Fuel cost / Tonne] x F475
G531 : G527 / 100 x [Fuel cost / Tonne] x G475
H531 : H527 / 100 x [Fuel cost / Tonne] x H475
I531 : I527 / 100 x [Fuel cost / Tonne] x I475
J531 : J527 / 100 x [Fuel cost / Tonne] x J475

(2) Initial Specific Weight times Applicable Tonnage

B536 : B475 x B483 } Total Tonnage for a certain Thickness of Product x Original kg / mm
C536 :
"
"

Revised Specific Weight times Applicable Tonnage

Similar to above but using data from part 2

Revised Basic Heating Cost D540 : H535 / H537 x E528
Saving is F540 : E528 - D540

(3) Total Potential Scale Savings

Based on one Hundredth of fuel savings

B549 : B527 / 100 x B475 x Prime Price / 100
C549 :
"
"

(4) Weight Ratio

B555 : T404 / D404
C555 : T146 / D146
D555 : (T80 / D80 + T344 / D344) / 2
E555 : R278 / D278
F555 : T15 / D15
G555 : R212 / D212
H555 : G555
I555 : H555
J555 : I555

Bar Ratio

B556 :	D402 / T402
C556 :	D144 / T144
D556 :	(D78 / T78 + D342/T342) / 2
E556 :	D276 / R276
F556 :	D13 / T13
G556 :	D210 / R210
H556 :	G556
I556 :	H556
J556 :	I556

Yield Ratio

B557 : B555 x B556
C557 :
"
"

New Yield

B558 : Crop Loss Rate / B557
C558 :
"
"

Time Saved

B559 : (Crop Loss Rate - B558) / 100 x B475
C559 :
"
"

Value $

B559 : B559 x (E547 - E546) → Difference between Scrap Price and Prime Price
C559 :
"
"

(5) **Value $**

B565 : G564 / 100 x B475 x (E547 - E546)
C565 :
"
"

(6) KwH / T

B572 :	P451 - T451
C572 :	P193 - T193
D572 :	(D127 + P391 - T127 - T391) / 2
E572 :	P325 - S325
F572 :	-T61 + D62
G572 :	P259 - R259
H572 :	G572
I572 :	H572
J572 :	I572

KwH

B573 :	B572 x B475
C573 :	
"	
"	

Annual Improvement in Profit

G585 : K576 x 12 x $\underbrace{\text{Percentage of Savings which can be realised}}$ / 100

Capital Charges

If Capital and Interest Charges are 20% and Total Capital Cost of Enco Panels and Interstand Cooling is $5 Million

I590 : $\underbrace{\text{G588}}_{\text{20\%}}$ / 100 x 5

Maintenance

Enco Panel Maintenance costs are 5 U.S. cents / Tonne

I591 : $\underbrace{\text{G590}}_{\text{5\%}}$ / 100 x 12 x K475 x 10^6

Payback Period

(Months)

F594 : 5 / $\underbrace{\text{(J596 + I596)}}_{\text{Net Profitability + Annual Capital Charges}}$ x 12

Return on Capital

After Interest charges of 10%

F595 : (J596 + I589 / 2) / 5 x 100

Base TPH

B490 :	D450
C490 :	D192
D490 :	D126
D491 :	D390
E490 :	D324
F490 :	D61
G490 :	G258

Tonnes / Hour @ 100% Efficiency
Part 1

New TPH

B502 :	T450
C502 :	T192
D502 :	T126
D503 :	T390
E502 :	S324
F502 :	T61
G502 :	R258

Tonnes / Hour @ 100% Efficiency
Full Slab   Existing
Tail End Load   < Tail End Load
Total RMS Power < Total RMS Power
Else Use Enco low temp.
The higher the temperature the greater the fuel usage.

INPUT DATA:-

Mill type is hot strip mill.
Mill size is 1739 mm/68 inch.
Table application is ingoing main table.
Single products are placed within 50 mm of the table centre.
Maximum product width = 1000 mm.
Amount of roller diameter modification = 0 mm.
Velocity of product = 1 m/s.
Acceleration rate of product = 1 m/s^2.
Mass of product = 30000 kg.
Number of products per hour = 7.
Number of passes per cycle = 7.
Mill base speed = 2 m/s.
Mill top speed = 4 m/s.
Base to base time = 2 s.
Top to top time = 5 s.

OUTPUT RESULTS:-

BASIC ROLLER TABLE DATA:

Roller is solid type.
Roller diameter = 400 mm.
Roller table pitch = 750 mm.
Roller barrel length = 1200 mm.
Roller mass = 1243 kg.
Roller GD^2 = 99 kg-m^2.
The number of rollers that the product rests on = 2.

MOTOR POWER CALCULATIONS:

Roller R.P.M. = 47.7 (at product velocity of 1 m/s).
Full load torque = 1562 N-m (at acceleration rate of 1/2 m/s^2).
Skid power = 51450 Watts (static coefficient of friction being 0.35).
Roller inertial acceleration torque = 124 N-m.
Product acceleration torque = 3000 N-m.
Total acceleration torque = 3124 N-m.
Total acceleration power = 15621 Watts.
RMS acceleration torque for mill affected rollers = 37 N-m.
RMS acceleration torque for product = 350 N-m.
RMS acceleration torque = 352 N-m.
Cycle time = 514.3 s.
Time product is on each roller per cycle = 10.5 s.

MOTOR SELECTION:
Standard drive type is ind dc 800 series.
Alternative drive type is ind ac.
Motor frame = 814.
Motor power = 112000 Watts.
Motor R.P.M. = 500.
Motor torque = 2139 N-m.
Single motor price = œ 23620.

Motor frame one size below the full load torque requirement:
Motor frame = 812.
Motor power = 74600 Watts.
Motor R.P.M. = 515.
Motor torque = 1383 N-m.
Single motor price = œ 20045.

IMPACT LOAD CALCULATION:
Impact load = 1.1277 MN.
Product front turndown = 50 mm.
Thickness of product = 382.2 mm

THE COUPLING BEING USED IS:
WELLMAN BIBBY GEAR COUPLINGS type GFS/GFSW
Specifications:
Size = 30
Rating kW per RPM = 1.1
Max. speed RPM = 4400
Max. bore flexible hub (mm) = 100
Min. bore diameter (mm) = 39

BEARING TYPE - Spherical roller
Specifications:

Principal dimensions:	d	= 90
(mm)	D	= 190
	B	= 64
Basic load rating:	Dynamic (C)	= 477000
(N)	Static (Co)	= 610000
Fatigue load limit (Pu) (N)		= 60000
Speed ratings:	grease	= 1800
(r/min)	oil	= 2400
Mass (kg)		= 8.6

Designations:
bearings with cylindrical bore 22318 CC/W33
tapered bore 22318 CCK/W33

SEAL SPECIFICATIONS:
Walkersele - Spring loaded lip seals for Rotary shafts
Part no = 99-999
Width of seal = 20
Thickness of seal = 16
Width of seal housing = 16
Diameter of seal housing = 144

ROLLER DIMENSIONS:

The barrel length of the roller			= 1200
The width of the coupling seat			= 183
The width of the bearing seat			= 124
The width of the seal seat			= 218
The width of the turn down between D1 and D2			= 148
Diameters:	D1	= 400	
	D2	= 104	
	D3	= 90	
	D4	= 87	
Fillet radii: between D1 and D2			= 148
	r2		= 2.5
	r3		= 2.5

UTILISATION FACTORS:
Bending Stress: Non - Fatigue
Utilisation ratio at section X - X = 0.81556
Utilisation ratio at section K - K = 1.08788

Bending Stress : Fatigue
Utilisation ratio at section X - X = 1.14331
Utilisation ratio at section K - K = 1.52506

Torsion : Non - Fatigue
Roller Stall Torque
Utilisation ratio at section X - X = 0.17781
Utilisation ratio at section K - K = 0.40658
Utilisation ratio at section Y - Y = 0.69436

Torsion : Fatigue
Roller Accelerating Product
Utilisation ratio at section X - X = 0.24951
Utilisation ratio at section K - K = 0.57052
Utilisation ratio at section Y - Y = 0.97434

DAVY SHEFFIELD HOT STRIP MILL PROGRAM EHSM OR EHSMW First Editio 17/4/92

A GUIDE FOR USERS PREPARED BY E. C. HEWITT. This Edition run: 22/4/92.

For all roughing layouts where slab width reduction by edging can be ignored, if not use RTRRE instead.
Input comprises 3 data sheets: M for layout, R for Rougher, W, P or S for Finishers. P & S can't use isc or enco.

LAYOUTS THAT CAN BE SIMULATED File ehsm You must use W sheet with EHSMW

1 **SEMI-CONTINUOUS WITH OR WITHOUT HSB**

If Line 8=YES, Temps on R sheet are at HSB entry

The EHSM program ignores the VSB

VSB HSB RR FSB X oo C/S F1 F2 F3

On the M SHEET:- Line 8=YES Line 9=NO, Line 10=YES, Lines 11 to 14=NO.

If Line 8= NO on M sheet, temps are at RR entry, not at furnace drop-out.

If there is no HSB, but you want temperatures of slabs as if they were at furnace drop out, include a dummy HSB at Furnace exit, and take no reduction, specify speed as approach table speed.

2 **THREE-QUARTER CONTINUOUS, WITH OR WITHOUT HSB**

If Line 8=YES on M sheet, temperatures are at HSB entry otherwise @ RR entry

ONE TO FOUR NON-REVERSING ROUGHERS

VSB HSB RR FSB X etc oo C/S

NON-REVERSING ROUGHERS.

The same comments about the HSB apply. If there is an HSB, but you want slab temperatures to be those at Furnace drop out rather than at the HSB, specify a Dummy HSB at the furnace and a NON-REVERSING ROUGHER where the HSB should be. Thus Lines 8 to 11=YES, Lines 12 to 14=NO

3 **TWIN REVERSING ROUGHERS**

Lines 9, 10, 11, 13 & 14=NO
Line 8=YES LINE 12 = YES

VSB HSB RR RR FSB X etc oo C/S

The same comments about HSBs & Slab temps apply. Where the bar couples the stands, the downstream stand synchronises with the upstream one. Specify which passes are on RR1 and which on RR2 on "R" Sheet. Inserting this line after Line 23 moves subsequent ones down one.

4 **FULLY CONTINUOUS MILL WITH UP TO SIXTEEN ROUGHERS**

Line 8=YES, Lines 9 & 10=NO, Line 11=YES, Lines 12 to 14=NO

VSB HSB R1 R2 R3 R4 R5 FSB X etc oo C/S

R4 & R5 close-coupled or spaced. Where they are close-coupled, the 1st stand synchronises with the 2nd.

5 **ANY OF LAYOUTS ONE TO FOUR ABOVE WITH AN "M-STAND"**

Put Line 13 = YES, and for free air, use "P" Sheet for Finishers.
For M-Stands with w/c isc or encos, L13=0, use "W" Sheet, put M-stand as F0, big gap, with fixed flow w/c to simulate FSB and FSB data for pre-M descaling.

M FSB X oo C/S F1 F2

6 **ALTERNATIVELY, ANY OF LAYOUTS ONE TO FOUR WITH A COILBOX**

Put Line 14 = YES
Beware that Line 15 then must include distance c/b to c/s & temp loss rate, and this moves all subsequent lines down one line.

7 **ANY OF LAYOUTS ONE TO FIVE WITH ENCOPANELS**

Ignore temperatures at crop shear calculated by Roughing Program.
Instead insert output from ENCO Program (set to give results at FSB) at Line 40 on "W" Sheet.

NOTE ON THE USE OF PROGRAM EHSM

1 The various layouts that can be simulated are shown on the diagram.

2 **Roughing Mill Calculations**

The program tells you what the head and tail powers, loads, torques and temperatures will be in the roll bite at each pass in the roughing mill. The program is unaware ofthe installed power, the mill base speed & top speed. The user must define sensible reductions that will not exceed bite angle limitations and must adjust these, together with the speeds, to keep within the proposed power and load limits.

{ N.B. Program RTRRE, used for calculating width reduction on single or twin reversing roughers, each with one or two edgers, prints out bite angles and warning messages where these exceed given limits. At present RTRRE is not connectible to other programs other than by manual input of results.}

Where the Rougher is a Reversing Rougher with a power that can easily impose peak limits, it is often better to take large reductions at very slow speeds rather than use two more passes and employ ligher reductions at higher speeds.

3 **Crop Shear Temperatures or Coilbox temperatures**

The Rougher program gives the temperature of the Front End as it reaches the crop shear. It also gives the temperature of the Back End at the same instant in time, which explains why the Tail is hotter than the Head. Where a Coil box is being used, the Rougher program gives the Head & Tail temperatures at the end of the coiling operation. Note that what was the Head is now the Inner End and what was the Tail is now the Outer End.

The program assumes that the transfer bar proceeds to the crop shear at the speed of the last rougher. There is no facility to allow for bar acceleration on tail out, nor to alter the point at which the bar starts to decelerate to cropping. The present ENCO program allows the latter, but not the former.

Where the last rougher is a Reversing Rougher, the best way to conserve energy on the delay table, under free-air conditions, is to take a small enough reduction on the last pass to allow the rougher to roll at the fastest practicable speed without exceeding peak power limits.

When using the STELCO Coilbox option this advice must be tempered by the fact that it is usual to enter a Coilbox at around 2 M/s and accelerate to about 4.5 M/s once the first wrap is formed, decelerating again at the tail, so the AVERAGE speed must be less than the maximum.

When simulating the Finishing Train, the "P", "S" or "W" Sheet may be used, but in each case it is necessary to estimate the loss in temperature in the transfer bar at Head and Tail whilst travelling from the Crop Shear to the Finishing Scalebreaker (FSB). { The ENCO program may be manipulated to give this figure if so desired.}

When using the "W" Sheet in conjunction with ENCOPANELS or Free-air, it is possible to use the ENCO program to calculate what the transfer bar temperature will be at the FSB under either Free-air or ENCOPANEL conditions, in which case the drop from Crop Shear to FSB is not used in the calculation. Instead, the FSB temperatures, inserted at Line 40 on the "W" Sheet, take precedence over the Free-air temperatures calculated by the "R" Sheet.

4 **Finisher Calculations with Free-air and without Interstand Cooling** Page Two

For free-air radiation on the delay table or with a Coilbox, the "P" or the "S" Sheet may be used to calculate the Finisher conditions, but neither permits the use of Interstand Cooling, for which the "W" Sheet must be used.

THE "P" SHEET is intended to allow several different attempts at simulating a selected reduction pattern and a given slab temperature, in an attempt to find, by trial & error, what thread speed, what acceleration rate and what maximum and tail out speeds will give the desired output rate whilst meeting, by inspection, Finishing temperature and Power stipulations.

THE "S" SHEET allows, for a selected slab temperature and reduction pattern, a Target Finishing Temperature to be set, together with maximum Thread and Tailout speeds. The program then attempts, within these parameters, to calculate what Thread speed, acceleration rate, Top speed and Tailout speed will best achieve the specified temperature.

5 **Simulating M-Stands without ENCOs or Interstand Cooling**

The M-Stand details are specified on the "M" & "R" sheets when using the "P" or "S" Sheets for the Finishers. A descaling operation must be specified in front of the M-Stand at Line 8 on the "R" Sheet. The action level (i.e the temperature drop) and the FSB action level must be set at Line 7 on the "M" Sheet.

The results are printed out with the M-Stand appearing as part of the Finishing Train.

6 **Simulating M-Stands with ENCOPANELS and/or Interstand Cooling**

When using the "P" or "S" Sheets, the program assumes free-air radiation between the last Rougher and the M-Stand. If the M-Stand is to be used in conjunction with ENCOPANELS, the ENCO program has to be used first to arrive at the temperatures that will occur at the descaling headers in front of the M-Stand. These temperatures can only be inserted into EHSM when using the "W" Sheet for the Finishers, and in this case the M-Stand has to be simulated by calling it an F0 Stand, spacing it far enough ahead of F1 to allow for the crop shear and FSB. The descaling action ahead of the M-Stand (F0) now becomes the FSB as far as the Program is concerned. The second descaling action at the real FSB has to be specified as a fixed flow on the F0 water curtains. If you also want to use other water curtains for temperature control to a selected target Finishing Temperature, you must use Program EHSMW. EHSM would ignore the Target Temperature and not call up any water in later gaps.

7 **Specifying entry temperatures to the Finishing Scalebreaker**

In the paragraphs that follow, reference to line numbers on the W sheet assume that a Stelco Coilbox is not in use. They would be 1 greater with a C/b.

The "W" Sheet allows you to over-ride the free-air temperatures at the FSB by specifying figures at Line 40 instead of putting in Zeroes for each of the points along the transfer bar. The points are specified at Line 39, with the number of points stated at Line 38.

Do not specify FSB temperatures with a Coilbox!

If the Target Temperature is specified at Line 33, the program calculates the water curtain flows in either Forward, Reverse or Equal Cooling mode to achieve this and ERROR MESSAGES will print out either if the Finishing Temperature is below target with no water or above target with maximum flow from all active curtains. NB: If you are using EHSM, whilst you can specify a FIXED FLOW in any desired Gap, this not only acts all the way down the bar, but it disables all the other curtains and the result ignores the Target Temperature.

8 **Including Water Curtains ahead of F1**

If you want to specify a water curtain in front of the First Finisher, you must insert a dummy stand in front of it, take no reduction, but either put in a desired flow or a Zero to allow it to calculate. Where you are trying to use this extra pair of curtains to keep the entry temperature into F1 down to a particular figure, this can only be achieved by trial & error, but it will only give the right answer at one point down the bar. It would be more usual to use such an extra curtain to give extra scale suppression between the FSB and F1, in which case a low flow of around 10-15% would achieve it. Care must be taken to see that this fixed flow does not put the Finishing Temperature below Target at any point down the bar. NB: When using Program EHSM, the addition of a fixed flow ahead of F1 will disable the other unspecified curtains. If you still want to control to Target Finishing Temperature, you must use EHSMW.

9 **Operating Water Curtains in the last Interstand Gap**

With the "W" sheet, the program ignores any attempt to make the curtains in the last interstand gap give any flow. This is because, when the program was designed, Davy felt that curtains should not be used in this position in case they gave uneven temperatures across the width and/or damaged strip shape.

In order to obtain flow in the last gap, specify an extra dummy finisher taking zero reduction. Place it very close to the real last Finisher so as not to artificially lower the Pyro reading. Setting the flow on what is now one before the penultimate stand is now possible, either as a fixed flow or as a calculated flow.

10 **Operating Water Curtains downstream of the last Finisher**

As at 9 above, this can only be achieved by specifying two dummy finishers taking zero reductions and located very close together. The flow after the real last Finisher can now be activated in either Fixed Flow or calculation mode.

Whilst there could be metallurgical advantages on some grades of suppressing surface temperatures or removing bulk temperature prior to the strip arriving at the first ROTC headers, there could be problems in measuring a meaningful Finishing Temperature at the Pyro and the widthmeter and X-Ray gauge readings might be adversely affected.

11 **Disabling Certain Water Curtains**

To do this, you must use EHSMW instead of EHSM. On Line 37 of "W" Sheet (Line 38 when using a STELCO Coilbox), you can disable any pairs of curtains by entering "-1" instead of "0". EHSMW allows Fixed Flows to be specified elsewhere and for calculations to be made of the flows needed, on the curtains where "0" applied, to hit Target Temperature. This version of the program allows the remaining "active" curtains to run in Forward, Reverse or Equal Cooling Mode.

12 **Simulations where part of the Bar will be Below Target Temperature**

The Davy Water Curtain type Interstand Cooling System has to be switched on at a flow level substantially above the minimum in order to establish. It can then be turned down to 10% flow level prior to the arrival of the Head end of the transfer bar. If X curtains will be required to control temperature at the hottest point, that number of curtains must be selected for the Head End. The EHSM and EHSMW Programs calculate the required flow entirely without regard to these practical problems. Thus in Forward or Reverse Flow, the program may well show that NONE or only one pair of curtains is needed at the Front End and then show additional pairs switched on at subsequent points. This can be important where the simulations are being undertaken as part of a Study of Interstand Cooling, particularly if Guarantees are involved.

Where the above considerations apply, the slab temperature/transfer bar thickness/thread speed combination should be chosen such that the Front End needs sufficient cooling to need say three pairs running at just over minimum flow. It is probably best therefore to simulate the curtains in Equal Flow Mode and disable one or two pairs provided that the hottest point does not then go above target.

Where ACCELERATION does not start until the Front End is some way down the Run-out Table or is at the Downcoiler, the point then at the Pyro will be colder than the Front End. If the Front End would only have been just above Target Temperature without ISC, the Coldest Point may well be below Target, even without ISC. This can be an important consideration when setting ISC guarantees.

Furthermore, EHSM & EHSMW have a quirk in that once a curtain a pair of curtains have been switched on, they will not switch off even if, at the position studied, the result is to push the Finishing Temperature below Target.

This can occur at the Tail End, particularly if the mill is decelerated to a Tailout Speed substantially below the Maximum speed reached. If, at the Penultimate Point computed, the Water Quantity used is substantial and causing a major drop in Finishing Temperature, the SAME QUANTITY of water will be applied at the Tail End, the result being that the Tail End is cooled excessively. This may not only cause an artificially low Finishing Temperature to be calculated, it will also result in much higher Rolling Loads and Peak Powers, resulting in the RMS Powers being too high.

The cure to the problem is to introduce one EXTRA point on the bar, just prior to the Tail. By trial & error, the position of this extra point must be found such that with only one pair of curtains then operating, at near minimum flow, the Finishing Temperature is still above Target. This problem could perhaps be avoided by disregarding the need to tailout at less than the Maximum speed, but such practice, as well as being unlike what happens in practice, will result in cycle times shorter than they should be, output rates higher than they should be, etc.

Each extra point on the bar adds to the computing time and, more importantly, adds to the length of the print-out and the time it takes. So, depending on how critical the results are and for what they are to be used, it is best to use the minimum number of points. THREE but preferably FOUR points is the minimum for the RMS calculation to have any meaning.

1 3 Computation of Finishing Train Data

It is important to appreciate that the Model works by tracking a segment of transfer bar, from either the Crop Shear or the FSB, through the FSB and through each Finishing Stand in turn, eventually printing out the temperature at which that segment will reach the Finishing Pyro.

The Davy Interstand Cooling Control Model works in the same way.

One consequence of this is that a print-out for the Head End does NOT show what the various measuring instruments would be indicating at the instant that the Head End reached the Finishing Pyro. As a result, a photo of a Pulpit Screen for the Head End would not agree with the Model's Head End print-out. EVEN IF THE MODEL WERE 100% ACCURATE.
To get such a comparison, a Data-logger would have to record the conditions on each stand in turn as the Head End passed it.

When using the "P" or "S" Sheets, it is possible to ask for a FULL print-out. This can comprise up to ten Blocks of data. The first Block is always the Head End, the second Block is the point on the bar when the head end reached the Finishing Pyro. The third Block is the point when the head end reached the coiler, if that is where acceleration is specified to start, if not, one mill fill after the second Block. Each subsequent Block is one mill fill further down the bar, with the final Block being the Tail End.

When using the "W" Sheet, you can specify the number of points to be computed and printed, their locations and the FSB temperatures at those points. Alternatively, by putting Zeroes on Line 40 against the temperatures, the computer will calculate the Free-air temperatures at the Crop Shear, take off the proportionate drop from C/S to FSB and then proceed as before. If Zero is put on Line 38, instead of the number of points, Lines 39 and 40 must be omitted. The program proceeds as described above for the "P" or "S" Sheet, but calculating the ISC quantities for each point as long as a Target Temperature has been specified at Line 32.

1 4 ERROR MESSAGES - Some examples of why they happen and what to do.

BEWARE!! If, when using the "W" Sheet, the number of points is put to ZERO at Line 38, but both point locations at Line 39 and temperatures at Line 40 are inserted, the Program will run, but there MAY be an ERROR MESSAGE at the foot of the print-out. The program will perceive an incorrect number for the Data Sheet Terminator, the Print-out Option, for the gap time between bars and for the Percentage of Full Output to be given. The RMS Powers and the output may well be wrongly stated.

BEWARE!! If the number of points at Line 38 does not agree with the number of data groups filled in at Lines 39 & 40, the Program will not run, but the ERROR MESSAGE will not be sufficiently explicit to find out WHY it did not run. Much the same thing will happen if any Line fails to contain the number of data groups expected. If you get into this sort of situation, call for a print-out of Lines 1 to 42, using EDLIN, and compare it with the same listing for a File that uses the same ["P", "S" or "W"] Data Sheet and DOES compute correctly. Check that the number of data groups on each line correspond.

If the number of passes called for does not agree with the number of individual thicknesses listed, either in the Roughing Sheet [R] or the Finishing Sheet [P, S, or W], the Program will either abort, giving an unhelpful ERROR MESSAGE, or, worse still, it may compute but give a different number of passes than you wanted, a different finished thickness, a wrong transfer bar thickness, a wrong cycle time, etc.

1 5 Data Files of INPUT and OUTPUT

Where the Data uses a "W" Sheet, the Input information for EHSM can be run on either EHSM or EHSMW without modification to the data itself. On EHSM, the specification of Fixed Flow for any water curtain disables the rest and causes the program to ignore the Target Finishing Temperature. If you do not want this to happen, or if you want to disable one or more pairs of curtains, you must type EHSMW when the Computer asks for the Program Name. You fill in "EHSM" on Line 2 of the "M" Sheet even when you are using EHSMW. When you run the program, you are asked for the Directory first. All the examples are in the "INLAND" Directory. You are next asked for the File name. After entering this the computer asks for the Program Name. Type EHSM or EHSMW.

File names can comprise up to SEVEN alphanumerics. There MUST NOT be a decimal point in the name. Where you want the name to include a gauge reference, such as 1.7mm, the Filename might be put as "EX1_7HG". The example programs are given names like WCTRIAL, WMTRIAL, PTRIAL, PMTRIAL, STRIAL, SMTRIAL, WMTRIAM or WMTRIAN. See spreadsheet EHSM3 for INDEX to printouts of Data sheets and output.

When using EHSM, the computer stores the Input Data, but once the computer has run the file, the output information is not stored, so a hard copy must be called for by printing it out. The program EHSM123 was conceived specifically to enable a file of certain selected Output Data to be stored for subsequent importation into LOTUS 123 to allow comparisons, graphs, tabulations, etc, to be incorporated into Reports. This Program still exists, but its use is really now limited to studies of mills like PEINE SALZGITTER, to which it was calibrated, or where materials data-logged at Salzgitter are concerned. {The P-S materials are accessed by using numbers from -1 to -40 on the third line of the "R" Sheet, but beware that the print-out always states "mild steel". }

For all applications where the Materials to be studied are either part of the Standard Davy List { 1 to 16 or (X)46, 52, 70 or 80 on the third line of the "R" Sheet. } or are those of the three digit code GARY materials data-logged there, { only accessible if the Mill Identification on Line 7 of the "M" Sheet is Gary, i.e. 2 }, the program to use if you want to produce an Output File is now EHSMW. This has the added advantage of the flexibility in the use of ISC outlined above. The Material selected is stated in the print-out at the head of the Roughing Mill.

The Output File created is in two forms, a TEXT-file and a NUMBERS-file. The TEXT-file is a list of the Headings for which data has been filed. This is the same list every time, so It is distinguished by being called "T" followed by up to seven identification characters. In like manner, the numbers corresponding to the text headings are filed in one called "N" followed by the same seven identification characters. Hence the stipulation that the Data file must not exceed seven characters.

Program EHSMW takes much longer to run than EHSM, because it pauses several times in the run to file data to hard disc, each such action taking ten to twenty seconds. EHSM, on the other hand, takes only 5 to 15 seconds for the whole model. There are some instances where you can prove the data by running in EHSM first and, perhaps after making modifications, run it in EHSMW for the definitive answers. For instance, data for the Roughing Mill only can be run, without running the Finishing Mill portion, by typing ==== in place of "W" on the input data. This part of the program can be run on EHSM to save time and the output is identical with that produced by EHSMW. Once the Roughing Mill module has been edited to your satisfaction, the ==== can be replaced by "W" and the Model name can be changed by adding a W. This method of operation speeds use when running the ENCO program.

If you do not wish to make a TEXT-file or a NUMBERS-file, there is no need to enter a file title, simply press {ENTER{ when asked for the name. This saves cluttering up the disc with unwanted files.

1 6 **Running EHSM or EHSMW in conjunction with ENCOPANELS**

Whereas either program can be made to run automatically with either Free-air cooling on the Delay Table or a STELCO Coilbox, this is not so with ENCOPANELS. The manner in which ENCOPANELS perform relative to the passage time of each part of the transfer bar and to the gap time between consecutive bars makes it difficult to combine the EHSM & ENCO programs. We are developing a linked program, but in the meantime the method of operation is outline below.

Step ONE. Run the Roughing Mill portion of EHSM to obtain the bar thickness, length and temperatures of head & tail in the Roll Bite and the speed at the last roughing pass.

Step TWO. Use the ENCO Program to obtain the temperature of the transfer bar at entry to the FSB when threading F1 in accordance with a predetermined speed and acceleration pattern.

Step THREE. Insert the Fourth Bar ENCO result predictions at the FSB at Line 40 of the "W" Sheet part of the EHSM program in respect of points defined on Line 39.
It would be usual to model at least the Head, Middle & Tail, but if the mill does not accelerate until the head end is some way past the Finishing Pyro, the point that is then at the FSB should also be modelled. Likewise, if the mill is to decelerate rapidly at the tail end, a point near where deceleration begins could with advantage be included.

Step FOUR. Examine the answers for the Finishing Mill to determine if they are within acceptable limits, such as:-

- Is the Head End above Target Temperature without ISC?
- Is the next point also above?
- Is the forecast quantity of ISC satisactorily above minimum flow at these points?
- Are subsequent points controllable to Target Temperature without exceeding say 85% of allowable water quantities?
- Are Peak Powers and RMS Powers within mill limits?
- Are Tail End Rolling Loads within limits and is the cascade of loads satisfactory for good shape and profile?
- Is the Output Rate satisfactory c.f. Furnace & Rougher limits & demand.

In the event that changes are needed to Transfer bar thickness, Slab temperature, Thread Speed, Acceleration Rate, Top Speed, etc, it will be necessary to re-run the Roughing Mill EHSM model and/or the ENCO model. With experience, good first estimates will give satisfactory results.

Where comparisons are being made between Free-air and ENCOPANEL cases, it is important to ensure that the temperature losses on the Delay Table are fairly compared. The passage time at F1 must be the same for the ENCO & EHSM programs. The ENCO program can be run in Logistics Mode to give the time for Head & Tail to reach any desired point. In this mode the program takes much less time to run than when calculating temperatures too.

It can be advantageous to use the ENCO program to predict both the Free-air and the ENCO temperatures at the FSB, so as to get a fair comparison. This is particularly important when trying to justify the purchase of ENCOPANELS or establish Performance Guarantees for these.

Where saving Fuel is important, ENCOPANELS allow thicker transfer bars to be used, reducing the rate of heat loss on the Delay Table even further, hence allowing colder slabs whilst generating more heat at the Head End in the Finishing Train to help hit Target Temperature.

Where increasing output is important, the effect of ENCOPANELS is to require lower acceleration rates unless powerful Interstand Cooling is also fitted. Where there is a tendency at the mid-point or tail to go above Target Temp with all ISC applied, you will have to reduce the thickness of the transfer bar, to generate less heat, but you may then have to increase the slab temperature or increase the Thread Speed to get the Head End to the Finishing Pyro hot enough.

One aim during such comparisons should be to make the Tail End Rolling Loads about the same under Free-air and ENCO conditions. This may allow the slabs to be made longer and colder and the transfer bar to be made thicker simultaneously.

The art of optimising schedules for best return on the capital is too complex to go into fully in this User Guide.

```
ata sheet identifier                                              | M |N|
rogram name                                                | EHSM/TRR |N|
ata sent by        |                                                  |N|
nits (delete one)                                 | METRIC | BRITISH |N|
ill identification |                                                  |N|
emperature units (C - degC, F - degF) (delete one)          | C | F |N|

ot strip mill model number (see below)                          |     |v|
inishing mill descaler const. & Roll temp.(degC or F) |  -1 |v|  -1 |N|

oughing mill description (delete one answer in each box)
                               Stelco coil box              | YES | NO |N|
o. MILL MODEL              |   Horizontal scalebreaker      | YES | NO |N|
-- ----------              |
1  SIDMAR (May. 87)        |   Non-reversing rougher        | YES | NO |N|
2  USS GARY (Sep. 87)      |
3  INLAND STEEL (Nov. 83)  |   Reversing rougher            | YES | NO |N|
4  RAUTARUUKKI (Nov. 83)   |
5  ENSIDESA (Jun. 84)      |   Continuous roughers          | YES | NO |N|
6  HEIDTMAN (Mar. 87)      |
                               Twin reversing rougher       | YES | NO |N|
                               M stand                      | YES | NO |N|

            Total number of roughing stands (maximum 16)   |          |N|

ork roll radii (mm or in) (OMIT if NO Roughing stands)
      |      |v|      |v|      |v|      |v|      |v|      |v|
      |      |v|      |v|      |v|      |v|      |v|      |N|

stance between roughing stands (m or ft) (OMIT if NO Roughing stands)
      |      |v|      |v|      |v|      |v|      |v|      |v|
      |      |v|      |v|      |v|      |v|      |v|
stance from last rougher to Crop shear or Coil box (m or ft) |       |N|

te of temp. loss during Stelco coiling procedure (degC/s or F/s)|    |N|
      (OMIT if NO Stelco coil box present)

            Total number of finishing stands (maximum 11)  |          |N|
rk roll radii (mm or in) (OMIT if NO Finishing stands)
      |      |v|      |v|      |v|      |v|      |v|      |v|
      |      |v|      |v|      |v|      |v|      |v|      |N|

stance between finishing stands (m or ft) (OMIT if NO Finishing stands)
      |      |v|      |v|      |v|      |v|      |v|      |v|
      |      |v|      |v|      |v|      |v|      |v|
                       Run-out table length (m or ft)      |          |N|
```

Sheet:

HOT STRIP MILL - ROUGHING SCHEDULE (EHSM/TRR)

ata sheet identifier ! R !N!

chedule title ! !N!

Slab details

Material code ! !v!

Width (mm or in) ! !v!

Length (m or ft) ! !v!

Thickness (mm or in) ! !v!

Front end temperature at first stand (degC or F) ! !v!

Back end temp when FE at first stand (degC or F) ! !v!

Total number of passes (maximum 16) ! !N!

--------------------OMIT REST OF SHEET IF NO ROUGHING MILL------------------>

.and number (0=HSB, 1 or 2) for Twin reversing rougher only

! !v! !v! !v! !v! !v! !v!

! !v! !v! !v! !v! !v! !N!

ır thickness after each pass (mm or in)

! !v! !v! !v! !v! !v! !v!

! !v! !v! !v! !v! !v! !N!

Speed units (delete two) ! RPM ! MPS ! FPM !N!

ıss speeds (in above units)

! !v! !v! !v! !v! !v! !v!

! !v! !v! !v! !v! !v! !N!

·lay time between passes in Reversing rougher (secs) (0 if no Rev. rougher)

! !v! !v! !v! !v! !v! !v!

! !v! !v! !v! !v! !v! / !N!

Gap time between slabs in Reversing rougher (sec) ! !v!
(put 0 if no Reversing rougher)

Percentage throughput figure (0.0 to 1.0) ! !N!

TE: 1. It is assumed that at least 1 pass is taken in each stand and that pass data is in pass order.

2. If any continuous roughers are close coupled the speeds and thicknesses should reflect this.

If last sheet, type ! ==== !N!

Date: HOT STRIP MILL - FINISHING SCHEDULE (EHSM) Sheet:

Data sheet identifier	! P !N
Schedule title	! !N

Wait on delay table or in SCB	(sec)	! !v
Front end temp. drop from C/S to F1 Descaler	(degC or F)	! !v
Back end temp. drop from C/S to F1 Descaler	(degC or F)	! !v
Total number of finishing passes (maximum 11)		! !v
Upper temperature limit (or 0 if no limit reqd.)	(degC or F)	! !v
Lower temperature limit (or 0 if no limit reqd.)	(degC or F)	! !v
Time before accel. starts after mill thread (for accel. to start when Front end at coiler enter -1)	(sec)	! !v
Total number of sets of speed data (maximum 8)		! !N

Threading speeds (m/s or ft/m) (one for each speed data set)

! !v! !v! !v! !v! !v! !N

Maximum speeds (m/s or ft/m) (one for each speed data set)

! !v! !v! !v! !v! !v! !N

Acceleration rates (m/s/min or ft/m/sec) (one for each speed data set)

! !v! !v! !v! !v! !v! !N!

Tail out speeds (m/s or ft/m) (one for each speed data set)

! !v! !v! !v! !v! !v! !N!

Indicate which (delete one) ! REDUCTION ! THICKNESS !N!

Pass reductions (fractional) or output thicknesses (mm or in)

! !v! !v! !v! !v! !v! !v!

! !v! !v! !v! !v! !v! !N!

Printing option (0=Full print, 1=Four blocks)		! !v!
Gap time between bars	(secs)	! !v!
Percentage throughput figure	(0.0 to 1.0)	! !N!
If last sheet, type		! ==== !N!

Date: | | Sheet:

HOT STRIP MILL - FINISHING SCHEDULE (EHSM)

Data sheet identifier ! S !N

Schedule title ! !N

Wait on delay table or in SCB	(sec)	!	!v
Front end temp. drop from C/S to F1 descaler	(degC or F)	!	!v
Back end temp. drop from C/S to F1 descaler	(degC or F)	!	!v
Total number of finishing passes (maximum 11)		!	!v
Target finishing temperature	(degC or F)	!	!v
Overriding tail out speed (or 0 if not reqd.)	(m/s or ft/m)	!	!v
Maximum threading speed (or 0 if not reqd.)	(m/s or ft/m)	!	!v
Time before accel. starts after mill thread (for accel. to start when Front end at coiler enter -1)	(sec)	!	!N

Indicate which (delete one) ! REDUCTION ! THICKNESS !N

Pass reductions (fractional) or output thicknesses (mm or in)

! !v!	!v!	!v!	!v!	!v!	!v
! !v!	!v!	!v!	!v!	!v!	!N

Printing option (0=Full print, 1=Four blocks) ! !v

Gap time between bars (secs) ! !v

Percentage throughput figure (0.0 to 1.0) ! !N

If last sheet, type ! ==== !N

```
ata sheet identifier                                                  ! W !N!
chedule title      !                                                      !N!

Wait on delay table or in SCB                               (sec)   !       !v!
Front end temp. drop from C/S or SCB to F1 Descaler (degC or F)     !       !v!
Back  end temp. drop from C/S or SCB to F1 Descaler (degC or F)     !       !v!
Total number of finishing passes (maximum 11)                       !       !v!
Target finishing temperature (or 0 if no target)    (degC or F)     !       !N!
 Time before accel. starts after mill thread                (sec)
 (for accel. to start when Front end at coiler enter -1)            !       !v!
Threading speed out of last stand                      (m/s or ft/m) !      !v!
Maximum speed out of last stand                        (m/s or ft/m) !      !v!
Tail end speed out of last stand                       (m/s or ft/m) !      !v!
Acceleration rate                                (m/s/min or ft/m/sec) !    !v!
Deceleration rate                                (m/s/min or ft/m/sec) !    !N!

ndicate which (delete one)                       ! REDUCTION ! THICKNESS !N!
ss reductions (fractional) or output thicknesses (mm or in)
          !       !v!     !v!     !v!     !v!     !v!     !v!
          !       !v!     !v!     !v!     !v!     !v!     !N!

oling mode (1 - Normal, 2 - Reverse, 3 - All on)                    !       !N!
terstand water flow rate (lpm/m) (0 if not known)
          !       !v!     !v!     !v!     !v!     !v!     !v!
          !       !v!     !v!     !v!     !v!     !v!     !N!

mber of points on bar under consideration (maximum 10)              !       !N!
stance of each point from head of breakdown bar (m or ft)
      !v!     !v!     !v!     !v!     !v!     !v!     !N!

mperature of each point at entry to descaler (degC or F) (0 if not known)
      !v!     !v!     !v!     !v!     !v!     !v!     !N!

             Printing option (0=Full, 1=Short)                      !       !v!
             Gap time between bars                        (secs)    !       !v!
             Percentage throughput figure            (0.0 to 1.0)   !       !N!

                           If last sheet, type                      ! ====  !N!
```

Materials available with Hot rolling programs 10/03/87

Material type	Code No.
Mild Steel	1
304 stainless Steel	2
High-Speed Steel	3
EN 52	4
EN 25	5
EN 45	6
0.56% Carbon Steel	7
Fortiweld HS	8
Fortiweld	9
EN 16	10
EN 31	11
1.00% Carbon Steel	12
EN 40	13
2.25% C, 13% CR Steel	14
COR-TEN	15
316 Stainless Steel	16
X42 HSLA	42
X46 HSLA	46
X52 HSLA	52
X60 HSLA	60
X70 HSLA	70
X80 HSLA	80

Materials available with Hot rolling programs 21/10/87

for USS Gary Hot Strip Mill

Material type	Code No.	Multiplier
Mild Steel	1	1.000
Grade 65	065	1.441
Grade 144	144	1.412
Grade 255	255	1.248
Grade 278	278	1.341
Grade 909	909	1.111
Grade 922	922	1.107
Grade 924	924	1.063
Grade 927	927	1.058
Grade 930	930	1.116
Grade 933	933	1.070
Grade 934	934	1.100

Davy

Procedure for using the EHSM --> Lotus 1-2-3 program

1. Run EHSM program
2. Enter file name for input data
3. Enter file name for output data (up to 7 characters)
4. If hard copy required, press CTRL + P

After the EHSM program has finished, two output files will be created incorporating the name you entered at step 3; one preceeded by a "T" and the other by an "N". To load into Lotus :

5. Enter Lotus
6. Change directory with the /FD command to the directory holding the EHSM output files
7. Move the cursor to the required position on the spreadsheet
8. Load the text file with the /FITfilename command *
9. Move the cursor six cells to the right
10. Load the numeric data file with the /FINfilename command **

* Do not forget to preceed the filename with the letter "T"

** Do not forget to preceed the filename with the letter "N"

ENCO PANELS 04/01/88

1. Data items

All LENGTH data items must be INTEGER only, i.e. must not contain any decimal points.

Line 1 : IOPT - Option to control the output produced by the program (must be either 1 or 2 or 3).

Line 2 : G9 - Guaranteed fraction of the maximum attainable bar temperature gain (values in the range 0.0 - 1.0).

Line 3 : LR - Length (m) measured from bar temperature measurement point to panel entry (0 if temperatures at panel entry).

LP - Length (m) measured from the panel entry to F1.

L8 - Length (m) measured from the panel exit to the Cropshear.

LP1 - Length (m) measured from the panel entry to the point where bar temperature results are required (must be < LP

Line 4 : V - Roller table speed (m/s) at which the bar travels under the panels before deceleration for cropping occurs.

U - Initial entry speed (m/s) to F1.

U2 - Final entry speed (m/s) to F1.

L2 - Length (m) from panel exit to point where deceleration starts. This length must be positive if between panel exit and the last Rougher, and must be negative if between panel exit and F1.

L3 - Length (m) over which the bar travels at initial speed U, in the Finishing mill.

L4 - Length (m) over which the bar travels whilst accelerating from initial speed U, to final speed U2, in the Finishing mill.

TCS - Delay time (sec) for cropping.

L6 - Length (m) over which the bar travels whilst accelerating back up to the F1 entry speed U, after stopping at the shear. If the bar is cropped on the fly then TCS will be zero and hence L6 should be zero.

Line 5 : L - Bar length (m).

BW - Bar width (mm).

TH2 - Bar thickness (mm).

H2 - Bar specific heat (kJ/kg.K) (typically 0.155).

E - Emissivity of the bar material (typically 0.66).

LG1 - Length (m) of panel system.

HV1 - Air gap (mm) between the underside of the panel and the top of the bar at panel entry.

HV2 - Air gap (mm) between the underside of the panel and the top of the bar at panel exit (0 if same as entry).

LG4 - Length (m) measured from panel entry at which the air gap changes (0 if constant air gap).

FCP - Efficiency factor for bottom roller pitch < 900mm (values in the range 0.1 - 1.0) (0 or 1 if > 900mm).

Line 6 : ITU - Temperature units indicator (1 - deg.C, 2 - deg.F)

T1 - Ambient temperature (deg.C or deg.F).

T2 - Head end temperature (deg.C or deg.F) of the bar at the measurement point.

T3 - Tail end temperature (deg.C or deg.F) of the bar at the same measurement point as for the head end.

T4 - Preheated temperature (deg.C or deg.F) of the entry panel prior to the 1st bar entering the panels (0 for no preheating).

LG2 - Length (m) measured from the panel entry over which panel preheating is effective. The panel preheated temperature profile is defined as a linear decrease from T4 at panel entry to T1 (ambient temperature) at LG2.

Line 7 : T6 - Gap time (sec) between bars arriving at F1 entry.

HTIM - Hold time (sec) of the 4th bar under the panel system.

LUF - Length (m) from the panel entry to where the 1st panel is raised.

LDWN - Length (m) from the panel entry to where the 1st panel is down following a continuous set of raised panels.

Note that if no panels are raised then LUP and LDWN should both be zero.

Line 8 : TITLE- Data title up to 40 characters long. This title is used to identify the data and is printed out with the results.

2. Data format

Data items must be separated by a SPACE or a COMMA and must be input in the following order:-

Line 1 : IOPT

Line 2 : G9

Line 3 : LR, LP, L8, LP1

Line 4 : V, U, U2, L2, L3, L4, TCS, L6

Line 5 : L, BW, TH2, H2, E, LG1, HV1, HV2, LG4, FCP

Line 6 : ITU, T1, T2, T3, T4, LS2

Line 7 : T6, HTIM, LUP, LDWN

Line 8 : TITLE

Line 9 : -1 <----------------------data terminator

If there is to be more than 1 set of data in a storage file then enter Lines 1 to 8 for each data set. Then after the last line of the final data set enter a line containing -1 only.

FERN DIAGRAMS

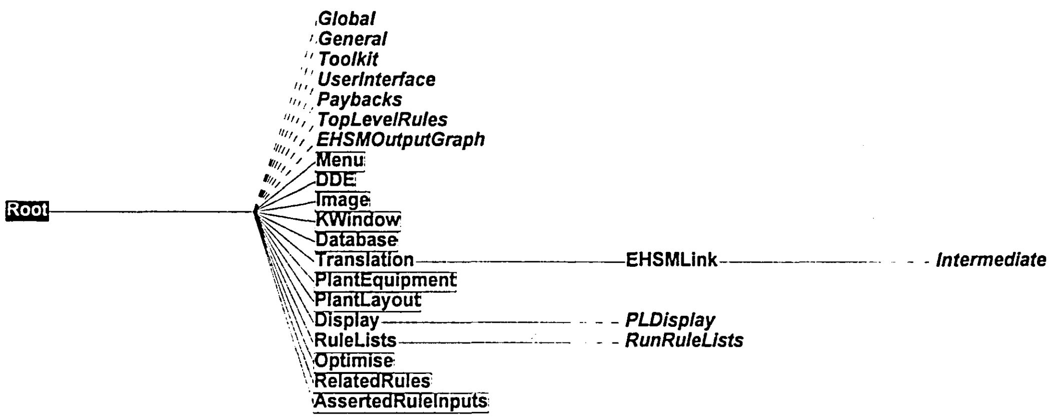


Figure D1

Figure D1 shows top level objects used in the P.L.D.P.. The 'Root' object is a empty object used by Kappa-Pc. A square around objects signifies that there are hierarchy details for this class not shown in the diagram.

Details of classes not discussed later, but referred to in the body of the thesis, these include:

- Translation - this translates a change of a control variable, from the Optimise class, into a numeric change in either the EHSM or ENCO instance.
- Display - which alters the reference in the User Interface images to display the current scenario.
- RuleLists - which is used to generate an the explanations and to recommend the piece of equipment to add to the current layout.

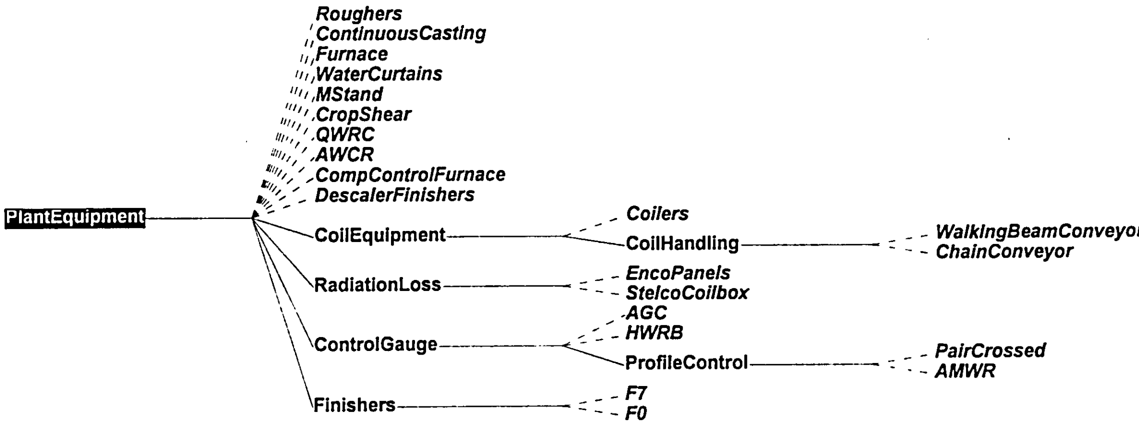


Figure D2

Figure D2 shows the class which is used as working memory for the rules when diagnosing the current plant layout. This class contains any knowledge which can be used to estimate the returns for capital invested.

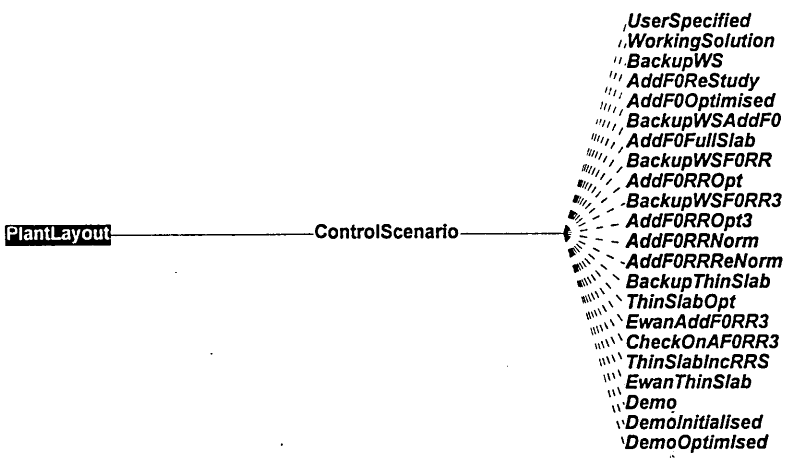


Figure D3

Figure D3 shows the class which contain details of the mill configurations for each scenario being considered.

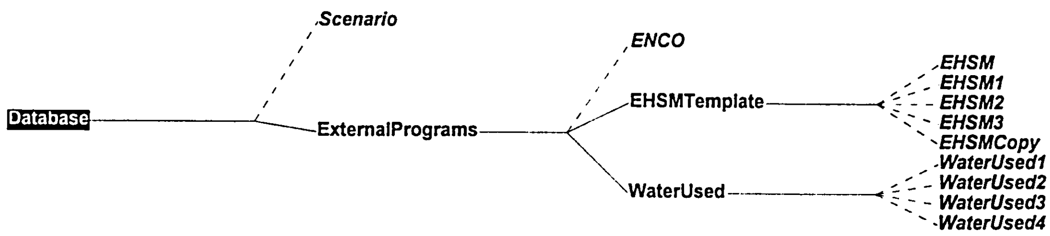


Figure D4

Figure D4 shows the class which communicates with the technical programs and stores selected results in database.

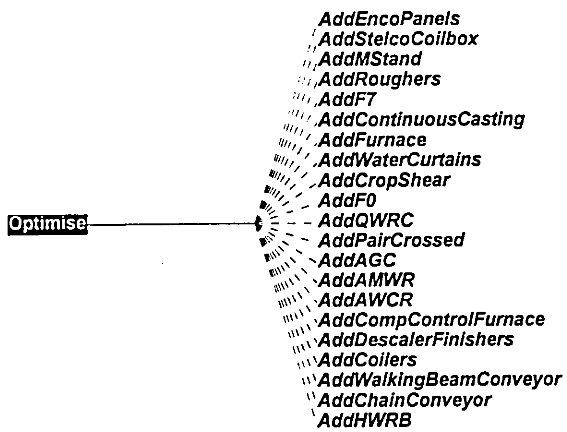


Figure D5

Figure D5 shows the class which optimises a layout after adding a piece of equipment.

Figure D6

Figure D6 shows the class which asserts the initial facts used by the rules.

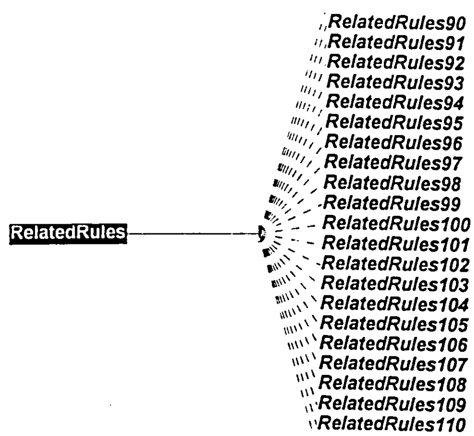


Figure D7

Figure D7 shows the class which duplicates the slots referenced in the rules. This information is used to determine if the rules are related whilst running the program.

OPERATIONS & EVENTS / OBJECT-FLOW DIAGRAMS

This section shows how the objects show in the fern diagrams inter-relate during some of the major operations.

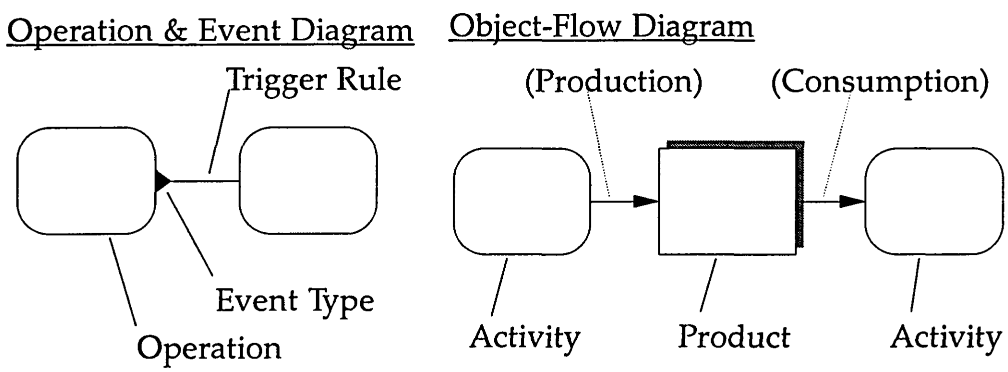


Figure D8

Figure D8 shows the definitions of the components of the diagrams used in this section (Martin, 1993).

Changing the Current Scenario

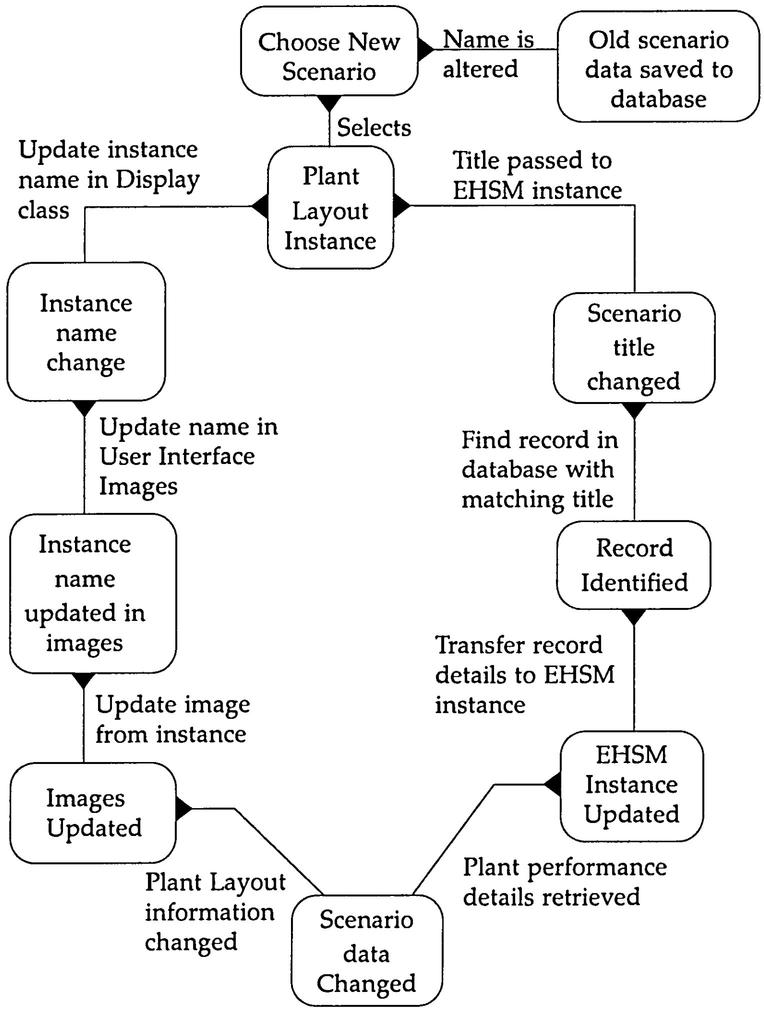


Figure D9

Figure D9 shows the operations that occur each time the user selects a different scenario to look at.

Optimising a Layout

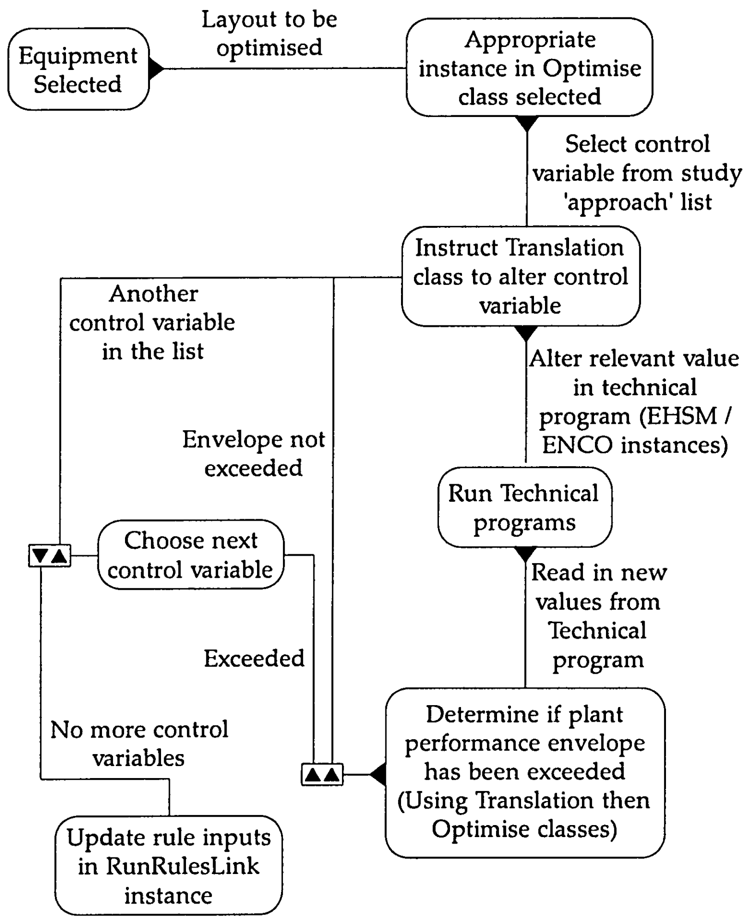


Figure D10

Figure D10 describes the processes that occur when a layout is optimised, after altering the plant's layout.

Firing the Rules - getting a cost justification

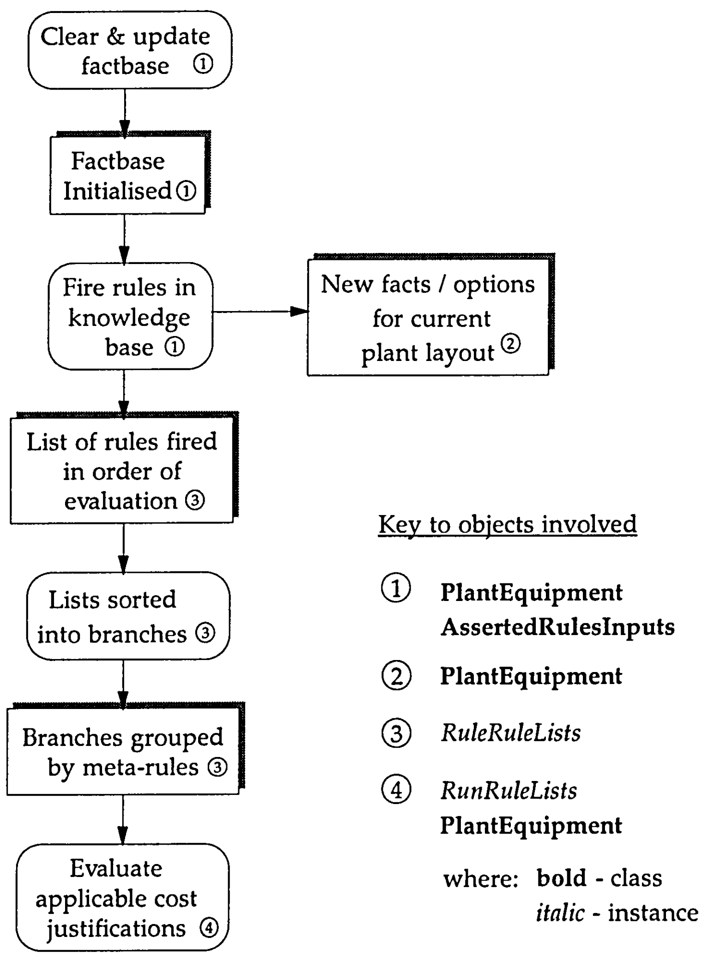


Figure D11

Figure D11 represents the operation show in figure 6.6, needed to ask the user the appropriate cost questions when firing the rules.

Firing the Rules - recommending equipment / producing explanations

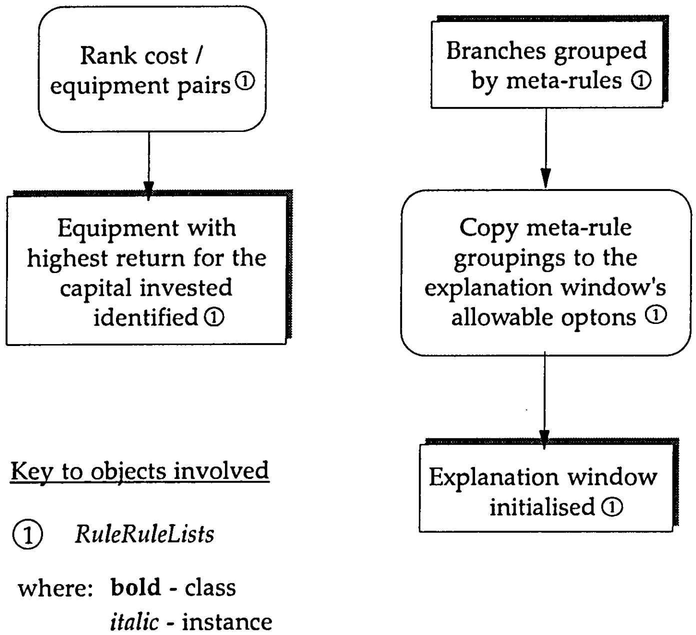


Figure D12

Figure D12 shows what occurs after the user has answer the cost questions of figure 6.6.