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AN EXPERT SYSTEM IN SHIP DESIGN FOR PRODUCTION

by

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ABSTRACT

This work examines the feasibility of applying expert system principles to ship structural design for production.

A brief study of existing design for production approaches is conducted and two major shortcomings are identified. These relate to the 'black-box' nature of current analytical approaches and their inability to account for subjective aspects of relationships between design and production parameters.

Expert system principles and their application to problems in marine and welding technologies are studied. The study has indicated that it is feasible, in principle, to apply such techniques to ship design for production.

The thesis then outlines two pieces of software which have been developed. 'SWES', which is written in Fortran, is a pilot scheme to test the application with respect to simple plate panels. Algorithms are verified through simple checking. 'Grillage', which is further developed from 'SWES', is based around a commercially available shell and is applicable to typical ship structural grillage panels.

Finally, based on these algorithms and their applications, certain areas for further work are identified.

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CONTENTS

CHAPTER 1. INTRODUCTION

Ship design is a complex process in which a large number of parameters are involved . As a result, a number of feasible solutions may be generated from a given set of requirements. These solutions have to meet the ship-owner's requirements, operational criteria and design criteria. The ship-owner's requirements depend on the ship type. For example, the requirements related to a cargo ship design can include criteria such as cargo hold capacity, cargo handling, maximum length, size of crew, cruising speed and the minimum range of operation. Besides these, operational criteria such as the fuel costs, crewing details, duration of loading/unloading and design criteria such as length-to-breadth ratio, bulkhead arrangement etc must also be considered. Further aspects needed to be taken into account are the stability, safety and strength of the ship. The strength of the ship is dependent on the scantling sizes and arrangement. The scantling sizes are normally calculated according to classification society rules. However, the scantling arrangement can vary and depends on subjective decisions of the designer. By choosing the optimum structural arrangement, it is possible to reduce the material weight and hence the material cost.

Besides material cost, the total building cost is also dependent on (labour or) production cost. Reducing structural weight does not always mean less production cost. Therefore, in order to minimise the production cost, the designer should also take into account the procedure by which the structure can be easily produced. The minimisation of production cost is particularly important in the present economic climate which has led to far greater competitiveness between shipyards.

Total building cost of a ship can be split into a number of components. It is evident that the steel cost, which includes material cost is a dominant component of the total cost. As shown in Figure 1.1, the steel cost of a container ship represents about 39% of the total cost - material cost of about 13% and steel labour cost for constructing the structure of about 26% . This labour cost is more than half of the total labour cost. Figure 1.2. shows the steel labour cost as a percentage of the total labour cost for four different types of ship. It can be seen from this figure that a reduction in steel cost can significantly affect the total building cost.

Broadly speaking, steel cost can be minimised by reducing the weight of the structure (material cost) and/or reducing the production time (labour cost). Both can be acheived by following the concept of 'Design for Production'. In this concept, production criteria such as the yard facilities, the production procedure and the building method are considered together with the design criteria in the design process. At present, there are three approaches for 'Design for Production', namely analytical, production based and organisational approaches. These approaches, which will be discussed in Chapter 2, consider the interaction between design and production criteria at different levels of objectivity. Incorporation of objective criteria is easy to achieve provided that data is available in an adequately usable manner. However, criteria of a subjective nature such as " I feel........" or " I think ......" are dependent on personal opinions and are more difficult to account for.

Up to now, subjective criteria have usually been ignored in the analytical approaches and have only been considered in an organisational sense. The present trend in analytical approaches is to bring increasingly objective, measurable parameters into decision making. Yet the most crucial design decisions depend on a designer's (subjective) experience. Therefore, there is a need to cater for both the objective and, especially, the subjective criteria in an analytical approach for 'design for production'. The principal aim of this work, as outlined in Chapter 3, is to examine these subjective criteria as well as objective criteria in an explicit manner through the application of expert system principles. Detailed explanations and the application of such an approach in the engineering field will be discussed in Chapter 4.

The application of expert system principles in ship design for production will be discussed in Chapter 5. The ultimate aim here is to introduce designer's opinions in the production cost analysis of a ship structure. Such structure is constructed from a number of production units each of which can be a grillage or combinations of a number of grillage panels. Therefore, the purpose of application is to analyse the production cost of a grillage panel by employing a 'proper' welding process for every joint within the grillage.

CHAPTER 2. DESIGN FOR PRODUCTION

2.1 CONCEPT

The concept of design for production which was introduced to the shipbuilding industry in 1972 (2.1), is a method involving the interaction between design parameters and production criteria for producing an easy-to-fabricate design. Factors involved in the interaction between design and production are categorised as below.

A. Design parameters controlling the decision making in the design process. These include the weight of the structure which is an important factor in determining the material cost and optimising the deadweight, the cost of production and reliability of the product.

B. Sufficient information on midship structure configuration, frame spacing, fabrication cost, scantlings of working unit, size and connection type.

C.Information on yard facilities to enable them to be optimally utilised, and production procedure to minimise the work content involved.

Thus, the overall objective of design for production can be defined as: " Design to reduce production cost to a minimum compatible with the requirements of the ship to fulfil its operational functions with acceptable reliability and efficiency" (2.2).

Various approaches have been tried to achieve this objective, which can be categorised under three headings: analytical, production based and organisational approaches.

2.2 REVIEW OF PREVIOUS APPROACHES

2.2.1 ANALYTICAL APPROACHES

Several analytical based approaches have been developed to study quantitatively the interaction between design and production.

Moe,J. and Lund,S. (2.3) minimise the total cost of a tanker, by optimising midship structure design with an emphasis on the longitudinal's spacing and ship length. An example of the relationship between the optimum longitudinal frame spacing, production cost and ship length is shown in Figure 2.1.

A more recent study of a similar nature has been conducted by Keil,H. (1.1) in a practical shipyard environment. The study examined alternative designs for container ships as shown in Figure 2.2. In this analysis, production time and cost are estimated from historical data recorded in a shipyard. Based on such analysis, it has been shown that improvements in structural design could reduce the labour cost by up to 5%.

Another approach for improving structural design from a production viewpoint was achieved by Kuo,C. et.al. (2.4) using the production unit method. This method is applied at the detail design stage where a number

Whereas the above studies (2.4 - 2.6) treat overhead cost as being variable depending on individual design characteristics (in a manner similar to labour and material cost components), another approach treats overheads as being fixed vis-a-vis all designs. Based on this, Winkle, I.E. and Baird, D. (2.7) developed a system to study the interaction between production variables and design parameters through an optimisation procedure. In this system, the structure is analysed according to a 'cost factor'. This factor is calculated based on total production time and weight of the structure. The study included an examination of a number of similar grillages which are structurally equivalent.

Production cost prediction can also be approached based on the length of joint and the weight of steel. The length of joint itself can be estimated from the existing ship data using statistical methods. The length of joint has been analysed by Brown,D. (2.8) as a function of steel weight for several different types of ships. The results of this analysis show that the minimum production cost can be achieved by minimising the welding length , the structure weight and the number of piece-parts.

2.2.2 PRODUCTION BASED APPROACHES

In order to minimise production cost, a structure has to be designed in such a way that it can be produced efficiently. This can be achieved by simplifying manufacturing procedures and maximising the automation process. Following this approach, a large construction such as a ship has to be broken down into smaller manageable production units. As shown in Figure 2.5, these production units can be blocks, semi blocks or panels depending on the building strategy and the facilities available in the yard. Basically, the production unit is a grillage or a combination of a number of grillages. A grillage is a stiffened steel structure which consists of plate and a number of transverse and/or longitudinal stiffeners. Appendix A discusses the shipbuilding strategies which are applicable in this context. Several production procedures relating to simplifying manufacturing and/or maximising automation have been introduced. They can be described briefly as follows:

A ship structure can be broken down into a number of production units which can be manufactured by using similar production methods and material so that the application of automatic processes or mechanised production lines can be maximised (2.9).

A ship structure can be divided into three zones, i.e. the hull zone, the deck house zone and the machinery space zone. The dimensions of the production units for each of these zones depend on the facilities of the work station (shop) in which these units will be constructed. For a given shipyard, these production units can easily be standardised, designed and produced (2.10 and 2.11).

Fabrication of these standard production units can be accelerated by using mechanisation along the production line. A number of machines have been designed and installed for this purpose. In the prefabrication line, activities such as loading parts, pre-positioning of plates and sections, fairing, etc. have been mechanised. These activities are supported by a matrix jig fitted to the working unit which can be rotated to avoid overhead and vertical welding (2.12).

In Japan, an automatic hull structure sub-assembly has been designed and installed (2.13). This machine, as shown in Figure 2.6.(a), consists of a stationary part and a roller conveyer, which are operated by a numerical control. The roller conveyer carries the plate panel and the stationary part assembles and welds the stiffeners on to the plate panel. The welding is carried out by a set of submerged arc welding heads . The machine can deal with production units (panels) up to 30 m long, 8 m wide and weights of about 30 tons.

The activities before fabrication of the production units such as plate marking, cutting and forming can also be automated/mechanised individually. This means that more production steps can be mechanised. Bellonzi, R.J. (2.14) introduced a method in which a low-technology and labour intensive mechanisation is employed in a number of such production steps and shown that a significant reduction in production cost can be achieved.

Another method to reduce the production cost (2.15) concerns a special fabrication procedure in which the longitudinal stiffeners are slotted into transverse stiffeners as shown in Figure 2.6.(b). By using this procedure, it is possible to handle about 78% of the total welding metal deposition by automatic processes.

Since a number of welding processes may be capable of welding a particular type of joint, both the welding cost and the welding time of these welding processes could be important in the minimisation of the total production cost (2.16). The welding time is directly related to the labour cost which can be a significant portion of the total production cost. It has been shown in references 2.17, 2.18, 2.19, 2.20 and 2.21 that the welding time can be reduced up to 30% by applying single side welding processes, though the structure/production unit has to be specially designed for these welding processes. Reduction in welding time, however, does not always minimise the total production cost. The cost of the welding process should also considered. An appropriate welding process should therefore be chosen in such a way that both the welding time and the welding cost are optimised. The balance between these two factors will be discussed in detail in later chapters.

2.2.3 ORGANISATIONAL APPROACHES

In order to produce a 'good' design, the production technology being applied has also to be considered. This consideration requires designers with adequate experience and sufficient information of the facilities and production procedure before a design appraisal or production based design is started. Therefore, good communication between various departments in the shipyard is an important asset.

The provision of information to and from various departments through a computer data base is shown in Figure 2.7. Each user/department responds to enter new information and updates existing data with which it is concerned. Through this procedure, the system provides a set of up-to-date data which is important to the design process (2.22). Such information can be classified into three specific levels of ship design i.e.: basic design, functional design and detail design as shown in Figure 2.8, (2.23).

Even though the organisation of one shipyard may be different to that of others, the information systems in the various yards can be generalised. A ready to use information system package has been introduced (2.24). This is built based on a set of modules as shown in Figure 2.9. Each module consists of an information set supplied by a particular department within shipyard.

The scope of information and responsibility of a department is classified and described with regard to the yard organisation. To support these a modern shipyard organisation was introduced by Chirillo,L.D. (2.25, 2.26) where people, information and work are organised in the same way to exactly match the product work breakdown structure (PWBS) employed. PWBS is a method where the work is classified into groups of products by similarities or common processes based on the working zone as shown in Figure 2.10.

2.3 SHORTCOMINGS IN EXISTING APPROACHES

From the three approaches discussed in the previous section, the one of immediate concern to this project is the analytical approach.

This is because such an approach can be readily applied by a structural designer as an integral part of the structural synthesis/analysis procedure. There are two main drawbacks in the analytical based design for production approaches.

The first concerns the "black box" nature of computer algorithms. Because the analysis procedures and calculations are hidden within the routine, many practising designers in shipyards are sceptical of the results. This is especially so when some of the computed results challenge traditionally held beliefs. Acceptance is also slow in forthcoming when new designs are being envisaged. This state of affairs has to be rectified.

The second shortcoming concerns the range of factors considered in the appraisal. Up to now only readily quantifiable and explicit production criteria have been incorporated in the design for production algorithms. However, there are several criteria which, at present, are accounted for only by the designer's and production engineer's experiences. There is no explicit place for such criteria in the analytical approaches.

CHAPTER 3. THE PROPOSED APPROACH

3.1 KEY AIMS

This research has been directed towards developing a fresh approach to overcome the drawbacks identified in the previous chapter. The main aims of the proposed method are as follows :

- to incorporate subjective criteria and uncertainty factors in the appraisal process,
- to study suitable welding processes for a particular joint according to both subjective criteria and uncertainty factors,
- to develop a method capable of predicting production costs in context of design for production.

In order to achieve these aims, with a special emphasis on the first of the above, it is necessary to consider the application of expert systems.

3.2 THE IMPLEMENTATION PROCEDURE

As a ship is a 'large structure'; it has to be designed and produced based on a number of manageable structural modules or production units. These production units can be a grillage panel or are constructed by combining a number grillage panels, called 'Semi block' or 'Block'. Therefore, the net production cost can be calculated based on the grillage cost.

Thus, the work is directed and concentrated on the analysis of grillage panels as a basic production unit. This analysis includes welding process selection for each joint in a grillage and production cost based on the selected welding process. The tasks involved in this work are as follows:

- Discuss the criteria involved in welding process selection, as shown in Appendix B.
- Select the salient objective and subjective aspects of grillage panels cost analysis.
- Build a knowledge base (rules and data base) to analyse production cost of a grillage panel.
- Compare and analyse the result against existing approaches.

CHAPTER 4. THE IMPLEMENTATION OF EXPERT SYSTEMS IN ENGINEERING

4.1 THE STRUCTURE OF EXPERT SYSTEMS

4.1.1 GENERAL

An Expert System is a computer program that simulates the reasoning of a human expert in certain domains (4.1). To simulate the performance of an expert, a computer needs a logical model of the problem, some means of using this model to produce a set of questions to ask and also some inference procedures to utilise its knowledge. A realistic answer will emerge as a result.

The model is often called a knowledge base and the set of inference procedures is called an inference engine or an interpreter. An interface is also needed in order to allow the users to interact with the expert system. The interface has two main functions. First, it gives advice and explanation to the user and secondly, it manages the knowledge acquisition. Figure 4.1 shows the basic structure of an expert system. This expert system is a computer program for solving problems involving knowledge, heuristics, and decision making and it is different from normal algorithm programs in that it requires continuous interaction between the user and the computer, as shown in Figure 4.2.

4.1.2 DECISION MAKING

The three types of decision making approach usually used in expert systems are: forward chaining, backward chaining and an approach combining both (4.1, 4.2).

Forward chaining is a method of producing a single decision to meet a set of input requirements. In this method the decision making process is divided into several stages. At each stage of decision making, a certain criterion related to the input requirements, i.e. 'rule', has to be satisfied. The final decision will therefore satisfy all the input requirements.

For example,

rule1: if A then B

rule2: if B and C then E

rule3: if E then F

'A' and 'C' are the input requirements which are given by the user. Therefore 'A' and 'C' are right. Since 'A' is right then 'B' is right. In the second stage, 'B' and 'C' are right then 'E' is right. Finally because 'E' is right then 'F' becomes the result.

Backward chaining method is used when the input requirements produce various alternative deductions (hypotheses). In this decision making process all hypotheses have to be checked against the input requirements and the result/suggestion will be arrived at from those proven hypotheses. The following example demonstrates the solution procedure of a backward chaining method:

rule1: B is right if A is right

rule2: G is right if A and F are right

rule3: D is right if C is right

rule4: Q is right if B and D are right

Conditions 'A' and 'C' are entered as the given requirements by the user. The 'A' condition corresponds to two hypothesis, rule1 and rule2. The combination of 'A' and 'C' conditions corresponds to three hypotheses, rule1, rule2, rule3. The decision can then be made through the process as follows:

Rule1 is proved because 'A' is right, then 'B' is right.

Rule2 is not proved because 'F' is not right.

Rule3 is proved because 'C' is right, then 'D' is right.

Rule4 is proved because 'B' and 'D' are right, etc.

Then, the result is 'Q'.

However, not all the problems can be analysed by applying either of the above approaches alone. Therefore, combining both of them is often necessary especially when the backward chain rules are supported by numerical calculations which are usually written as a forward chaining rule. For example :

rule5 : C is right if C = 5.5   (backward rule)

rule6 : C = A + 2.5

if A = 1 then C = 3.5
if A = 2 then C = 4.5 } (forward rule)
if A = 3 then C = 5.5

In this example, the hypotheses in rule5, i.e. "C is right", can only be proved by the support of a forward chain rule (rule6).

The rules in the above example are based on deterministic facts or conditions, so the answer to the problem can easily be obtained following the decision trees until the only feasible alternative is reached. Yet, in some cases, a number of alternative solutions may be presented. So, a 'best' solution is chosen from them as the final decision. The "best" solution is the one with the highest degree of confidence (or confidence factor).

4.1.3 CONFIDENCE FACTORS AND FUZZY LOGIC

A. CONFIDENCE FACTOR

The confidence factor (CF) of a condition is a number in the interval [0,1] obtained by subtracting the degree of disbelief (DD) from the degree of belief (DB). However, in some cases, the condition itself has a specific degree of uncertainty (C), the evidence that the condition is true. In this case, the confidence factor can be obtained from the relation;

$$CF = [C \times DB] + [(1-C) \times DD] \qquad \text{............... (4.1)}$$

where DB and DD denote degrees of belief and disbelief of a fact pertaining to a certain condition. A value of [+1] indicates an absolutely believable fact while value of [0] indicates an absolutely disbelievable fact (4.3). Both DB and DD might be determined by using statistical formulation if previous (recorded) data are available. If the supporting data are not available, however, it would be necessary to obtain them (DB and DD) by applying fuzzy logic theory.

B. FUZZY LOGIC

Fuzzy logic is necessary for analysing conditions or facts which contain fuzzy relationship. Such conditions are those of 'probably', 'maybe', 'most', 'perhaps', etc, which are neither absolutely right nor wrong. In this case, a fact is analysed based on its relationship with the absolute condition (right or wrong) which is called the 'reference point' or 'constraint'. The value of relationship of a condition with respect to a reference point is called the 'degree of membership'. This is calculated according to a membership function which represents the relationship between the fact (as a member) and the reference point. The membership function can be determined either by statistical formulae or by mathematical models depending on the conditions and the parameters involved. If a number of conditions are related to a reference point, a set of 'degrees of membership' can be produced and this is called the "Fuzzy set".

For example:

If a man with a height of 7 feet is " Tall " (absolute) and a man with a height of 5 feet is " Short " (absolute), then a man with a height of 6 feet, is neither absolutely "Tall" and nor absolutely "Short"; he has a height that lies between both criteria. Thus, he is "Tall" with a degree of membership of 50% or 0.5, or he is "Short" with a degree of membership of 50% or 0.5. A similar approach can be applied to evaluate other conditions such as a height of 6.5 feet or 5.5 feet. If the degrees of membership for all conditions are stored in a set, called a fuzzy set, then the results can be displayed in a tabular form as in Tables 4.1.a and b.

C. ALGEBRAIC OPERATION OF FUZZY SET

To determine a degree of belief or disbelief of a condition in an expert system, it may be necessary to construct a fuzzy set from two or more related fuzzy sets. There are two important algebraic operation modes applicable to manipulate such sets (4.3).

The first operation is 'AND'. Considering the previous example, if the condition of a man is 'Tall' AND 'Short' then the man is of 'Medium height'. In fuzzy set algebra operations this implies the intersection between "Tall" and "Short" ("Tall" $\cap$ "Short"). The results are shown in Table 4.2. A similar argument can be put forward for the condition "not Tall" AND "not Short".

The second operation mode is 'OR'. In the above example, if the condition of a man is now either 'Tall' OR 'Short' it would imply that the man is 'not Medium height'. In this case, the 'not Medium height' is a union of 'Tall' and 'Short' ('Tall' $\cup$ 'Short'). The results are shown in Table 4.3.

The above examples demonstrate the means of constructing a fuzzy set based on two fuzzy sets and the same concept can be extended to construct a fuzzy set from a number of sub-fuzzy sets. Consequently, such an approach can be applied to analyse the degrees of belief/dis belief (DBs/DDs) of a set of alternative results for a given aspect/criteria. Once the DBs and DDs of the alternative results upon all given criteria have been obtained, then the confidence factors of these results can be calculated.

Formula 4.1 is readily applicable in the case of one criterion or condition. When two or more criteria/conditions requires to be analysed, a joint confidence factor can be calculated on the basis of Bayes theory.

4.1.4 BAYES THEORY

Bayes theory is one way to calculate relational probabilities associated with two or more events (4.4). Consider, for example, two events E and H with associated probabilities of occurence P(E) and P(H) respectively as shown in the Figure 4.2.a. The sample space shown as hatched indicates both events E and H occuring at the same time. It is clear from the figure that probability of event H occuring provided event E has occured is given by the expression :

$$P(H|E) = \frac{P(H \text{ and } E)}{P(E)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

P(H and E) and P(E) can be obtained from the relations:

$$P(H \text{ and } E) = P(H) \times P(E|H) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

and

$$P(E) = P(H) \times P(E|H) + P(not\ H) \times P(E|not\ H) \quad ....(4.4)$$

Thus, the joint probability, P(H|E) can be written as :

$$P(H|E) = \frac{P(E|H) \times P(H)}{P(E|H) \times P(H) + P(E|not\ H) \times P(not\ H)} \quad ....(4.5)$$

Similarly, the joint probability (P(H|notE), is given by :

$$P(H|notE) = \frac{P(E|notH) \times P(H)}{P(E|notH) \times P(H) + P(E|H) \times P(not\ H)} \quad ..... (4.6)$$

where P(H) is the probability of occurrence of event H

P(not H) is the probability of non occurrence of event H

P(E|H) is the probability of event E which is related to P(H)

In the present work, the above formulae are used to calculate the joint confidence factor involving two conditions. The CF of an alternative result based upon a given condition can be calculated from the degree of belief (DB), degree of disbelief (DD) and the degree of uncertainty/evidence of the condition (C), as shown in expression (4.1). For instance, if the degree of belief, degree of disbelief and degree of uncertainty of the first condition are DB(1),DD(1) and (C1), hence, the first confidence factor, CF(1), is given by :

$$CF(1) = [C1 \times DB(1)] + [(1 - C1) \times DD(1)] \quad .... (4.7)$$

Since the CF of the first condition will be combined with the second condition, which has degree of belief of DB(2), degree of disbelief of

DD(2) and degree of uncertainty of (C2), the joint confidence factor of these two conditions, CF(2¦1), will be calculated based on the first confidence factor, CF(1), the joint degree of belief, (DB(2¦1)), degree of disbelief, (DD(2¦1)) and the degree of uncertainty of the second condition, (C2). In this case, DB(2¦1) is calculated from the formula 4.5, where the probabilities (P(H)), P(E¦H) and P(E¦not H) are denoted by the (CF(1)), DB(2) and DD(2) respectively (4.5). Thus, the joint degree of belief of the first and the second conditions, (DB(2¦1)), is

$$DB(2|1) = \frac{DB(2) \times CF(1)}{[DB(2) \times CF(1)] + [DD(2) \times (1-CF(1))]} \quad \ldots\ldots\ldots (4.8)$$

Similarly, the joint degree of disbelief, (DD(2 1)), can be obtained from the formula 4.6 as :

$$DD(2|1) = \frac{DD(2) \times CF(1)}{[DD(2) \times CF(1)] + [DB(2) \times (1-CF(1))]} \quad \ldots\ldots (4.9)$$

and the joint confidence factor is given by :

$$CF(2|1) = [C2 \times DB(2|1)] + [(1 - C2) \times DD(2|1)] \quad \ldots\ldots (4.10)$$

The above theory can be extended to calculate the joint confidence factor for more than two conditions. Further details of application of this theory will be discussed in Chapter 5 and Appendix D.

4.2 EXPERT SYSTEM LANGUAGES

There are three major groups of computer languages that can be used to develop an expert system . They are LISP group, PROLOG group and procedural language group (4.6).

'LISP' is the acronym for LISt Processing. It was invented by McCarthy in 1960 for non-numerical computation (4.6). It is widely used and is considered as a major advancement of expert systems in the United State of America (4.7). LISP has been further developed into various forms, for example: ELISP, McLISP, FranzLISP, INTER LISP, OPS5 and OPS83, according to the relevant purposes. In general, the features and advantages of LISP can be summarised as follows (4.6):

- Very powerful to manipulate symbolic expressions
- Data and program are treated in the same way because both of them are represented as lists; thus it is very easy to make changes or alterations.
- The functions in such programs can recursively call themselves.
- The unused lists are erased automatically by the system; so, a programmer does not need to worry about the storage arrangement.
- It has simple syntax and is quite easy to read.

However, LISP also has some disadvantages such as :

- It has been designed primarily for non-numerical analysis.
- Unfinished rules will be erased by the system.
- No standard procedure among the family.
- It needs a compiler to compile the program.

'PROLOG' is the acronym for PROgramming LOGic, which is a language based on formal logic and is most popular in Europe. Although PROLOG is a versatile language, like LISP, it has limited power for processing numerical data. According to Adeli. H. (4.6) the advantages of PROLOG over most of the other languages are :

- It has its own inference engine,
- Easy to use,
- It has facilities for error checking and debugging.

However, it does have the following disadvantages :

- Limited in numerical manipulation
- Large memory requirement
- Slow execution with many implementations of the language.

The third group is procedural languages such as Fortran, Basic, Pascal and C. These languages are used in the development of many engineering expert systems where numerical algorithmic computation and symbolic manipulation are involved. For developing an engineering expert system both PROLOG and LISP may not be the most suitable languages, and among popular algorithmic languages, Pascal and C might be the better candidates. The following features demonstrate the suitability of 'Pascal' as a language to support an expert system (4.6):

- No limitation in using variables type (character, string, integer, real number, and array).
- Pascal supports recursion, because a subroutine may call itself.
- It has the variable-type pointer which makes it possible to define a logical tree.

- Various type of variables can be stored and lumped together.
- But, all variables must be defined before any executed statement.

C also has a number of positive features :

- High performance.
- A very efficient language
  (less memory space is needed)
- Good ability for numerical manipulation.
- Suitable for graphical representation.

Because of the above positive features, 'C' language has been used in commercial applications such as the 'Crystal' shell which, in turn, has been used in this work.

4.3 AN OVERVIEW OF EXPERT SYSTEMS IN ENGINEERING DESIGN

Expert systems have been widely used in the field of engineering, typically in Civil, Petroleum, Geology, Marine engineering and welding engineering. The work in this report, however, will concentrate on the applications of the expert systems in marine technology and welding engineering.

4.3.1 APPLICATIONS IN MARINE TECHNOLOGY

Within the marine field, there is wide scope for application of expert system principles. Table 4.4 shows some of the problems that can be solved by the application of expert system principles (4.8). A number of expert systems have been developed in the field of marine engineering to analyse dynamic modelling (4.9), ship maintenance (such as hull maintenance and main engine fault diagnosis) (4.10) and logistic support (4.11). However, a few studies have been conducted to support marine design related to the present work.

The "Designer system" is an expert system supporting ship design at the basic design stage where initial ship parameters i.e. the length, breadth, draft, depth, weight, approximate power, deadweight and centre of gravity, are analysed. A data base, which contains the initial dimensions of many existing ships, is used to back up the system as comparative objects (4.12).

The "Designer system" is further developed along two lines (4.13). The first concerns the application of factors which are derived from the nature of uncertainty in ship design (such as : specification, route etc.) and reliability. It also depends on the relationship between the parameters involved. An example of the relationship of parameters involved in a ship design process is shown in Figure 4.3. The second development of the "Designer system" is the so-called "SERF system". This system is developed based on a building blocks approach where the knowledge base analyses the possibility of alternative building blocks, such as: double bottom, side shell, decks, stern etc., to support a design. The user then has the ability to "construct" a ship by assembling a number of the possible building blocks together.

Similarly, some expert systems have been developed to analyse offshore structure design. An expert system has been developed which could offer some intelligent assistance to the designer of semi-submersible rigs stability (4.14). Recently, another system has also been developed in order to support the preliminary design of offshore jacket structures. In this system, the number of legs, the appropriate platform size and the framing systems are analysed (4.15).

The purpose of the above applications are to decide a set of appropriate design variable/criteria supporting the design process. However, the trend of recent application of expert system integrates the knowledge base of the system to the computer aided design (CAD). Such integration makes the expert system more applicable for design purpose (4.16). Following this principle, Akagi et.al.(4.17) develops a system which assists the ship-designer to optimise the ship power plant design. Recently, this integration principle is also applied in order to analyse the ship hull form and to predict the production cost in pre contract design stage (4.18).

Expert system principles can be effectively applied to a design environment where there are a large numbers of variables and parameters, and where spatial considerations are fundamental to the design process (4.19). Significant benefits are to be gained by utilising such principles to support, for example, a container ship design which requires to satisfy a broad range of operational and technical considerations.

The above applications demonstrate that expert system principles are appropriate to analyse the design variables/criteria. However, the present work integrates such design criteria with production criteria including the analysis of welding process applications which are the biggest part of the shipbuilding work.

4.3.2 APPLICATIONS IN WELDING ENGINEERING

To weld a joint, a number of activities have to be carried out including edge preparation, fairing and tacking as well as welding itself. There are a number of processes which might be available to weld a joint. Every welding process has a specific application and must fulfill a number of criteria to produce the best result. Some of these are subjective in nature. Hence, the application of expert system principles is necessary. Based on this, a number of welding expert systems have been developed.

A general purpose shell, called "Jayman CAMS", has been developed and applied in order to calculate the welding costs (4.20). This system considered the thickness, type and position of joint to select the right welding process. Based on these and actual arc time (burning time), the welding costs are calculated.

Another expert system in this area covers such aspects as: weld preparation, type of material and weld economics. These data are used to find a suitable process of welding, in particular, between two different materials (4.21).

The University of Southampton has been conducting research in order to choose a process for welding nuclear reactors. The system is dependent upon the user responding to a number of queries. These answers are then applied on a set of specific criteria (in knowledge base) to become confidence factors of every possible alternative welding process. The best suggestion, of course, is the welding process which has the highest confidence factor (4.22). "Expert-ease" is a general purpose expert system shell, which has been examined in order to select the right process for a specific joint by the Welding Institute, Abington (4.23).

After the right welding process has been selected, a skilled worker is needed to produce the best result. However some defects might occur during the weld execution. Thus in addition to welding process selection, an expert system has been built in order to analyse the problems relating to welding defects. This system was designed in the context of metal inert gas welding (MIG) only. The system output deals with ways of improving the weld (4.24).

In a similar context, another expert system, called Naval Expert Welding Control System (NEWCS), has been developed with a view to control the welding in shipbuilding. This controls the welding during execution; parameters include the frequency, amplitude, heat (current) and travel speed ,etc. (4.25).

4.4. REQUIREMENTS FOR SHIP STRUCTURES DESIGN

As discussed in the above sections , the expert system principle is capable of analysing problems in which the subjective criteria are involved in addition to the objective ones. Both aspects will be taken into account in every decision within the problem and consequently, the decisions will reflect the opinions of the user. The dialogue between the user and the computer can also be maintained by interrogating and asking the user's opinions. Such system has been applied to solve a number of problems including the engineering field.

In the engineering field, as mentioned in Section 4.3, systems have been applied successfully in both design and production areas. Hence, it can also be applied to address the difficulties in the present approach in which a number of criteria need to be combined together.

The present approach, as mentioned in Chapter 3, is directed to analyse the ship structure design into which ship design and production criteria will be taken into account. A number of decisions have to be made during the design process. Some of them should be decided by the user/designer on the basis of their experience. The relationship between subjective and objective criteria in this present approach is shown in Figure 4.4. Thus, the application of the expert system is appropriate to assist the designer to make decisions. A number of requirements should be fulfilled in order to combine the criteria and opinions into decisions in design process. They can be listed as follows :

- Maintain dialogue between the user and computer by asking the opinion of the user on important aspects which have to be decided.

- Analyse these opinions together with the objective criteria in the decision making process.

- Produce a set of suggested results instead of a single result from which the user can select the one according to his/her opinion.

- Apply the present approach to predict the production cost of a part of a ship structure.

CHAPTER 5. THE APPLICATION OF EXPERT SYSTEMS TO GRILLAGE STRUCTURE

5.1 GENERAL

According to the requirements mentioned in Section 4.4, the present approach will be applied to analyse the production cost of a part of ship structure. The ship structure is broken down into a number of production units. The most basic units in a ship structure, as explained in Appendix A are grillage panels. Therefore, the production cost of a ship structure can be predicted by analysing the production cost of a grillage. It can be obtained as a sum of the labour cost and the material cost. The material cost is calculated based on the steel weight and the steel price, whilst the labour cost varies with a number of cost components. The biggest component of this labour cost is welding cost, including the costs of fairing and tacking and welding the joints. The calculation of this cost is dependent on the welding process used to weld the joints. Since there are a number of possible alternatives of welding processes, it becomes necessary to select the proper process for each joint.

Hence, the present approach initially aims to build an expert system to select a proper welding process for every joint within a grillage from a set of alternative processes and to calculate its welding cost. An expert system, called 'Ship Welding Expert System' (SWES), has been constructed as a trial to select a reasonable process to weld a single joint. The main aim of this trial is to discover whether an expert system is applicable to analyse the combined subjective and objective criteria in order to support the decision making. This system was developed to be suitable to run on personal computers and has written in Basic language. Due to the limited memory available in this language, Fortran language was then used for the development of the SWES system; this will be discussed in more detail in Section 5.2.

Further development of this led to the 'Grillage System'; Fortran language was not used in this because it cannot easily handle complex logic. Additional difficulties with screen handling, character input and data transfer also had adverse effects. As a consequence, a commercial package shell has been used instead of Fortran in building the program. The detail and sample applications of this program are discussed in Section 5.3 and Section 5.4.

5.2 SINGLE JOINT ANALYSIS

5.2.1 BACKGROUND

As mentioned above, the SWES system was developed and applied to obtain a set of suggested welding processes for a specific joint. These are selected from a number of welding processes commonly used in the shipbuilding industry. These can be categorised into four groups: Manual Metal Arc (MMA), Metal Inert Gas (MIG), Submerged Arc (SAW), and Fusarc processes. They are further classified on the basis of the diameters of the electrode. The classification and the details of these processes will be discussed in Appendix B.

Other features distinguishing choice of a particular process include the thickness of weld and the choice of welding position, i.e. downhand, horizontal, vertical and overhead. Thus, based on these welding positions and the five ranges of thickness of weld, the processes are grouped and arranged to form a decision tree, as shown in Figure 5.1. The decision tree is based on a score system. Each branch of the tree has been scored in such a way that there is a unique score at the end of that branch. For example, the score for a butt weld of a plate with thickness between 5 and 10 mm carried out in a downhand position is 1+2+10 or 13. Similarly, the score for a Tee fillet between plates of thickness 5 and 10 mm carried out, again, in a downhand position is 40+2+10 or 52.

Once the thickness and the position of a particular joint are known, a set of alternative welding processes can be obtained from the decision tree. As the features of these welding processes might differ, it is necessary to calculate their confidence factors (CFs) first in order to classify them. As mentioned in Chapter 4, CFs should be calculated based on the capabilities of the process and the user opinion on specific criteria. In this case the criteria involved in the decision making are the location of execution, the importance of welding speed, welding efficiency and production cost.

Because the program is written in Fortran, the numerical answers representing the user's opinions upon the above aspects are required. The CFs are calculated following the Bayes theory (formulae 4.7, 4.8, 4.9) based on both these answers and their capabilities data. These welding processes are arranged in sequence to form a set of reasonable suggested processes according to the values of their confidence factors.

This set provides the user with ideas and ranks of the alternative welding processes according to the objectives of the joint and the given opinions. Furthermore, the decision of which process to use to weld the joint is arrived at by the user subjectively. The welding time can be obtained from this decision.

The welding time is calculated based on the number of joints and the volume/weight of weld metal at the joint and the deposition rate of the selected welding process. The weld metal volume is found from the length of the joint and its edge design/preparation. The edge design of a joint is determined according to welding regulations, thickness of the joint and the selected type of welding process. Details of this edge design can be seen in Appendix B.2.

Production time can be obtained by adding this welding time to the fairing and tacking time (which is needed to arrange the joint into a proper arrangement including alignment with the right gap). This fairing and tacking time is dependent on the type and thickness of the joint, and is taken from work study data (5.1).

After production time is obtained, the production cost can be calculated by multiplying the production time by the labour rate. The labour rate may vary among yards; hence, it is designed as an input data.

5.2.2 PROGRAM STRUCTURE

Because the program deals with a number of calculations, therefore, initial development of this welding process selection, is written in Fortran. The knowledge base of this program is built as forward chaining rules and divided into three parts (stages) as shown in the flow chart in Figure 5.2.a :

-First stage: choosing the alternative welding processes.

-Second stage: processing the suggested welding process.

-Third stage: calculating the production times and costs.

(a). First Stage

The main task at this stage is to decide the available and appropriate welding processes applicable for a particular joint, based on its objective aspects including the geometry and position. These aspects are processed down a decision tree (see Figure 5.1) by the first inference engine (inter 1). A valid process will have "scored" at every level of the decision tree. Based on these scores, the possible processes applicable to weld the joint can be found from the knowledge base 'W1'. These possible processes are arranged and displayed as the 'alternative welding processes' set.

(b). Second Stage

The alternative welding processes which are based on the objective criteria defining the joint, are further analysed based on the subjective aspects provided by the user. These include the location of work, the percentage of volumetric inspection, the speed of process and welding cost. For each of these four aspects, the program will require a numerical answer which ranges from (-5) for absolutely wrong to (+5) for absolutely right. This represents the degree of belief of the user on the criteria. The second inference engine (inter2) then calculates confidence factors for each alternative welding process based on the values of the 'subjective' criteria in accordance with 'Bayes' theory. Then, the 'suggested welding processes' set is displayed.

From this suggested processes set, the user decides the selected process. This process is then sent to the third stage of the program, in order to calculate the production time.

(c). Third Stage

The time needed to weld the joint, is calculated at this stage. This calculation is based on the weight of the welding metal and the deposition rate of the selected welding process. The weight of welding metal is calculated according to the geometry of the joint, the welding edge preparation and the approximate welding reinforcement which will be explained in Appendix B.

In addition to the welding time, it is also necessary to take into account the time required for preparing the job. The preparation time is constant for every job and therefore is usually known as the 'Job constant'. This 'Job constant' does not include the time for setting up the welding process. The total preparation time is therefore equal to the sum of the 'Job constant' and the time for setting up a welding process, known as the 'Welding constant'. In this work, both of these constants are taken from the same work study data base which has been mentioned before.

Before the welding process is executed, the work pieces should be set in the proper arrangement. In order to keep this arrangement in its position, it is necessary to weld the joint at some points. This calls for fairing and tacking. The time taken for fairing and tacking is also calculated based on the above work study data base. The time is a function of type, length and thickness of the joint. As in the case of welding this also takes time to prepare the job and leads to a "fairing and tacking job constant" which is added to fairing and tacking time of each group. The total welding time is the sum of welding time and fairing and tacking time.

5.2.3 RUNNING THE PROGRAM

From the main menu displayed at the beginning of program (Figure 5.2.b), the user can choose from two options -namely creating new data or using existing data. To create new data, the user has to choose menu option [1] and then enter the required data . The data can be stored in the data file if necessary. To make sure that the data is stored in the file, the user can check the filename from the list which is produced by choosing menu option [3]. Otherwise, the user can work upon existing data by choosing menu option [2]. A list of data appears and the user can choose the specific file. Then, based upon the data above, inter1 produces the list of possible processes for each joint of the grillage. The next step involves processing the possible processes to produce the the suggested process. This can be done by choosing menu option [4]. A set of questions appears in this stage. The user has to answer these questions numerically in the range of [-5] up to [+5]. This is then processed to become the confidence factor by "inter2".

Based on these CFs a list of suggested processes is arranged and displayed in sequence. The process which contains the highest CF should become the best suggestion. However, the user has a chance to choose the selected process which will be used to weld the joint. Then, according to this process, the menu option [5] calculates fairing, tacking and welding time. Additionally, there is also a facility to display the reasons, conditions and technical details of the processes. Finally, the results have to be stored in a file under specific file name. Then, a hard copy can be obtained by following the instruction in the menu option [6].

5.2.4 APPLICATION

This program has been applied to analyse a single butt joint which is shown in Figure 5.2.c. These results have been checked manually to see that the program is working properly. The details including the example of application and manual checking of this program are illustrated in Appendix C. The principal purpose of the examples is to check that the weld times obtained are correct. When compared with time obtained using work study data (5.1), the SWES calculated times for MMA application show a difference of 0.72%.

This example of application of the program indicated that expert system principles can be applied to analyse welding in a marine context and that weld time can be predicted with reasonable accuracy. However, the application did highlight two major problems. First, user opinion had to be expressed in a numerical form. In context of subjective opinion, this therefore did not represent an ideal way for a program to function. Secondly, a program such as this needs to be reasonably 'user-friendly' with a judicious choice of screen information and screen-handling. Use of the Fortran language did not permit such features to be built-in.

There was therefore a need to consider other options which, while enabling the use of expert system principles, would overcome the above drawbacks. There is also a need to develop a method to investigate multiple joints such as those found in ship's grillage panels.

5.3 GRILLAGE STRUCTURE ANALYSIS

One way of overcoming the drawbacks mentioned above and extending expert system principles to ship grillage structure analysis is through the development or adoption of expert system shells.

5.3.1 USE OF COMMERCIAL SHELL

As mentioned in Section 4.1.1, an expert system consists of three parts; the knowledge base, an inference engine and an interface. The inference engine together with the interface is merely a piece of software that links the user to the knowledge base. This piece of software, the 'Shell', does not depend on the nature of the knowledge base and can usually be developed separately.

In order to analyse and to indicate the welding processes suitable for joints within a grillage, the system has to deal with a large amount of data and numerical computations. Hence, the shell has to have the following capabilities including:

- As the work deals with numerical computation in addition to logical manipulation, the shell should be written in a 'convenient' language to handle both aspects. As mentioned in Section 4.2, 'C' is a logical choice.
- Decisions are made on the basis of a set of confidence factors, which are analysed following 'Bayes theory'; thus, the shell should be able to handle this theory.
- A ship structure consists of a number of plates and stiffeners and there could be several permutations to this arrangement. The shell has to be able to handle a large volume of data and may be interfaced with an external data base.
- The shell has to have an ability to process a set of meta rules i.e. where the rules can be used more than once.

- Because the memory space in the machine being used (a PC) is limited, the shell has to be able to link two or more sub-programs.

Based on the above criteria , "Crystal shell version 3" was just fit to support this work. In addition to the above criteria, principal features of Crystal3 are listed as follows (5.2):

- Rules can be altered easily, because these are written in simple English.

- Although the rules are normally built as backward chaining rules, there is also a facility to combine these with forward chaining rules.

- This shell has the ability to handle a large volume of data through interface facilities. There are two built in interface facilities i.e: to Lotus 123 (spread sheet) with a capacity of 6500 cells and to Dbase3, where a maximum 60 KByte data can be handled. Thus, it can export/import a set of data or rules or variables to/from these files.
- Export/import facilities can also be used in order to join two or more sub-programs.

- The rules are very easy to make, because most general commands, such as: display (input and output), test statements, sorting, etc, have been installed as built in menu (menu driven).

- Screen and graphic handling are very simple which is necessary to express the user's opinion in better way.

- However, running the program, especially for numerical calculations, is very slow.

5.3.2 CRITERIA INVOLVED

The aim of this program, called 'Grillage', is to analyse the production cost of a grillage structure based on a selected welding process for every joint in it. This welding selection process is basically similar to SWES. However, the structure of the knowledge base is different because a different language is used. The criteria involved and their inter-relationship are shown in Figure 5.3.

This analysis also aims to open a part of the 'black box' process. This has been achieved by creating a dialogue between the computer and the user. The program asks the user to give his opinions on a set of criteria; this allows the user to make up his judgement at every step of process. The program is facilitated to express the user's opinions (as the subjective variables) on a set of aspects. These opinions will be analysed in such a way as to build a set of suggestions which assists the user decision.

These subjective aspects can be classified into three groups and listed as follows:

(a). The aspects, from which the options should be selected from a set of given menu, are :

- Type of welding: i.e. Butt joint and Tee (fillet) joint.
- Position of welding: i.e. Downhand, Horizontal, Vertical and

Overhead positions.

- Location of execution: i.e. Indoors and Outdoors

(b). The aspects which require numerical answers:

- Reject rate: Even though every welding machine is well designed, human error which may occur during welding execution can not be avoided. Reject rates therefore are dependent on the skill of personel involved, the type of production facilities and experience of the yard.
- Rewelding factor: Repairing a weld defect, normally, takes more time compared to making a new weld. The figure varies among the yards. Therefore, this factor is requested from the user as a expression of their opinion.

(c). The aspects which require user opinions upon how important the aspects are along a line scale between 'not relevant' and 'very important', shown in Figure 5.4. They are:

- The importance of the welding speed to take account of differences in deposition rate of various welding processes.
- The importance of the welding process's efficiency.
- The importance of production cost which is related to differences in deposition rate, reject rate and rewelding factor among the welding processes.

Based on the above aspects and the dimensions and position of the joints, the suggested welding process sets are produced. These sets are built based on the scheme as shown in Figure 5.5. However, the logic being used is different. The score system is no longer used in this program but this set can be found by examining the objective of the particular joint against the related rules. After this set of alternative processes is found, the confidence factors are then calculated by following 'Bayes' theory.

The 'best' process for a particular joint is then selected in a manner similar to that in SWES. Thus, welding time and the production cost of this joint can be calculated by following the same method which has been validated and used in the previous program. Since a grillage structure consists of a number of groups of joints, the selected welding process has to be found for each such group. Hence, the total production time and production cost of the grillage can be calculated. The structure of the program and the interaction of the rules will be discussed in the next sub-section.

5.3.3 THE PROGRAM STRUCTURE

The program is designed to run on a personal computer such as IBM XT. The knowledge base contains 294 rules which are written in simple English; hence, the rules are readable and easily changed. The majority of rules are built following backward chaining logic. However some rules are constructed as a combination both of backward and forward chaining.

Figure 5.5.a shows an example of the backward chaining type of rules. What is implied that rule number 1 is true or proved if rule numbers 70, 127, 64, 30, 112 are also true or proved. To prove of these individual rules in turn, there needs to be a further consideration along the

decision tree structure. For example, to prove rule number 30, it is necessary to prove rule numbers 71 and 145. Ther may be a further requirement to prove these as well. The chain is carried out until the tip of the root of the decision tree. A rule which is a combination between backward and forward chaining can be structured as shown in Figure 5.5.b. Here rule number 26 is of the backward chaining type. Proof of this, however, is obtained through a forward chaining mechanism by stating that if the 'type' is of the 'butt' variety then rule number 9 applies and if the 'type' is not of the 'butt' variety then rule number 134 is valid. (The basic principles here are as outlined in Section 4.1.2, page 17.)

Due to the fact that available memory space in these computers is limited, the rules can also be designed by following the meta rule principle in which a rule can be used more than once. For the same reason , all the support data are stored in a separate data base. In this program, the welding processes data, both numerical and string data, are stored in Lotus 123 data base file. This kind of data base is managed by the program by using the built-in interface facility during running time. However, at the moment, the data can only be altered through the Lotus 123 program.

To run the program, the details of the grillage including the dimensions and the scantling sizes, as shown in Figures 5.6 and 5.7, should be entered. In addition to these and in order to have dialogue between the user and the computer, a set of questions (see Section 5.3.2) need to be answered. The input to these is done on a linear scale, as shown in Figures 5.8, 5.9, 5.10, 5.11 and 5.12.

Based on this data, a set of suggested welding processes with corresponding CFs for a particular joint is displayed, as shown in Figure 5.13. The user can decide the process which will be used to weld the joint by choosing one process out of the set. After this, the program will ask the user whether the result is satisfactory or not. If it is unsatisfactory, the program will then ask the user to change his opinions on the subjective aspects until he is satisfied with the result. The program will then continue to calculate the production time and production cost based on this selected process. The selected process of others joints are decided in the same way. Therefore, the total production cost of the grillage can be obtained.

The detail of this system including the aspects involved in this welding selection process, the detail structure of program and decision making logic, and the program validation is discussed in Appendix D.

5.4 EVALUATION OF THE PROGRAM

As mentioned in the previous section, one part of the production cost is the welding cost which is dependent on the welding process used. The process, in this 'Grillage' program, is selected subjectively from a set of alternative processes of welding which are suggested by the program for a specific joint. As discussed in Section 5.3, both objective and subjective aspects are involved in this selection process. Section 5.4.1. below evaluates the choice of welding process. An example of the application of this program to analyse the grillage structures is discussed in Section 5.4.2.

5.4.1 WELDING PROCESS SELECTION

In this study, the joint of the grillage shown in Figure 5.2 will be analysed as an example analysis. According to the capabilities of the alternative processes, the set consists of seven types of process which can be seen in Table 5.1.

The confidence factors (CFs) of these alternative processes are analysed on the basis of a set of degrees of belief/disbelief and the three subjective aspects. The value of these CFs vary according to the relative importance of these three aspects. If the degrees of belief of the process are above average, the CFs values will increase when the importance of the subjective aspect is increased. On the other hand, it will decrease if the DBs are below average.

The detailed results of the CF analysis for the above joint is discussed in Appendix E. In this case, the result is divided into two group according to the location of execution. Figures E.1 to E.27 of this appendix show the result of the CFs as a set of indoor processes. Figures E.1 to E.9 show the curves of CFs related to the importance of the welding speed aspect, Figures E.10 to E.18 related to the importance of the welding efficiency aspect and Figures E.19 to E.27 related to the importance of the production cost aspect. The results of a set of outdoor processes are shown in Figures E.28 to E.54 of this Appendix in which the classifications are similar to the indoor processes.

The curves of CFs related to the importance of the welding speed aspect (Figures E.1 to E.9 and E.28 to E.37 of Appendix E) show that the CF curves of the MMA process decline sharply, when the importance of the welding speed aspect is increased. Its deposition rate is very low compared to the others (below the average rate); hence the degree of belief upon this aspect is also very low (and degree of disbelief is high). Similar to the MMA process, the CF curves of the fusarc process also decline. However, it is not as sharp as the MMA process due to the fact that degree of belief of this process is higher than the MMA one. Although less than both these processes, the CF curves of the MIG dip and the MIG pulse processes decline too. However,the CF curves of the MIG spray and the SAW processes incline upwards gradually.

The CFs of most of these welding processes related to the importance of the welding efficiency (Figures E.10 to E.18 and Figures E.38 to E.46 in the same Appendix), incline upwards when the importance of welding efficiency is increased. It is in accordance with the assumption taken to calculate their degrees of belief/disbelief of this aspect in which the DB is taken equal to zero if the efficiency is zero percent and DB equal to one when the efficiency is 100%. in line with this assumption, all the DBs are above average (as shown in Table D.2 of Appendix D). Hence, the CF curves have a gradual upward slope.

With respect to the importance of the production cost aspect (Figures E.19 to E.27 and Figures E.47 to E.54), the CF curves of the

MMA, the MIG pulse and the Fusarc decline when this aspect is deemed more important. However, the CF curves of the MIG spray, the MIG dip and the SAW processes show an upward trend because their deposition rates are above average. However, this is dependent on the reject rates which are used.

The above discussions reveal that the CF values of the welding processes vary depending on their DBs/DDs and the importance of the three subjective aspects. Also, the results of the above example demonstrate that the program can give the user a set of reasonable alternatives in accordence with given opinions to assist him to choose a welding process suitable for a particular joint. Hence, this selection process can be applied to obtain the appropriate welding process for every joint within the grillage, in order to analyse the production cost of a part of a large structure, i.e. a grillage.

5.4.2 APPLICATIONS TO GRILLAGE ANALYSIS

As mentioned in Chapter 3, a grillage panel is a basic part of a large structure such as ship or barge. A number of alternative structural arrangements may be made. Therefore, in this case study, the 'Grillage' program is applied to analyse five structurally equivalent ship grillage panels. All of these grillage panels have a length of 10.7 m and a width of 9.5 m, but, they have different stiffener sizes and are also arranged differently , as shown in the Figure 5.14.

Besides the above data, user opinions on the criteria mentioned in Section 5.3.2 are needed. In real analysis, such opinions should be given on the basis of the yard experiences or their standards and the decisions are taken by the user. Based on these input data opinions, the welding processes which will be used in this production cost analysis are selected. These selected processes might be changed when the opinions on these subjective aspects are changed. It is possible to alter these opinions by choosing the 'Yes' from the menu as shown in Figure 5.15 and expressing the new opinions upon the subjective aspects (Figure 5.8 to 5.12). However, in this example these opinions are taken randomly by the author.

For comparison purposes, the cost factor, the 'Cost Equivalent Relative Weight (CERW)', is used. This factor is defined as :

$$CERW = (manhours \times k) + weight \quad (tonnes)$$

where: - $k = \dfrac{\text{labour rate}}{\text{material rate}}$

- Manhours is the total time to produce the grillage including fairing and tacking, and welding time.
- Weight is the total weight of the grillage.

In this study, the factors are calculated for the alternative welding process for each joint within the grillage. The calculations are based on the assumption that only one type of the automatic welding process (in addition to a manual one) will be employed to weld a structure or grillage. As shown in Tables 5.2.a, b, c, d, the CERWs vary depending on the welding process being used.

The next step is to examine the impact of changes in subjective aspects as shown in Figures 5.16, 5.17, 5.18.a, b and c. The result pertaining to this case are shown in Table 5.2.a . The low deposition rate mma process is the 'best' suggested process and grillage no.5 is the structure with the lowest CERW and hence the cheapest design. Although it is not as light as the third grillage, it contains minimum work which is represented by minimum production time.

Rank order changes when the opinions are altered. Assuming that the opinions on the aspects as shown in Figures 5.16 and 5.17 are unchanged and only three of the aspects shown in Figures 5.18.a, b, c, are changed to become as shown in Figures 5.18.e, f, g, the high deposition rate process (SAW process) will become the 'best' selection

Table 5.2.b shows the results when the SAW process is employed. Although grillage no.3 contains more work/joints, it becomes the lowest CERW structure due to its minimum weight. Thus, a light weight structure may become the cheapest structure if the high deposition rate welding process is employed.

In reality, the welding processes which will be used in such structural analysis are decided by the user. There are another two alternative welding processes which can be chosen to weld the structures, i.e. MIG pulse and MIG dip process. The MIG pulse process will become the selected process if the opinions upon the above three aspects are decided as shown in Figures 5.18.i, j, k. The results which are calculated based on this process are shown in

Table 5.2.c. However, when these three aspects are decided as

shown in Figures 5.18.m, n, o, the MIG dip process will become the 'best' selected process and the result is depicted in Table 5.2.d. The detailed results of these five grillage structures which are analysed by the 'Grillage' program according to this set of alternative welding processes, are shown in Appendix F.

These grillage structures have previously been analysed by Winkle, I.E and Baird, D (2.7) and the corresponding results can be seen in Table 5.3. These CERW factors are calculated based on the production time which is obtained according to the 'welding rate per meter' taken from the work study data (5.1).

The same grillages have also been studied by Emmerson, A. (5.3). Production times which include preparation and overhead time, are also calculated according to the work study data (5.1). The results of his study are given in Table 5.4.a. In order to compare them with the present results, which do not include these preparation and overhead times, it is necessary to subtract them from the production time, as shown in Table 5.4.b.

The CERW factors of these five grillage which are calculated based on the use mma process, Tables 5.2.a, 5.3, 5.4.b, have been compared. As shown in Figure 5.19, the values of CERW which are produced by the 'Grillage' program, are different compared to the results obtained by either 'Winkle' and/or 'Emmerson'. The above tables shown that the weight calculation results of these three method are relatively close. Hence, the difference should be in the way to calculate production time.

At first glance this seems inexplicable because both References 2.7 and 5.3 used the same source work study data as outlined in Reference 5.1. Furthermore, this latter is also the basis for a part of the Grillage system's calculation procedure as well. If the data are the same but the results are different, then the only reason for the differences lies in the application and interpretation of data.

Three such differences can be attributed to :

- choice of rolled versus fabricated sections,
- plate and profile standard sizes,
- application of the work study data.

Consider the first aspect. An examination of Figure 5.14 reveals that some of the profiles can be obtained as rolled sections directly from steel mills while others could be fabricated within the yard (see Figure 5.21). If it assumed that all sections are obtainable in pre-rolled form from steel mills, then the production time required to fabricate the grillages, as calculated manually using data from Reference 5.1, are given in the first column of the Table 5.5 (under 'WSD'). The lowest time, as expected, is achieved by design number 5 with simple longitudinal framing. The CERW factor is lowest in case design number 3 principally because of its low weight. The highest CERW is for design number 2.

If the consideration was changed such that any section with different web and flange thicknesses would need fabrication within the yard, then the corresponding production time figures are given in the third column in Table 5.5 (under WSD*). Again, design number 5 is the quickest to fabricate while design number 3 has the lowest CERW. The ranking of the designs, coincidentally is the same in the both cases (WSD and WSD*). However, there could be a change in this depending on the interpretation of what is a rolled stiffener and which stiffener needs to be fabricated.

The second possible cause for the differences is the assumption of standard plate and section sizes. For example, if the shipyard buys in plates of 6m x 2m from steel mills then it would require 10 sub-panels to fabricate a 10.7m x 9.5m panel - see Figure 5.20.a. Similarly, if the standard plate size is 9m x 3m, there would be a requirement for 8 sub-panels as shown in Figure 5.20.b. Such a difference in sub-panels or piece-parts would be equally applicable in case of profiles as well. Table 5.6 lists the number of piece-parts as given by Grillage, as listed in References 5.3 and 2.7 (incomplete) and, in the last column, as calculated by hand. (The values are based on a standard plate size of 6m x 2m.) It will be noticed that the hand calculated values confirm the results given by Grillage and that they are at variance with results obtained from Reference 5.3.

This difference in the number of piece-parts does have implications in the calculation of production time. To illustrate the reasons behind this, consider the activities involved in fabricating the grillage. These could be typically be as below.

- Transport plate piece-parts to assembly area. *)
- Fair and tack plate together.
- Weld plates - butt and seams.

- Transport piece-parts for transverses and for girders. *)
- Sub-assemble the transverses and/or girders.
- Fair and tack transverses and/or girders to plate panel.
- Weld transverses and/or girders to plate panel.
- Transport (any) intercostal members to work area. *)
- Fair and tack (any) intercostal members to plate panel.
- Weld (any) intercostal members to plate panel.
- Add lugs at intersections.

(*) Tranport activities are not covered in Reference 2.7 and the present work, but are included in Reference 5.3.)

The time taken to undertake each activity, other than transporting parts, is the product of the 'standard' time and the number of workers required for that particular task. The 'standard' time , in turn, is calculated in the format as set out below:

'Standard' time = (Plate/profile constant x no. of plates/profiles)
+ (Rate x contact length)

Thus, it can be noticed that standard plate/profile sizes which affect the numbers of plate/profile piece-parts do have an impact on the activity time.

The third aspect which could account for the differences is the manner in which the work study data is applied to calculate production time. This, in turn is dependent upon three sub-aspects:

- Application of job constant: This is a component of work study associated with various activities which accounts for preparation for that particular activity and includes time for receiving instructions and relaxation. This should be applied only once for a given work package. The definition of what constitutes a 'work package' is dependent on the interpretation in different yards. For example, one interpretation is to consider the whole grillage assembly as one work package. In this case, only one (-the largest for any activity-) job constant is applied. However, other yards could interpret each set of activities to be individual work packages, in which case the job constant gets taken into account each time.

- Incorporation of transport activities: As mentioned earlier, this has not been allowed for in the present work and in Reference 2.7. However, Emmerson (5.3) has strictly adhered to the definitions of what constitutes the total work package and included transport time as well.

- Number of workers: There is no explicit mention of this figure for different activities in either of References 2.7 or 5.3. In the present work, it has been assumed that a single person will carry out the welding while the fairing and tacking activities will require two people. There could be variations here. For example, Reference 5.1 indicates that fairing and tacking of light sections could be carried out by one person, though heavier sections would require two people. Hence, if Emmerson (5.3) or Winkle and Baird (2.7) have strictly adhered to the work study data, then this could be another potential cause for differences.

The above explanation gives an insight into the complexities (and differences) in calculating the production time. The differences in the answers, as indicated in Figure 5.19, are primarily due to the differences in the application and interpretation of the basic data.

Overall, however, the Grillage application has shown that it is possible to analyse a ship-type structure in an expert system context. The Grillage system is an interactive, relatively user-friendly environment in which a designer can analyse new designs from a production view-point. Objective as well as subjective interaction criteria have been considered here. This is a considerable advancement on presently available technique.

However, before transfering such a technique into shipyard environments, further work needs to be undertaken in order to clarify some practical aspects.

CHAPTER 6. GENERAL DISCUSSION

6.1 DISCUSSION

The examples of application in the previous chapter demonstrate the manner in which expert system principles can be applied in context of design for production. The work involved in this development and application has highlighted some areas for further examination. These can broadly be split into two categories namely expert systems related topics and design for production related areas.

6.1.1 ASPECTS OF EXPERT SYSTEMS

These are three fold. The first concerns the logic pattern adopted in the present work. This combines forward and backward chaining procedures. Certain aspects are deterministic or objective in nature and in such cases it is appropriate to approach the problem using forward chaining rule. However, there are occasions when more than one outcome is possible and in this case the requirement relates to proving various sets of hypotheses leading to alternative solutions. Both, the objective and subjective criteria based rules are dependent to a very large extent on the knowledge base. These, in turn, are dependent upon the particular design procedures, production facilities and fabrication methods employed in a particular shipyard. If there is a change in design procedure (eg: a 'new' stress constraint), or a new machine is bought or production procedures are streamlined, then there may be a change in the logic procedure. Hence this is one area which will need constant and continous updating.

Related to this aspect is the fact that there is a need to re-examine the knowledge and data bases themselves. In the present context, all data of an objective nature has been gathered from published sources. This may have to be reassessed depending on the context of application. For example, practices in U.K. differ from those in Indonesia. Hence, data which is valid here may not be relevant there. New sources may need to be used. Apart from measurable or objective data items, there is a big question-mark concerning subjective opinions as well. The program is currently design on the basis of fuzzy logic which is dependent on the user opinions input each time the program is run. This process is time consuming. If one set of 'global' or universally acceptable opinions were to become available, then the process would become better. However, arriving at this 'global' data base set is difficult. Even experts disagree among themselves, probably because of differing experience backgrounds. This is undoubtedly one of the key areas that will require further study.

A third related aspect concerns the 'black box' nature of programs and the requirement to maintain dialogue between the user and the program. In the present case, there is ample scope for the user to influence or change a decision with respect to the type of welding procedure (for example). This permits the user to be in 'control'. The extent of the user's influence is dependent on how many choices the user has to make which, in turn, dictates the amount of time at the terminal. More control generally implies more time at the terminal. The result, in this instance would still be the same, i.e. choice of a welding process or time required for a particular activity. So, an examination of the criticality of any additional user contact on the result is required. There is a fine balancing line between opening the 'black box' more and more and refining the result.

6.1.2 ASPECTS OF DESIGN FOR PRODUCTION

The applications in Chapter 5 have demonstrated how design and production parameters can be made to interact. The interaction, in this case, has been made for both objective and subjective criteria. The structural units, forming the vehicles of interaction, have been stiffened grillage panels. These are adequate for demonstration purpose, i.e. as a pilot study. However, as has been outlined in Chapter 2 and Appendix A, ship production relies more on semi-blocks and blocks as the basic entities for erection on a building berth. The interactions between design and production and among different production parameters themselves are more complex than in the case of panel structures. Account has got to be taken of the PWBS scheme operated in a shipyard. There is therefore a need to examine this aspect thoroughly before a practical proposition is made to a shipyard.

Linked to this proposition is the need to ensure information requirements are compatible with those available in practice. For example, all data items required for 'Grillage' are currently stored in spreadsheet files. In case of grillage panels, the number of items is relatively limited. For complete structural blocks there will be a considerable increase. Additionally, in a shipyard context many of data items will already be a part of the existing information system. Consequently, a more practically oriented system will require a study of information technology and an optimisation of data storage and transfer.

Lastly, as discussed in Chapter 5, there is some ambiguity about the manner in which production data is interpreted. There is therfore a need to study work content estimation procedures and their validity in a rapidly advancing technology.

6.2 FURTHER WORK

Based on the above discussion, there are five areas for further work:

- Investigation of the dependence of program logic on availability of data and updating of design and production procedures;
- Study of the methods of data acquisition along with the validity of these in specific contexts;
- Examination of the 'optimum' amount of dialogue between a program and the user;
- Extension of the grillage study to include structural semi-blocks and blocks;
- Incorporation of 'real-life' information system based constraints existing in shipyards.
- Study of work content estimation procedures and validation of developed technique.

CHAPTER 7. CONCLUDING REMARKS

The work in this thesis is concerned with the application of expert system principles in ship structural design for production. To support this work an extensive study of current design for production approaches has been carried out. Based on this study, some major shortcomings in the existing approaches have been identified. These have formed the basis for developing a new approach to the problem.

This new approach involves the use of expert system principles. A study of the theoretical aspects of this subject has been conducted. Practical applications of this technique in ship design and welding engineering have been examined. These studies indicate that the expert system principle is a suitable tool for design for production analysis.

The method has been applied to explicitely analyse some criteria of a subjective nature which are related to the interaction between design and production aspects of grillage panels. The program is developed to analyse both aspects to suggest appropriate welding processes for every joint within the grillage panel. The results of this analysis have been checked manually. Furthermore, by choosing one of the suggested welding process for each joint, the total production cost of the grillage panel can be predicted.

The numerical computation part of the program has also been tested successfully by comparing the computed results with manual calculations based on work study data for simple plate panels. The computational results for a set of various grillage panels obtained by other authors have also been compared with those calculated by the previous studies. This comparison shows that the results are dependent on the way in which production times are calculated and on the interpretation of available (work study) data.

The application of the higher deposition rate welding process on more welding joints within a grillage reduces the 'cost factor'. Compared to the application of the manual metal arc process, this reduction, which is in the range of 10% to 32%, depends on the length and the size of welding joints.

Overall, this work has demonstrated that expert system principles can be applied to ship structural design for production. The present work has looked at simple grillage panels. Before practical application in a yard, this simple approach does need to be extended to cover complex units such as blocks or semi-blocks. However, importantly, it has been shown here that it is feasible to have a dialogue between the designer and the program. Both subjective and objective criteria governing the decision-making process can be accounted for.

REFERENCES

In Chapter 1

1.1 Keil, H.
'Methods Covering the Technical and Production Costwise Optimization of a Shipbuilding Project and Their Effects on the Planning Work of the Shipyard'
Proceedings of the First International Marine Systems Design Conference, London, 1982

1.2 --
Proceedings of Seminar on Design for Production,
BSRA, Newcastle-upon-Tyne, April 1978

In Chapter 2

2.1 Caldwell, J.B
'Design for Production'
de Ingenieur 84/49, December 1972

2.2 -
'Design Philosophy, Criteria and Procedure'
Report of Committee V.1, 7th International Ship Structures Congress, Paris, 1979

2.3 Moe, J. and Lund, S.
'Cost and Weight Minimization with Special Emphasis on Longitudinal Strength of Tanker'
Transactions of the Royal Institution of Naval Architects, 1968

2.4 Kuo, C., MacCallum, K.J.,Shenoi, R.A. and Theophanetes, A.
'Design for Production of Ship and Offshore Structures'
STAR Symposium of Society of Naval Architects and Marine Engineers, Washington, April 1983

2.5 Kuo, C., MacCallum, K.J. and Shenoi, R.A.
'An Effective Approach to Structural Design for Production'
Transactions of the Royal Institution of Naval Architects, 1983

2.6 Shenoi, R.A. and Emmerson, A.
'Structural Producibility Considerations on a Micro Computer',
Proceedings of the International Conference on Computer Applications in the Automation of Shipyard Operations and Ship Design, V, Trieste, 1985

2.7 Winkle, I.E and Baird, D.
'Toward more Effective Structural Design Through Synthesis and Optimization of Relative Fabrication Cost'
Transactions of the Royal Institution of Naval Architects, 1986

2.8 Brown, D.
'An Aid to Steel Cost Estimating and Structural Design Optimization'
Transactions of the North East Coast Institution of Engineers and Shipbuilders, October 1987

2.9 Graves, R.J.,McGinnis,L.F. and Robinson, R.A.
'Shipyard Production Standards'
Journal of Ship Production, 4/1, 1988

2.10 Lamb, T.
'Engineering for Ship Production'
Journal of Ship Production, 3/4, 1987

2.11 Wade, M.
'Use of Standard Task Blocks to Simplify the Ship Production Process'
Journal of Ship Production, 2/2, 1986

2.12 Forbes, S. and Varney, J.B.
'Ship Assembly Technology'
International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.13 Kamata, A. and Hori, K.
'Automatic Hull Structure Sub-assembly Machine'
International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.14 Bellonzi,R.J.
'Islands of Automation in Shipbuilding'
Journal of Ship Production, 2/1, 1986

2.15 Ohta, M.

'The Construction and Welding of Sections in the New Shipyard'

International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.16 Lucas,W

'Advances in Arc Welding Process for Shipbuilding'

Proceeding for 4th International Conference on Shipbuilding and Ocean Engineering, Helsinki, 1986

2.17 Sekine, M., Irie, H., Ohki,M., Mimura,M.

'Improvement in Welding Technology at the Tsurumi Shipyard'

International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.18 Koshiga,F., Tanaka,J., Watanabe,I., Suzuki,M.

'High Productivity One-sided MIG Welding Process'

International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.19 Akahide,K., Agusa,K., Tsuboi,J.

'The One-sided Submerged-arc Deep Penetration Welding Process with Lower Heat Input'

International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.20 Kalb,J.G. and Verbree,M.
'Berth Welding Development in the Netherlands'
International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.21 Mikalsen,M., Braathen,C.M. and Baggerud,A.
'One-sided Welding with Controlled Penetration'
International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

2.22 Williams, E.A.
'Role of Information Systems in Design for Production'
Seminar on Advances in Design for Production
Southampton 4/1984.

2.23 Forrest, P.D.
'Information Systems in the Design for Production'
Seminar on Advances in Design for Production,
Southampton 4/1984.

2.24 Jones, C.
'The Information Systems at Harland and Wolff'
Seminar on Advances in Design for Production
Southampton 4/1984.

2.25 Chirillo, L.D., Inuki, I. and Kobayashi, I.
'Shipyard Organization and Management Development'
Journal of Ship Production, 2/2, 1986

2.26 Chirillo, L.D.
'Product Work Breakdown: The Challenge to Production and Design Engineers'
Journal of Ship Production, 5/2, 1989

<u>In Chapter 4 :</u>

4.1. Chadwick,M. and Hannah,J.
'Expert Systems for Personal Computers.'
Sigma Press, Chichester, 1986

4.2. Naylor,C.
'Build Your Own Expert System"
Sigma Press , Chichester, 1983

4.3. Negoita,C.V
'Expert Systems and Fuzzy Systems"
The Bunyamin Co , 1985

4.4. Kennedy, J.B. and Neville, A.M.
'Basic Statistical Methods for Engineers and Scientists',
Harper and Row Inc, New York 1986

4.5. Meacock, S.E.
Unpublished Lecture Notes
Statistics Lecture Text VI,
University of Southampton, Undated.

4.6. Adeli,H.
'Expert Systems in Construction and Structural Engineering'
Chapman and Hall , New York , 1988

4.7. Harmon,P. and King, D.
'Artificial intelligent in Business'
John Wiley, New York, 1985

4.8. Hartman, P.J.
'Practical Applications of Artificial Intelligence in Naval Engineering',
Naval Engineers Journal, November 1988

4.9. Kishi, M., Noda, K., Yamashita, Y. and Taguchi, K.
'Design and Implementation of an Expert System for System Dynamics Modelling',
Proceedings of the Third International Symposium on Practical Design of Ships and Mobile Units, Trondheim, June 1987

4.10. Katsoulakos, P.S. and Hornsby, C.P.W.
'Expert Systems and Marine Applications',
Institute of Marine Engineers Seminar, London, October 1988

4.11. Drew,S.

'Advance in Condition Monitoring'

Institute of Marine Engineers Seminar, London, October 1988

4.12. MacCallum, K.J.

'Creative Ship Design by Computer'

Proceedings of the International Conference on Computer Applications in the Automation of Shipyard Operation and Ship Design IV, Maryland, 1982

4.13. MacCallum, K.J. and Martins, P.D.

'Towards a Concept Design Assistant for Ships'

Proceedings of the Second International Marine Systems Design Conference, Lingby, 1985

4.14. Kristiansen, S.

'The Application of Expert Systems in Marine System Design'

Proceedings of the Second International Marine Systems Design conference, Lingby, 1985

4.15. Soh, C.K. and Soh, A.K.

'Using Meta-level Knowledge in the Design of Offshore Strructure'

Engineering Applications of Artificial Intelegence, September 1989.

4.16. MacCallum, K.J

'Expert Systems in Engineering Design'

Proceedings of the Institution of Engineers and Shipbuilders in Scotland, vol. 130, January 1987

4.17. Akagi,S., Tanaka,T. and Kubonishi,H.

'An Expert System for the Design of Marine Power Plants Using Artificial intelligence',

J.M.S.E. International Journal,

series III, vol 31/1, 1988

4.18. Hills,W. and Buxton,I.L.

'Integrating Ship Design and Production Consideration during the Pre-contract Phase'

The Naval Architect, September, 1989

4.19. Welsh, M., Buxton, I.L. and Hills, W.

'The Application of an Expert System to Ship Concept Design Investigations'

The Royal Institution of Naval Architects, Spring Meeting 1990

4.20. Truouleeyre,J. and Grand,J.L.

'Data Base in Relation to Welding Process'

Proceedings of the First International Conference on Computer Technology in Welding, London, June 1986

4.21. James, E.B. and Baker, J.L.

'The Application of Knowledge Based System in Welding'

Proceedings of the First International Conference on Computer Technology in Welding, London, June 1986

4.22. Turner,J.D.,Farrar,R.A and Riberio, E.A.
'Research in Welding Expert Systems at Southampton University'
Proceedings of the First International Conference on Computer Technology in Welding, London, June 1986

4.23. Lucas, W.
'Micro Computer Systems, Software and Expert Systems for Welding Engineering'
Welding Journal, April 1987

4.24. Kuhne,A.H., Cary,H.B. and Prinz,F.B.
'An Expert System for Robotic Arc Welding',
Welding Journal, November 1987

4.25. Reeves, T.D., Manley,T.D., Potter,A. and Ford,D.R.
'Expert System Technology - An Avenue to an Intelligent Weld Process Control System',
Welding Journal, June 1988

<u>In Chapter 5.</u>

5.1. --
'British Shipbuilders Work Study Data'

5.2. --
'Crystal' Manual Book,

5.3. Emmerson, A.

'Structural Design for Production on a Micro Computer'

M.Phil Thesis, University of Southampton, 1987

In Appendix A

A.1. Terai, K., Kurioka, T., Kanatani, F. and Nakayama, S.

'Some Considerations about Value Analysis in the Assembly of Hull Panel Units'

International Conference on Structural Design and Fabrication in Shipbuilding, London, 1975

In Appendix B

B.1. McMahon, B.P.

'The Price of Welding'

The Welding and Metal Fabrication, January 1970.

B.2. Gray, T.G.F., Spence, J. and North, T.H.

'Rational Welding Design'

Newnes-Butterworths, London, 1975

B.3. Kearns, W.H.

'Welding Processes- Arc and Gas Welding and Cutting, Brazing and Soldering'

American Welding Society, Miami, 1978

B.4 Horwitz, H.P.E.

'Welding: Principles and Practice'

Houghton Mifflin Co, Boston, 1979

B.5. Lundqvist, B.

'Sandvik Welding Handbook'

Sandvik AB, Sanviken, Sweden, 1977

FIGURES

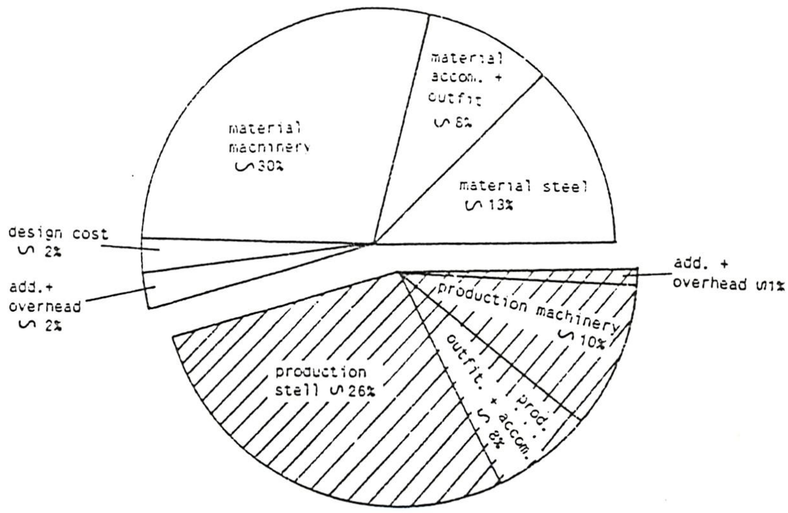


Figure 1.1 Cost Splitting of a Container Ship
(source : ref. 1.1)

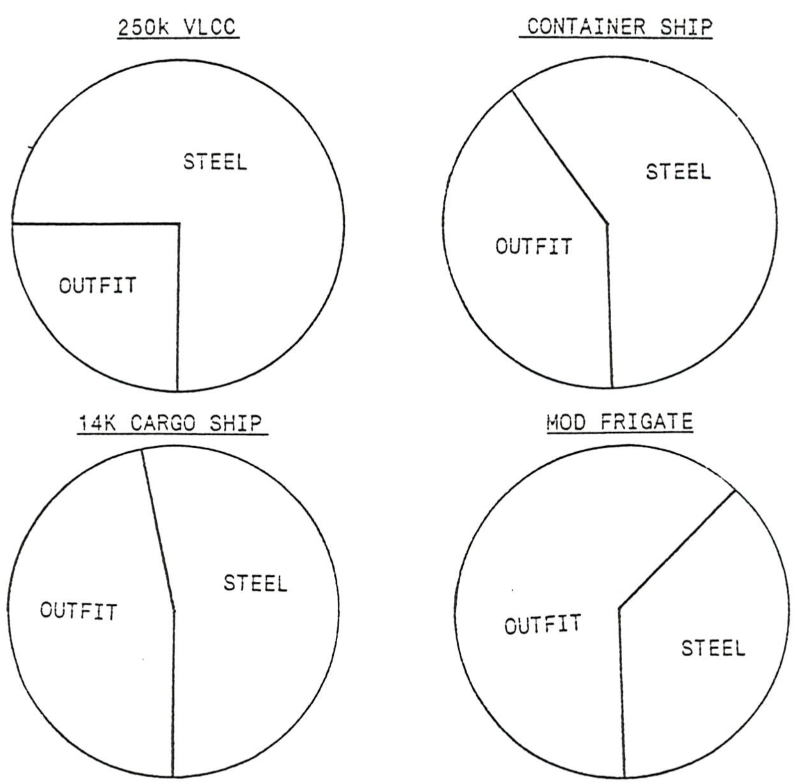


Figure 1.2 Comparison of Labour Cost
(source : ref. 1.2)

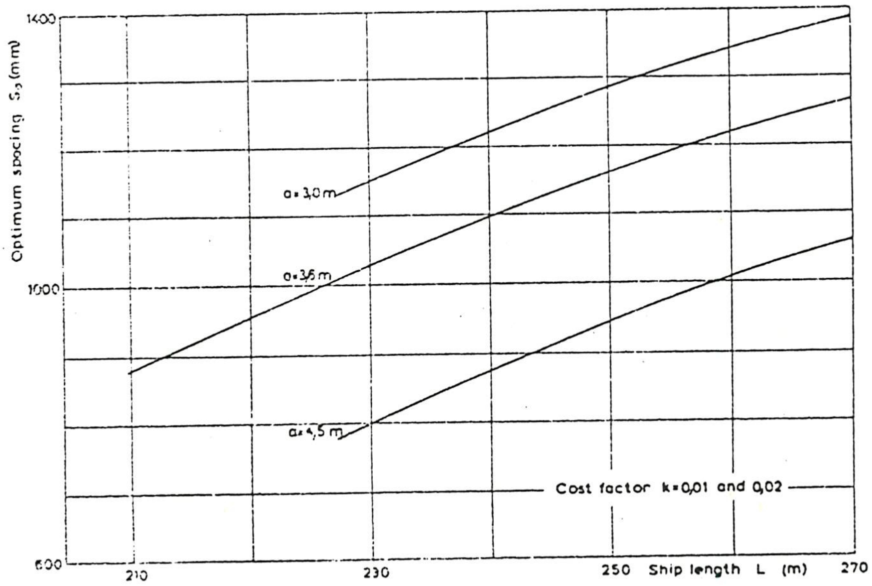


Figure 2.1 Optimum Longitudinal Frame-spacing
(source : ref. 2.3)

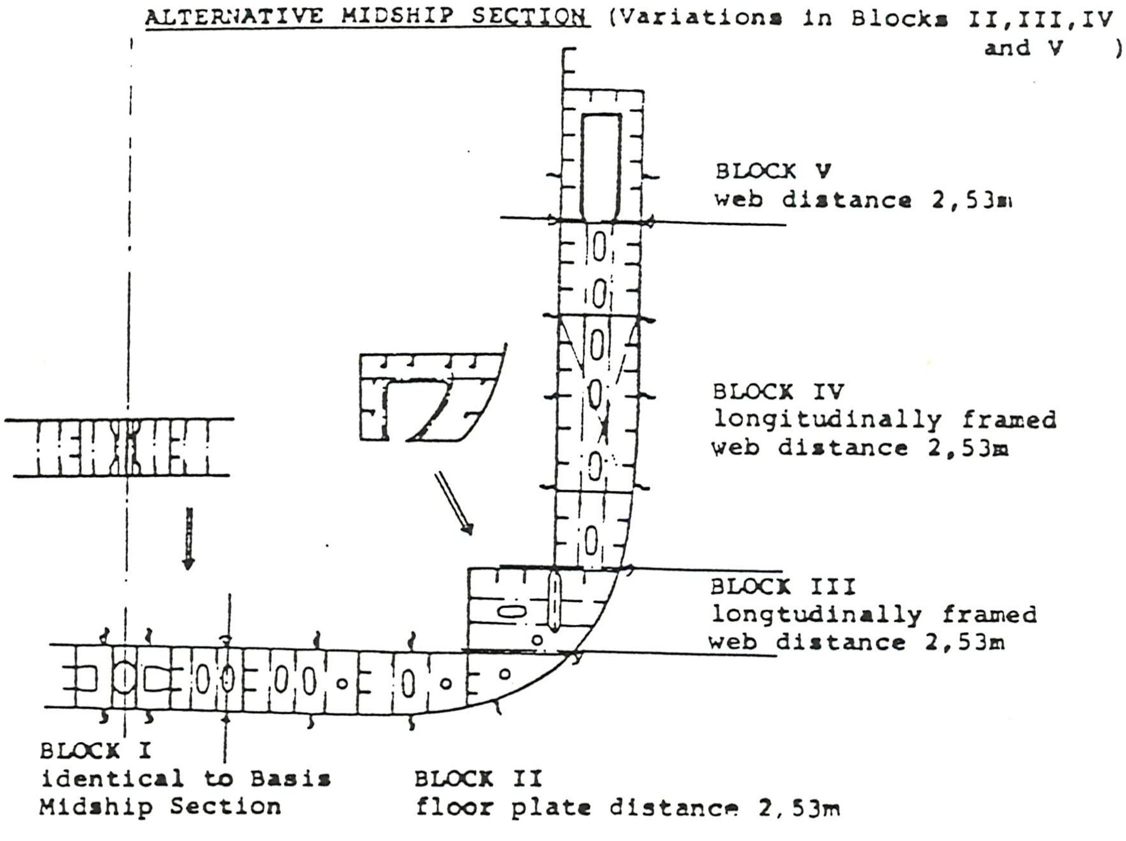


Figure 2.2 An Alternative Midship Structure
Design of a Container Ship (source : ref. 1.1)

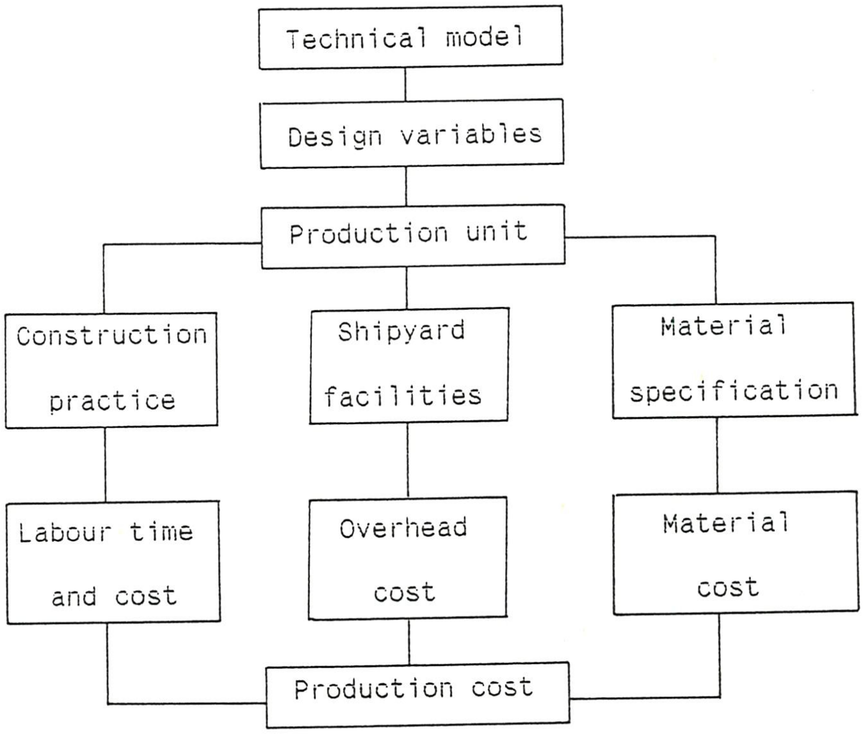


Figure 2.3 Linking of Design and Production
(source : ref. 2.4)

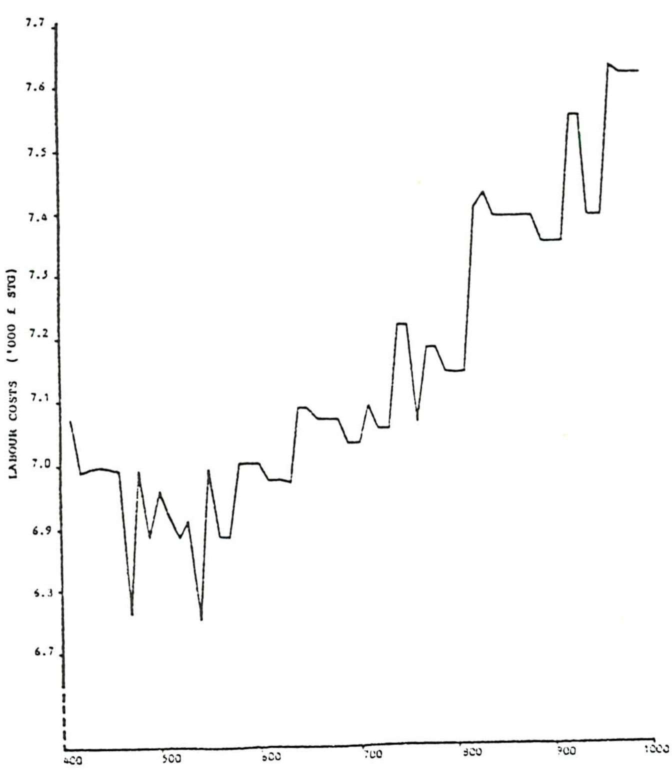


Figure 2.4 Stepped Variation in Labour Cost
(source : ref. 2.5)

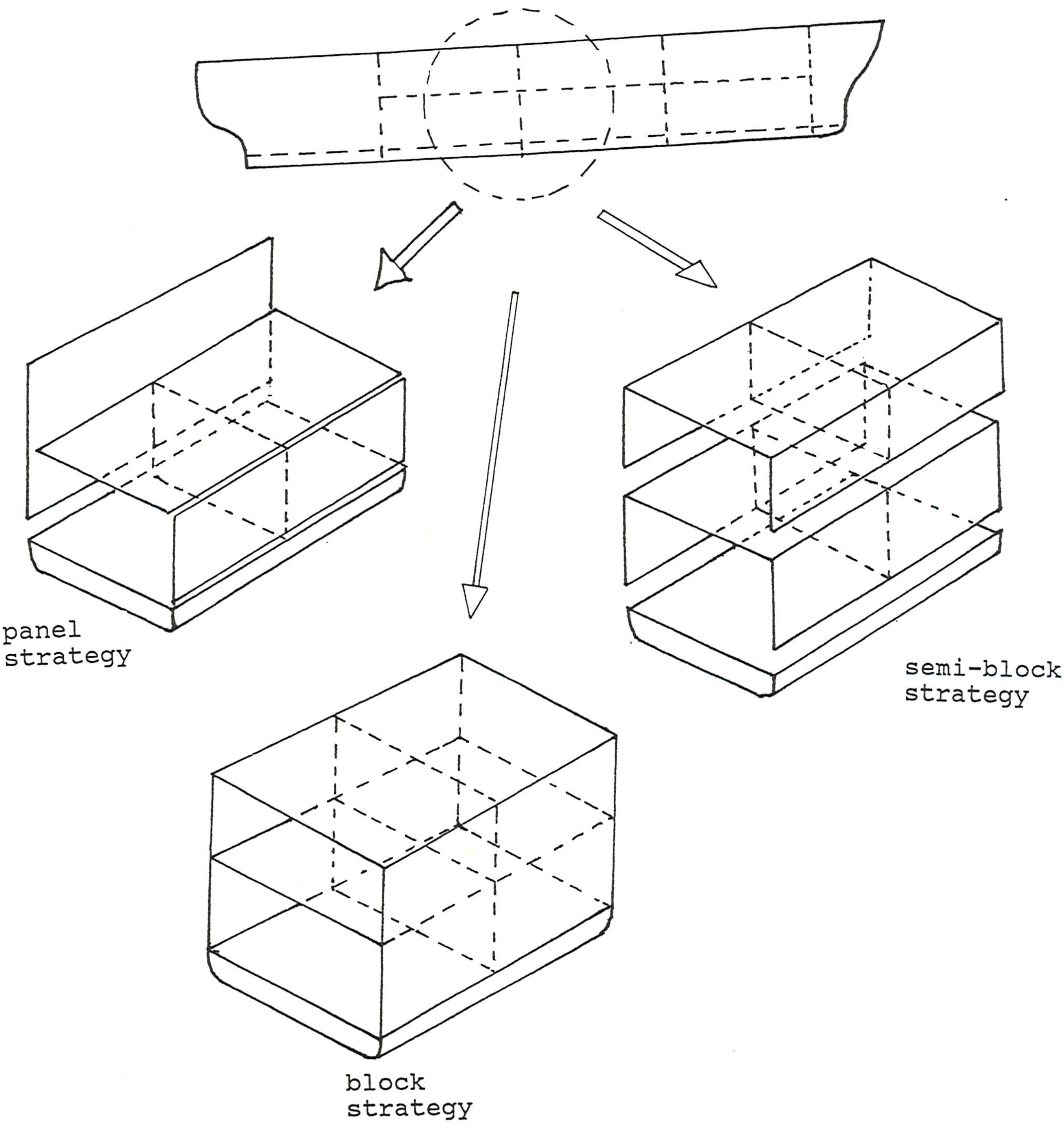
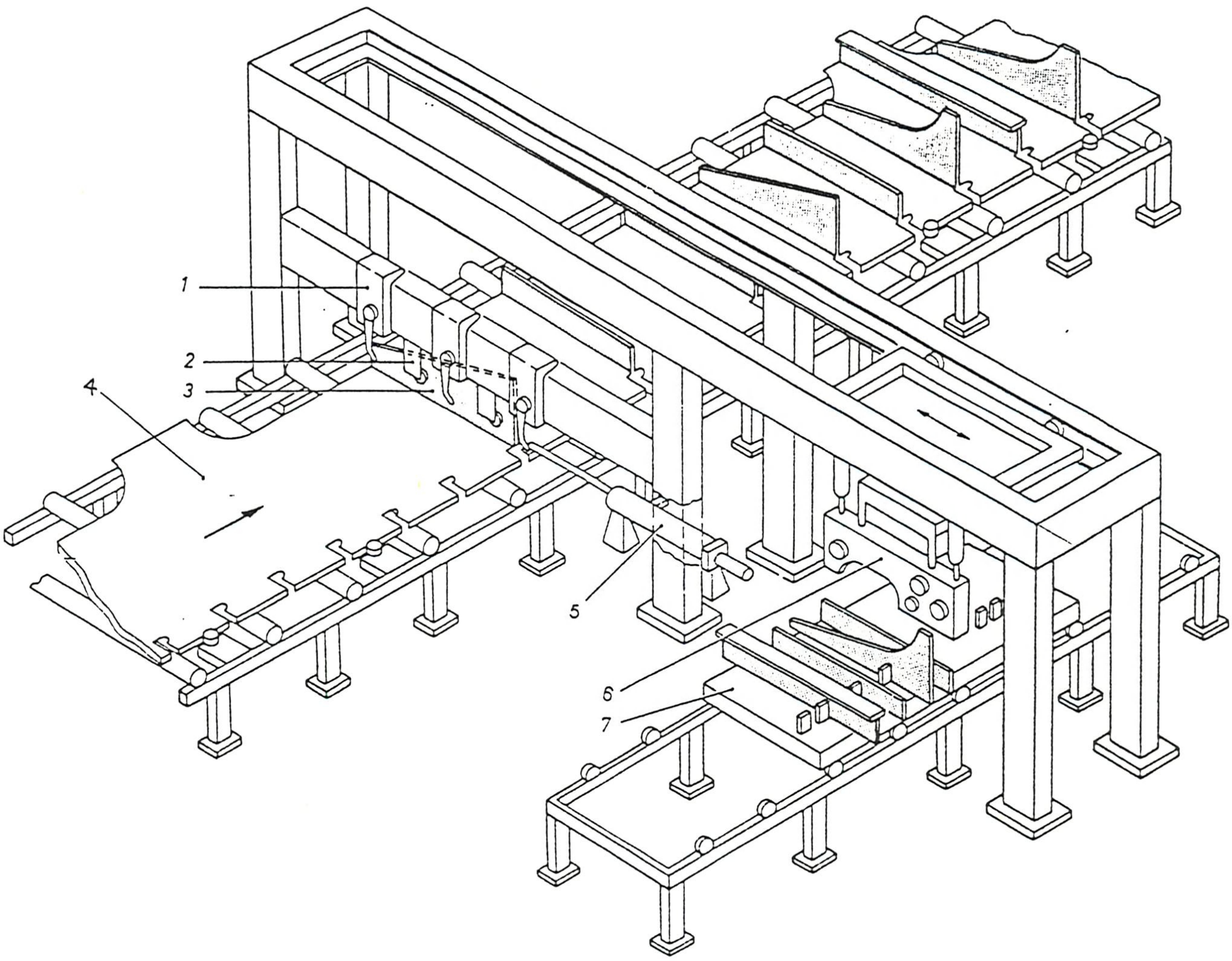


Figure 2.5. A Ship Structural Breakdown



1—welding head; 2—part holder; 3—bracket underfitting; 4—web plate; 5—part positioner; 6—part carrier; 7—sliding part rack

Figure 2.6 (a) Auto Hull Assembler (source : ref. 2.14)

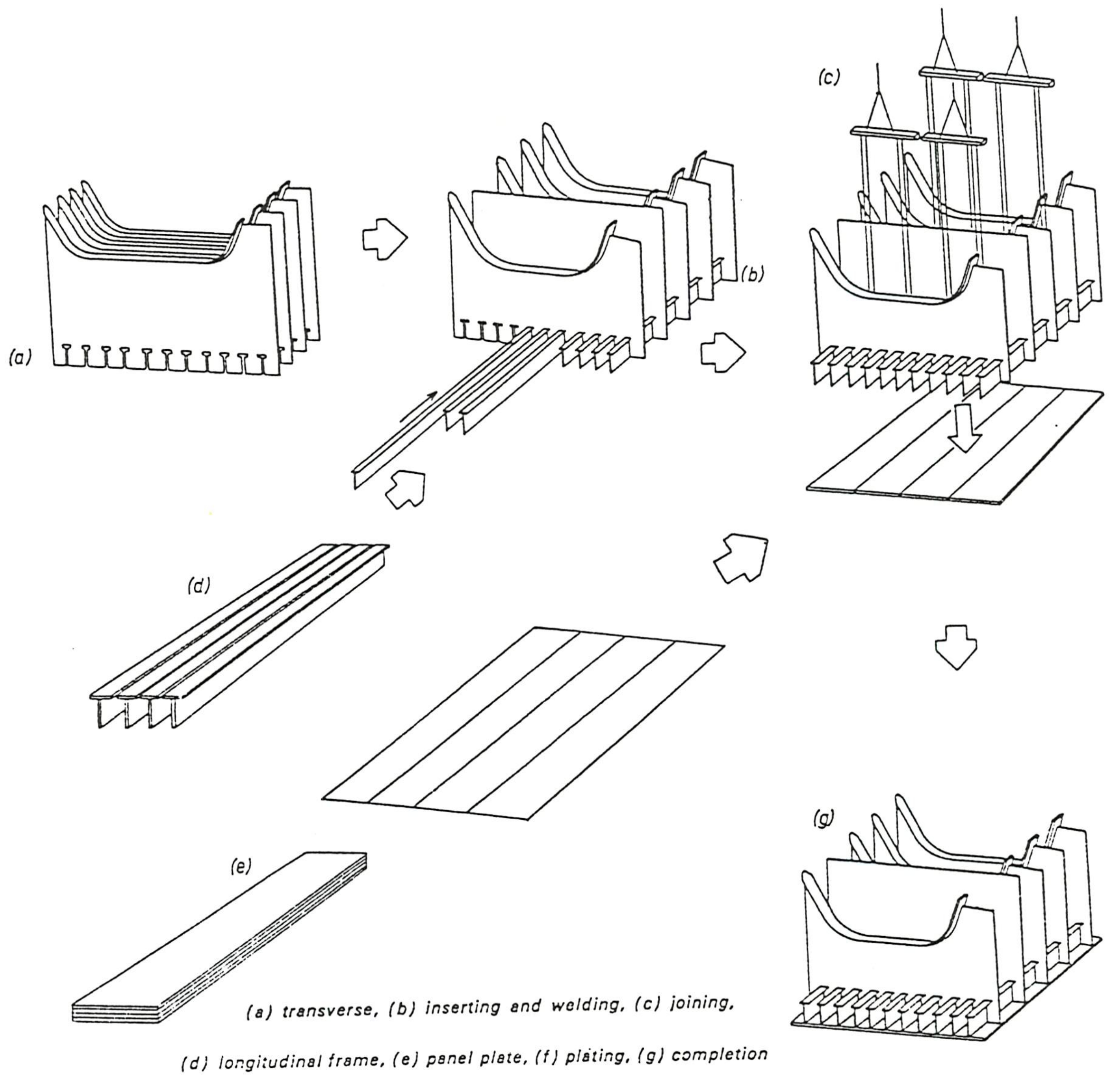


Figure 2.6.b 'Hi Panel' Method (source : ref. 2.15)

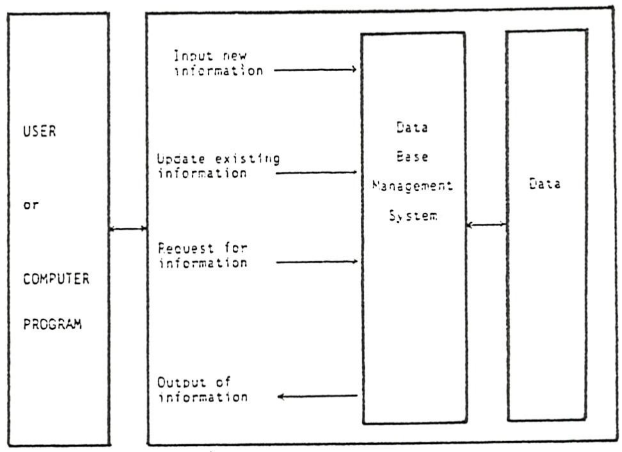


Figure 2.7 Relationship between Information System and Data Base Management (source : ref. 2.22)

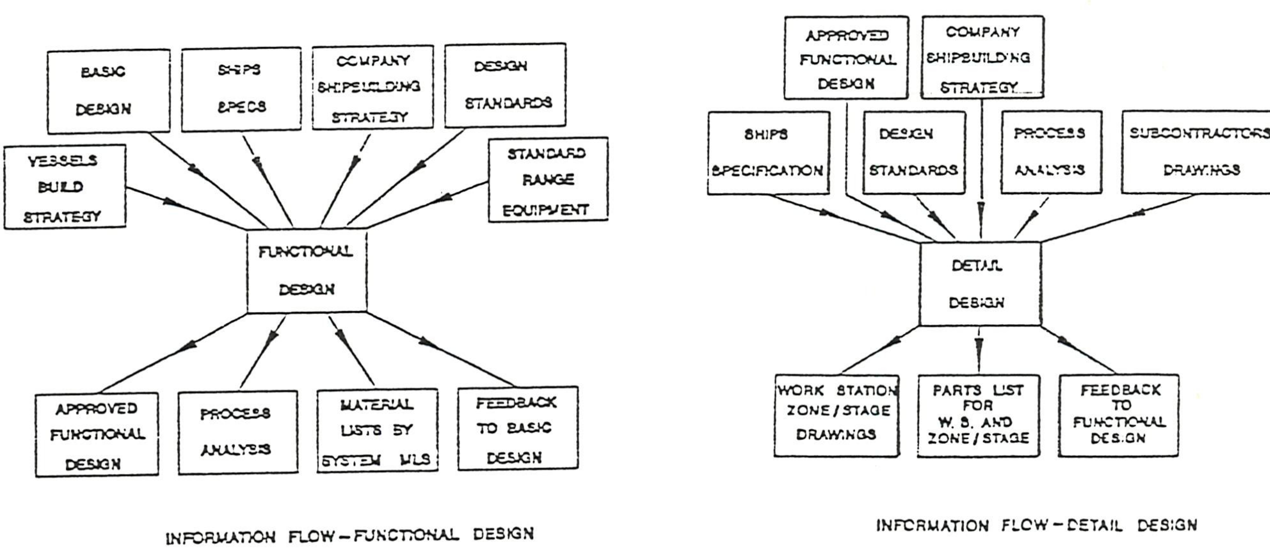


Figure 2.8 Information System in PWBS (source : ref. 2.23)

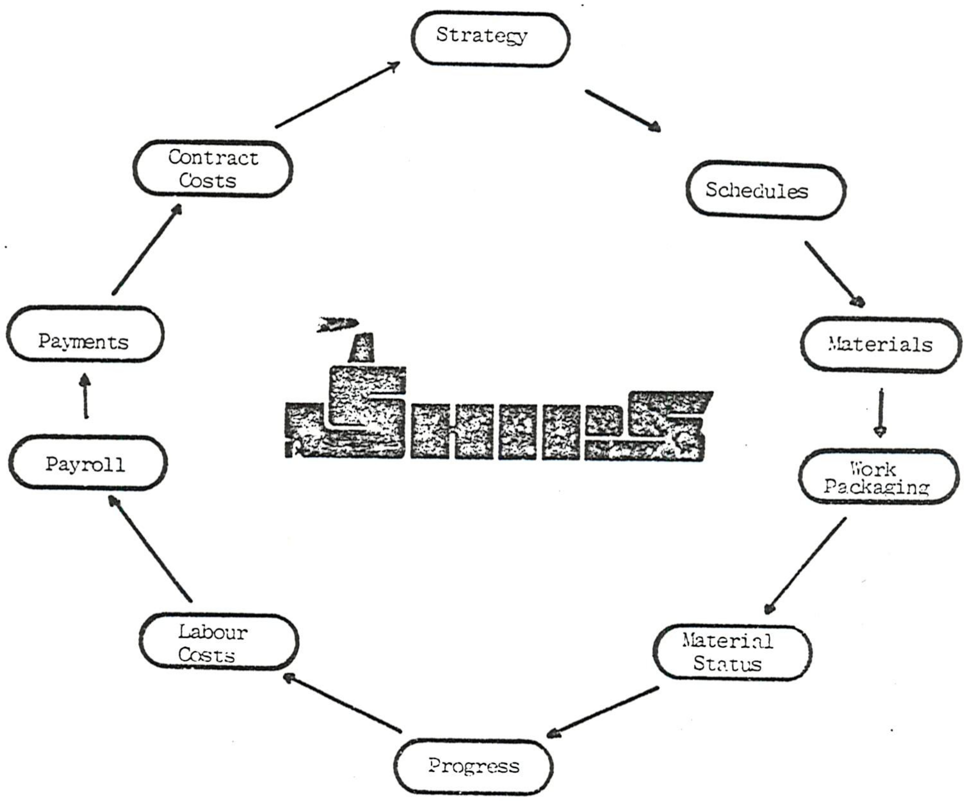


Figure 2.9 Link between Modules in 'SHIPS' System
(source : ref. 2.24)

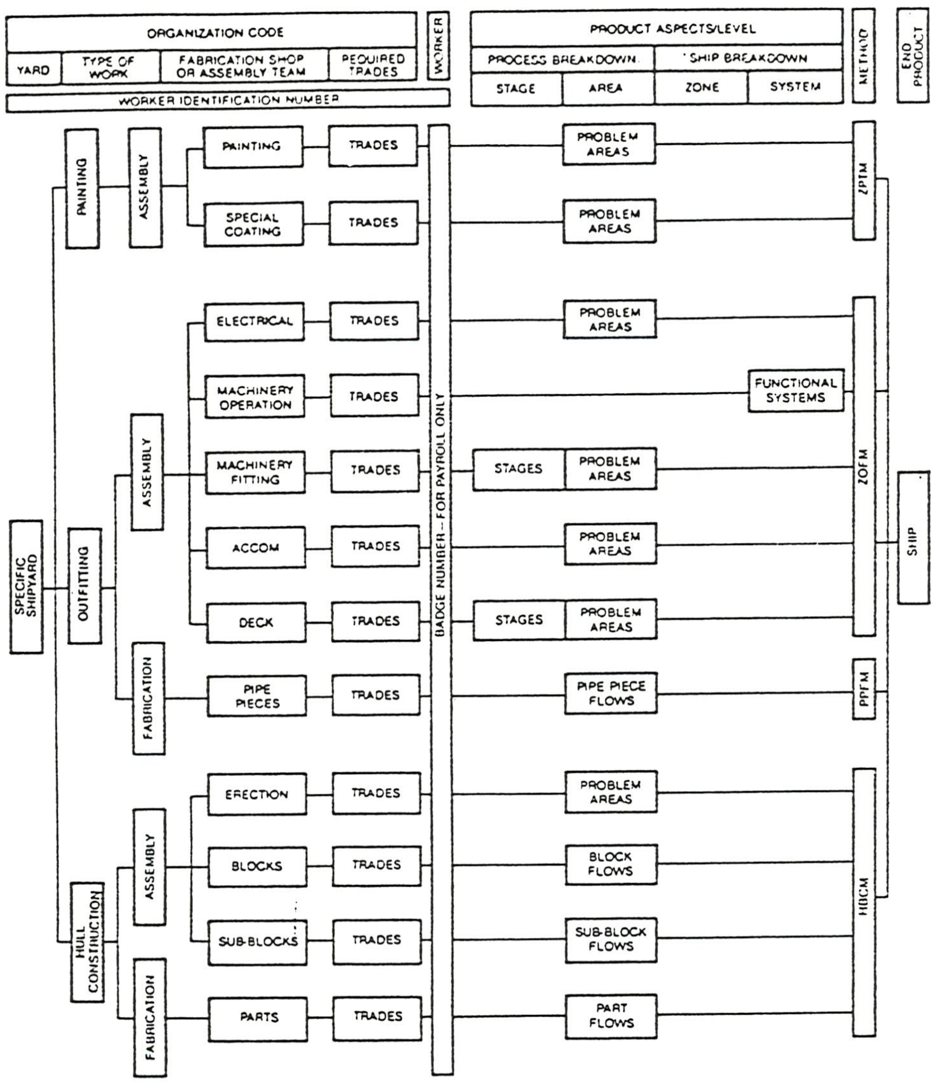


Figure 2.10 Organisation Based on Work Classifications (source : ref. 2.25)

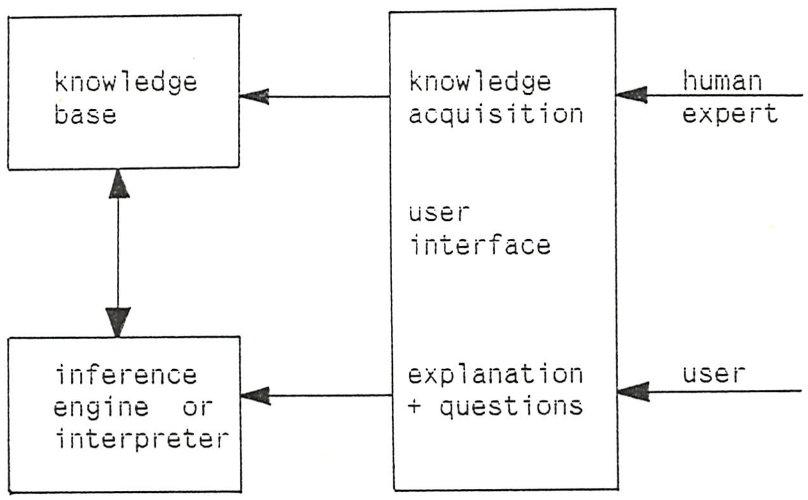


Figure 4.1 Basic Structure of Expert System
(source : ref. 4.1)

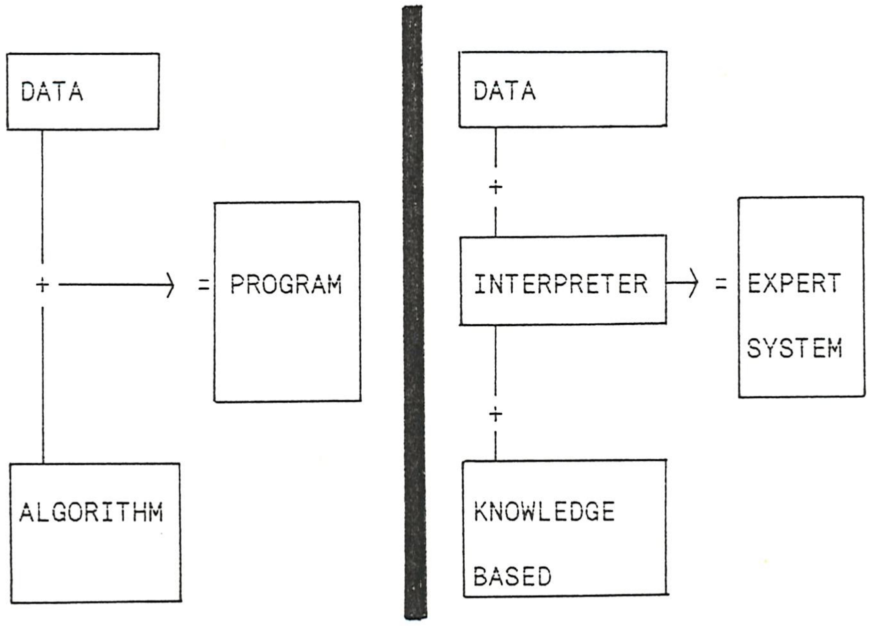


Figure 4.2 Structures of Algorithm Program and
Expert System (source : ref. 4.2)

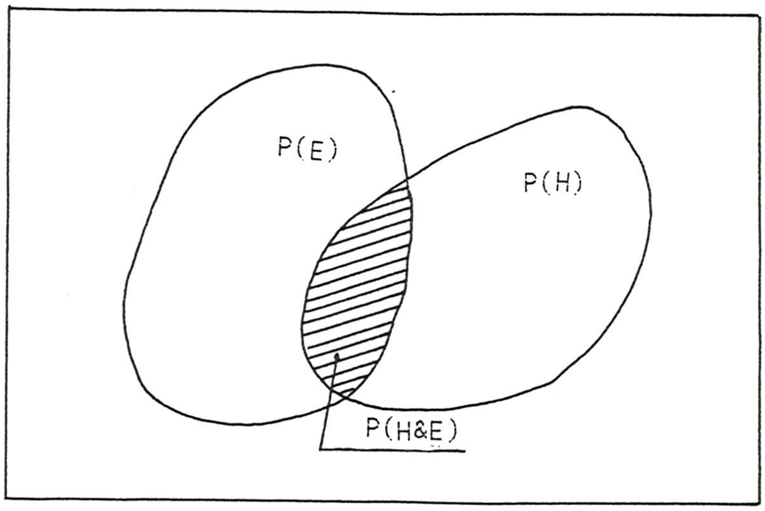


Figure 4.2.a A Joint Probability

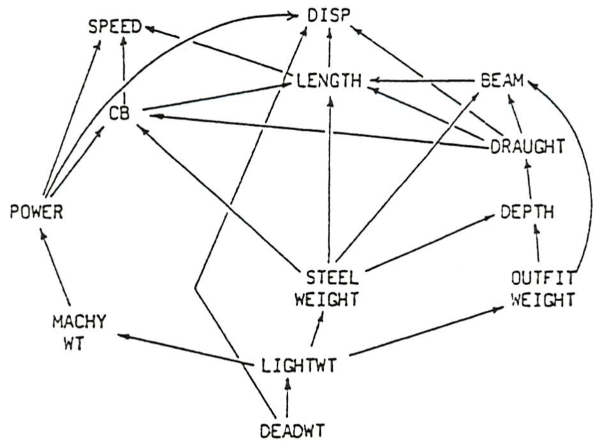


Figure 4.3 Design Parameters and Their Relationship
(source : ref. 4.13)

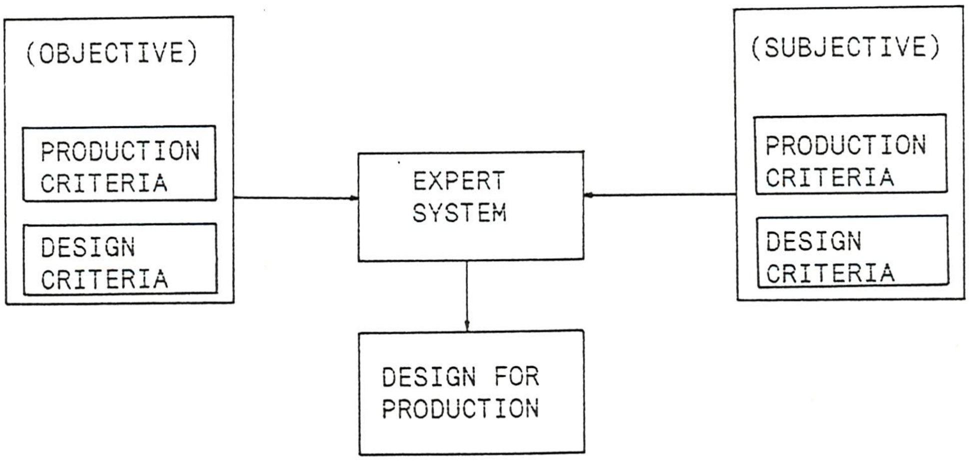
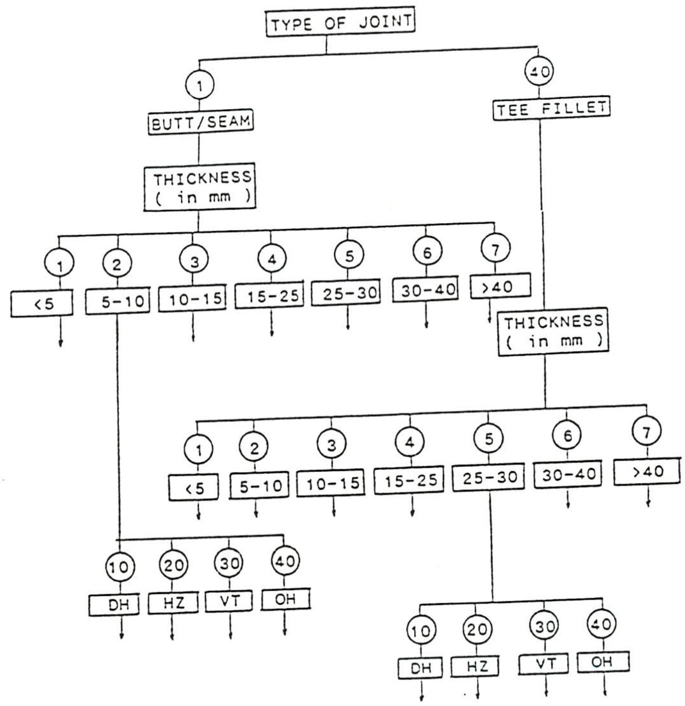


Figure 4.4 Expert System in Ship Design for Production



DH = downhand; HZ = Horizontal; VT = Vertical; OH = overhead

Figure 5.1 Welding Process Decision Tree for 'SWES' program

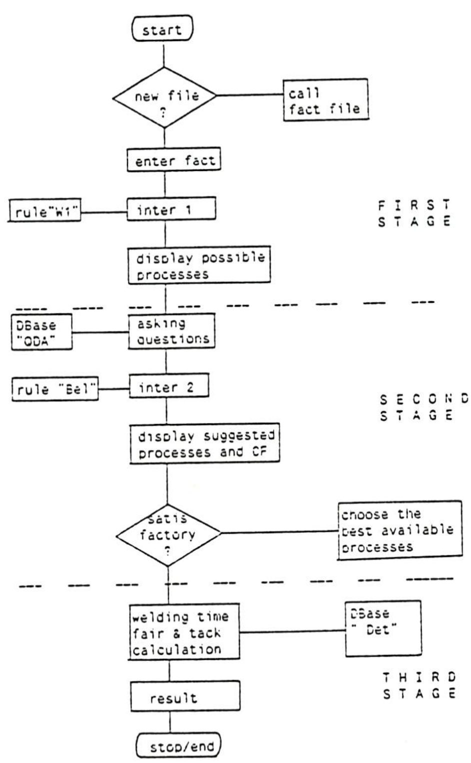


Figure 5.2.a The Flow Chart of 'SWES'

```
.............. S W E S ..............
...... SHIP WELDING EXPERT SYSTEM ......
.........  SUSANTO SUKARDI  ............

[1]    CREATE A NEW GRILLAGE DATA
[2]    USING EXISTING GRILLAGE DATA
[3]    CHECK THE FILE
[4]    PROCESS THE CONFIDENCE FACTOR
[5]    CALCULATE THE PRODUCTION TIME
[6]    PRINT OUT THE RESULT
[9]    STOP
```

Figure 5.2.b The SWES Main Menu Display.

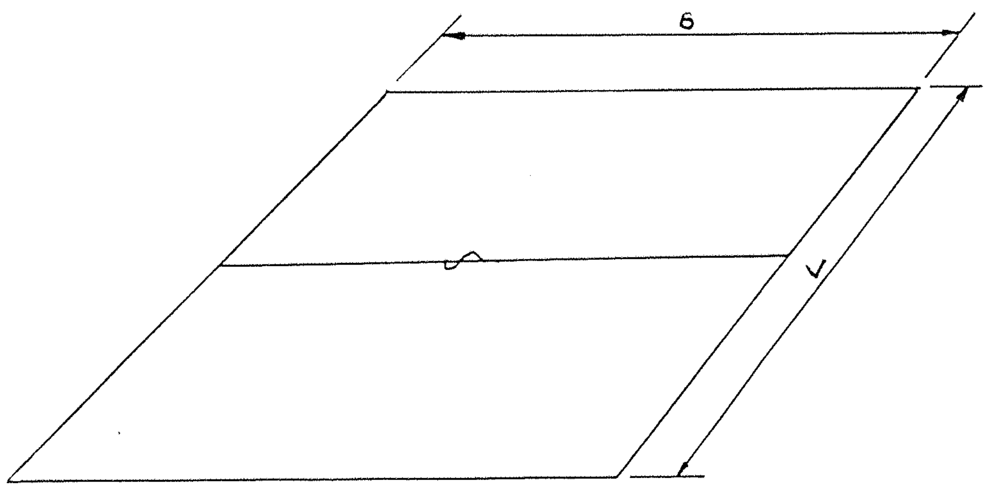


Figure 5.2.c The Single Joint Grillage

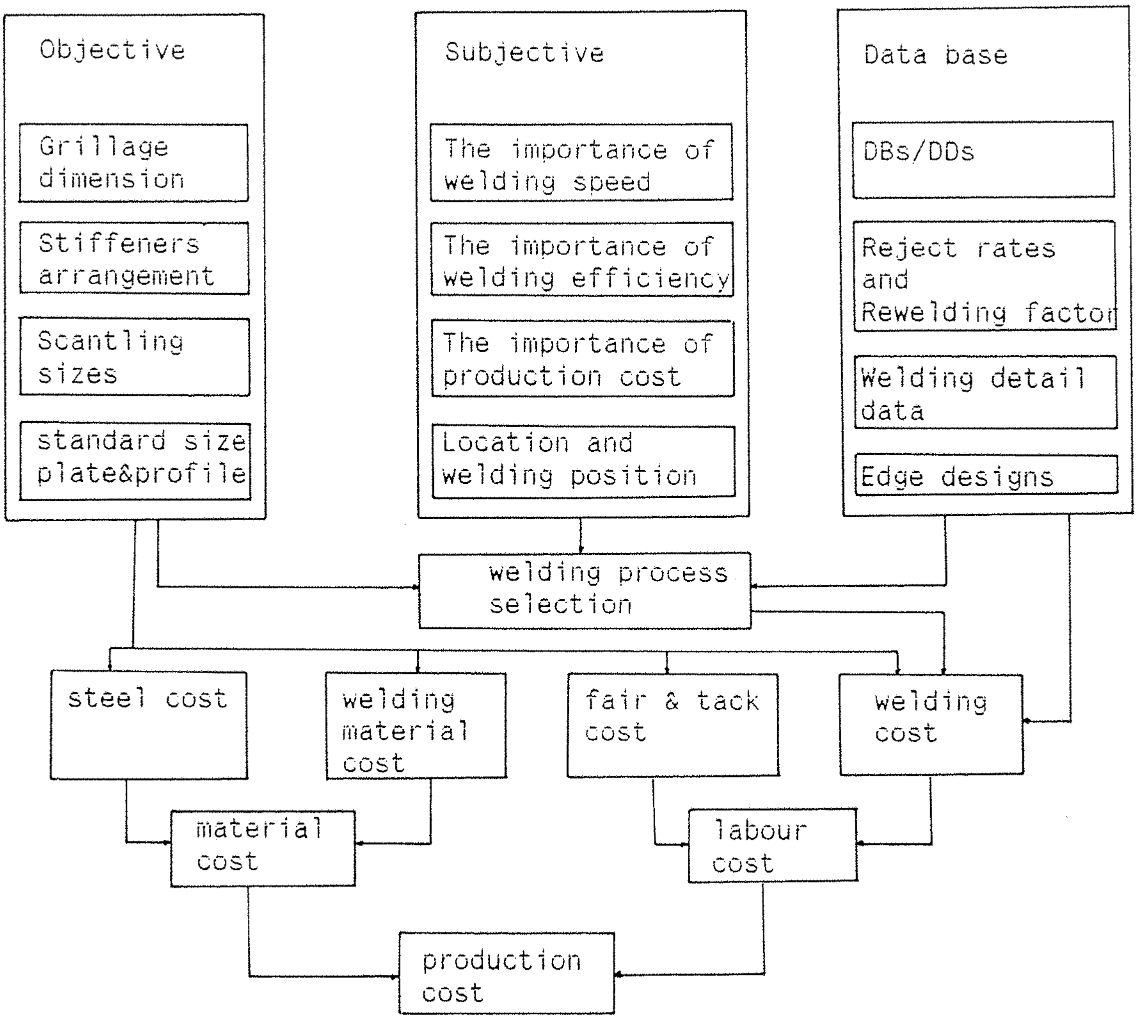


Figure 5.3 The Involved Criteria and Their Relationship

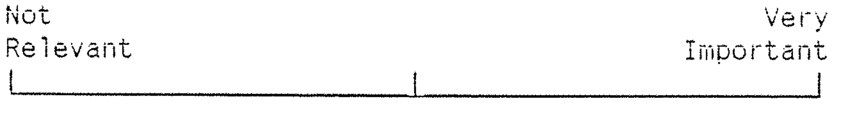


Figure 5.4 The Line Scale for Subjective Expession

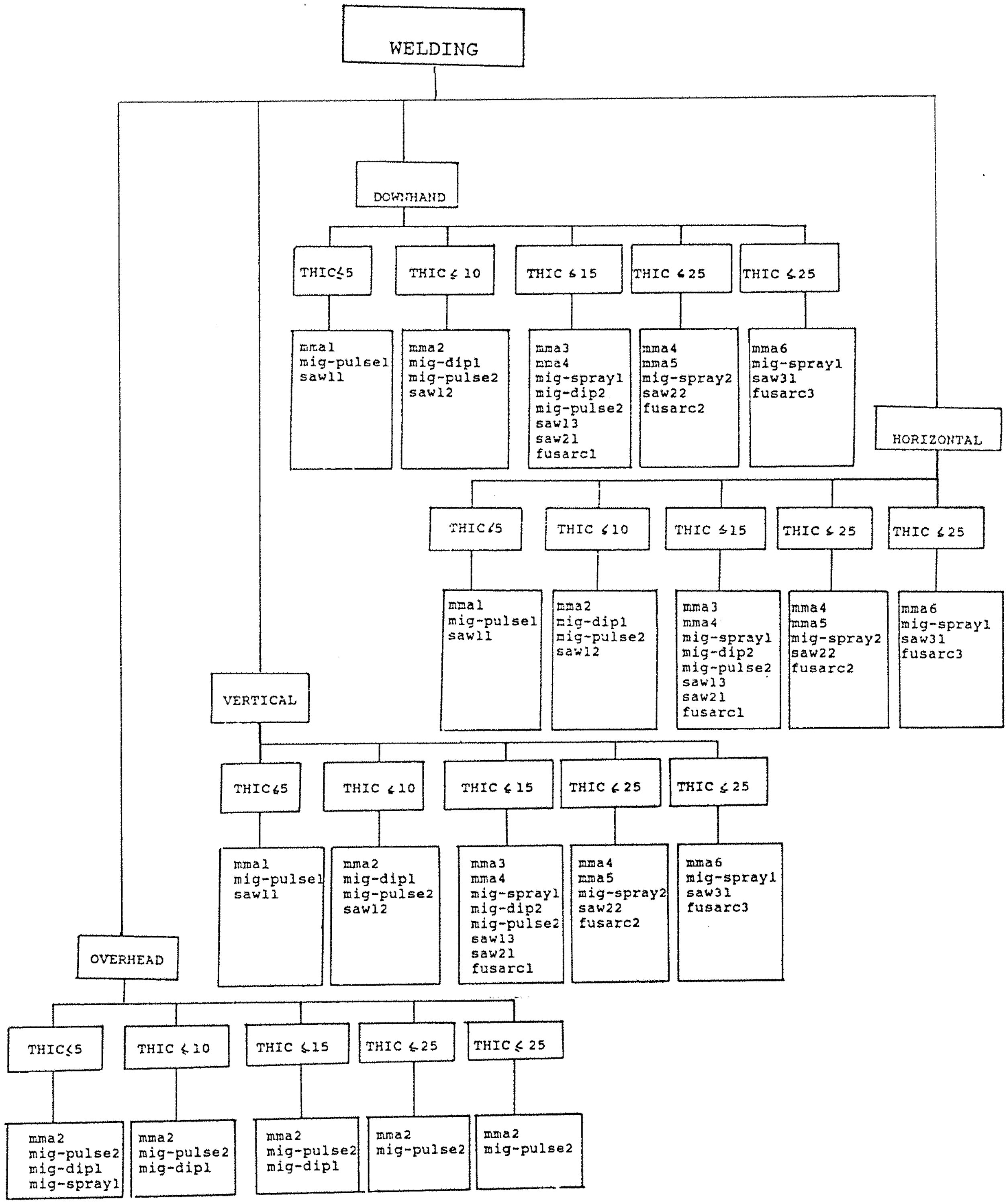


Figure 5.5 The Welding Process Decision Tree For 'Grillage' program

```
*
*  RULE LIST                                    Tue Jan 01 03:19:25 1980  Page:     1
*  ---------

[    1]  alternative processes are selected                                          Sp
           + IF    [  70] cost degrees of belief have been found
           +   AND [ 127] speed confidence factors have been calculated
           +   AND [  64] efficiency confidence factors have been calculated
           +   AND [  30] cost confidence factors have been calculated
           +   AND [ 112] production time and cost have been calculated



[   30]  cost confidence factor have been calculated                   Sp
             IF              DO: Assign Variable
                               wp:=0
               AND           DO: Assign Variable
                               wpa:=0
           +   AND [  71] cost's degree of belief is found
           +   AND [ 145] third cf has been calculated
```

Figure 5.5.a An Example of Backward Chaining Rule

```
[   26]  the edge preparation has been checked                        Sp
             IF              DO: Test Expression
                               type$="Butt"
           +   AND [   9] Butt edge preparation is found

           + OR    [ 134] tee edge preparation is found
```

Figure 5.5.b A Combination Backward and Forward Chaining Rule

Grillage no :

Length	:	m
Width	:	m
Plate thickness	:	mm

Transverse stiffeners

Main stiffener			Web stiffener		
web height	:	mm	web height	:	mm
web thickness	:	mm	web thickness	:	mm
flange thickness	:	mm	flange thickness	:	mm
no's of stiffener	:	mm	no's of stiffener	:	mm

Figure 5.6 The Input Data (Screen Dump (1))

Longitudinals Stiffeners

Main stiffener			Web stiffener		
web height	:	mm	web height	:	mm
web thickness	:	mm	web thickness	:	mm
flange thickness	:	mm	flange thickness	:	mm
no's of stiffener	:	mm	no's of stiffener	:	mm

Plate size :	Length	:	m
	Width	:	m

Figure 5.7 The Input Data (Screen Dump (2))

List of input rates/cost (in pound sterling) :

Skill labour rate	:	15.00
Unskill labour rate	:	12.00
Steel plate cost	:	250.00
Steel profile cost	:	250.00
Welding electrode cost	:	400.00

Figure 5.8 The Labour rate (Screen Dump (3))

Welding process	Reject rate
MMA	20.0 %
MIG spray	10.0 %
MIG dip	10.0 %
MIG pulse	10.0 %
SAW	15.0 %
Fusarc	20.0 %

Rewelding factor is 5.0

Figure 5.9 The Reject Rate and the Rewelding Factor (Screen Dump (4))

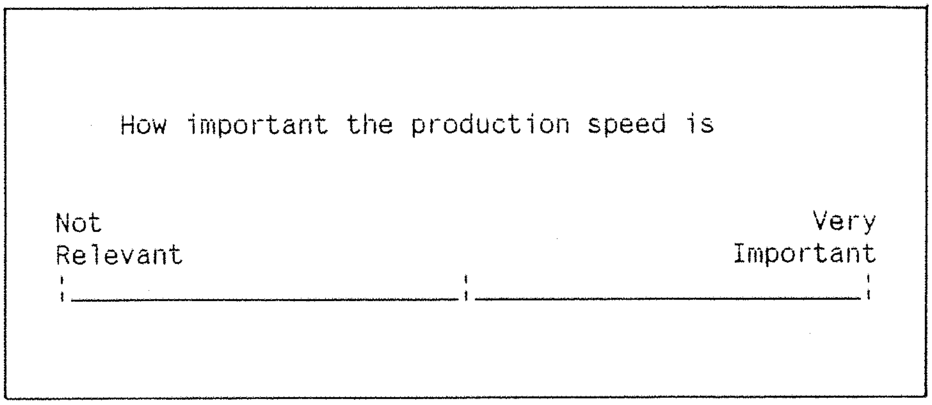


Figure 5.10 The Importance of the Production Speed Opinion Expression

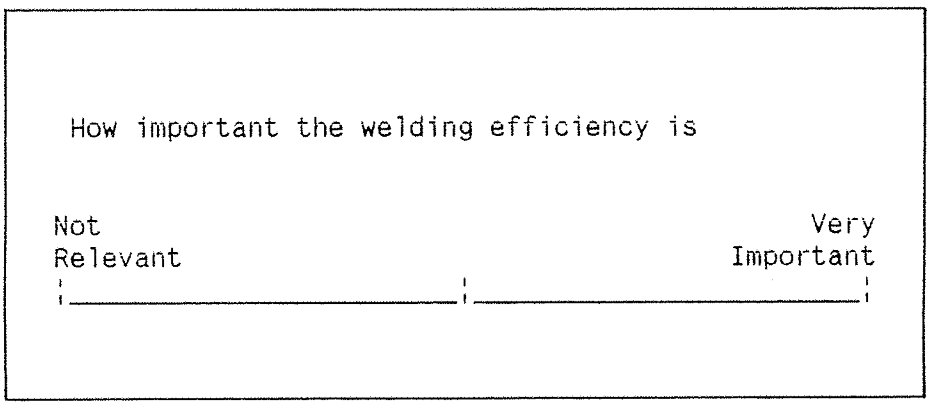


Figure 5.11 The Importance of the Welding Efficiency Opinion Expression

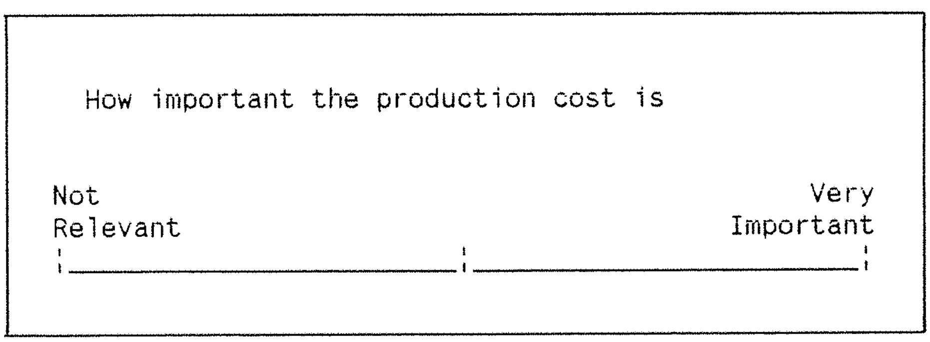


Figure 5.12 The Importance of the Production Cost Opinion Expression

The suggested processes Butt

Subjective conditions
Improtant of weld speed Important 52.0 % important
Important of weld eff. Important 52.0 % important
Important of prod. cost Not important 16.0 % important

Weld processes	Confidence factor
mma4	0.6599
mma5	0.6378
fusarc2	0.5248
mig sprav2	0.3891
saw13	0.1600
	0.0000
	0.0000

Suggested welding process for

Long'l Web stiff. joint is mma2

Resume of chosen welding processes :

Butt joint	mma4
Trans. Web stiffener to plate	--
Trans. Main stiffener to plate	mma3
Long'l Web stiffener to plate	mma2
Long'l Main stiffener to plate	mma2
Stiffener connection	--

Figure 5.13 Example of the Suggested Welding Process

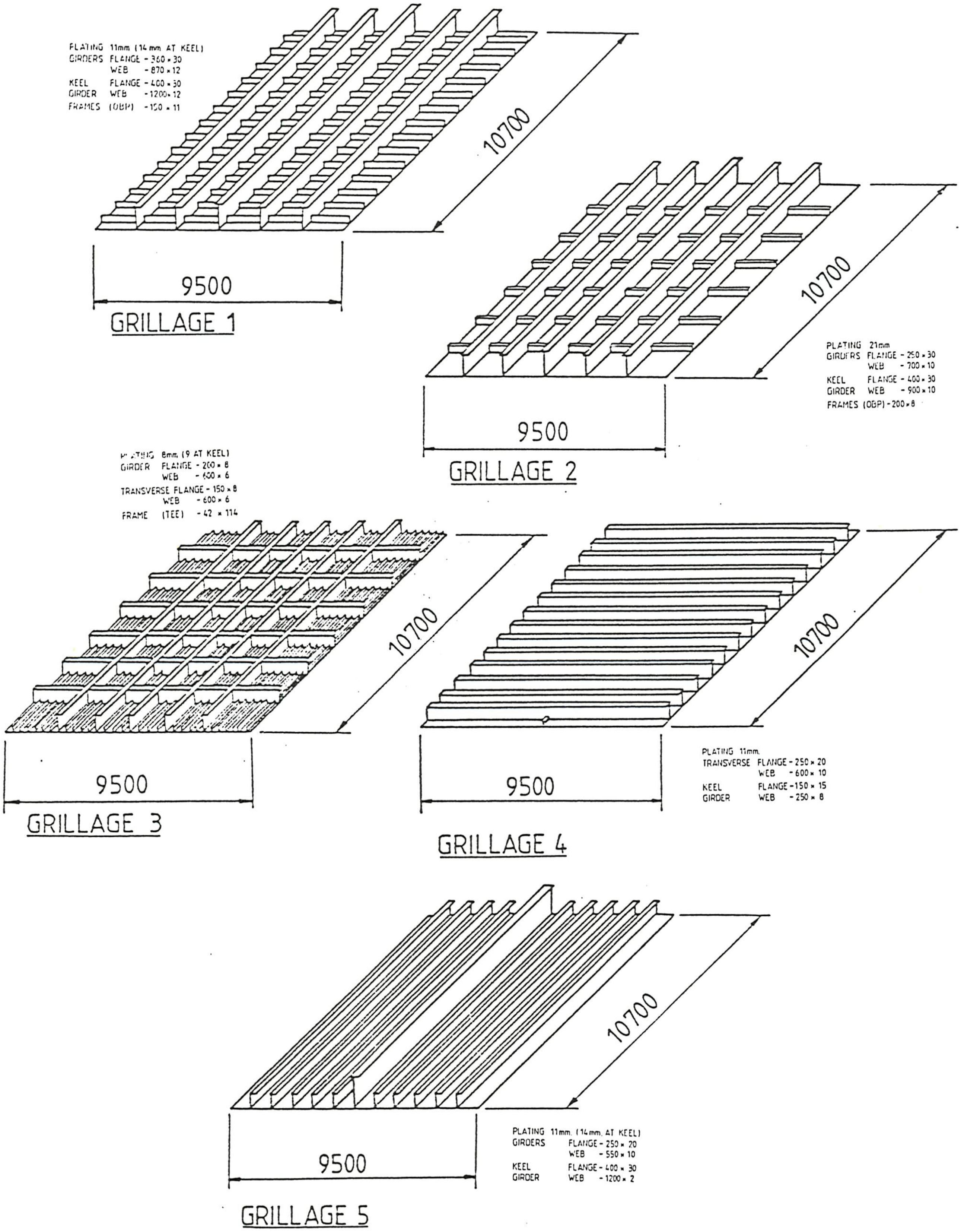


Figure 5.14 The Grillages; a Case Study
(Source : ref. 2.7)

Grillage no : 1

Length	:	10.70	m
Width	:	9.50	m
Plate thickness	:	11.00	mm

Transverse stiffeners

Main stiffener				Web stiffener			
web height	:	150	mm	web height	:	0	mm
web thickness	:	11	mm	web thickness	:	0	mm
flange width	:		mm	flange width	:		mm
flange thickness	:	0	mm	flange thickness	:	0	mm
no's of stiffener	:	14		no's of stiffener	:	0	

Longitudinals Stiffeners

Main stiffener				Web stiffener			
web height	:	870	mm	web height	:	1200	mm
web thickness	:	12	mm	web thickness	:	12	mm
flange width	:		mm	flange width	:		mm
flange thickness	:	360	mm	flange thickness	:	400	mm
no's of stiffener	:	4		no's of stiffener	:	1	

Plate size : Length : 6.00 m

Width : 2.00 m

Figure 5.15.a The Scantling Detail of Design no: 1

Grillage no : 2

Length	:	10.70	m
Width	:	9.50	m
Plate thickness	:	21.00	mm

Transverse stiffeners

Main stiffener				Web stiffener			
web height	:	200	mm	web height	:	0	mm
web thickness	:	8	mm	web thickness	:	0	mm
flange width	:		mm	flange width	:		mm
flange thickness	:	0	mm	flange thickness	:	0	mm
no's of stiffener	:	6		no's of stiffener	:	0	

Longitudinals Stiffeners

Main stiffener				Web stiffener			
web height	:	700	mm	web height	:	900	mm
web thickness	:	10	mm	web thickness	:	10	mm
flange width	:	250	mm	flange width	:	400	mm
flange thickness	:	30	mm	flange thickness	:	30	mm
no's of stiffener	:	4		no's of stiffener	:	1	

Plate size : Length : 6.00 m

Width : 2.00 m

Figure 5.15.b The Scantling Detail of Design no: 2

Grillage no : 3

Length	:	10.70	m
Width	:	9.50	m
Plate thickness	:	8.00	mm

Transverse stiffeners

Main stiffener				Web stiffener			
web height	:	600	mm	web height	:	0	mm
web thickness	:	6	mm	web thickness	:	0	mm
flange width	:	150	mm	flange width	:	0	mm
flange thickness	:	6	mm	flange thickness	:	0	mm
no's of stiffener	:	6		no's of stiffener	:	0	

Longitudinals Stiffeners

Main stiffener				Web stiffener			
web height	:	114	mm	web height	:	600	mm
web thickness	:	8	mm	web thickness	:	6	mm
flange width	:	0	mm	flange width	:	200	mm
flange thickness	:	0	mm	flange thickness	:	8	mm
no's of stiffener	:	36		no's of stiffener	:	5	

Plate size	:	Length	:	6.00	m
		Width	:	2.00	m

Figure 5.15.c The Scantling Detail of Design no: 3

Grillage no : 4

Length	:	10.70	m
Width	:	9.50	m
Plate thickness	:	11.00	mm

Transverse stiffeners

Main stiffener				Web stiffener			
web height	:	600	mm	web height	:	0	mm
web thickness	:	10	mm	web thickness	:	0	mm
flange width	:	250	mm	flange width	:	0	mm
flange thickness	:	20	mm	flange thickness	:	0	mm
no's of stiffener	:	14		no's of stiffener	:	0	

Longitudinals Stiffeners

Main stiffener				Web stiffener			
web height	:	250	mm	web height	:	0	mm
web thickness	:	8	mm	web thickness	:	0	mm
flange width	:	150	mm	flange width	:	0	mm
flange thickness	:	15	mm	flange thickness	:	0	mm
no's of stiffener	:	1		no's of stiffener	:	0	

Plate size :	Length	:	6.00	m
	Width	:	2.00	m

Figure 5.15.d The Scantling Detail of Design no: 4

Grillage no : 5

Length	:	10.70	m
Width	:	9.50	m
Plate thickness	:	11.00	mm

Transverse stiffeners

Main stiffener				Web stiffener			
web height	:	0	mm	web height	:	0	mm
web thickness	:	0	mm	web thickness	:	0	mm
flange width	:	0	mm	flange width	:	0	mm
flange thickness	:	0	mm	flange thickness	:	0	mm
no's of stiffener	:	0		no's of stiffener	:	0	

Longitudinals Stiffeners

Main stiffener				Web stiffener			
web height	:	550	mm	web height	:	1200	mm
web thickness	:	10	mm	web thickness	:	12	mm
flange width	:	250	mm	flange width	:	400	mm
flange thickness	:	10	mm	flange thickness	:	30	mm
no's of stiffener	:	10		no's of stiffener	:	1	

Plate size : Length : m

Width : m

Figure 5.15.e The Scantling Detail of Design no: 5

The location of execution :

Indoor

Outdoor

Figure 5.16 The Chosen Location

Welding process	Reject rate
MMA	20.0%
MIG Spray	10.0%
MIG Dip	10.0%
MiG Pulse	10.0%
SAW	15.0%
Fusarc	20.0%
Rewelding factor	5.0

Figure 5.17 The Reject Rate and the Rewelding Factor (Author's opinions)

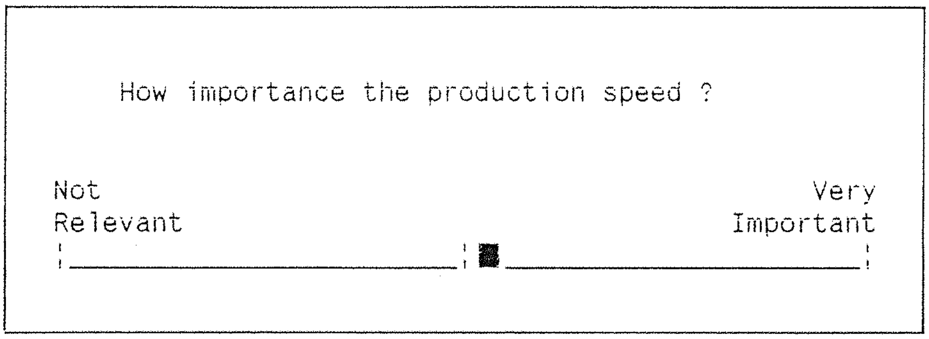


Figure 5.18.a The Importance of the Production Speed (Author's opinion)

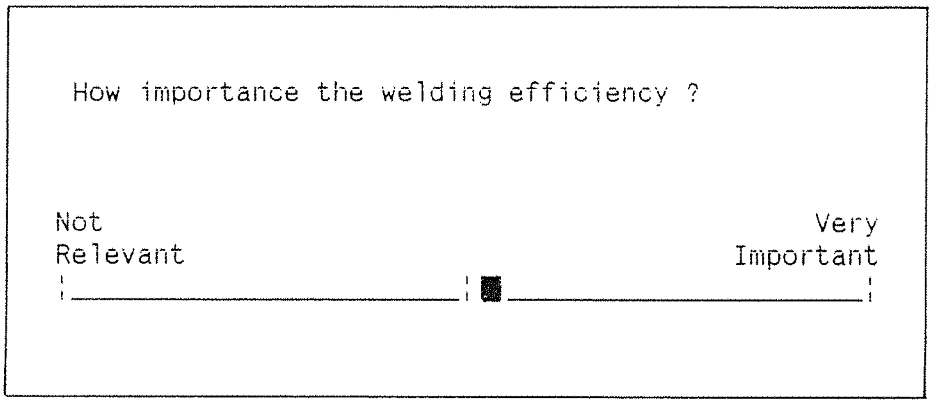


Figure 5.18.b The Importance of the Welding Efficiency (Author's opinion)

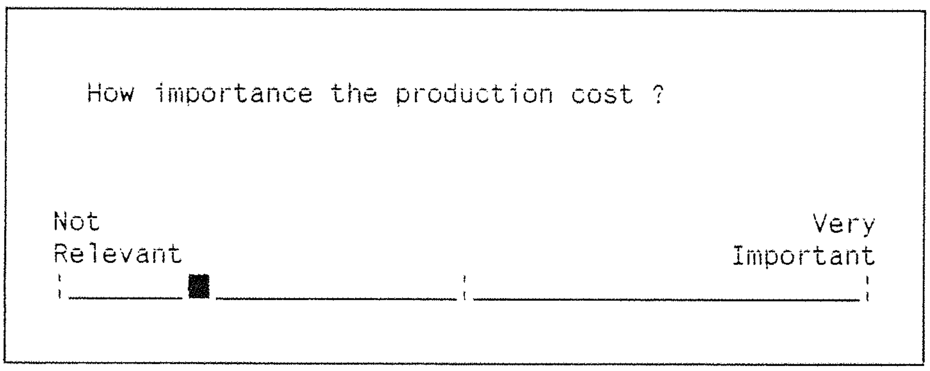


Figure 5.18.c The Importance of the Production Cost (Author's opinion)

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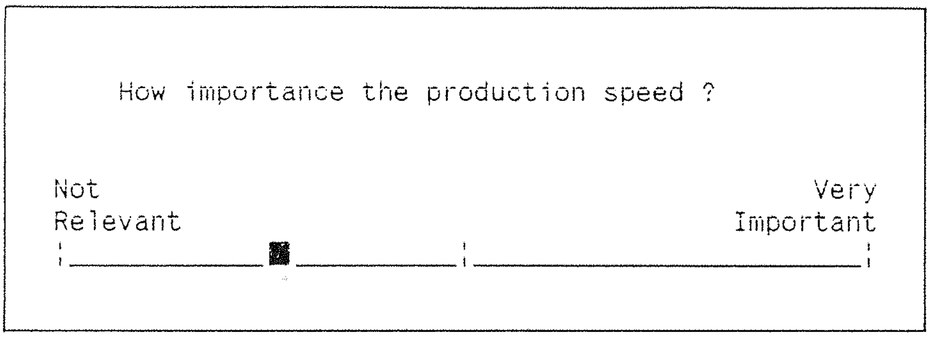

Figure 5.18.e The Importance of the Production Speed
(Author's opinion)

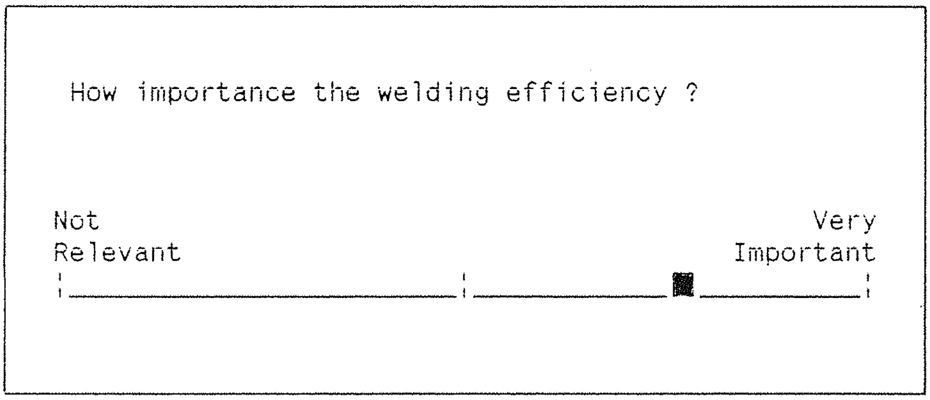

Figure 5.18.f The Importance of the Welding Efficiency
(Author's opinion)

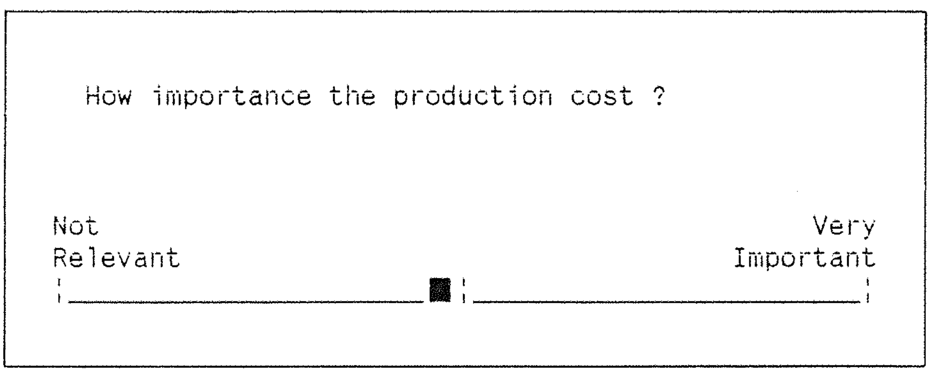

Figure 5.18.g The Importance of the Production Cost
(Author's opinion)

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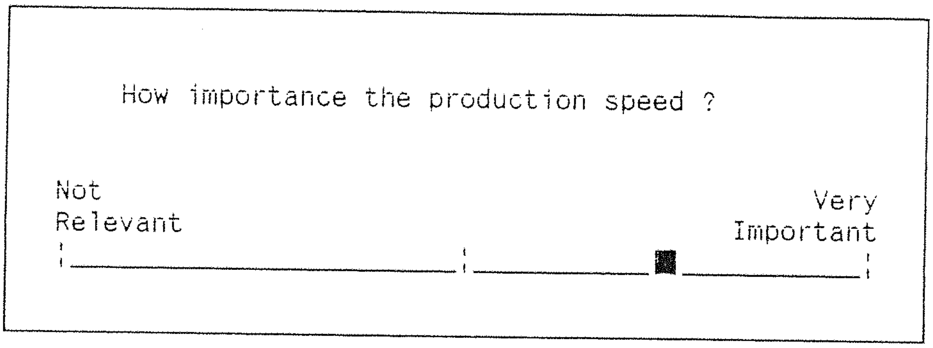

Figure 5.18.i The Importance of the Production Speed (Author's opinion)

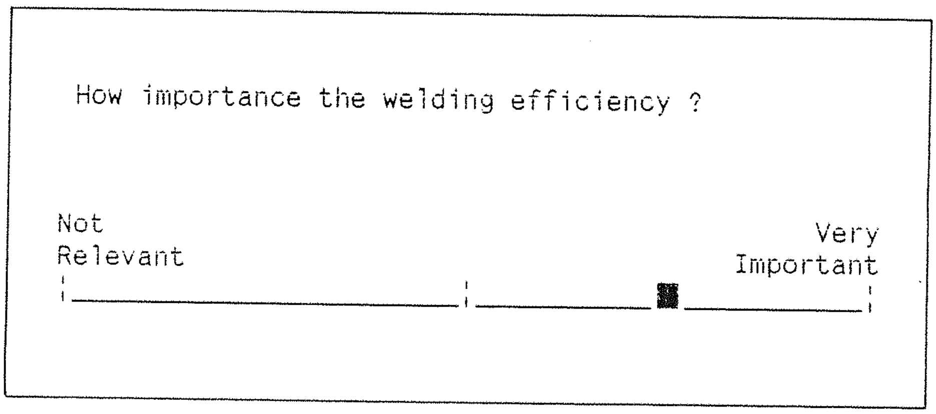

Figure 5.18.j The Importance of the Welding Efficiency (Author's opinion)

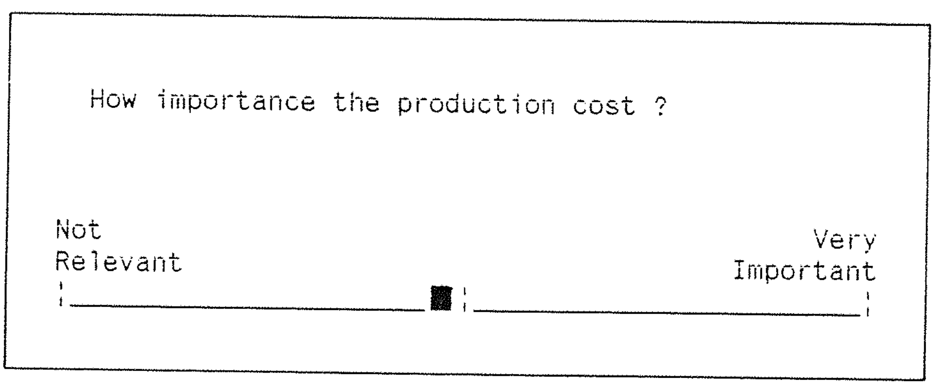

Figure 5.18.k The Importance of the Production Cost (Author's opinion)

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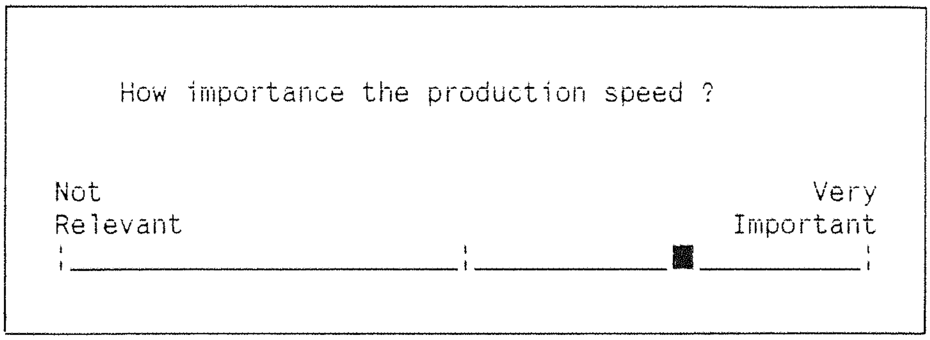

Figure 5.18.m The Importance of the Production Speed (Author's opinion)

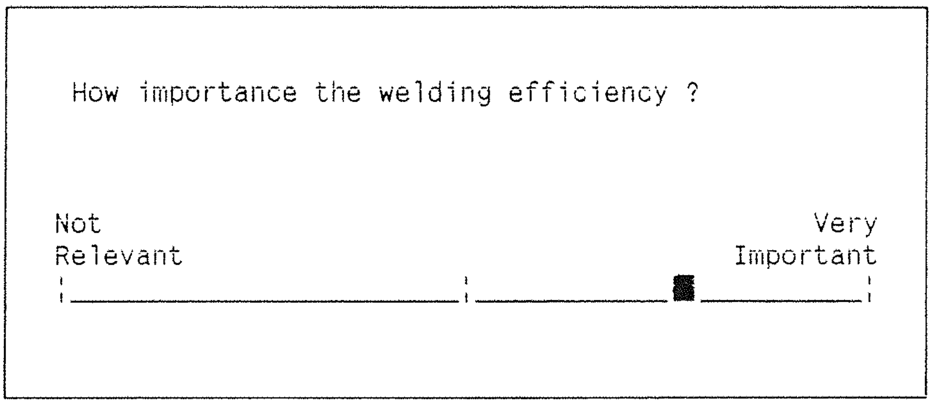

Figure 5.18.n The Importance of the Welding Efficiency (Author's opinion)

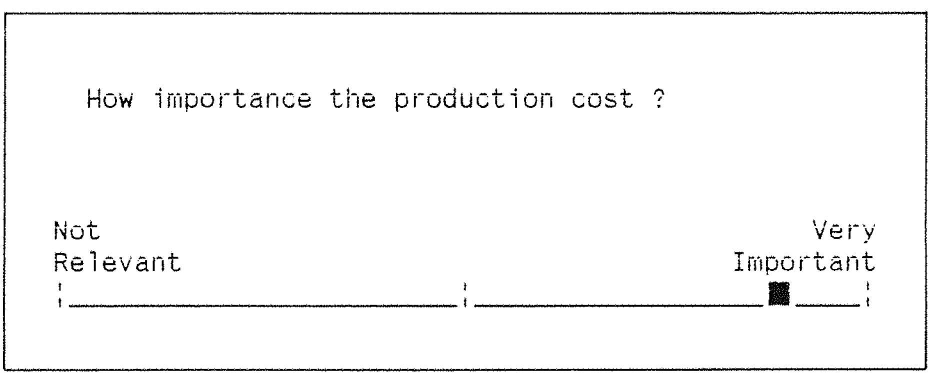

Figure 5.18.o The Importance of the Production Cost (Author's opinion)

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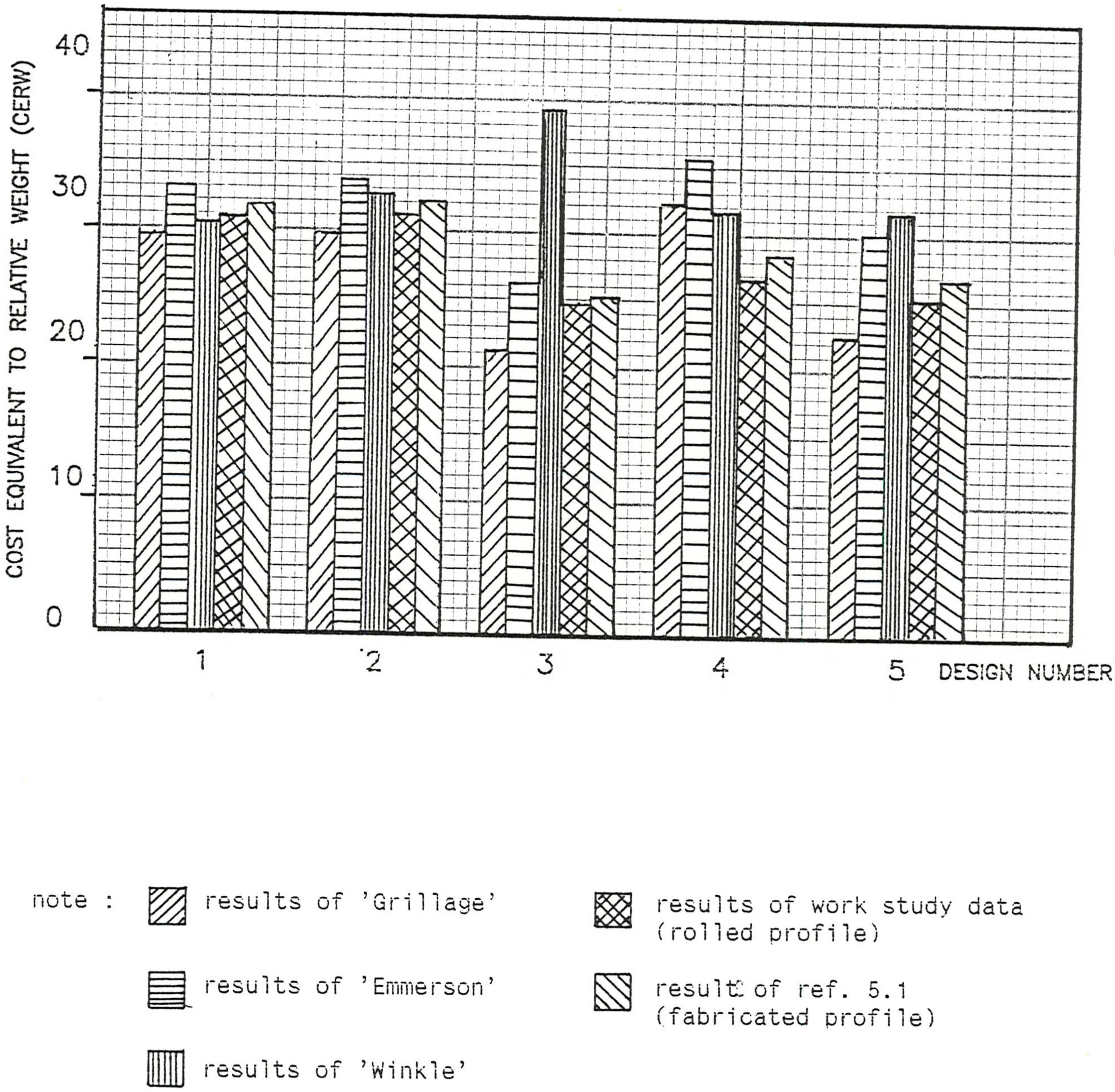


Figure 5.19 CERW of the Five Grillages

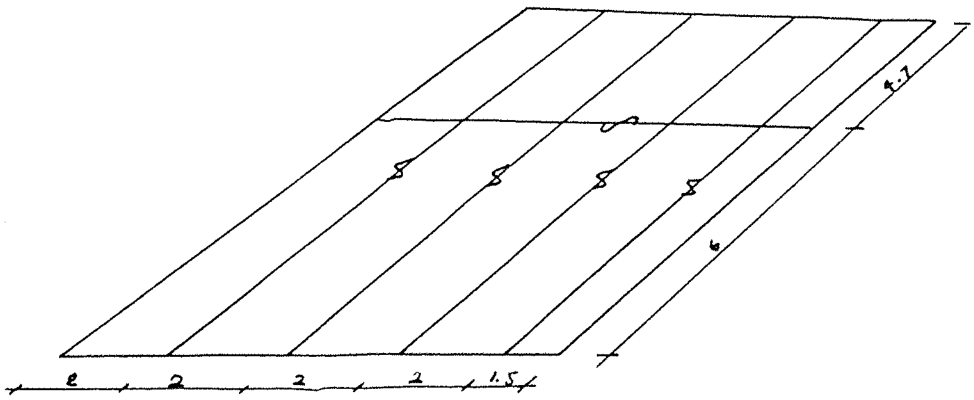


Figure 5.20.a Plate Arrangement Based on 6 x 2 m

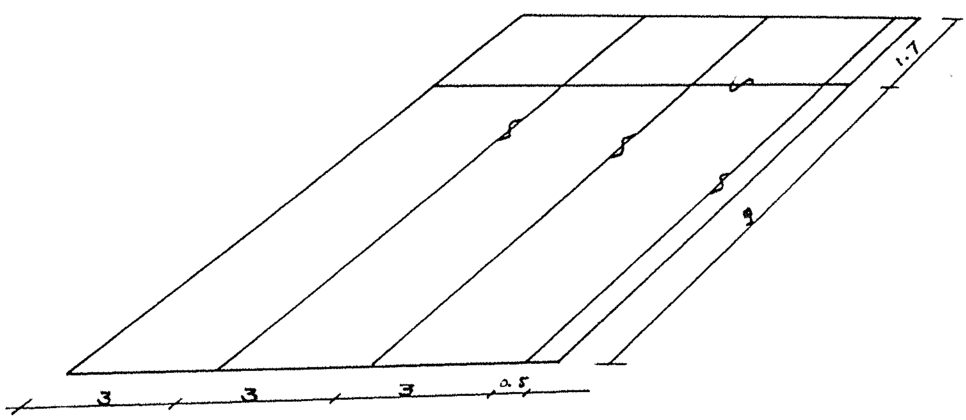


Figure 5.20.b Plate Arrangement Based on 9 x 3 m

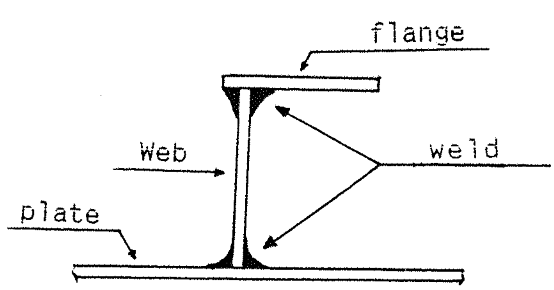


Figure 5.21 Fabricated Profile

TABLES

Condition	degree of membership
7'	1
6'8"	0.8
6'4"	0.6
6'0"	0.5
5'8"	0.4
5'4"	0.2
5'0"	0.0

Table 4.1.a The Degree of Membership: 'Tall'

condition	degree of membership
5'0"	1.0
5'4"	0.8
5'8"	0.6
6'0"	0.5
6'4"	0.4
6'8"	0.2
7'0"	0.0

Table 4.1.b The Degree of Membership: 'Short'

"Tall"			"Short"		"Medium height"	
7'0"	1.0		7'0"	0.0	7'0"	0.0
6'8"	0.8		6'8"	0.2	6'8"	0.2
6'4"	0.6		6'4"	0.4	6'4"	0.4
6'0"	0.5	AND	6'0"	0.5	6'0"	0.5
5'8"	0.4		5'8"	0.6	5'8"	0.4
5'4"	0.2		5'4"	0.8	5'4"	0.2
5'0"	0.0		5'0"	1.0	5'0"	0.0

Table 4.2 The Degree of Membership: 'Tall' AND 'Short'

"Tall"			"Short"		"not Medium height"	
7'0"	1.0		7'0"	0.0	7'0"	1.0
6'8"	0.8		6'8"	0.2	6'8"	0.8
6'4"	0.6		6'4"	0.4	6'4"	0.6
6'0"	0.5	OR	6'0"	0.5	6'0"	0.5
5'8"	0.4		5'8"	0.6	5'8"	0.6
5'4"	0.2		5'4"	0.8	5'4"	0.8
5'0"	0.0		5'0"	0.1	5'0"	1.0

Table 4.3 The Degree of Membership: 'Tall' OR 'Short'

Adaptive systems	Knowledge acquisition	Quality control
Artificial intelligence	Knowledge based systems	Reasoning/decision making
Automatic programming	Knowledge representation	Making reconnaissance
Automatic repair	Logistics	Resource management
Autonomous vehicles	Machine learning	Robotics
CAD	Maintenance	Sensors
Command and control	Management	Shipbuilding
Communications	Man machine systems	Signal processing
Computer based instruction	Manufacturing technology	Simulation
Computer hardware	Materials handling	Speech recognition
Computer programs	Natural language processing	Strategy analysis
Conferences	Navigation	Tactical problem solving
Countermine vehicle	Night vision	Target analysis
Data fusion	Operations research	Terrain analysis
Database management	Painting	Threat evaluation
Decision aids	Pattern recognition	Training
Electronic warfare	Performance measurement	Vision systems
Energy conservation	Planning	Weapon systems
Expert systems	Power sources	Welding
Image processing	Problem solving	
Information fusion	Programming tools	
Instrumentation		

Table 4.4 Some Areas Appropriate to Artificial Intelligence (source: ref. 4.8)

Process type	diameter of rod	notation
Submerged Arc Welding (single wire)	6.3	SAW13
Fusarc	2.5	Fusarc1
Mig Spray	1.2	Mig-spray1
Mig dip	1.6	Mig-dip2
Mig pulse	1.6	Mig-pulse2
Manual Metal Arc	3.0	mma3
Manual Metal Arc	4.0	mma4

Table 5.1 The Alternative Welding Process Suitable for a Joint of 12 mm Thickness

Grillage	Weight (tonnes)	Production time (hours)	CERW	Rank	Production cost (in pounds)
1	19.727	211.64	29.38	3	9 864.1
2	23.954	121.77	29.43	4	8 715.2
3	13.127	174.06	21.19	1	6 792.4
4	20.488	193.13	32.29	5	10 313.5
5	19.670	103.05	22.57	2	6 787.8

Table 5.2.a The Results Based on the Manual Metal Arc Process

Grillage	Weight (tonnes)	Production time (hours)	CERW	Rank	Production cost (in pounds)
1	19.727	119.15	25.09	3	7 370.3
2	23.954	53.67	26.37	4	6 956.3
3	13.387	98.40	17.78	1	4 771.6
4	20.488	92.05	27.74	5	7 651.1
5	19.670	43.87	19.91	2	5 245.6

Table 5.2.b The Results Based on the SAW Process

Grillage	Weight (tonnes)	Production time (hours)	CERW	Rank	Production cost (in pounds)
1	19.727	200.48	28.75	3	8 808.3
2	23.954	-	-	-	*)
3	13.387	162.60	20.68	1	5 945.5
4	20.488	215.72	33.31	4	9 838.8
5	19.670	98.19	22.35	2	6 201.6

Table 5.2.c The Results Based on the MIG Pulse Process

note: *) The process does not fit to the structure

Grillage	Weight (tonnes)	Production time (hours)	CERW	Rank	Production cost (in pounds)
1	19.727	153.49	26.63	3	7 927.8
2	23.954	–	–		– *)
3	13.387	134.59	19.41	1	5 402.0
4	20.486	144.27	30.09	4	8 499.1
5	19.670	71.78	21.17	2	5 706.4

Table 5.2.d The Results Based on the MIG Dip Process

note: *) The process does not fit to the structure

Grillage	Weight (tonnes)	Production time (hours)	CERW	Rank
1	19.61	211.60	30.19	1
2	24.41	165.2	32.67	4
3	12.98	526.2	39.29	5
4	20.43	271.1	31.48	3
5	19.62	243.4	31.78	2

Table 5.3 The Result of the 'Winkle & Baird' Program Based on 'mma' Welding Process (2.8).

Grillage	Weight (tonnes)	Production time (hours)	CERW	Rank
1	20.45	558.32	41.20	4
2	24.71	395.47	39.36	3
3	12.27	725.71	36.28	1
4	22.10	618.06	44.59	5
5	19.84	473.39	36.88	2

Table 5.4.a The Result of 'Emmerson' Program (6.1) Based on 'mma' Welding Process

Grillage	Weight (tonnes)	Production time (hours)	CERW	Rank
1	20.45	207.71	32.91	3
2	24.71	146.70	33.51	4
3	12.27	230.18	26.08	1
4	22.10	224.85	35.59	5
5	19.84	170.35	30.06	2

Table 5.4.b The Modified Results of the 'Emmerson' Program

Design number	WSD		WSD *)	
	Prod. time	CERW	Prod. time	CERW
1	223.2	30.88	242.4	31.84
2	148.7	31.38	163.6	32.13
3	232.8	24.72	238.9	25.07
4	120.1	26.49	159.6	28.47
5	109.2	25.13	143.2	26.82

Table 5.5 The Result of Work Study Data Method (5.1)
note: *): used fabricated profile

Design number		Grillage	Emmerson	Winkle	WSD/WSD*)
1	plate	10	9	-	10
	section	19	19	19	19
	total	29	28	-	29
2	plate	10	9	-	10
	section	11	11	11	11
	total	21	20	-	21
3	plate	10	15	-	10
	section	37	37	37	37
	total	47	52	-	47
4	plate	10	18	-	10
	section	15	16	15	15
	total	25	34	-	25
5	plate	10	15	-	10
	section	11	11	11	11
	total	21	26	-	21

Table 5.6 Pieceparts Number of the Grillages

note: - : no support data
*): use fabricated profile

Appendix A : SHIPBUILDING STRATEGY

In order to simplify the production process, a large structure, such as ship or barge, has to be constructed based on a number of production units. Such units can be panel grillages or a combination of a number of grillage structures. The way to construct the structure from such production units is called the build strategy. This can be broadly classified into three categories i.e.: panel, semi-block and block strategies.

The panel strategy, as the name implies, involves panel grillage structures as basic production units, as shown in Figure A.1.a. These grillage panels can be constructed in several ways. Figure A.1.b shows the traditional building process of constructing. The steps involved are:

- lay down the shell plate and weld the butt joints,
- fit the transverse webs, transverse mains, longitudinal webs and longitudinal main frames to become a matrix structure,
- weld the matrix onto the shell to construct a grillage,
- assemble the grillage to construct the ship or barge

In this build strategy, apart from the butt joints which can be welded by employing automatic welding, the greater part of welding has to be done manually. This is because the length of the joints are relatively short. As mentioned in the main text, one way to reduce the production cost is by employing an optimum building procedure where an automatic or semi automatic welding process can be employed to the maximum extent.

Such a procedure, as shown in Figure A.1.c, demonstrates that more joints can be welded automatically compared to the traditional one. There are at least two welding procedures that can be followed. The first is as follows :

- layout the shell plate and machine weld seams (one side or both sides),
- layout the transverse web and main stiffeners, also machine weld (fillet/tee),
- lay down and weld the longitudinal web and main stiffeners to construct the grillage. Because the length of partial joints is relatively short, it should be welded manually.

The second procedure introduced is the 'hi panel' method where the steps are:

- layout the shell plate and machine weld seams (one side or both sides),
- slot the longitudinals into the transverse ones,
- weld all the joints by using an automatic welding machine.

This procedure is applicable when the the total joint length of transverse stiffeners is more than the longitudinal ones. However, the longitudinals will be welded using the automatic process when its length of joint is longer than the length of the transverse.

Such a strategy is usually employed when the yard facilities such as cranes and shop floor size, are very limited. So, to assemble these units, on the berth, a number of joints which have to be welded in vertical and over-head positions, can not be avoided (as shown in Figure A.2). Welding at these positions needs more time compared with the down-hand position. In practice, welding in overhead position takes thrice as long and in vertical position twice as long as the time taken in a down-hand position. Due to these factors and when all of the assembling process activities are done in the berth, a relatively long building time is necessary.

In order to reduce the number of vertical and overhead welding joints, some grillage panels are combined and welded together to form a semi-block unit in the sub-assembly shop; these are later assembled on the berth, as shown in Figure A.3. By following this strategy, less welding time is needed because it involves more downhand welding compared to the previous strategy. Also, it will reduce the activities on the berth, leading to a reduction in berth time.

In a yard with large crane capacities and adequate shop space, a number of semi block units can be assembled to become a block unit before the assembling process in the berth, see Figure A.4. Such a strategy will reduce the overhead welding and the contents of work in the berth area, because most joints would have been welded in the prefabrication and sub-assembly shops. Hence, The production cost should be relatively less compared to both previous strategies, due to less vertical and over-head welding and less berth time. However, in order to support such a building process, large crane capacities and space are necessary.

The above indicates that a large structure can be built from a number of production units which are basically panel grillages. Therefore, the production cost of such structure can be approached by analysing grillage structure cost and considering the cost needed to assemble these production units.

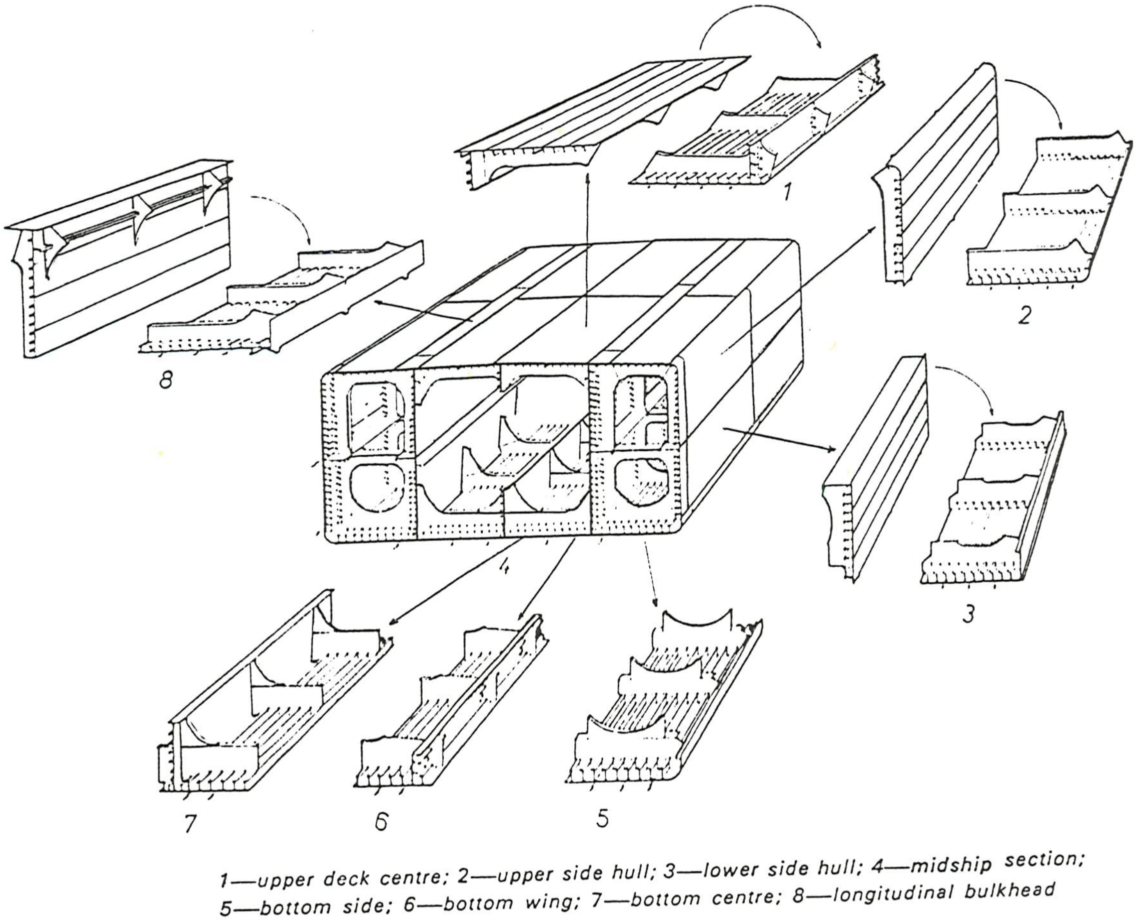


Figure A.1.a Structure Breakdown
(source : ref. A.1)

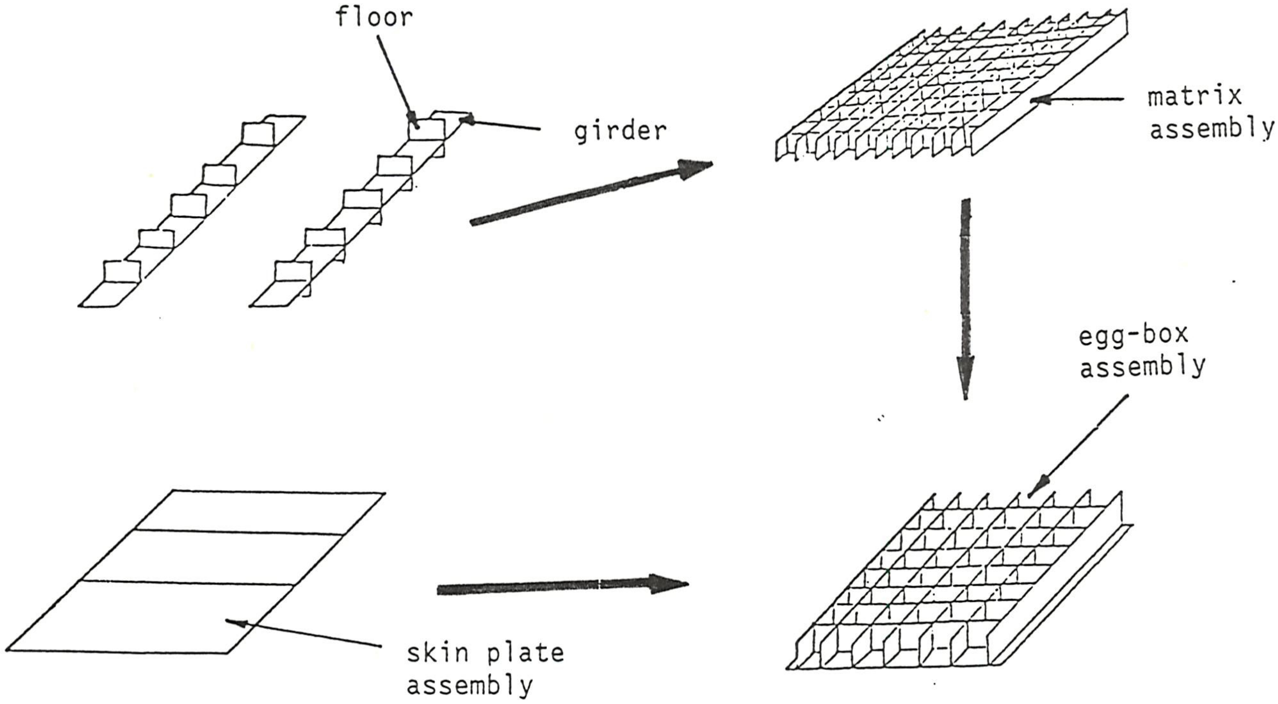


Figure A.1.b Conventional Procedure

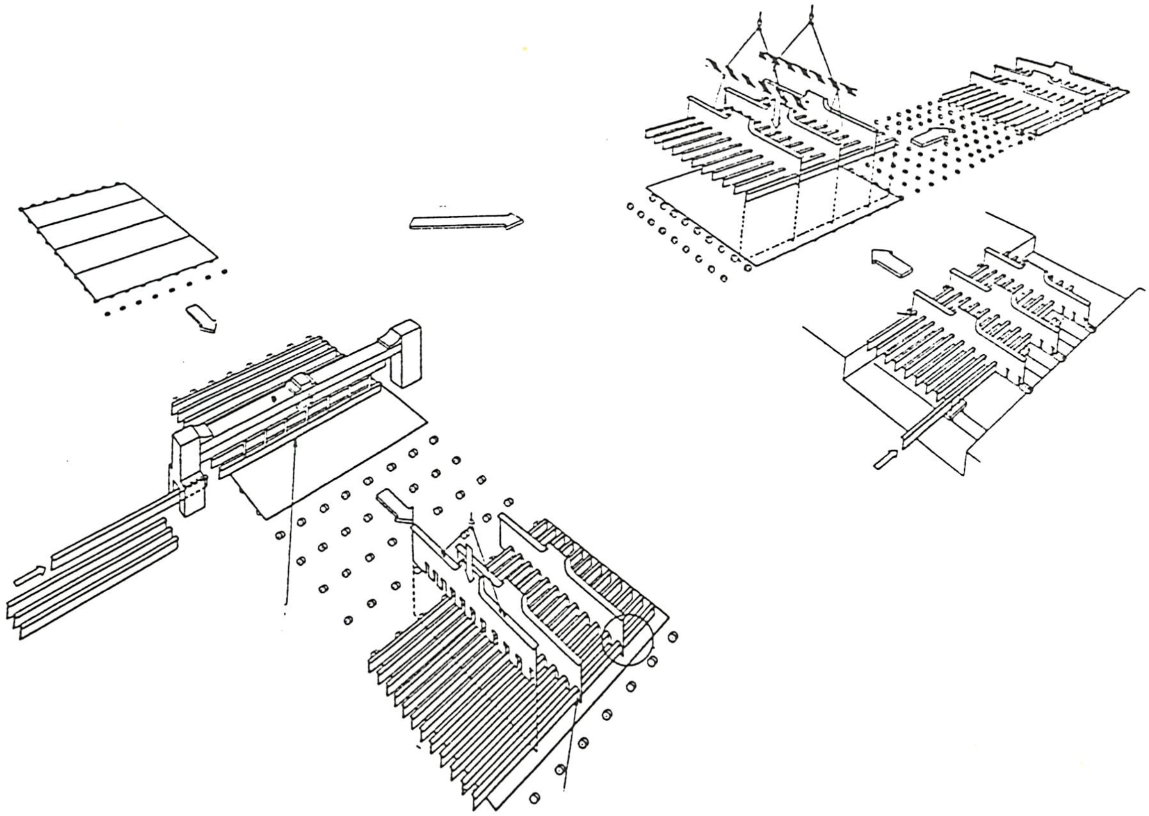


Figure A.1.c. 'Line Welding Procedure'

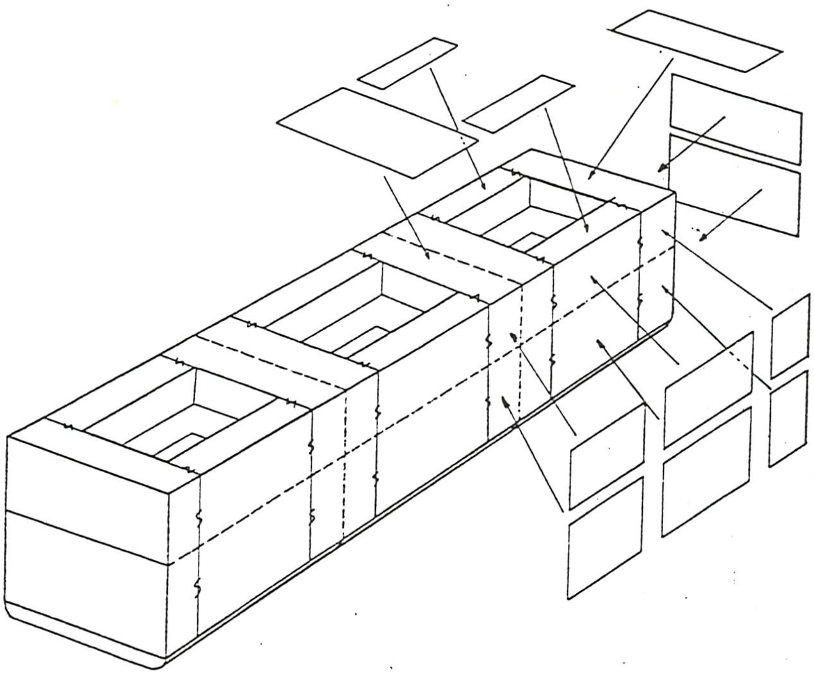


Figure A.2 Panel Units Strategy

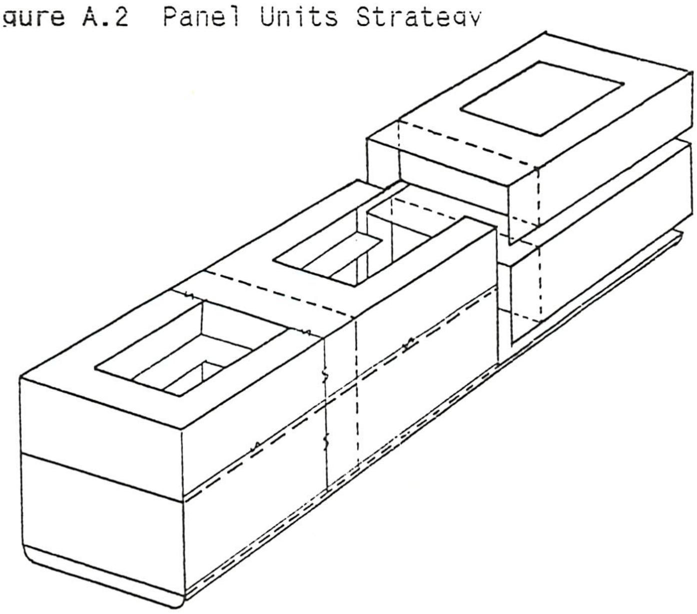


Figure A.3 Semi-block Units Strategy

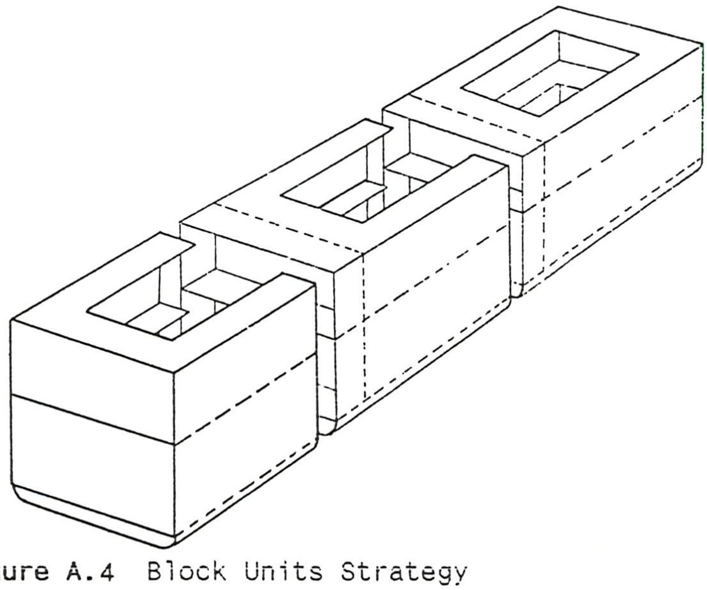


Figure A.4 Block Units Strategy

Appendix B : WELDING PROCESSES AND EDGE PREPARATION DESIGN

B.1 Welding Processes Characteristics

A number of welding processes can be used in the ship industry. These welding processes can be classified into five groups according to type of process. They are:

1. Manual Metal Arc (MMA):

This is a manual process. There are two types of electrode which are usually used in this process i.e. conventional and iron powder. The conventional electrode can be used in all positions (downhand, vertical, horizontal and overhead) , while the iron powder electrode can only be used in the downhand and horizontal position . Both can also be used either inside the work shop or outdoors. At the moment, only the conventional electrode is considered to support the present work. The speed of depositions are functions of the diameter of electrode and amperage as shown in Table B.1. below,

DIAMETER (mm)	DEPOSITION RATE (kg/Hr)	AMPERAGE (Amperes)	THICKNESS (in mm)
3.2	0.5 - 1.3	80 - 120	> 3
4.0	0.9 - 1.5	120 - 200	to
5.0	1.3 - 2.2	150 - 250	any
6.0	1.5 - 3.0	185 - 320	thickness
8.0	2.8 - 5.0	300 - 510	

Position : All Positions

Table B.1 Details of Manual Metal Arc Process

2. Fusarc :

A continuous coated electrode is used in this semi or fully automatic process. It can be used to weld plates of 10 mm thickness and upwards. Because it uses coated electrodes , this process can be operated inside shop or outdoors. Speed of deposition is a function of diameter and amperage. There are three sizes of electrode which are usually used in this process as shown in Table B.2 .

DIAMETER (mm)	DEPOSITION RATE (kg/hr)	AMPERAGE (amp)	THICKNESS (mm)
2.5	1.5 - 3.5	200 - 700	10 - 15
4.8	3.0 - 7.5	400 - 900	15 - 25
7.0	6.5 - 10.0	1000 - 1200	> 25

Position : Downhand, Horizontal and Vertical

Table B.2. Details of Fusarc Process

3. Submerged Arc Welding (SAW) :

In this semi or fully automatic process ,an uncoated wire is used along with a flux powder for a shield . There are three types of process, namely single wire (SAW1), two wires (SAW2) and three wires (SAW3). The single wire process is preferred to weld plates of thicknesses up to 20 mm and the multi wire process could weld plates up to 40 mm. However, the single wire process will be considered in this present work where there are three sizes of electrode used. The speed of deposition can be seen in the Table B.3. Combination of the electrodes can be applied in order to find suitable deposition of a joint. As with the fusarc process, this process can be operated either indoors or outdoors.

DIAMETER (mm)	DEPOSITION RATE (kg/hr)	AMPERAGE (amp)	THICKNESS (mm)
3.2	4.0 - 8.7	300 - 700	< 5
4.8	4.8 - 12.7	400 - 900	5 - 10
6.3	7.9 - 13.5	700 - 1220	< 10

Positions : Downhand, Horizontal and Vertical

Table B.3 Details of Submerged Arc Welding Process

4. Metal Inert Gas (MIG)

In this automatic process an uncoated wire is used along with gas as the shield such as Carbon dioxide (CO_2), Argon (Ar) or a mixture of carbon dioxide and Argon. The processes can be classified into three groups according to the current used i.e: the spray transfer with CO_2 or Ar, DIP transfer with CO_2 and MIG Pulse with Ar or Ar+CO_2, as shown in Table B.4.

DIAMETER (mm)	DEPOSITION RATE (Kg/hr)	AMPERAGE (amp)	THICKNESS (mm)
MIG SPRAY (Down-hand, Horizontal and Vertical positions)			
1.2	3.5 - 7.2	225 - 350	10 - 15
1.6	3.7 - 8.0	270 - 400	> 15
MIG DIP (All Positions)			
1.2	3.2 - 5.0	50 - 200	5 - 10
1.6	3.5 - 6.0	50 - 200	10 - 15
MIG PULSE (All Positions)			
1.2	0.9 - 3.2	50 - 225	< 5
1.6	1.5 - 3.4	125 - 300	5 - 15

Table B.4 Details of Metal Inert Gas Process

Note:

1. Wind and water vapour will badly affect the welding product of gas shielded process. Therefore a gas shielded process is suggested to use as an indoor process, while a flux shielded or coated electrode can be used either indoors or outdoors.

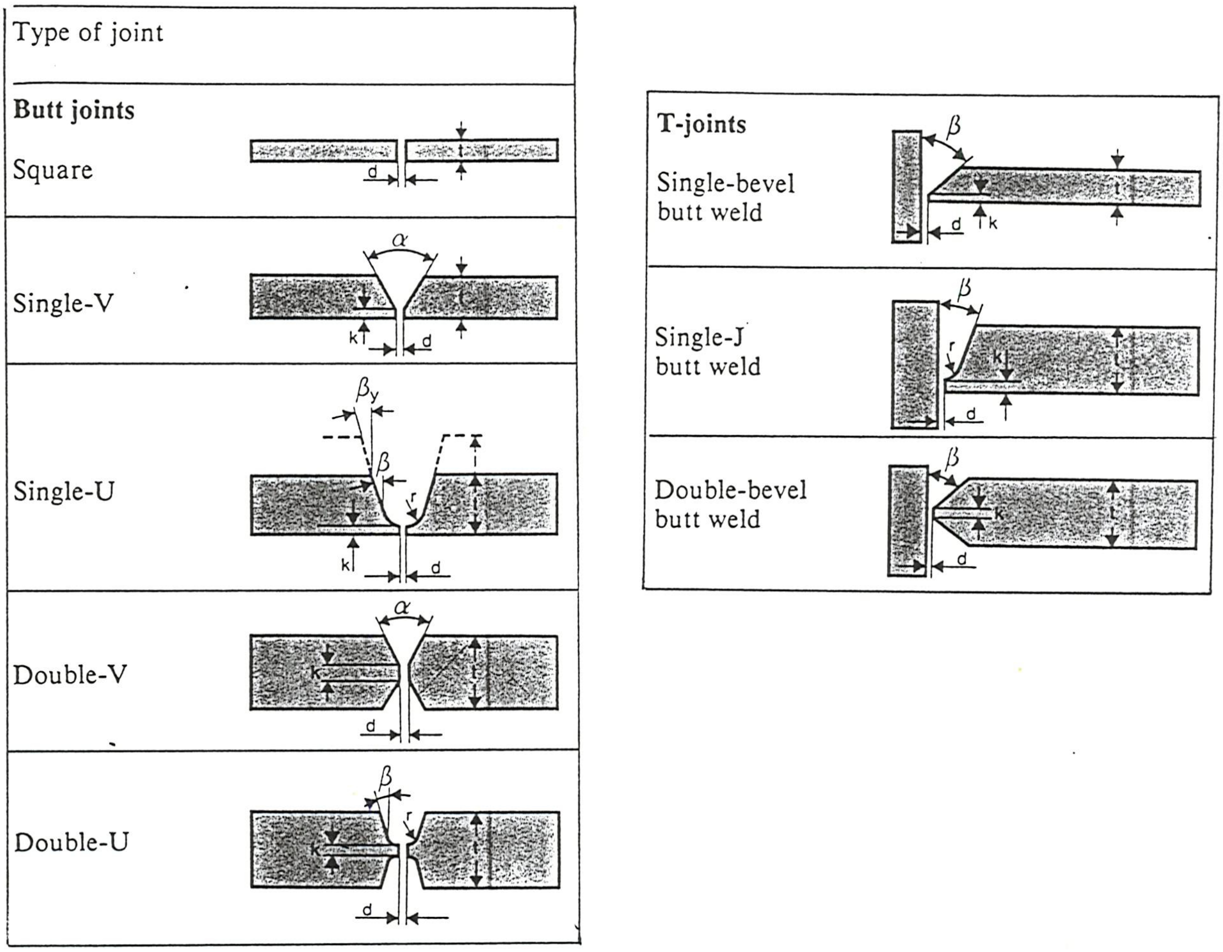
2. Group classification and deposition rates in the above tables are taken from Reference B.1.

3. The thickness of weldabilities are taken based on Reference B.2.

B.2 The Edge Preparation Designs

In order to make the welding acceptable and lessen the possibility of defects, the edges of the joints have to be well designed. The joint edges are designed based on a number of factors such as: the use of welding process, the materials, the type, the position and the thickness of joint. Thus, for normal applications, the edge design can follow the existing regulations in welding such as shown in pages 63 - 64, Figures 2.8 - 2.10 of the American Welding Society (AWS) regulation (B.3) and the American Society for Metals in Reference B.4, pages 20 - 22, Figures 2.11.a, b , c, d. In practical applications, the edge designs can be divided into two groups of joints; Butt and Tee/Fillet joints. Figure B.1 shows edge designs based on the British standard regarding to the thickness and the types of joint.

However, the present work concerns the welding processes in shipbuilding applications. Therefore, the edge has to be designed for mild steel and for two basic joints, namely Butt joints and Tee/Fillet joints. The above regulations show that there are a number of variations of both the gap and the angle for a joint. However, in order to simplify the calculations of the joint's cross sectional area, both of have been generalised as shown in Figure B.2.



Type of joint	square[1])	single-V	single-U	double-V	double-U	single-bevel	single-J	double-bevel
t (mm) (inch)	1.5–3 (1/16–1/8)	4–20 (5/32–3/4)	≧20 (≧3/4)	>15 (>5/8)	≧40 (≧1 1/2)	≦25 (≦1)	20–50 (3/4–2)	15–50 (5/8–2)
d (mm) (inch)	0–1 (0–3/64)	0–3 (0–1/8)	0–3 (0–1/8)	0–3 (0–1/8)	0–3 (0–1/8)	2–4 (5/64–5/32)	2–4 (5/64–5/32)	2–4 (5/64–5/32)
k (mm) (inch)		0–2 (0–5/64)	2–3 (5/64–1/8)	0–2 (0–5/64)	2–3 (5/64–1/8)	0–2 (0–5/64)	2–3 (5/64–1/8)	0–2 (0–5/64)
r (mm) (inch)			6 (1/4)		6 (1/4)		8 (5/16)	
α (degrees)		60		60				
β (degrees)			10–15		10–15	≧50	≧20	≧50
β_Y (degrees)			2–3[2])		2–3[3])			

Figure B.1 Edge Design Simplification
(source : ref. B.5)

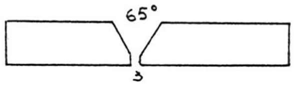
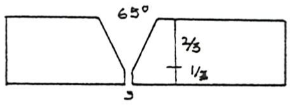
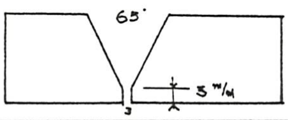
Thickness (in mm)	Edge Design	Cross section Area (in sq.mm)
<= 5		XS = ((3 x thic) + (0.577 x thic)^2) x 1.15
5 - 10		XS = ((3 x thic) + (0.577 x thic)^2) x 1.15
10 - 40		XS = ((3 x thic) + (0.577 x thic)^2) x 1.15

Figure B.2.a The Edge Design for Butt Joint, Manual Welding Process

note: XS : the cross section area

Thic : the thickness of joint

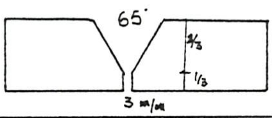
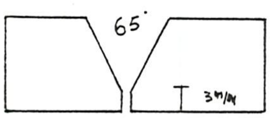
Thickness (in mm)	Edge Design	Cross section Area (in sq.mm)
<= 5		XS = 3 x thic
5 - 10		XS = ((3 x thic) + (0.577 x thic)^2) x 1.15
10 - 40		XS = ((3 x thic) + (0.577 x thic)^2) x 1.15

Figure B.2.b The Edge Design for Butt Joint, Automatic Welding Process

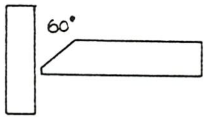
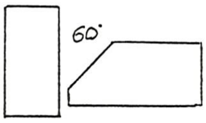
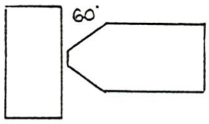
Thickness (in mm)	Edge Design	Cross section Area (in sq.mm)
<= 5		XS = 0.893 x ((thic/2)+3)^2
5 - 10		XS = 0.893 x ((thic/2)+3)^2
10 - 40		XS = ((0.525 x thic^2) + (0.460 x thic)^2) x 1.15

Figure B.2.c The Edge Design for Tee Joint (Fillet), Manual Welding Process

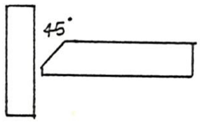
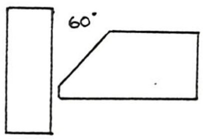
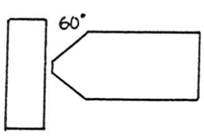
Thickness (in mm)	Edge Design	Cross section Area (in sq.mm)
<= 5		XS = 0.681 x ((thic/2)+3)^2
5 - 10		XS = 0.893 x ((thic/2)+3)^2
10 - 40		XS = ((0.525 x thic^2) + (0.460 x thic)^2) x 1.15

Figure B.2.d The Edge Design for Tee Joint (Fillet), Automatic Welding Process

APPENDIX C : SHIP WELDING EXPERT SYSTEM (SWES)

C.1 The Aims

There are a number of welding processes applicable to weld a joint. The choice depends on the geometry, the condition of the joint and the requirement of the user. Some of these are of a subjective nature. Thus, the aim of the SWES is to investigate whether an expert system can be used to analyse such subjective aspects/criteria in order to find a set of welding processes which can be used to weld a particular joint.

C.2 Welding Selection Process

(a) Objective Criteria

In this selection process, the welding process is analysed on the basis of criteria which are directly related to the type, geometry and position of the joint. Two particular types of joint (butt and tee) with seven different groups of thickness and four different welding positions; Downhand, Horizontal, Vertical and Overhead, will be considered in the present selection process. It is a known fact that a welding process has a limited welding capability with respect to the thickness of a joint and that it can only be used in a certain number of positions. Therefore, a suitable welding process should be chosen in such a way that the thickness and position of the joint would not exceed the limitation of its weldability.

One criterion in weld process selection is length of joint. In this study, it is assumed that all joints of length less than 2 metres will be welded manually. This assumption ties with the experience of shipyard where the time to set-up automatic welding machinery is not compatible for such short weld runs. Hence, a manual process is normally chosen due to its relatively short preparation time.

Choice of weld is also dependent upon whether the work is to be carried out indoors or outdoors and upon the type of shield used. This is due to the possibility that gas shield based processes might produce some defects in welding if they are done outdoors. Therefore, such type of welding process is not highly recommended for outdoor applications. However, flux shielding can be applied to outdoor as well as indoor applications.

(b) Subjective Criteria

In addition to the above aspects, there are three criteria which require the opinion of the user including volumetric inspection, welding process speed and its operational cost.

The whole length of welding has to be checked at least by visual means. However, for certain parts an internal inspection (through an 'X ray' test) is necessary. The number of points which have to be checked, depends on the opinion of the user. If few defects are envisaged, then fewer check points.

The production/welding speed becomes one of the important aspects, particularly when a short production time is important and essential. When a short production time is required, a higher deposition rate process should be suggested.

The cost of welding will vary according to which welding process is employed. The gas shielding process is cheaper than the flux shielding one, because the deslagging process (to clean up weld) is not necessary after welding.

(c) Selection Logic

The welding processes are analysed on the basis of objective criteria and according to the user's opinion on subjective aspects. The abilities of the processes can be represented in the confidence factors (CFs) associated with them. The CFs of the welding processes are calculated based on the Bayes theory, according to the DBs and DDs of the processes and the user's opinion on the subjective aspects. The values of these DBs and DDs, in this work, are taken tentatively by the author according to their capabilities.

Once the set of suggested processes has been arranged, the user can decide a suitable welding process for the particular joint by selecting one out of this set. Hence, based on this selected welding process, the production cost of welding a particular joint can be calculated.

(d) Production Cost Calculation

The production cost is calculated as a sum of the time taken to arrange the joint (fairing and tacking) and the time taken to weld the joint (welding time). The fairing and tacking time is calculated according to the thickness and type of joint and based on data obtained from the work study carried out by British shipbuilding group (5.1).

The fairing time is the time which is needed to arrange or set up the joint (plate to plate or stiffener to plate) in a proper gap and arrangement as required. Tacking time is the time needed to weld the joints at some points in order to keep the arrangement in their position. The fairing and tacking times are calculated based on the job, the plate and profile constants, types, thicknesses and lengths of the joints. The job constant is the time which includes receiving the instruction, preparing the tools and relaxation. The plate and profile constant is the time constant which includes handling the plates and profiles proportional to the number of plates or profiles. For example, to fair and tack 5 m butt joint with thickness of 12 mm,

- Job constant	:		34.75 minutes per job
- Plate constant	:		5.43 minutes per plate
- Fair and tack per metre	:	6.26 minutes	
- per 5 metres	:	5 x 6.26 = 31.30	minutes
Total fair and tack time	:	76.61	minutes

The welding time is the time needed to weld the joint according to the selected welding processes appropriate for each joint. Since the dimension of the joint is known, the weight of welding metal can be calculated based on the length and the cross sectional area. Thus, the welding time can be calculated by dividing the weight of welding metal by the deposition rate of the welding process used. The time is needed to weld the joint can be expressed as follows :

$$weldtime = \frac{leng * xsec}{depo}$$

where: weldtime : welding time of the joint

leng : length of the joint

xsec : cross sectional area of the joint

depo : deposition rate of the selected welding process.

C.3. Program Validation

Although the DBs and DDs are taken tentatively, they give the proper decision logic. In order to validate the program, the production cost calculations will be checked manually. These results will be compared against the results of the work study data (5.1).

For example :

The analysis will be applied on a grillage without stiffener in order to check the production/welding time of a butt joint by using the manual metal arc process (mma process),

length of panel	:	10.00 m
width of panel	:	4.00 m
thickness of panel	:	14.00 mm
Plate size	:	5.0 x 2.0 m
Length of joint (butt)	:	(1 x 10) + (1 x 4)
	=	14 m

In the following calculation, there are some special terminologies and some abreviations. They are:

= Terminology (Reference 5.1)

- Job constant: time required to prepare for an activity and includes receipt of instruction, location of tools, preparing the work-place, etc.
- Plate constant: time needed to make ready a plate up to the condition when it is ready to be welded.
- Profile constant: time needed to make ready a profile up to the condition when it is ready to be welded.
- Butt constant: time needed to prepare a butt welding joint.
- Tee constant: time needed to prepare a tee welding joint.
- Standard minutes (sms): time needed to do a job under pre-defined or standard conditions using adequately qualified workers with well equipped tools.

Variables

- Thip : Thickness of plate/profile
- FT : fairing and tacking time per metre
- cvol : cross sectional area of the welding including reinforcement
- manning : number of workers

(a). Production time calculated by 'SWES'

** Fairing and tacking (1 skilled , 1 unskilled):

Job constant = 2 x 34.75 = 69.50 sms.

Plate constant = no. plate x sms x manning

= 4 x 5.43 x 2 = 43.44 sms.

fair and tack = length of joint x FT x manning

thip = 14 mm

then FT = 6.26 sms/metre.

fair and tack = 14.00 x 6.26 x 2 = 175.28 sms.

+

Subtotal fair & tack time = 288.22 sms.

= 4.73 hours.

** Welding (1 skilled , 0 unskilled) :

Job constant = 17.57 sms = 0.29 hours.

- BUTT joint :

Butt constant = 2 x 1.53 = 3.06 sms = 0.05 hours.

cvol = 1.15(0.577((th-3)**2)+th*3)

= 1.15(0.577((14-3)**2)+14*3)

= 128.589 sq.mm.

According to table B.1, the deposition rate (depo)= 3.00 kg/hour

welding time= (7.8 x length x cvol)/depo*1000

= (7.8 x 14 x 128.589)/3 x 1000 = 4.68 hours

+

Subtotal welding time = 5.02 hours

+

Total production time = 9.75 hours

(b). Production time calculated based on work study data (5.1)

** Fairing and tacking (1 skilled , 1 unskilled):

Job constant = 2 x 34.75 = 69.50 sms.

Plate constant = no. plate x sms x manning

= 4 x 5.43 x 2 = 43.44 sms.

fair and tack = length of joint x FT x manning

thip = 14 mm

then FT = 6.26 sms/metre.

fair and tack = 14.00 x 6.26 x 2 = 175.28 sms.

\+

Subtotal fair & tack time = 288.22 sms.

= 4.73 hours

** Welding (1 skilled , 0 unskilled) :

Job constant = 17.57 sms = 0.293 hours

Butt constant = 2 x 1.53 = 3.06 sms = 0.051 hours

welding standard = 9.74 + 9.91

= 19.65 sms/metre.

welding time = 14 x 19.95

= 279.3 sms = 4.656 hours

\+

Subtotal welding time, total = 4.949 hours

\+

Total production time = 9.679 hours

The difference between the result of 'SWES' and the result of 'Work study data' is :

$$\frac{(9.75 - 9.679)}{9.679} \times 100\ \% = 0\ .72\ \%$$

The difference of 0.72% is relatively small and can be disregarded. Therefore, the welding time calculation method which is used in 'SWES', is reasonable and can be used in further development of production cost analysis.

Appendix D: THE 'GRILLAGE' EXPERT SYSTEM

As a further development of the SWES, this system is directed to analyse the production cost of a grillage structure which consists of a number of different joints. Generally, the joints can be classified into two groups i.e.: butt and tee joints. Butt joints are joints between plates. Tee joint is joint between a plate and a stiffener. This can be divided into five categories; main longitudinal, web longitudinal, main transverse and web transverse stiffeners and the joint between the stiffeners, as shown in Figure D.1. Thus, there are six different joints which need to be analysed within a grillage. They are,

1. Butt joint between plates
2. Tee joint between main longitudinals and plate
3. Tee joint between web longitudinals and plate
4. Tee joint between main transverses and plate
5. Tee joint between web transverses and plate
6. Tee joint between longitudinals and transverses

Besides variations in the type, the dimensions of one joint maybe also different from the others. Then, in order to calculate the production cost of a grillage, it is necessary to select a welding process which suitable for welding every joint within the grillage.

The welding process selection for a specific joint within a grillage, is done in a similar way to SWES (Appendix C). The welding process selection is still related to both objective and subjective aspects. The objective aspects are taken to be the same as the aspects which are used in SWES. However, there are some alterations leading to improvements in dealing with subjective criteria.

D.1. Improvement in Subjective Criteria

In addition to taking into account the weight of welding metal deposition and deposition rate, the production cost calculation also considers the reject rate and the rewelding factor.

The reject rate represents the percentage of reject work related to the possibility of defects which might occur during execution. This rate varies according to the yard experience and type of welding process. Therefore, it is necessary to ask the user to put in his opinion on the percentage of work which might be rejected for every possible welding process for a joint.

The rejected welding must obviously be repaired. More time and hence cost is necessary to repair such welding. This is due to removal of the reject welding (either by grinding or gouging), to make other grooves and to fill them up (reweld). The ratio of the time consumed to reweld such joint upon the time needed to make a new welding is called the rewelding factor. This factor varies and is dependent on the experience of the yard (user).

There are three other aspects which also require subjective answers or opinions of the user. They are related to the welding speed, the welding efficiency and the production cost.

The welding speed is related to the production time and hence delivery time. Sometimes a short delivery time is essential and more important than the production cost. The welding speed is represented by the manhours which are needed to weld a specific joint within a grillage. Here, the opinion of the user is necessary in order to determine the confidence factor of a welding process upon this welding speed. In this case, the user has the possibility of expressing his opinion, called 'subjx(1)', along the scale line between 'Not relevant' and 'Very important', as shown in Figure 5.4.

The welding efficiency is represented by the total weight of welding rod which is used to weld certain length of joint upon the total welding metal for a particular joint. Some yards judge that the welding efficiency is not related to welding selection process and put it into overhead cost. However, it becomes an important aspect (in welding process selection), for it can cause a reduction in the welding cost. Therefore in this welding process selection, the opinion of the user is necessary. As in the welding speed aspect, the user has the possibility of putting forward his opinion, called 'subjx(2), on a scale between 'Not relevant' and 'Very important', as shown in Figure 5.4.

In addition to being dependent on welding speed, the production cost is also dependent on the reject rate and rewelding factor. Thus, the cost needed to produce certain length of joint varies depending on the welding process used. The welding process able to weld a certain joint in the lowest production cost has to be the 'best' process. However, sometimes production cost may not be an important aspect in welding process selection. Therefore, it is necessary to ask the user about the relative importance of production cost in the welding process selection. As in the two previous aspects, the user has possibility of expressing his opinion, called 'subjx(3)'.

D.2. Program Logic

According to the capabilities of welding processes explained in Appendix B, a decision tree is built. In this decision tree these welding processes are classified based upon their capability for welding positions (Downhand, Horizontal, Vertical and Overhead) and their thickness of weldability. Thus, once the thickness and position of a joint is known (entered) and a set of alternative welding processes can be found according to the decision tree. Furthermore, the confidence factors of these processes can be calculated according to the aspects which have been explained in Section D.1. Then, the set will be rearranged sequentially according to the value of their confidence factors and produce 'suggested welding processes' for the joint.

D.2.1 Confidence Factor

The confidence factor of a welding process (CF(x)) is calculated based upon four sub-confidence factors, CFX(1), CFX(2), CFX(3) and CFX(4) which can be explained as follows:

(a). Location

The first sub-confidence factor (CFX(1)) is incorporated with two choices of location namely Indoor and Outdoor. These locations are related to the different types of shielding of welding processes. Most processes can be used indoors. However for outdoor applications, some especially gas shielded processes, are not recommended. This means the confidence factor (CFX(1)) of gas shielding processes is lower compared to flux shielding processes if the processes are used outdoors.

(b). Welding Speed

The second sub-confidence factor is calculated based on the welding speed. This is represented by the time needed to weld a joint and the user's opinion on how important the welding speed is. This opinion (subjx(1)) together with the degree of belief (DB(2)) and disbelief (DD(2)) will be analysed to become the second sub-confidence factor of a welding process upon the welding speed (CFX(2)).

(c). Welding Efficiency

The third sub-confidence factor (CFX(3)) is based on the relative efficiency of the welding processes represented by the DB(3) and DD(3), and according to the user's opinion on the relative importance of welding efficiency in the welding selection (subjx(2)).

(d). Production Cost

The fourth sub-confidence factor (CFX(4)) is calculated based on the production cost needed in welding the joint. The production cost is related to production time and labour rate. The production time is dependent on the time for welding and to reweld the rejected welding. The welding time is calculated based on the dimensions of joint and the deposition rate of welding processes. Because of the different production times required by welding processes, the degree of belief (DB(4)) and DD(4)) of a welding process can be approached by fuzzy logic based upon the minimum production time. Based on DB(4) and DD(4) and depending on how important production cost (subjx(3)), the fourth sub-confidence factor is calculated.

After the four sub-confidence factors of each welding process are found, then the total confidence factor of process(x) can be calculated. It can be done by combining the four sub-confidence factors and is written as follows:

$$CF(x) = CFX(4|(3|(2|1))) \qquad \text{..................(D.1)}$$

Bayes theory is applied in this combining process. As this can only combine two sub-confidence factors at a time the combining process is done in three steps. The first step is to combine the first sub-confidence factor (CFX(1)) with the second sub-confidence factor (CFX(2)) and this becomes CFX(2¦1). The other steps similarly account for the third and the fourth sub-confidence factors.

$$DB(2|1) = \frac{DB(2) * CFX(1)}{[\ DB(2) * CFX(1)\ ] + [\ DD(2) * (1 - CFX(1)\ ]} \quad \ldots\ldots\ (D.2.a)$$

$$DD(2|1) = \frac{DD(2) * CFX(1)}{[\ DD(2) * CFX(1)\ ] + [\ DB(2) * (1 - CFX(1)\ ]} \quad \ldots\ldots\ (D.2.b)$$

$$CFX(2|1) = [Subjx(1) * DB(2|1)] + [\ (1 - Subjx(1)) * DD(2)] \ \ldots (D.2.c)$$

Or in accordance with the built-in function of the 'Crystal' shell, it can be written as:

$$CFX(2|1) = Bayes\ (\ CFX(1),\ DB(2),\ DD(2),\ Subjx(1)\ ) \ \ldots\ldots (D.2.d)$$

The second task is to combine CFX(3) with CFX(2¦1). Since CFX(3) depends on DB(3), DD(3) and Subjx(2) then the combination becomes;

$$CFX(3|(2|1)) = Bayes\ (\ CFX(2|1),\ DB(3),\ DD(3),\ Subjx(2)\ ) \ \ldots. (D.3)$$

Finally, the total confidence factor of a welding process, CF(x), can be found by combining the CFX(4) with the CFX(3¦2¦1). Since the CFX(4) is dependent on DB(4), DD(4) and subjx(3) the factor becomes:

$$\begin{aligned} CF(x) &= CFX(4|(3|(2|1))) \\ &= Bayes\ (\ CFX(3|(2|1)),\ DB(4),\ DD(4),\ Subjx(3)\ ) \ \ldots\ldots\ (D.4) \end{aligned}$$

The values of Subjx(1),(2),(3) are taken from the opinion of the user upon how important the welding speed, welding efficiency and production cost are, as mentioned in the previous section. On the other hand, the degrees of belief and disbelief are calculated from the capabilities of these welding processes.

D.2.2 Degree of Belief/Disbelief

The degrees of belief and disbelief of a welding process with regard to welding speed, efficiency, and production cost, have been approached by fuzzy logic. In this context, the degree of belief is based on the membership function which is in the form of linear interpolation.

$$DB(x) = \frac{(X - Xmin) * (Dmax - Dmin)}{(Xmax - Xmin)} \quad \text{................(D.5)}$$

where: X : the capability of the welding process (x).

Xmin : the minimum capability of welding process.

Xmax : the maximum capability of welding process.

Dmin : the degree of belief of the minimum capability process

Dmax : the degree of belief of the maximum capability process

A welding process attains full membership in a specific aspect if its capability is the 'best'. Thus, these degrees of belief can be determined as follows:

(a). Welding Speed

Welding speed is proportional to the deposition rate of the process. The one with the highest rate will attain full membership and a zero deposition rate means zero membership. The net result is shown in Table D.1.

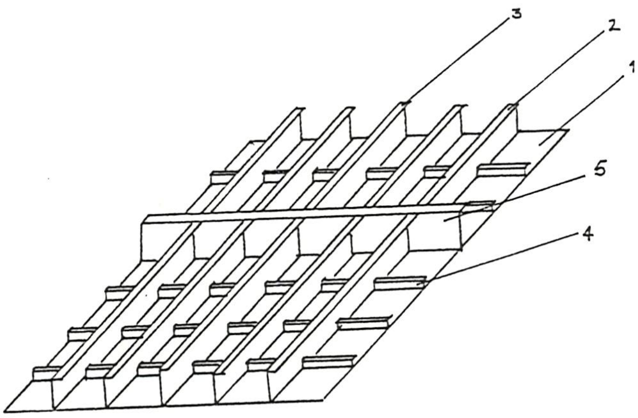
(b). Welding Efficiency

The degree of belief/disbelief with regard to welding efficiency is calculated in a similar way to finding out the DB/DD of welding speed where a 100% efficiency becomes the full membership. These DB/DD 's are shown in Table D.2.

(c). Production Cost

Production cost is dependent on the reject rate and rewelding factor in addition to welding speed. It is calculated based on the total welding time, which includes rewelding time for the rejected joints. Hence, the DB/DD with regard to production cost can be calculated based on the total welding time. Again, the process with minimum welding time attains full membership.

After the confidence factors of all alternative welding processes are calculated, these have to be rearranged in a sequence according to their confidence factors. This set is termed 'suggested welding process' which will enable the user to know the 'best' process for the joint. However, the user has the possibility of deciding subjectively on a welding process which is most applicable to weld the joint.



1. Plate
2. Longitudinal (main)
3. Longitudinal (web)
4. Transverse (main)
5. Transverse (web)

Figure D.1 The Grillage

Welding process	Dia. rod (in mm)	Deposition rate (in kg/hr)	Degree of belief	Degree of disbelief
MMA1	1.5	0.6	0.04	0.96
MMA2	2.0	0.8	0.06	0.94
MMA3	3.0	1.3	0.09	0.91
MMA4	4.0	1.5	0.11	0.89
MMA5	6.0	3.0	0.22	0.78
MMA6	8.0	5.0	0.37	0.63
SAW11	3.2	8.7	0.64	0.36
SAW12	4.8	12.7	0.94	0.06
SAW13	6.3	13.5	0.999	0.001
Fusarc1	2.5	3.5	0.26	0.74
Fusarc2	4.8	7.5	0.55	0.45
Fusarc3	7.0	10.0	0.74	0.26
MIG-Spray1	1.2	7.2	0.53	0.47
MIG-Spray2	1.6	8.0	0.59	0.41
MIG-Dip1	1.2	5.0	0.37	0.63
MIG-Dip2	1.6	6.0	0.44	0.56
MIG-Pulse1	1.2	3.2	0.23	0.77
MIG-Pulse2	1.6	3.4	0.25	0.75

Table D.1 Deposition Rate: DB/DD

Welding process	Efficiency rate (%)	Degree of belief	Degree of disbelief
MMA1	60	0.6	0.4
MMA2	60	0.6	0.4
MMA3	60	0.6	0.4
MMA4	60	0.6	0.4
MMA5	60	0.6	0.4
MMA6	60	0.6	0.4
SAW11	98	0.98	0.02
SAW12	98	0.98	0.02
SAW13	98	0.98	0.02
Fusarc1	79	0.79	0.21
Fusarc2	79	0.79	0.21
Fusarc3	79	0.79	0.21
MIG-Spray1	93	0.93	0.07
MIG-Spray2	93	0.93	0.07
MIG-Dip1	91	0.91	0.09
MIG-Dip2	91	0.91	0.09
MIG-Pulse1	95	0.95	0.05
MIG-Pulse2	95	0.95	0.05

Table D.2 Welding Efficiency: DB/DD

D.3. Production Cost Calculation

After the welding processes for all joints within a grillage have been selected, the production cost of the grillage can be calculated. In this program, the production cost is represented by a direct production cost and material cost. The calculations are done in the same manner as outlined in Appendix C (Section 2.c).

D.4. Program Validation

Grillage : Length = 10.00 m

Width = 4.00 m

Plate thickness = 14.0 mm

Position : Downhand

Location : Indoor

Plate size : 5 x 2 m

(a) Determining the Set of Alternative Welding Processes

According to the decision tree, alternative welding processes capable of welding the downhand joint of 14 mm thickness, can be seen in Table D.3 below:

Welding processes
MMA5 MMA6 MIG Spray1 MIG Dip2 MIG Pulse2 SAW12 Fusarc1

Table D.3. The Set of Alternative Welding Processes (Thickness of 14 mm)

(b) Finding Out the Degree of Belief/Disbelief

The degrees of belief/disbelief of the above welding processes with regard to welding speed and welding efficiency can easily be found from Tables D.1 and D.2. However the degrees of belief/disbelief with regard to the production cost have to be calculated according to the time taken by each process to weld the joint. This welding time can be represented by welding time factor and is calculated by using the formulae (D.5). To use such formulae it is necessary to know the deposition rate, the reject rate and the rewelding factor of the welding processes in addition to the length and the cross sectional area of the joint. In this example the deposition rates are obtained from Table D.1 and listed in Table D.4 . The reject rates are taken subjectively as shown in Table D.6. For the joint's thickness of 14 mm the cross sectional area (xsec) is:

$$Xsec = ((3 \times thic) + (0.577 \times (thic-3)^2) \times 1.15$$

where thic = thickness of the joint in mm (14 mm)

$$Xsec = ((3 \times 14) + (0.577 \times (14-3)^2) \times 1.15$$

$$= 128.589 \text{ sq.mm}$$

Thus, the welding time factor (wtime) can be calculated as follows:

$$wtime(mma5) = \frac{(1 + (rrate(mma) \times rfac)) \times (xsec \times length)}{depo(mma) \times 1000}$$

where :

rrate(mma) : the reject rate of the mma process

rfac : the rewelding factor

xsec : the cross sectional area of the joint

length : the length of the joint

$$wtime(mma5) = \frac{(1 + (0.20 \times 5)) \times (128.589 \times 14)}{3.01 \times 1000}$$

$$= 1.196$$

depo(mma) = 1.3 from Table D1

The welding time factor for the rest of the alternative welding processes is calculated in the same way. The degree of belief/disbelief of a welding process is calculated by comparing its welding time factor linearly to the minimum value. In this case the factor of SAW13 process is the minimum, therefore, the DB/DD of the various welding processes can be calculated as follows:

DB(x) = (minimum factor)/ (welding factor(x))

DD(x) = 1 - DB(x)

The minimum factor = 0.232

The results of this calculations can be seen in Table D.7.

Welding process	Deposition rate (kg/hr)	Degree of belief	Degree of disbelief
MMA5	3.0	0.22	0.78
MMA6	5.0	0.29	0.71
MIG Spray1	7.2	0.53	0.47
MIG Dip2	6.0	0.44	0.56
MIG Pulse2	3.4	0.25	0.75
SAW13	13.5	0.999	0.001
Fusarc1	3.5	0.55	0.45

Table D.4. Deposition Rate of Alternative Welding Processes: DB/DD

Welding process	Efficiency rate (%)	Degree of belief	Degree of disbelief
MMA5	60	0.6	0.4
MMA6	60	0.6	0.4
MIG-Spray1	93	0.93	0.07
MIG-Dip2	91	0.91	0.09
MIG-Pulse2	95	0.95	0.05
SAW13	98	0.98	0.02
Fusarc2	79	0.79	0.21

Table D.5. Efficiency of Alternative Welding Processes: DB/DD

Welding process	Reject rate (in percent)
MMA5	20%
MMA6	20%
MIG Spray1	10%
MIG Dip2	10%
MIG Pulse2	10%
SAW12	15%
Fusarc1	20%
Rewelding factor	5.00

Table D.6. The Reject Rate of Alternative Welding Processes

Welding process	Weld time factor	Degree of belief	Degree of dis-belief
MMA5	1.196	0.194	0.806
MMA6	0.900	0.257	0.743
MIG Spray1	0.372	0.622	0.378
MIG Dip2	0.450	0.515	0.485
MIG Pulse2	0.794	0.292	0.708
SAW12	0.232	1.000	0.000
Fusarc1	1.029	0.225	0.775

Table D.7. Production Cost Aspect: DB/DD

(c) The Subjective Aspects

Besides the degrees of belief/disbelief, confidence factors are also dependent on the subjective aspects which should be provided by the user. In this example, the subjective aspects are taken as follows:

- The welding speed is an important aspect

Not relevant | Very Important

- The welding efficiency is not important aspect

Not relevant | Very Important

- The production cost is important aspect

Not relevant | Very Important

When the degree of belief/disbelief and the subjective aspects are known, the confidence factor can be calculated by using the formulae D.1. As an example of this calculation, the MIG spray1's confidence factor will be shown below :

$$CF(\text{MIG spray1}) = CFX(4|(3|(2|1)))$$

where:

$$CFX(2|1) = [subjx(1) \times DB(2|1)] + [(1 - subjx(1)) \times DD(2|1)$$

$$subjx(1) = 0.76$$

The joint degree of belief DB(2¦1) is calculated based on the formulae D.2.a,

$$DB(2|1) = \frac{DB(2) \times CFX(1)}{[\ DB(2) \times CFX(1)\ ] + [\ DD(2) \times (1 - CFX(1)\ ]}$$

$$CFX(1) = DB(1) = 0.50 \qquad \text{(Indoor process)}$$

$$DB(2) = 0.53$$

$$DD(2) = 0.47$$

Thus,

$$DB(2|1) = \frac{0.53 \times 0.50}{[\ 0.53 \times 0.50\ ] + [\ 0.47 \times (1 - 0.50)]}$$

$$= 0.53$$

And the joint degree of dis-belief is calculated based on the formulae D.2.b,

$$DD(2|1) = \frac{DD(2) \times CFX(1)}{[DD(2) \times CFX(1)] + [DB(2) \times (1 - CFX(1)]}$$

$$= \frac{0.47 \times 0.50}{[\ 0.47 \times 0.50\ ] + [\ 0.53 \times (1 - 0.5)]}$$

$$= 0.47$$

Thus, the joint confidence factor is,

$$CFX(2|1) = (0.76 \times 0.53) + ((1 - 0.76) \times 0.47)$$

$$= 0.5156$$

The second joint CFX(3|(2|1)) can be calculated based on the second joint degree of belief/disbelief, which are calculated as follows :

$$DB(3|(2|1)) = \frac{DB(3) \times CFX(2|1)}{[DB(3) \times CFX(2|1)] + [DD(3) \times (1 - CFX(2|1)]}$$

$$DB(3) = 0.93$$

$$DD(3) = 0.073$$

$$DB(3|(2|1)) = \frac{0.93 \times 0.5156}{[0.93 \times 0.5156] + [0.07 \times (1 - 0.5156)]}$$

$$= 0.9339$$

and,

$$DD(3|(2|1)) = \frac{DD(3) \times CFX(2|1)}{[DD(3) \times CFX(2|1)] + [DB(3) \times (1 - CFX(2|1)]}$$

$$DD(3|(2|1)) = \frac{0.07 \times 0.5156}{[0.07 \times 0.5156] + [0.93 \times (1 - 0.5156)]}$$

$$= 0.0741$$

Thus, the second joint CF is,

$$CFX(3|(2|1)) = [0.24 \times 0.9339] + [(1 - 0.24) \times 0.0741]$$

$$= 0.28045$$

The final CF combines the third subjective aspect with the second joint CF and is calculated as follows:

$$DB(4|(3|(2|1))) = \frac{DB(4) \times CFX(3|(2|1))}{[DB(4) \times CFX(3|(2|1)] + [DD(4) \times (1 - CFX(3|(2|1))]}$$

$$DB(4) = 0.622$$

$$DD(4) = 0.378$$

$$DB(4|(3|(2|1))) = \frac{0.622 \times 0.28045}{[0.622 \times 0.28045] + [0.378 \times (1 - 0.28045)]}$$

$$= 0.3907$$

$$DD(4|(3|(2|1))) = \frac{0.378 \times 0.28045}{[0.378 \times 0.28045] + [0.622 \times (1 - 0.28045)]}$$

$$= 0.1915$$

$$CF(\text{MIG spray1}) = [0.48 \times 0.3907] + [(1 - 0.48) \times 0.1915]$$

$$= 0.287116$$

=============

The confidence factors (CF) of other welding processes can be calculated in the same way. The above manual calculations agree with those given by the program. This verifies that the CFs calculation in the program is working in the right order.

The production cost calculations are carried out in the same manner as in the case of SWES and these have been validated already.

Appendix E. THE RESULTS OF WELDING PROCESS SELECTION

As mentioned in Chapter 5, the CFs are dependent on the subjective aspects and the abilities of a welding process. Due to varying abilities of the welding processes, as shown in Appendix B, the value of their CFs differ upon a set of the subjective aspects. These values of CFs will change when the opinions on subjective aspects are changed. In order to analyse the variation of the CFs, a simple example has been examined by the program.

As an example, the welding selection process has been applied onto a butt joint with a thickness of 14 mm, a length of 3.5 m and in the downhand position, as shown in Figure 6.1. Depending on the thickness and position of the joint, there are seven types of possible welding processes of four groups:

- Manual metal arc; mma3 and mma4
- Submerged arc welding; saw13
- Metal inert gas; mig-spray1, mig-dip2 and mig-pulse2
- Fusarc ; fusarc1.

These processes are further analysed and arranged sequentially according to their confidence factors of their capabilities and subjective aspects which depend on the yard experience and the user's opinion.

As mentioned in Appendix D, the reject rates and the rewelding factor are two aspects related to the yard experience and have to be decided based on it. However, in this example the values of both aspects are taken randomly by the author without considering a specific yard experience, as shown in Table E.1 below:

Welding process	Reject rate
mma3	20 %
mma4	20 %
saw13	20 %
mig-spray1	10 %
mig-dip2	10 %
mig-pulse2	15 %
Fusarc1	20 %
Rewelding factor is 5.0	

Table E.1 Reject Rate and Rewelding Factor

Three other aspects, besides the reject rate and the re-welding factor are taken into account. As previously mentioned in Appendix D, they are the welding speed, the welding efficiency and the production cost aspects. The confidence factors of the alternative welding processes are calculated by combining sub-confidence factors of these aspects. These sub-confidence factors, called CFX, are calculated according to the importance of the related aspect and their capabilities which are represented by their degrees of belief/disbelief. Generally, CFX will increase when the degrees of belief in the process and the importance of the aspect are larger than their average values. On the other hand, the CFX will decrease if these values are less then their averages. The average value of DB/DD is the median value between the minimum and the maximum degrees of belief/disbelief. Thus, based on variation in the combination of these three aspects and their DBs/DDs, the value of the confidence factors are calculated.

Since the scale of these three subjective aspects is between 0% and 100%, a large number of combinations might occur which produce a large number of results (CF). Hence, a set of figures are necessary to represent the results. The set is divided into two groups i.e.: as an indoors application as shown in Figures E.1 to E.27 and the outdoors one shown in Figures E.28 to E.54.

Figures E.1 to E.9 represent the CFs of the processes where the importance of welding speed is a variable option and where welding efficiency and production cost aspect are taken as constant factors. Figures E.10 to E.18 show the CFs where the importance of welding efficiency varies and welding speed and production cost are the constant aspects. The results where the importance of production cost aspect varies and the other two are constant, are shown in Figures E.19 to E.27. The same conditions are also used for outdoors applications results.

The broad trends of curves have been discussed in Chapter 5. These can also be examined in a quantitative manner with reference to Bayes theory and the formulations in Chapter 4 and Appendix D. However, there is also a need to study these from a qualitative viewpoint.

Such a study can be done in context of a couple of welding processes - MMA and Mig Spray - in both indoor and outdoor applications (Figures E.2 and E.29 respectively). Consider their application when it is assumed that cost is not an important aspect (@ 25%) and efficiency is considered to be marginal or 'irrelevant' (@50%). It is best to concentrate attention on the end point of the two curves, i.e. when welding speeds are either unimportant (@25%) or important (75%).

From Figure E.2 it is evident that MMA is a 'better' process than Mig Spray (i.e. with a higher CF) when welding speed is deemed not important. It can be argued that welding speed being not important could be 'equated' to a preference for a process which is inherently slow. The MMA process certainly 'wins' on this count (-see Table D.1). Similarly, the cost criterion being unimportant could be 'equated' to a non-preference for a fast process with less rework. Again, the MMA process 'wins' over the Mig Spray process -see Table D.6. Welding efficiency at a 50% level of importance (i.e. indifference) would not affect the result either way.

When the welding speed criterion is deemed by the user to be more important (@75%), the picture changes slightly. It can be seen from Figure E.2 that the CF for the MMA process is less than that for the Mig Spray process. The argument here is that importance in weld speed being high could be 'equated' to a process which is inherently faster, i.e. Mig Spray. Again, weld efficiency is only a marginal consideration @ 50%. The constraining criterion is cost being deemed unimportant. So, this would influence the choice of a Mig Spray in a negative sense. This is the cause for the gradient in the line (corresponding to Mig Spray) being only marginally upwards. The implication is that this low importance of cost marginally balances out the higher importance of the speed aspect.

Results for the outdoor location, with the same set of subjective opinions, are given in Figure E.29. It is noticeable the curve for the MMA process is identical to that in Figure E.2 (i.e. indoor application). This is because the operation of the MMA process is unaffected as regards the location and with respect to the three subjective criteria considered. However, Mig Spray process, because of its very nature , is affected. There will be a slight lowering of confidence in the process being operated outdoors as opposed to indoors. This is reflected in the CF curve for Mig Spray being 'depressed' in comparison with its counterpart in the indoors location. The trend, however, is the same. There is a marginal increase in CF when the cost factor becomes relatively more important @75%. That it is higher than the corresponding value for the MMA process is a matter for quantitative assessment using the formulae derived in Chapter 4 and Appendix D.

The important conclusion with respect to the above discussion is that the results can be justified in a qualitative aspect as well (and in addition to a purely quantitaive one).

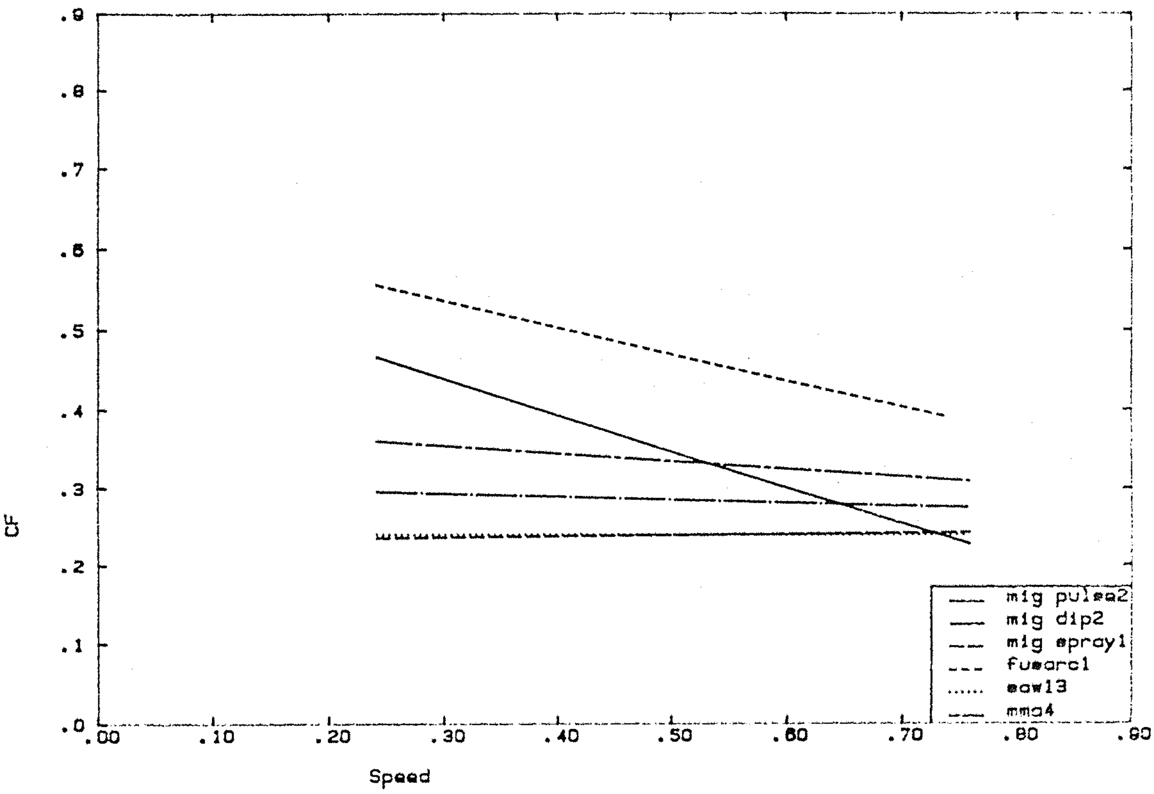


Figure E.1 Indoors Welding Processes, Eff. 25% and Cost 25%

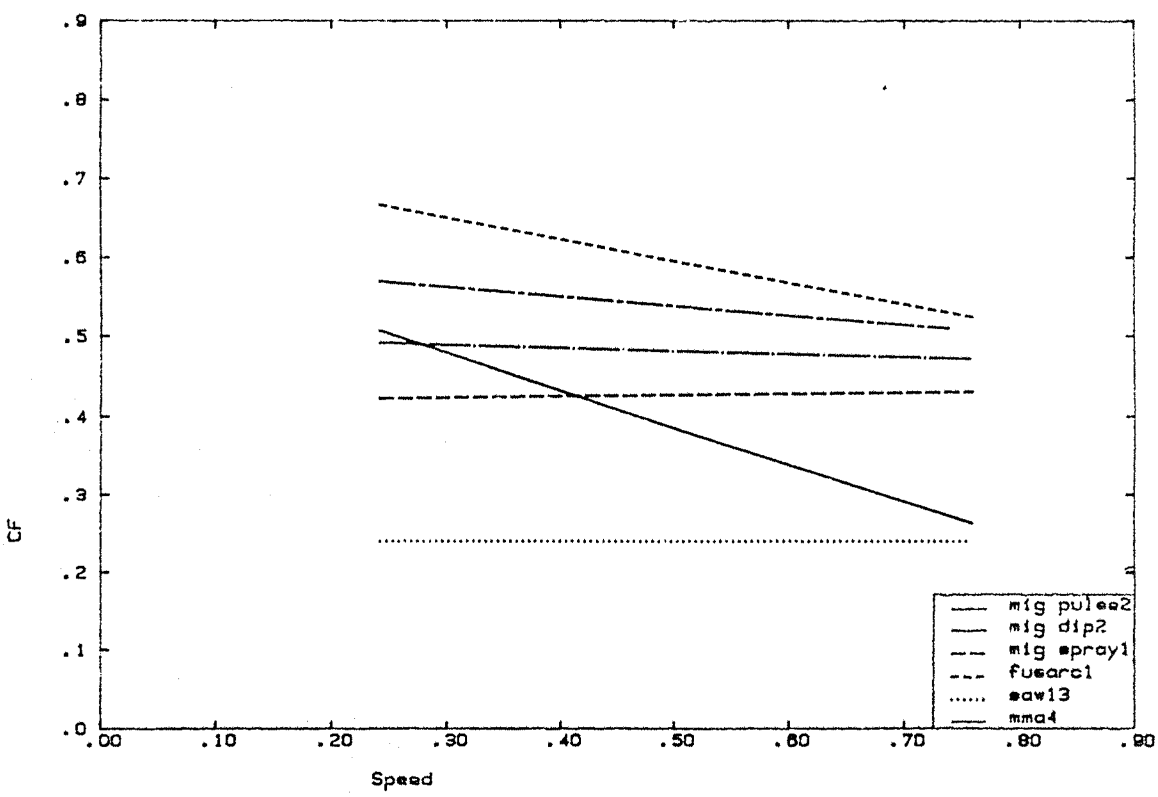


Figure E.2 Indoors Welding Processes, Eff. 50% and Cost 25%

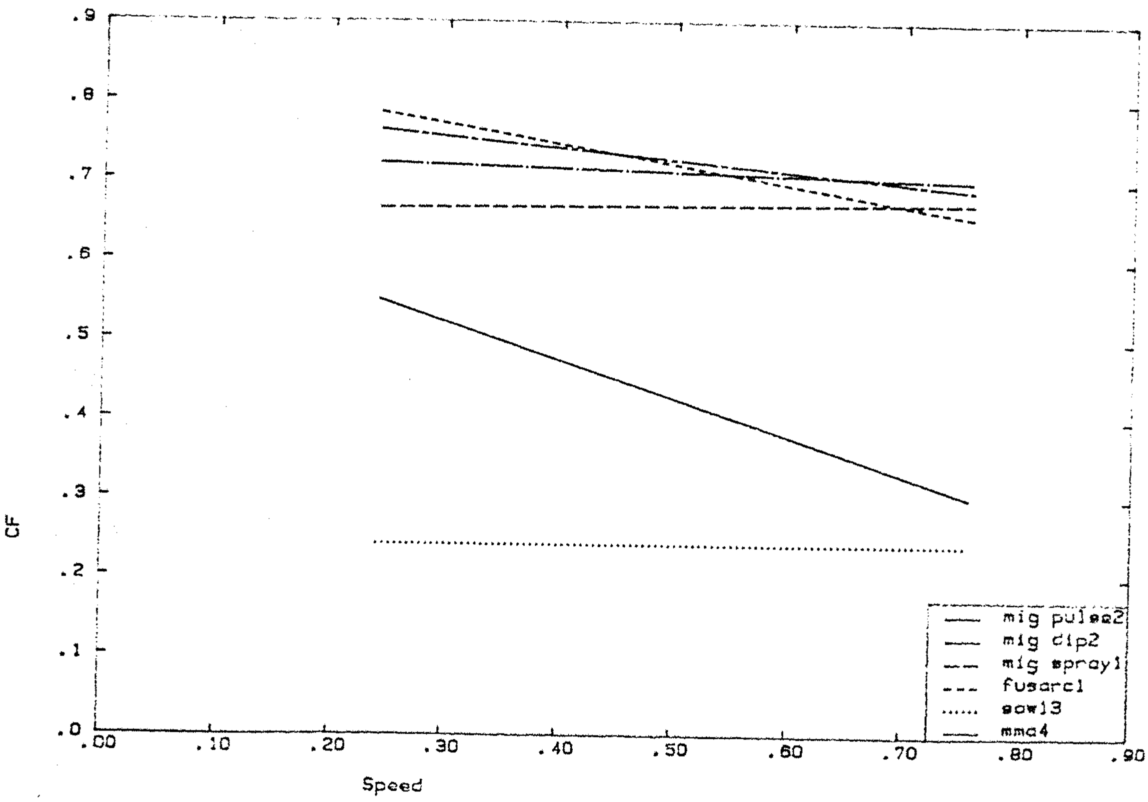


Figure E.3 Indoors Welding Processes, Eff. 75% and Cost 25%

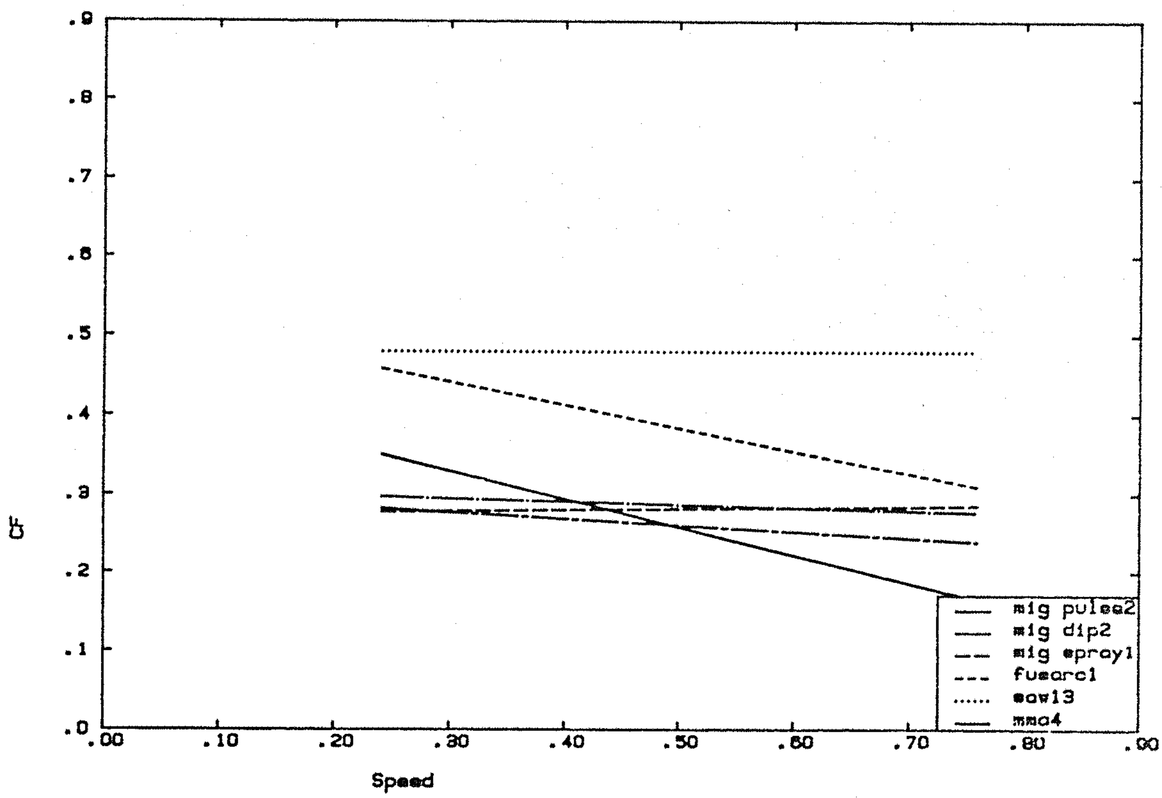


Figure E.4 Indoors Welding Processes, Eff. 25% and Cost 50%

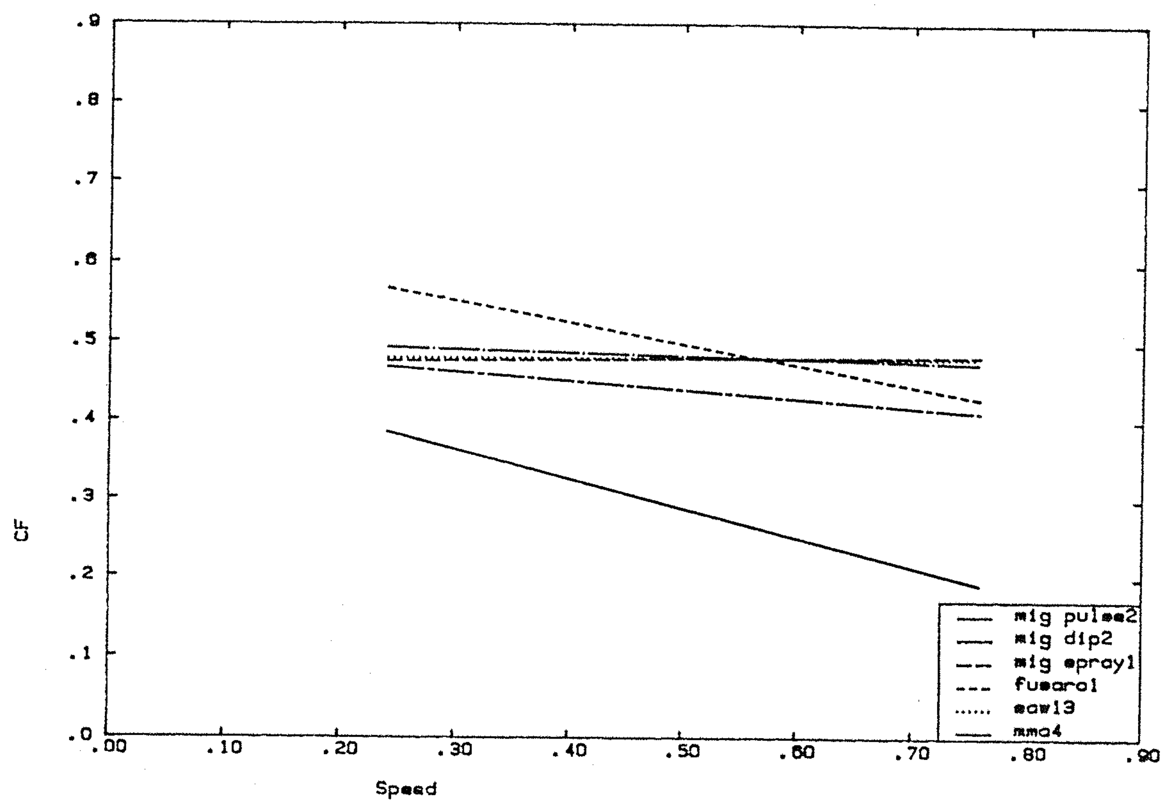


Figure E.5 Indoors Welding Processes, Eff. 50% and Cost 50%

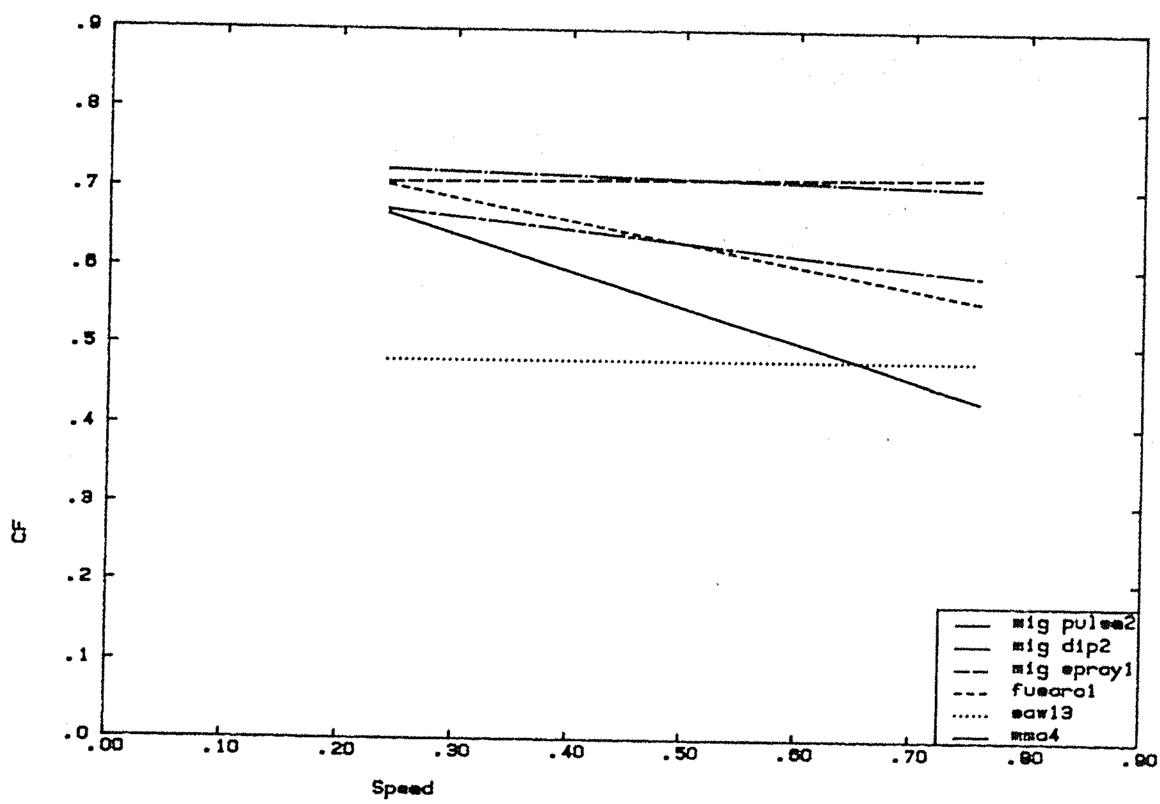


Figure E.6 Indoors Welding Processes, Eff. 75% and Cost 50%

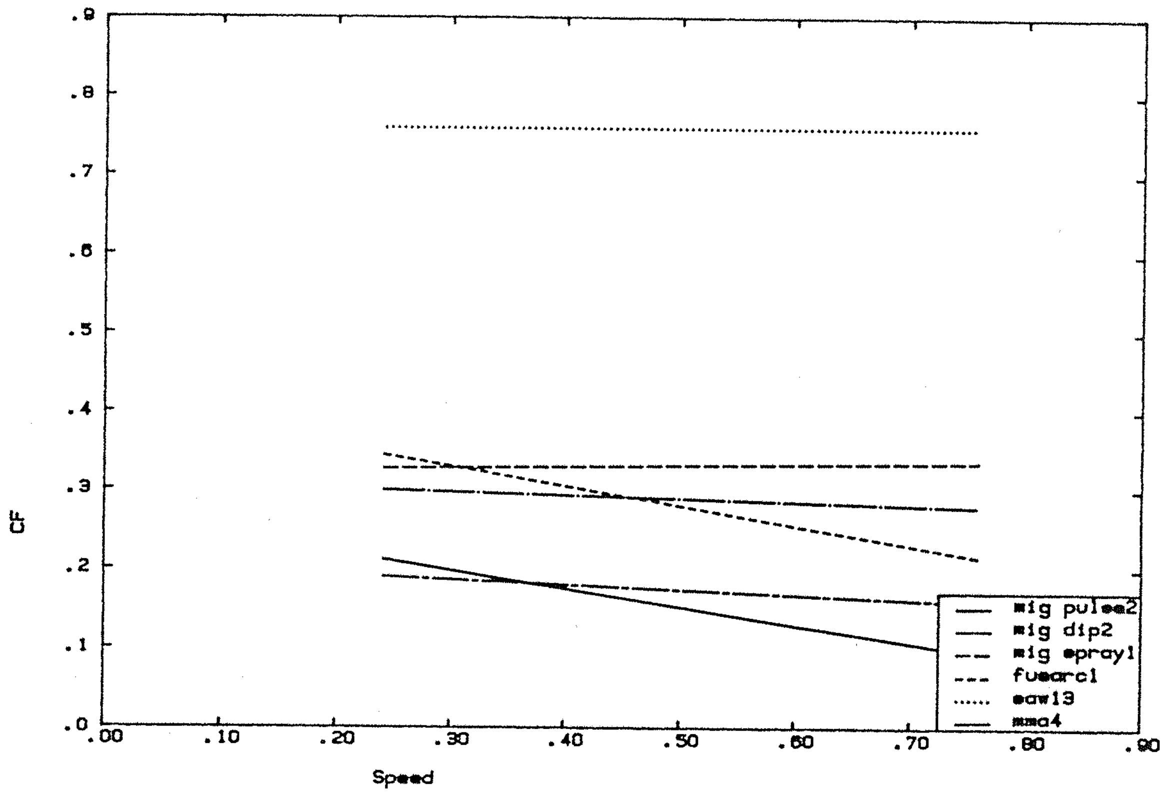


Figure E.7 Indoors Welding Processes, Eff. 25% and Cost 75%

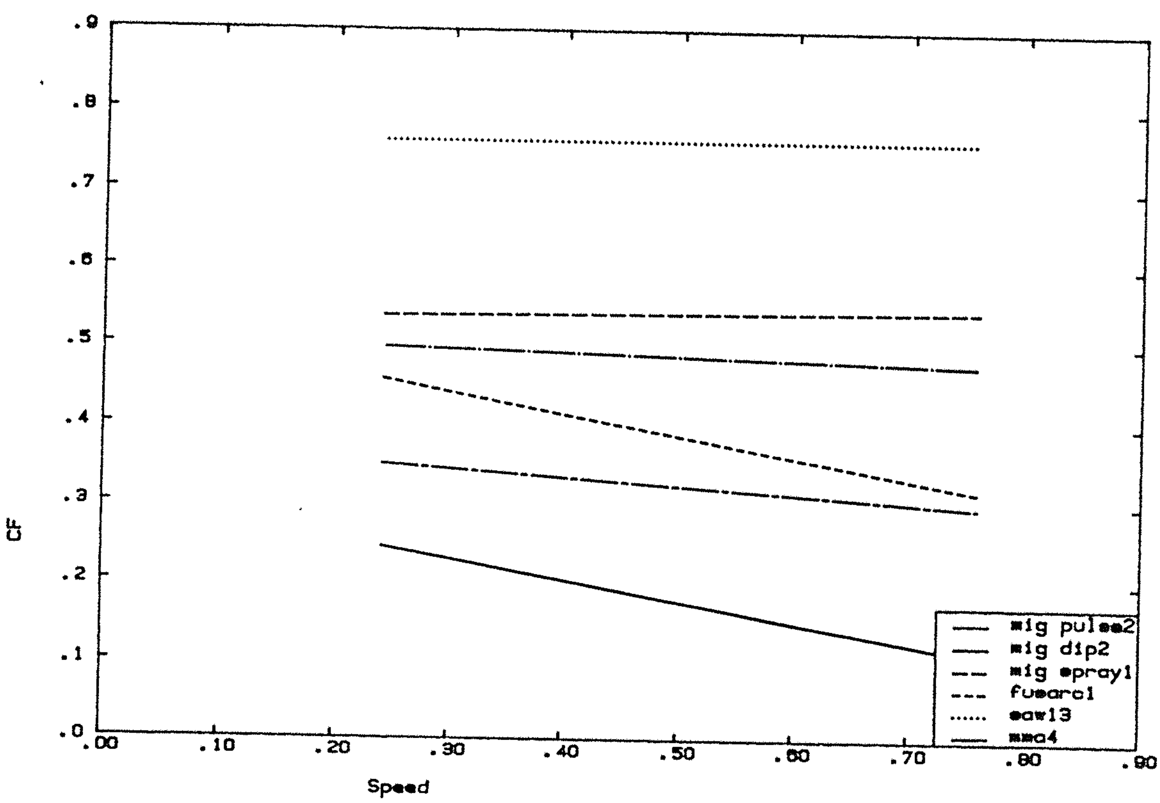


Figure E.8 Indoors Welding Processes, Eff. 50% and Cost 75%

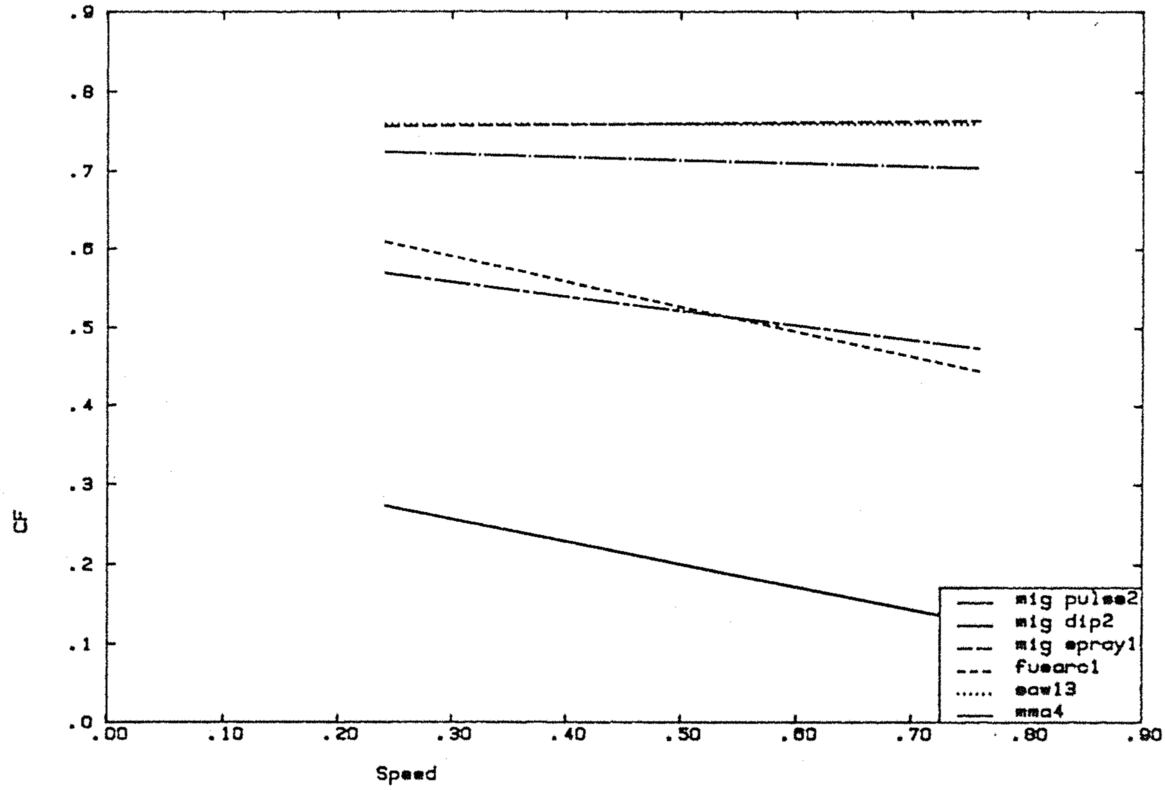


Figure E.9 Indoors Welding Processes, Eff. 75% and Cost 75%

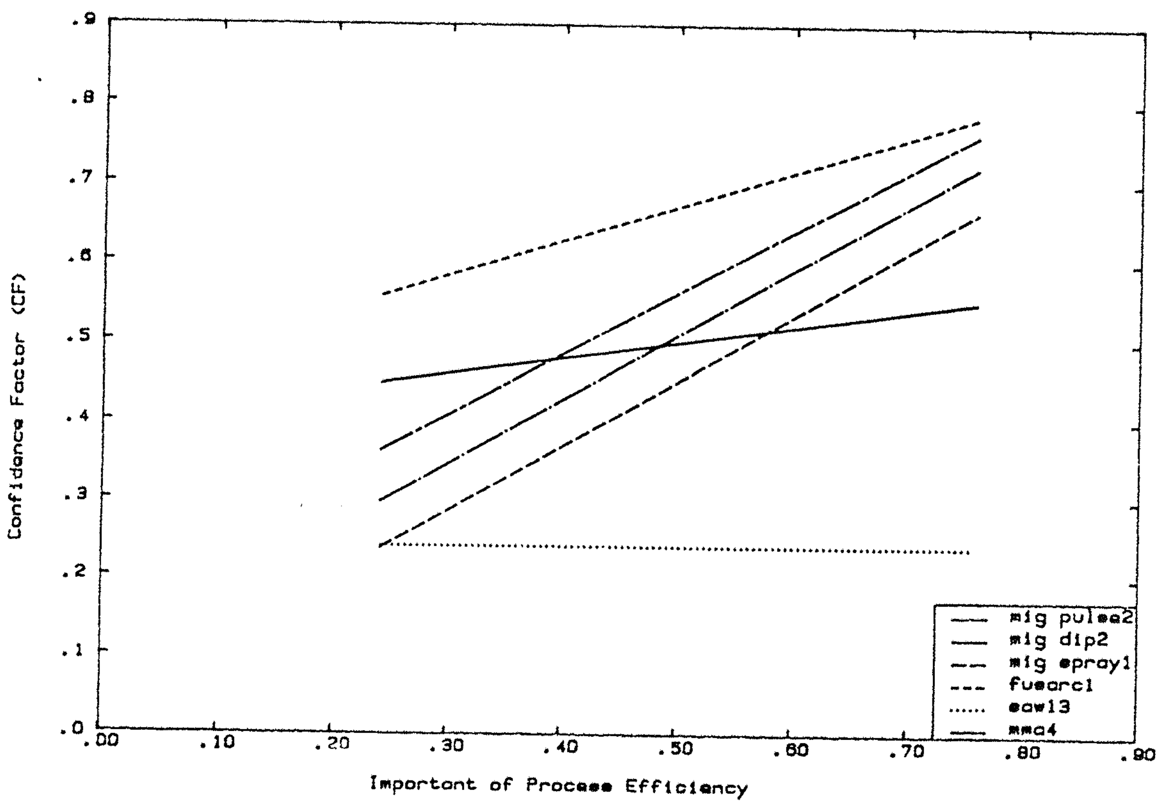


Figure E.10 Indoors Welding Processes, Speed 25% and Cost 25%

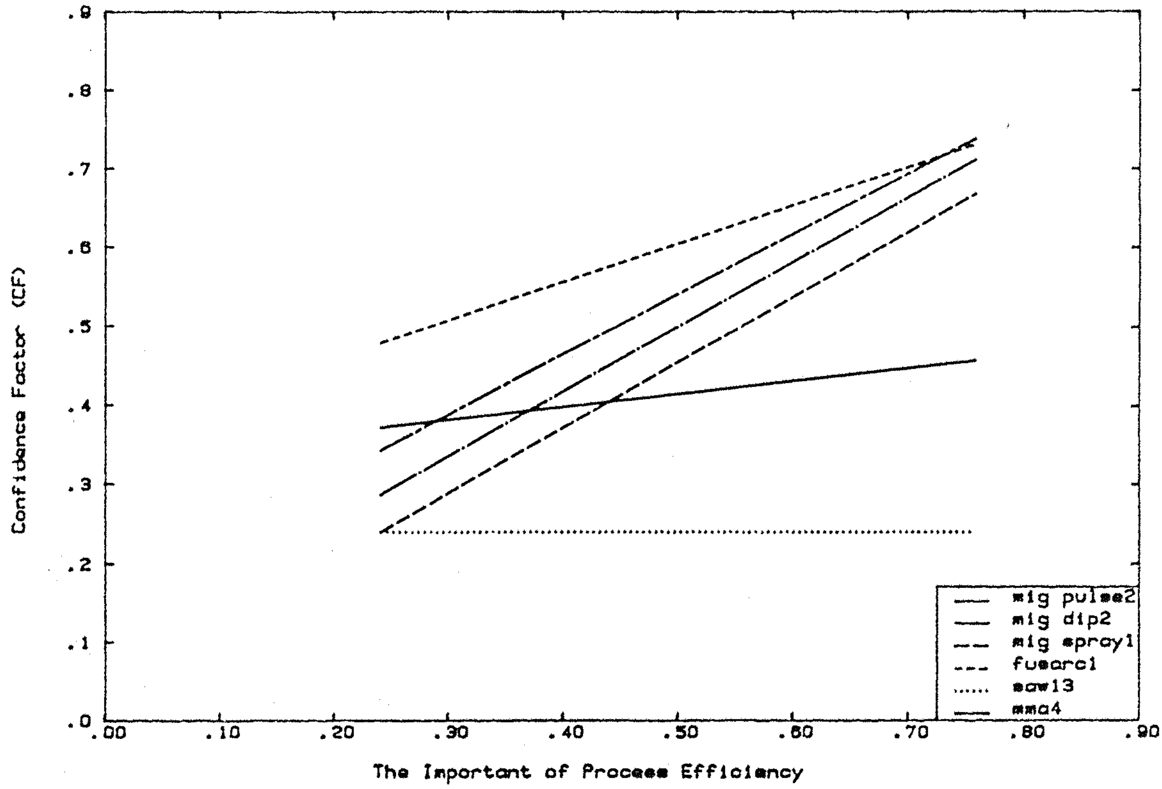


Figure E.11 Indoors Welding Processes, Speed 50% and Cost 25%

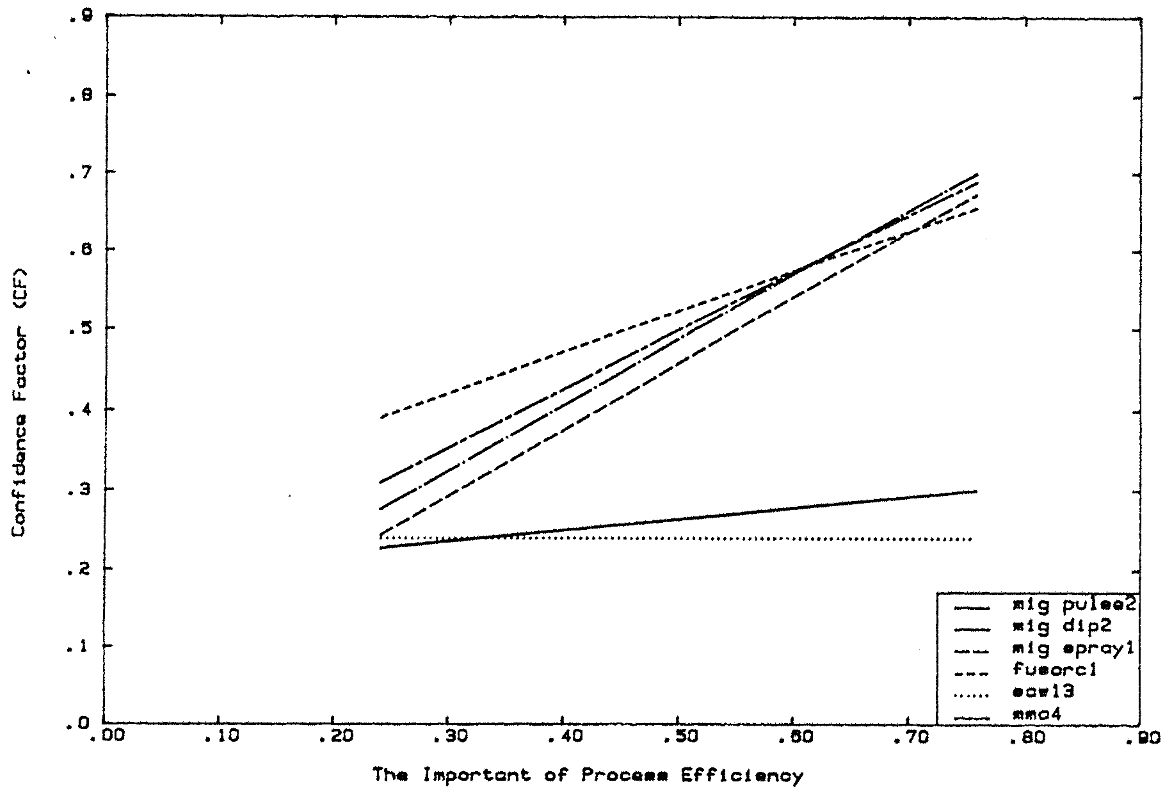


Figure E.12 Indoors Welding Processes, Speed 75% and Cost 25%

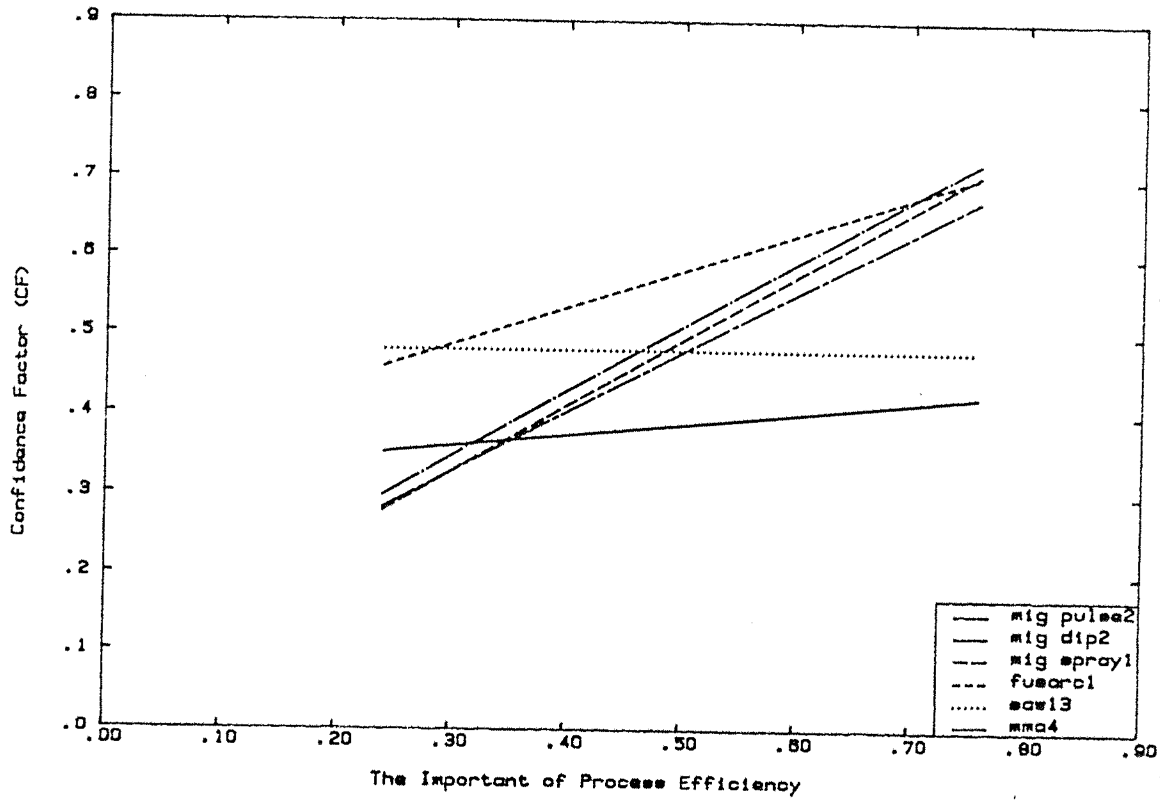


Figure E.13 Indoors Welding Processes, Speed 25% and Cost 50%

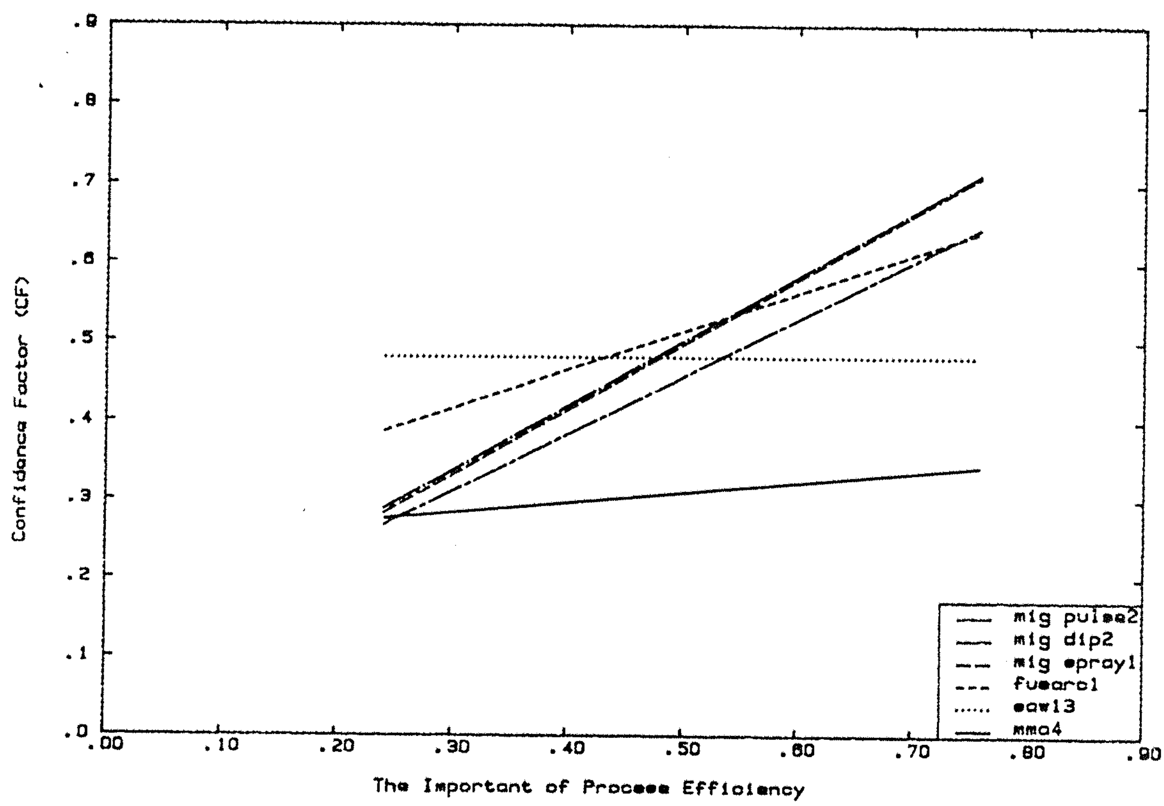


Figure E.14 Indoors Welding Processes, Speed 50% and Cost 50%

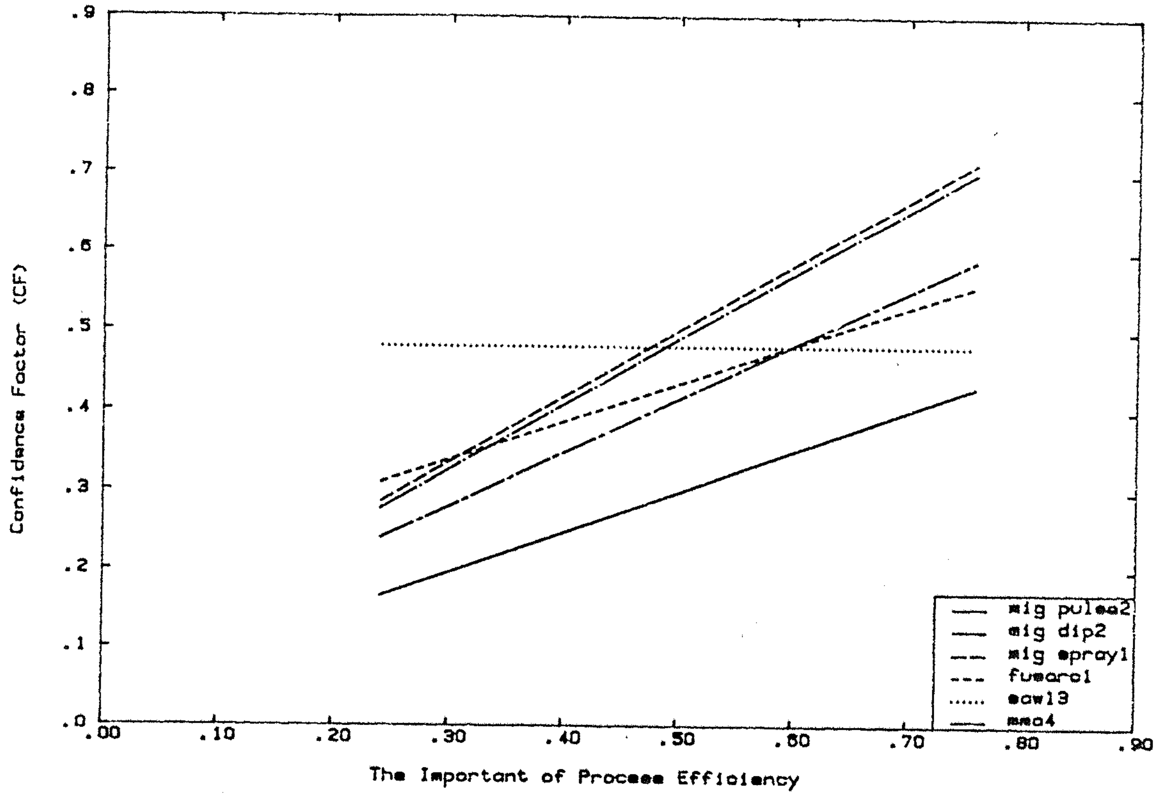


Figure E.15 Indoors Welding Processes, Speed 75% and Cost 50%

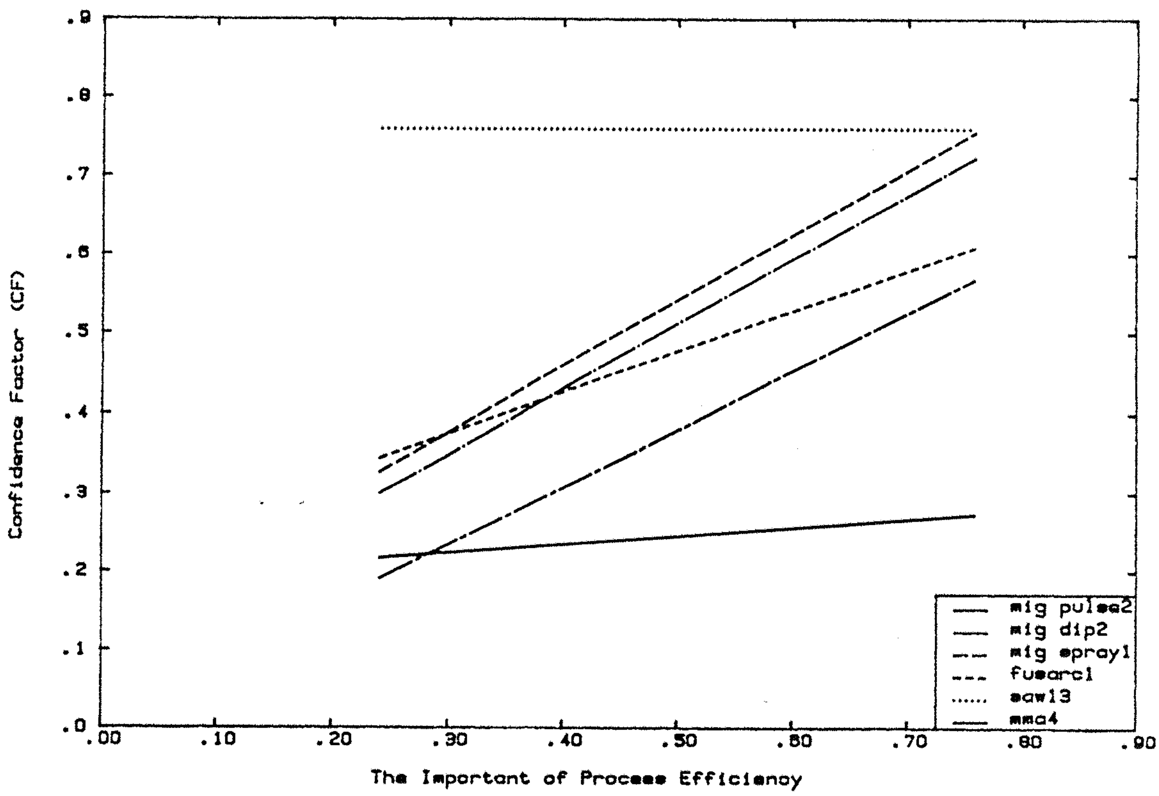


Figure E.16 Indoors Welding Processes, Speed 25% and Cost 75%

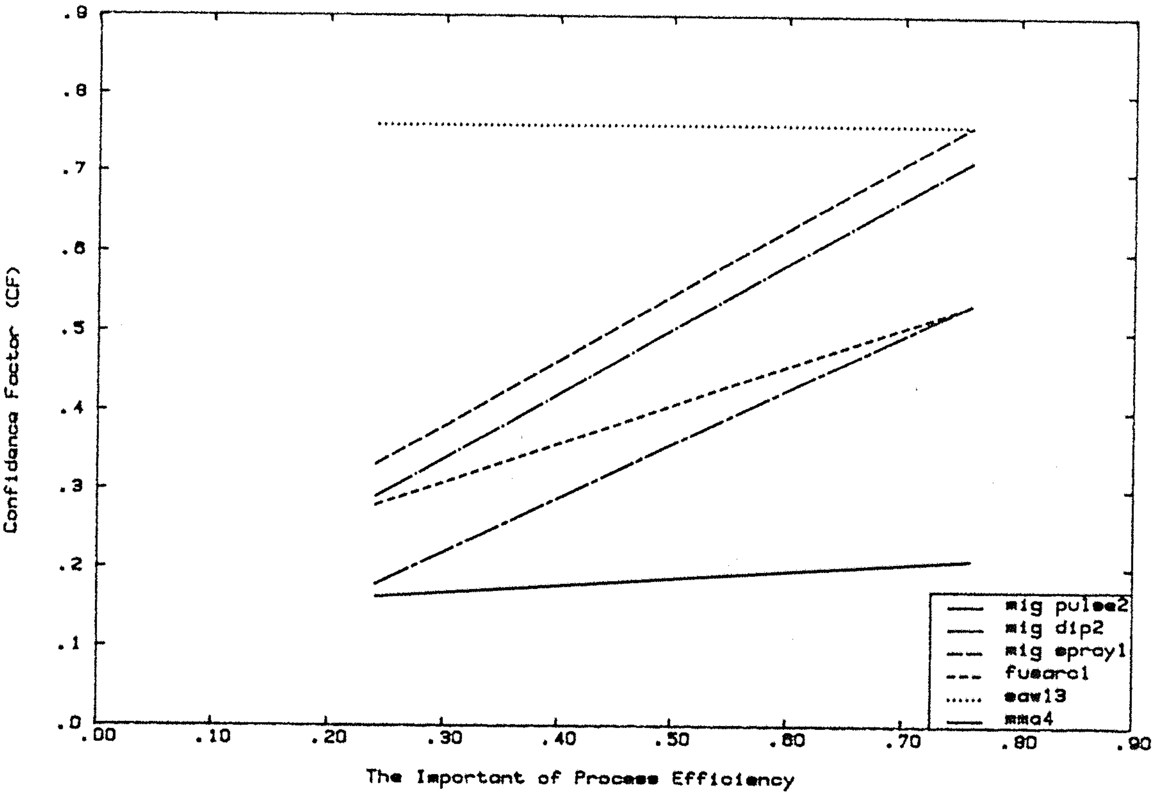


Figure E.17 Indoors Welding Processes, Speed 50% and Cost 75%

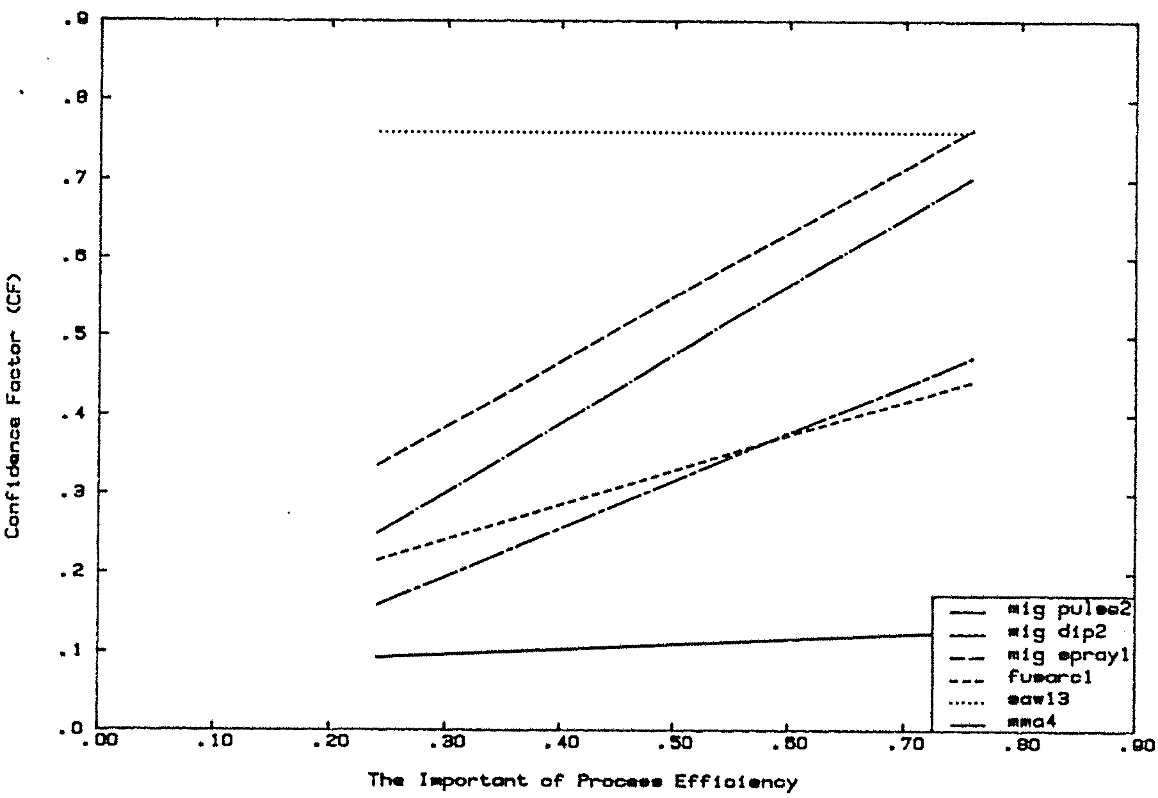


Figure E.18 Indoors Welding Processes, Speed 75% and Cost 75%

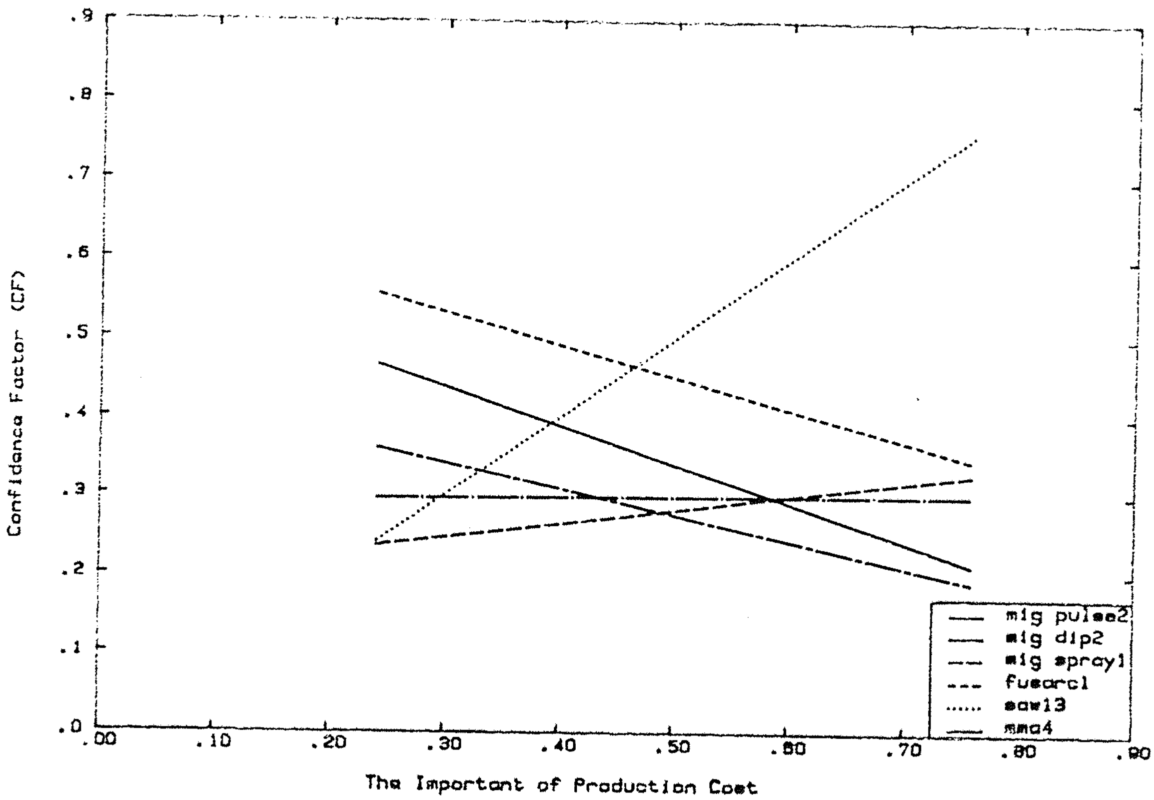


Figure E.19 Indoors Welding Processes, Speed 25% and Eff. 25%

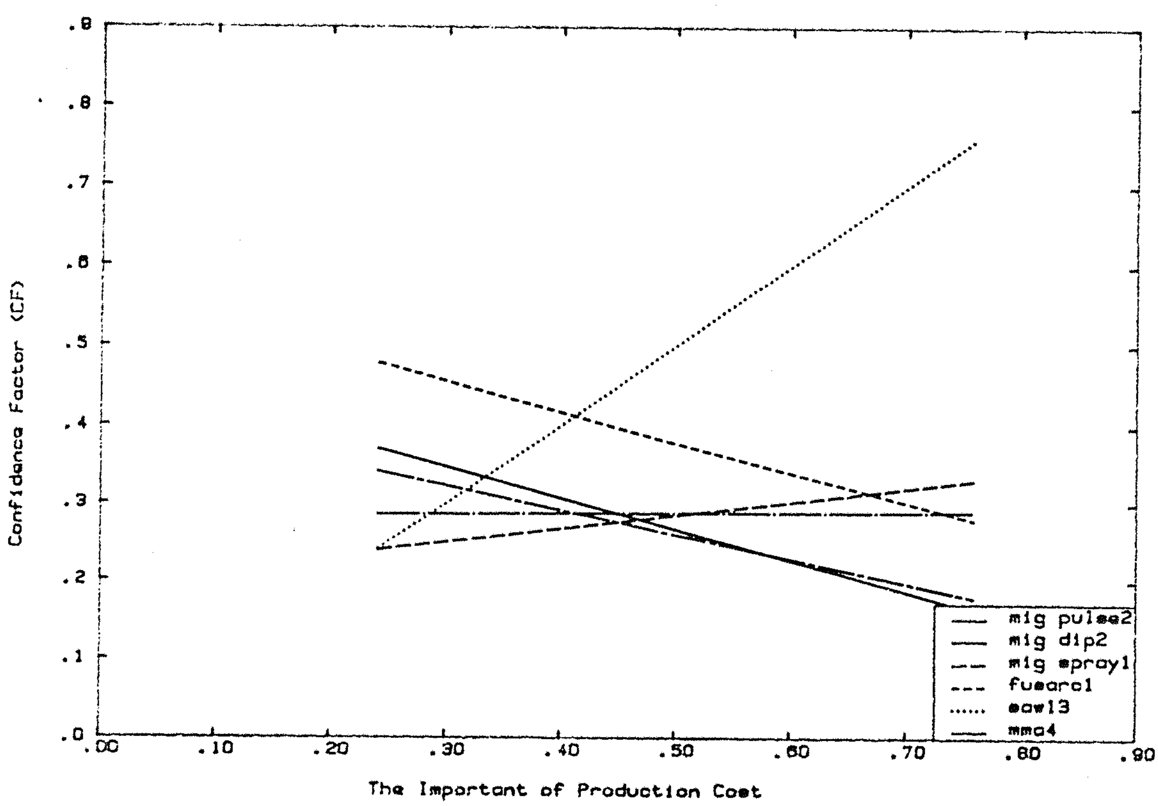


Figure E.20 Indoors Welding Processes, Speed 25% and Eff. 25%

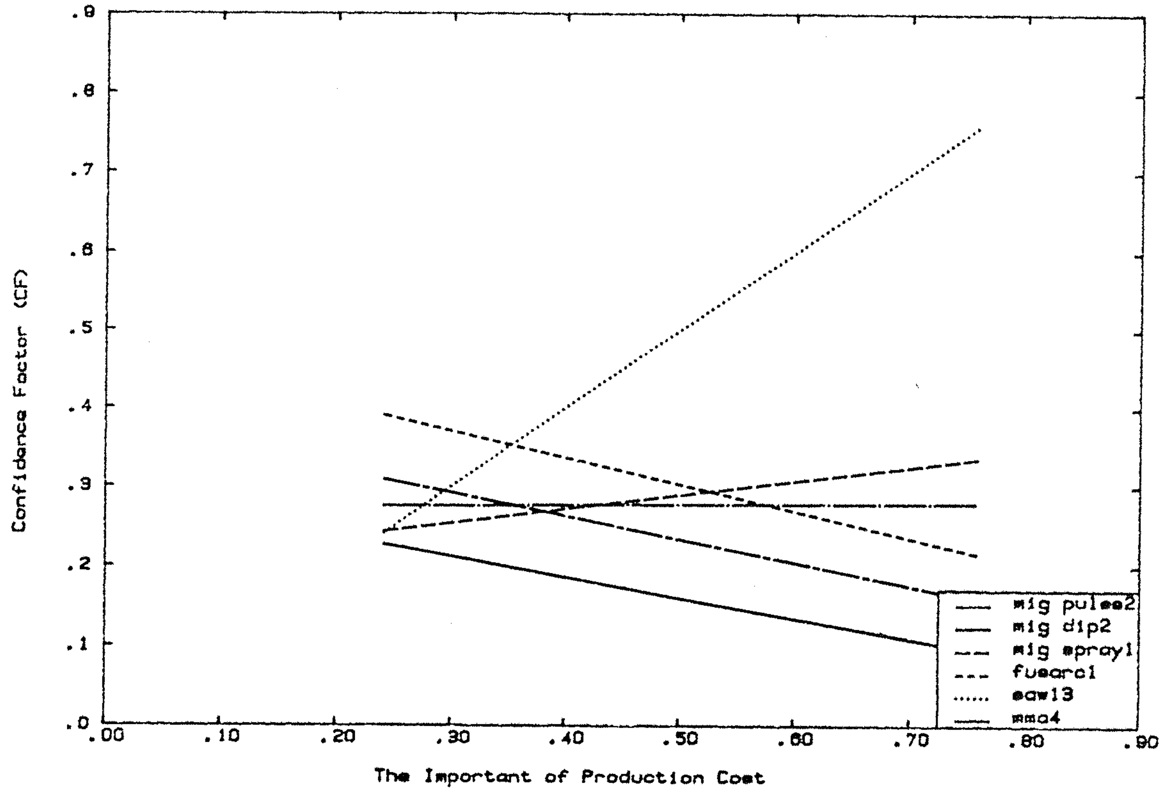


Figure E.21 Indoors Welding Processes, Speed 25% and Eff. 25%

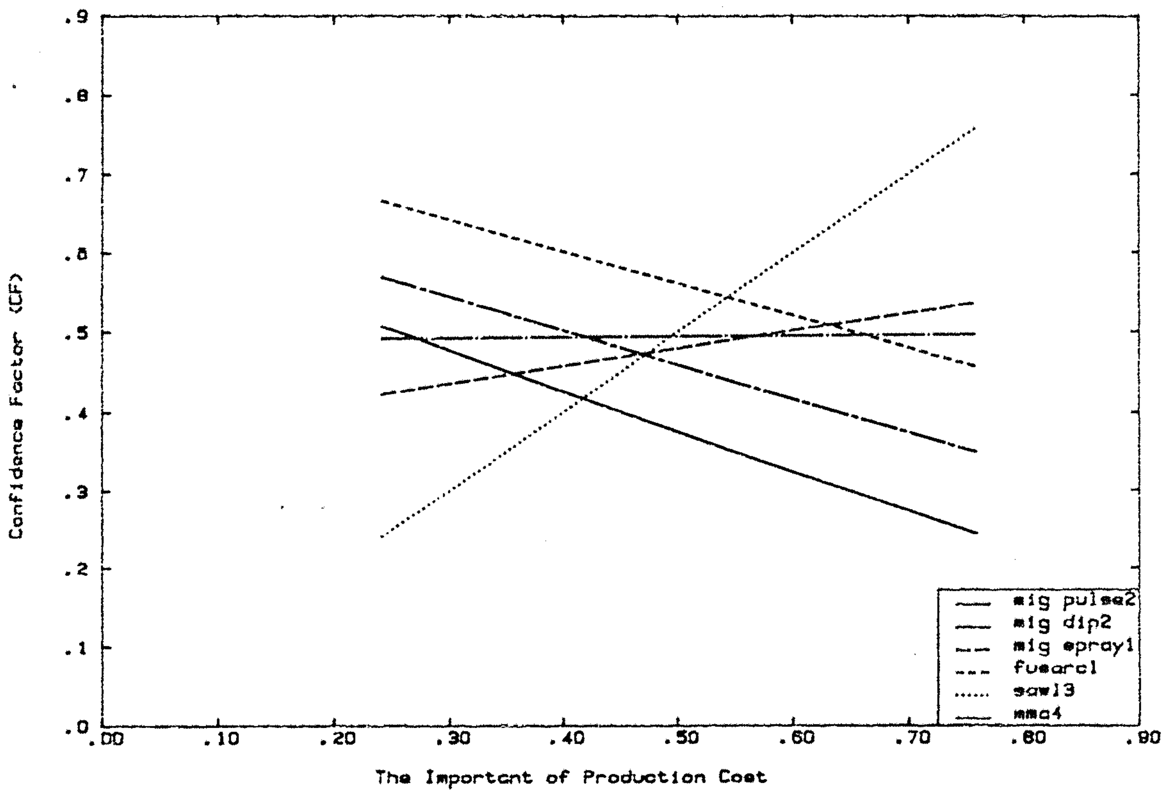


Figure E.22 Indoors Welding Processes, Speed 25% and Eff. 50%

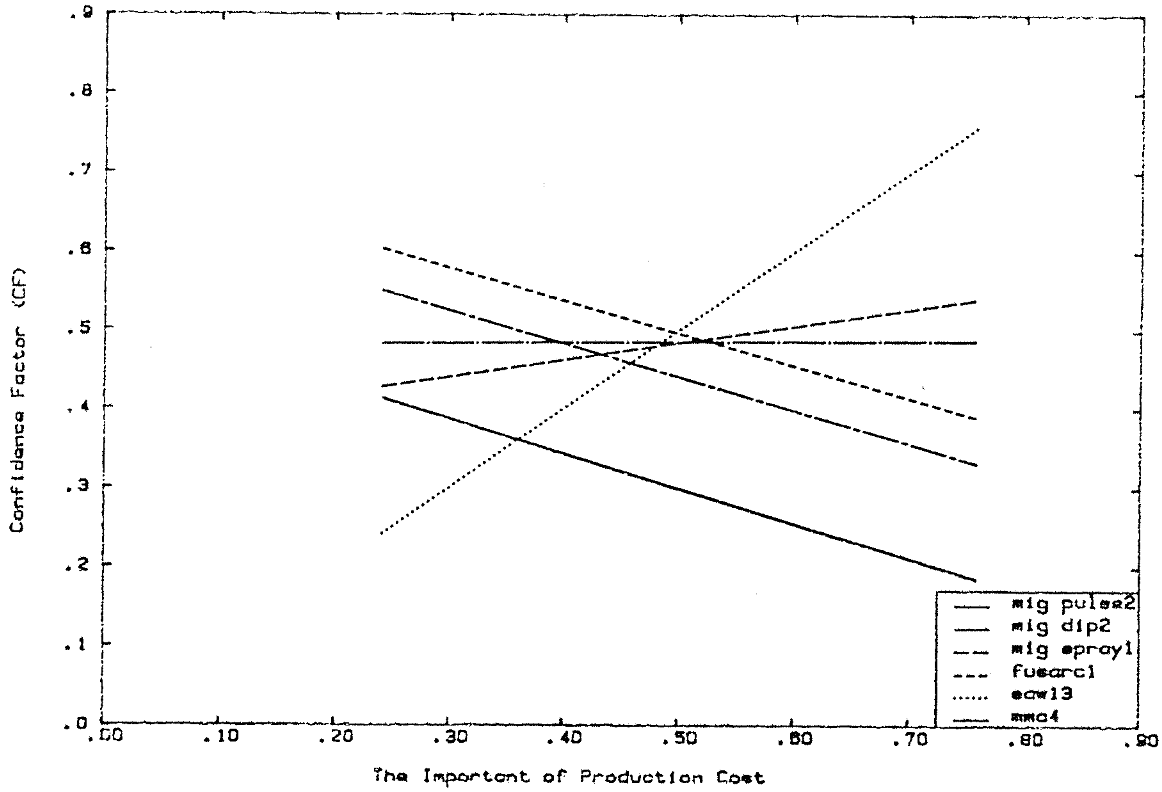


Figure E.23 Indoors Welding Processes, Speed 25% and Eff. 50%

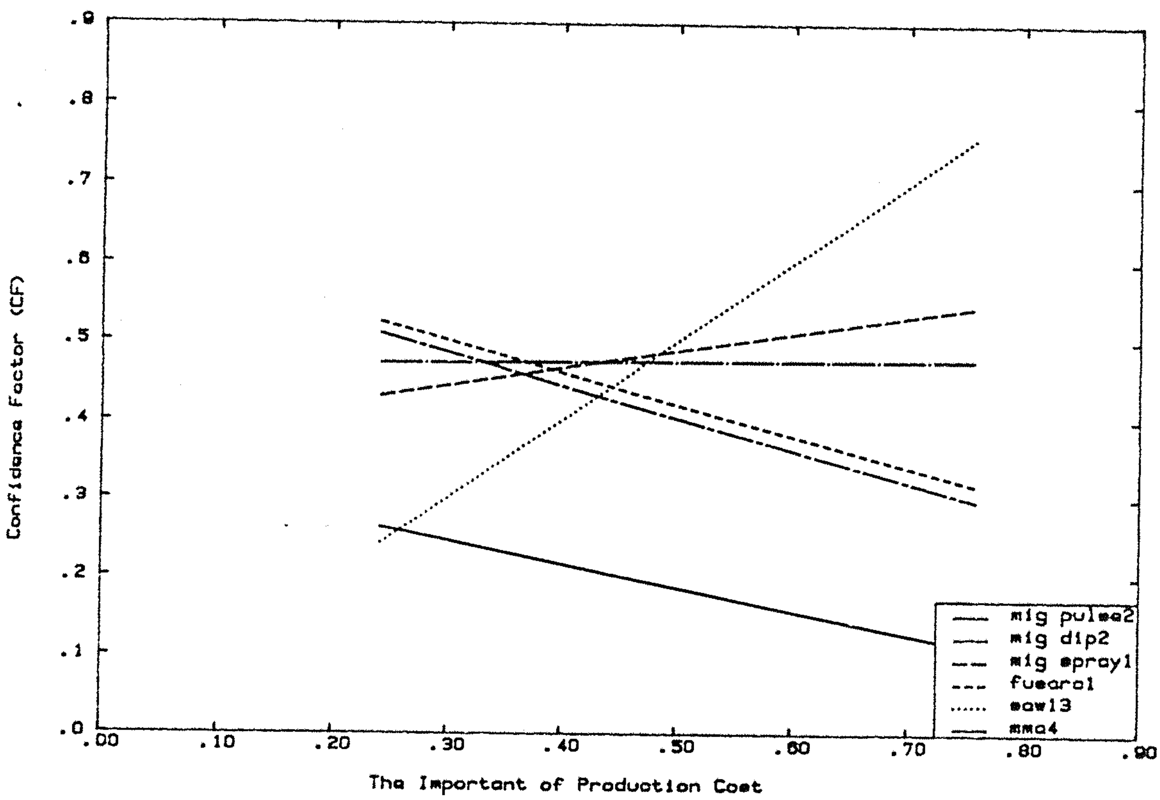


Figure E.24 Indoors Welding Processes, Speed 25% and Eff. 50%

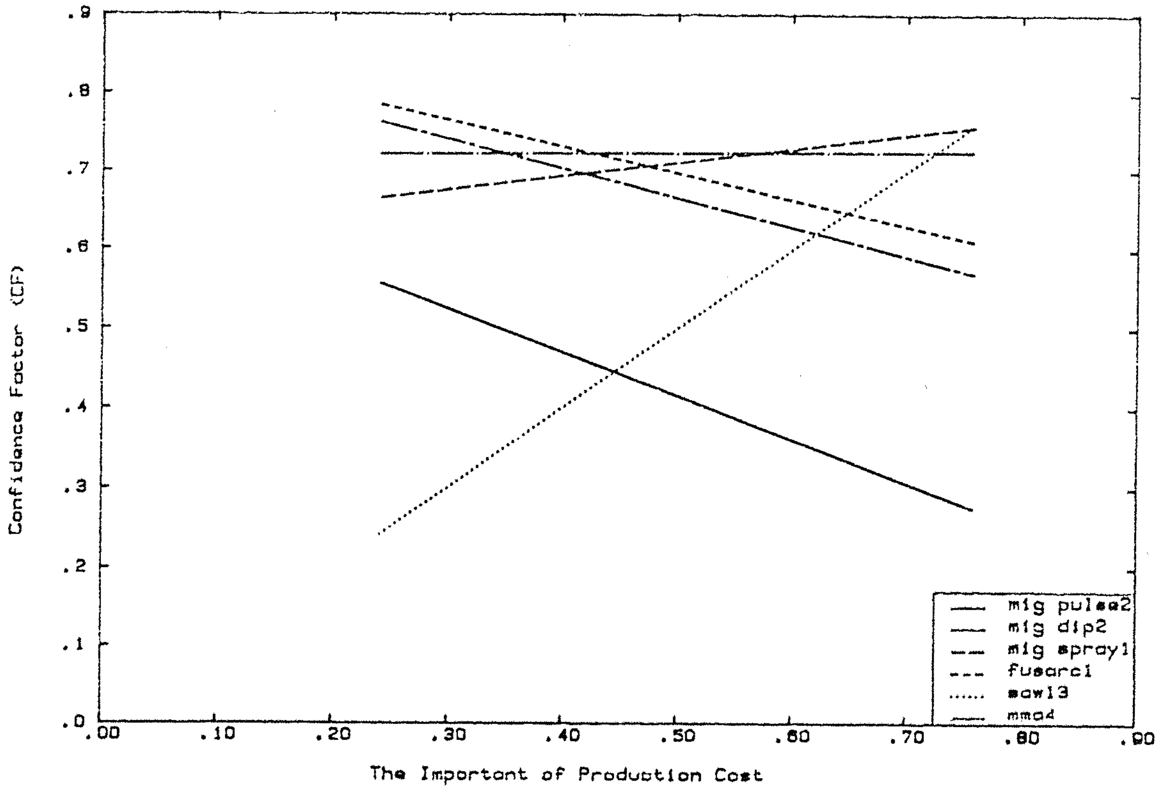


Figure E.25 Indoors Welding Processes, Speed 25% and Eff. 75%

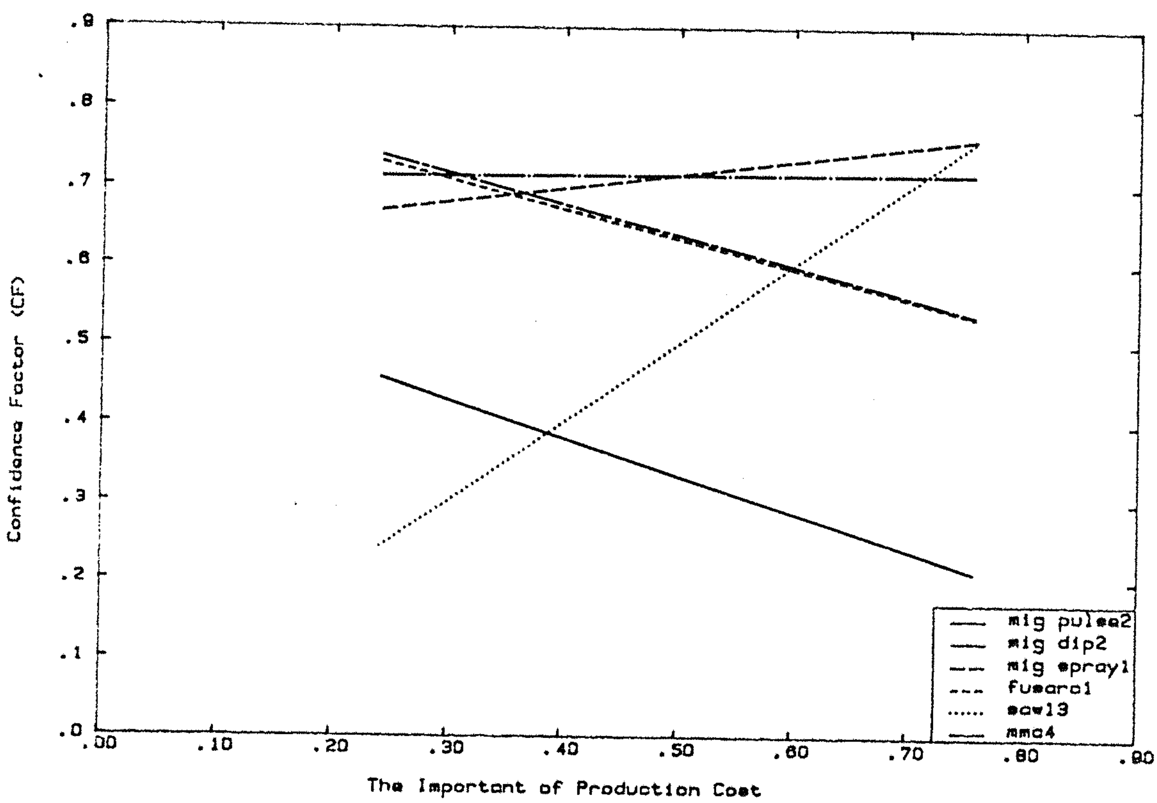


Figure E.26 Indoors Welding Processes, Speed 25% and Eff. 75%

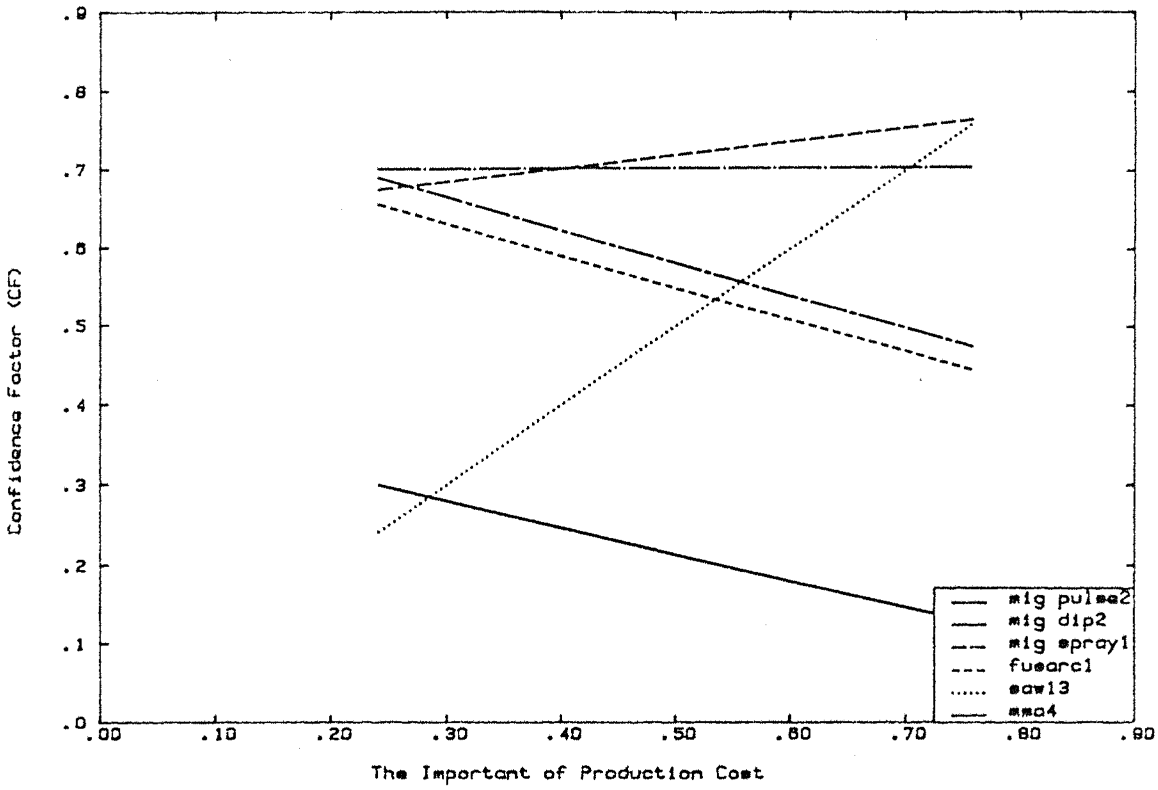


Figure E.27 Indoors Welding Processes, Speed 25% and Eff. 75%

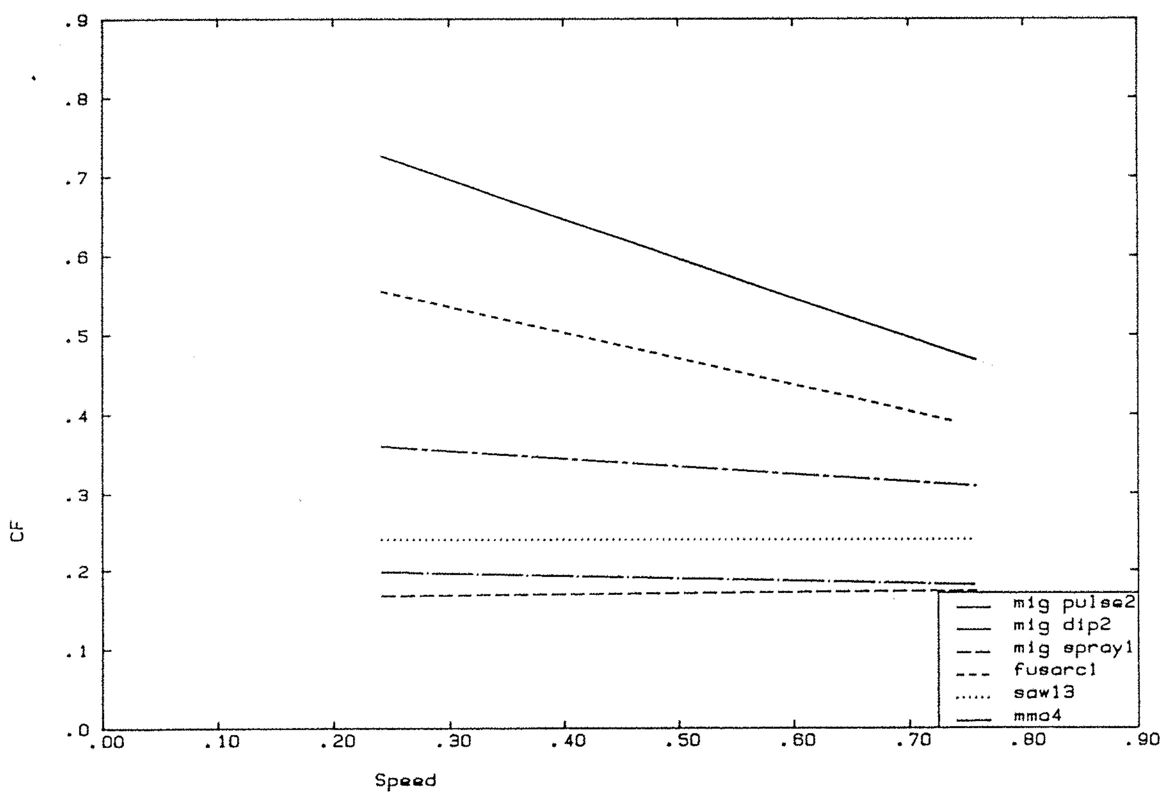


Figure E.28 Outdoors Welding Processes, Eff. 25% and Cost 25%

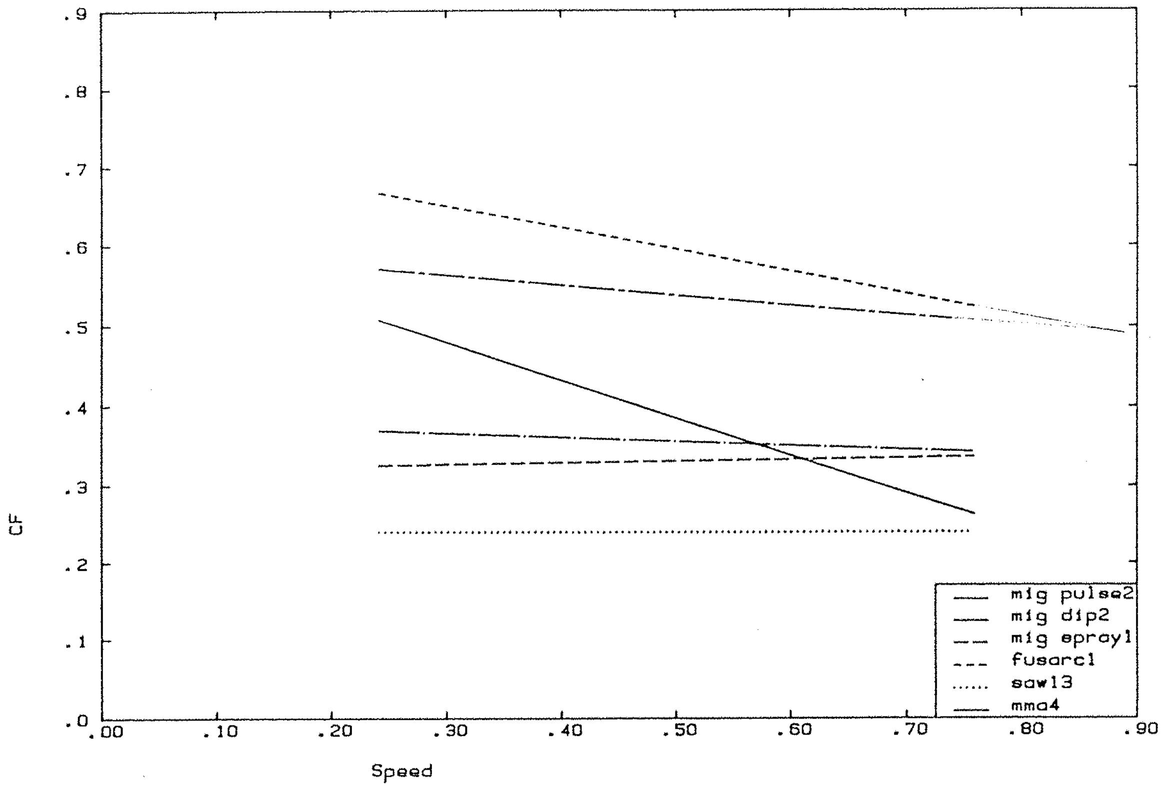


Figure E.29 Outdoors Welding Processes, Eff. 50% and Cost 25%

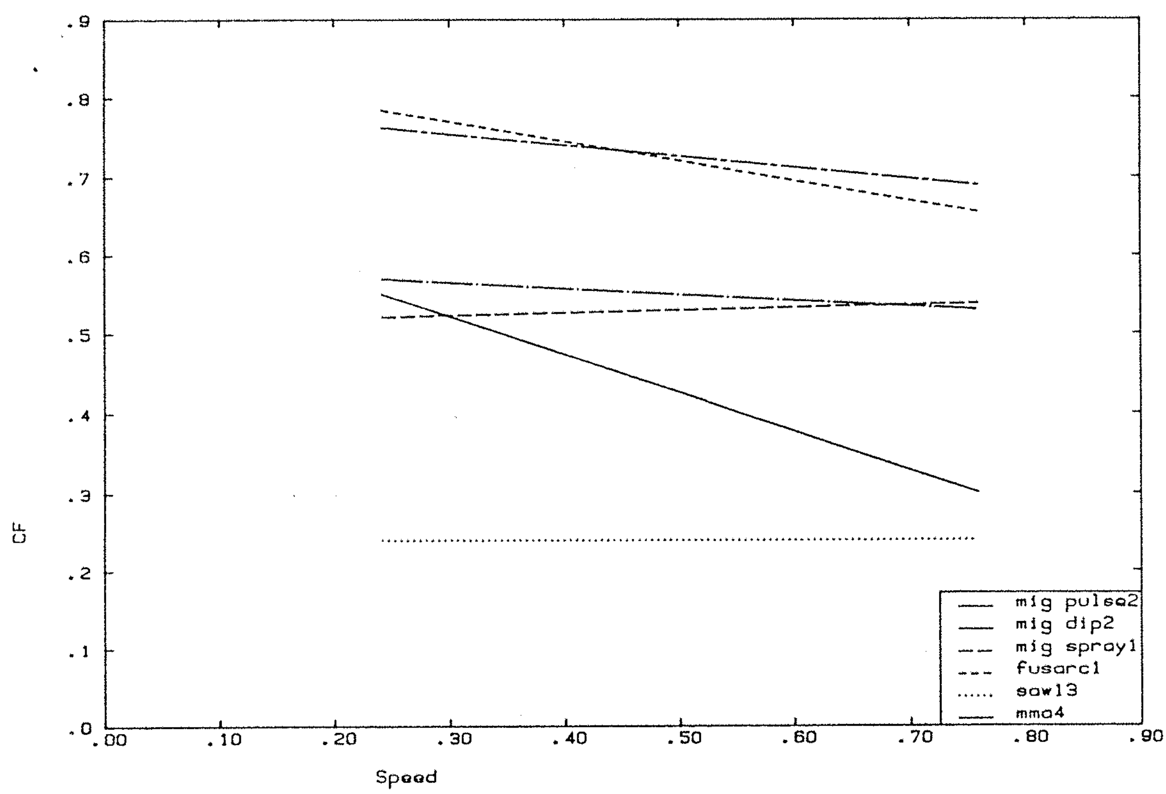


Figure E.30 Outdoors Welding Processes, Eff. 75% and Cost 25%

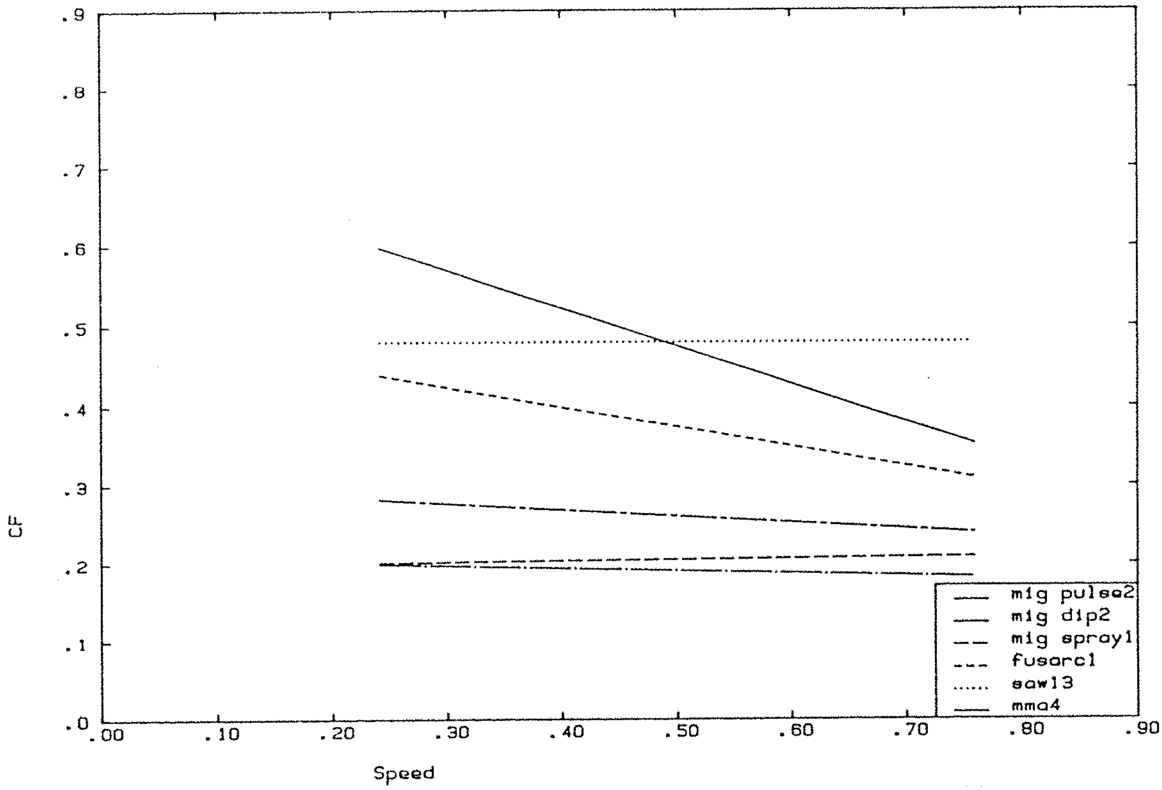


Figure E.31 Outdoors Welding Processes, Eff. 25% and Cost 50%

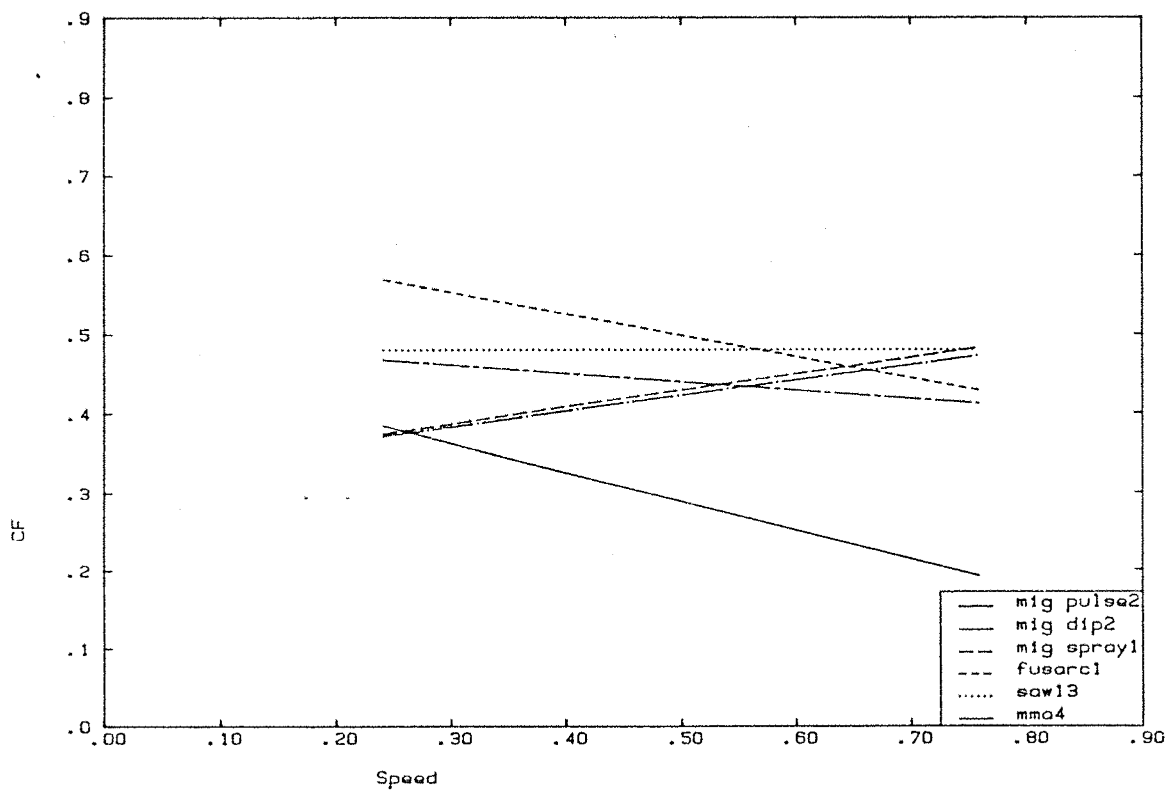


Figure E.32 Outdoors Welding Processes, Eff. 50% and Cost 50%

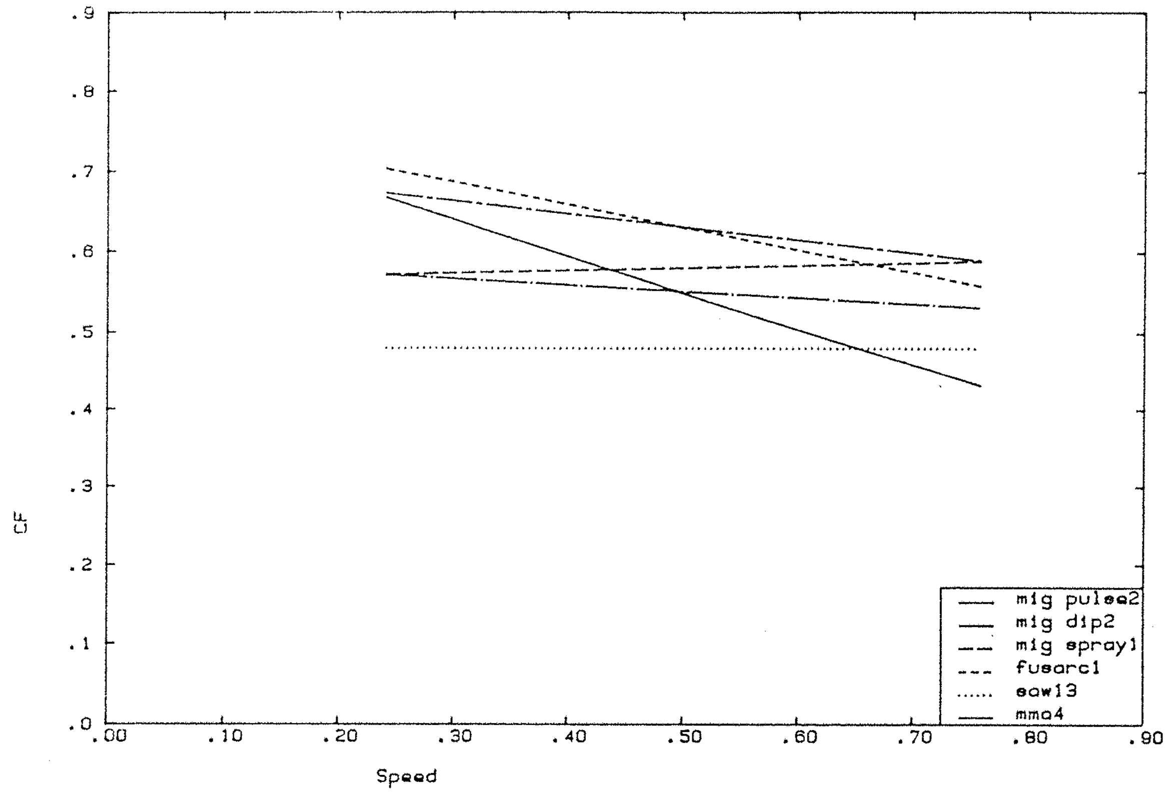


Figure E.33 Outdoors Welding Processes, Eff. 75% and Cost 50%

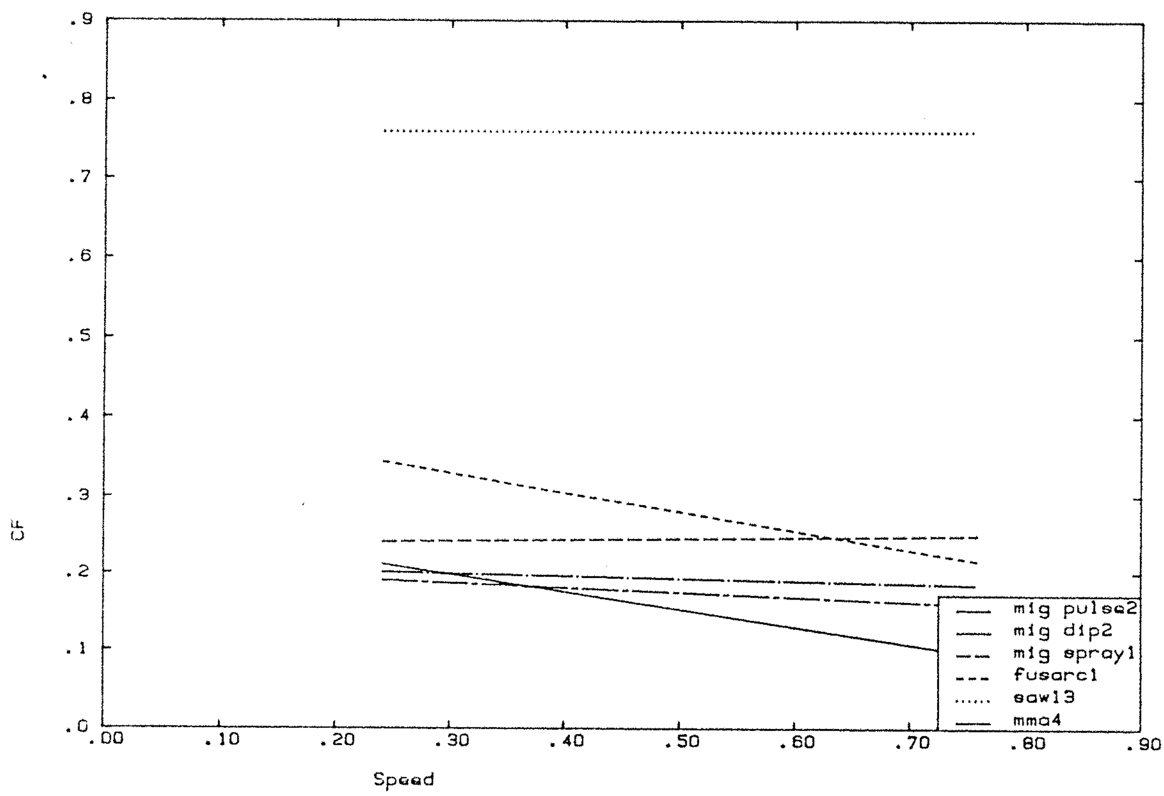


Figure E.34 Outdoors Welding Processes, Eff. 25% and Cost 75%

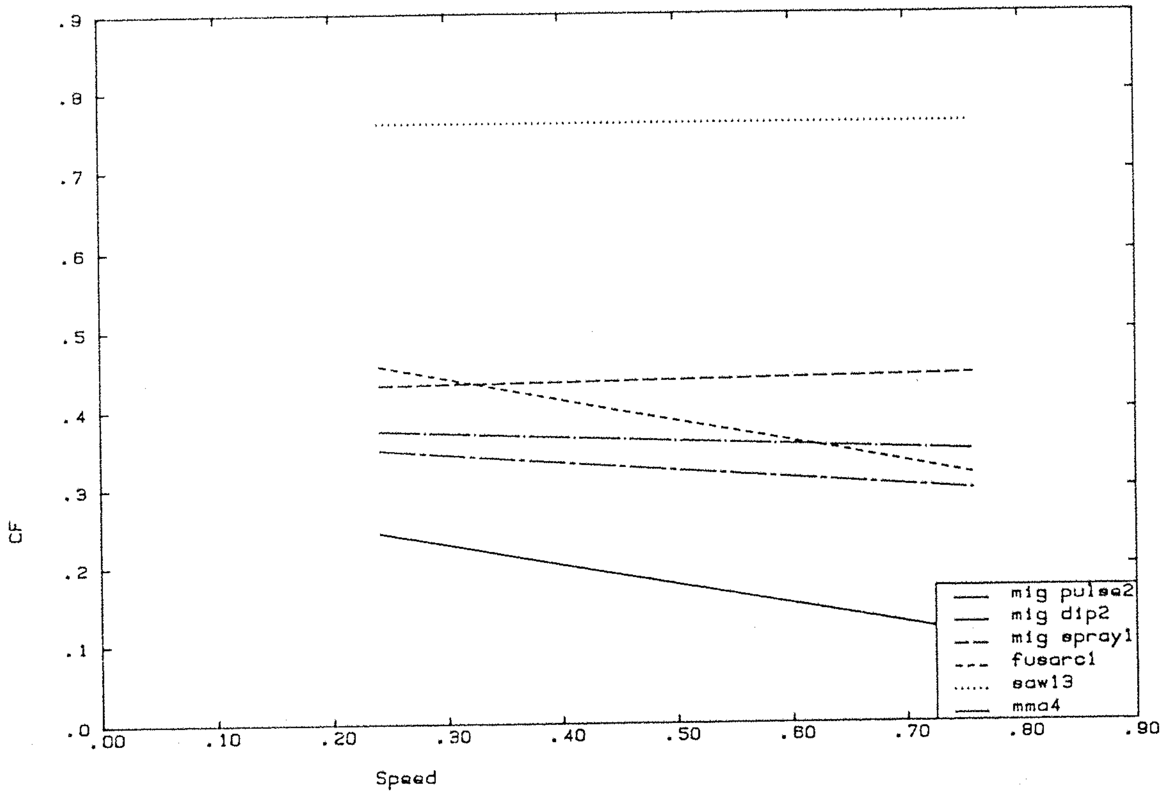


Figure E.35 Outdoors Welding Processes, Eff. 50% and Cost 75%

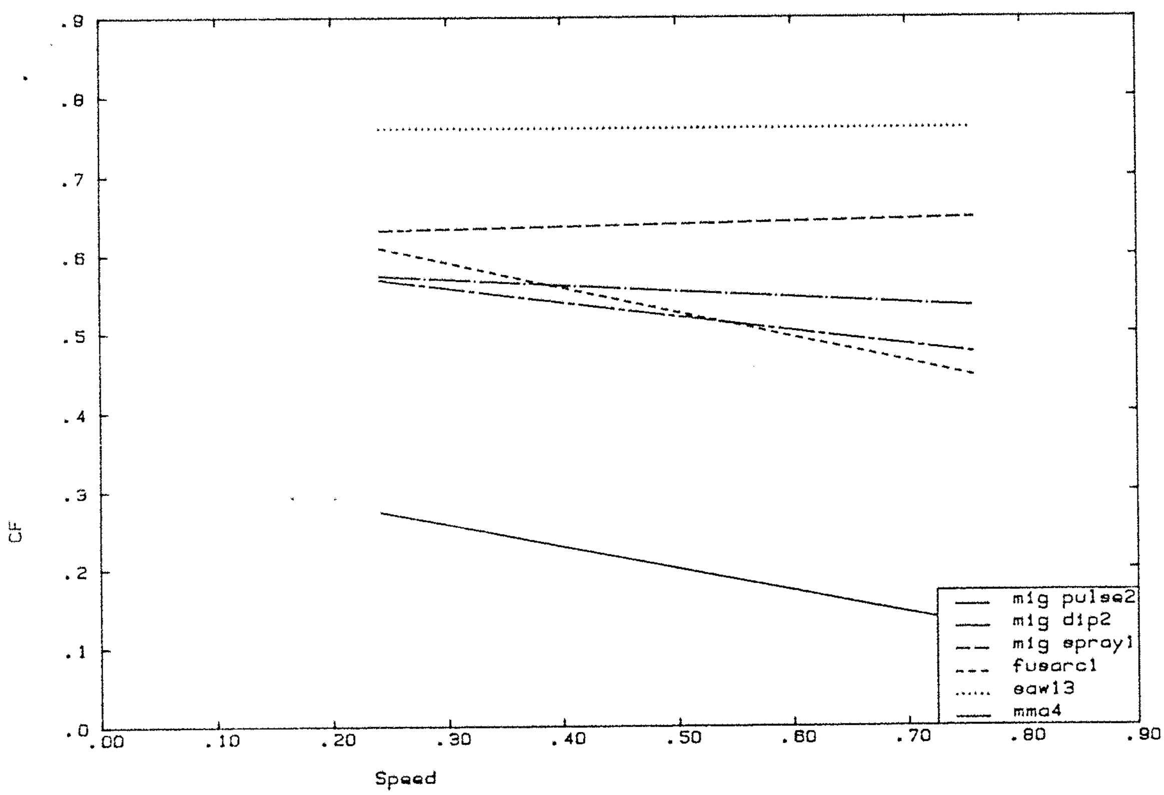


Figure E.36 Outdoors Welding Processes, Eff. 75% and Cost 75%

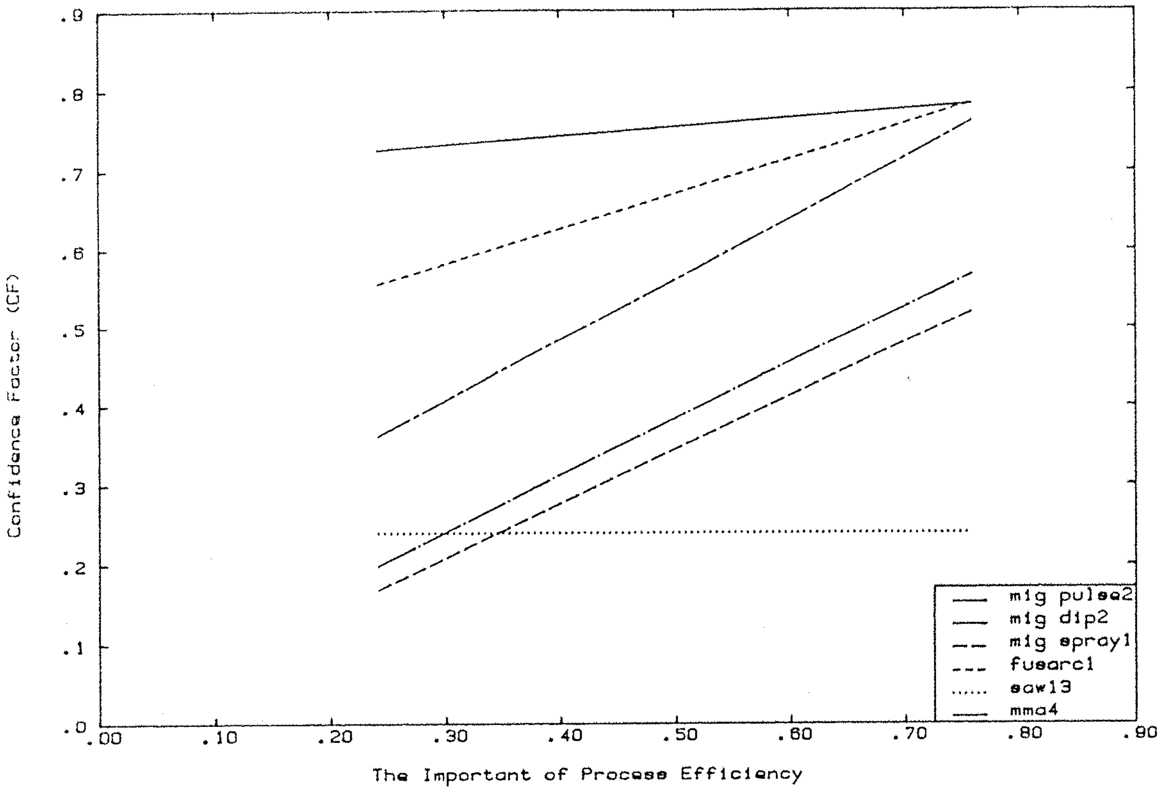


Figure E.37 Outdoors Welding Processes, Speed 25% and Cost 25%

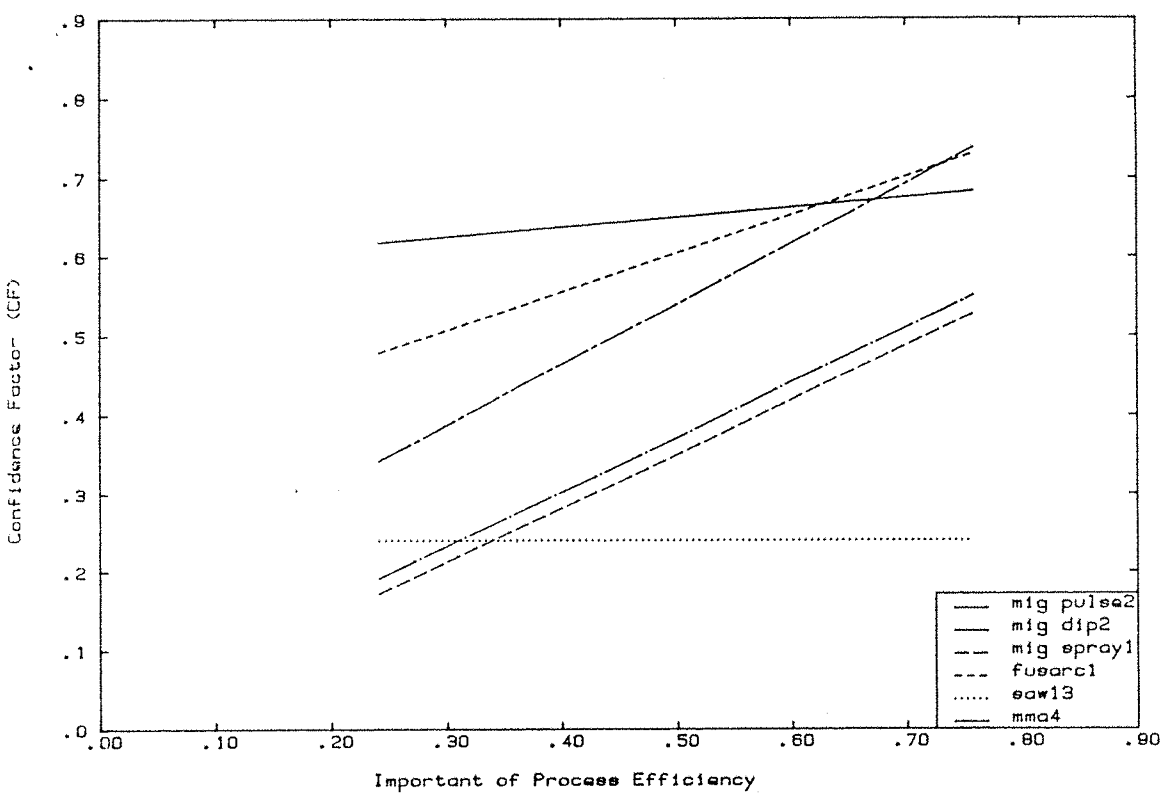


Figure E.38 Outdoors Welding Processes, Speed 50% and Cost 25%

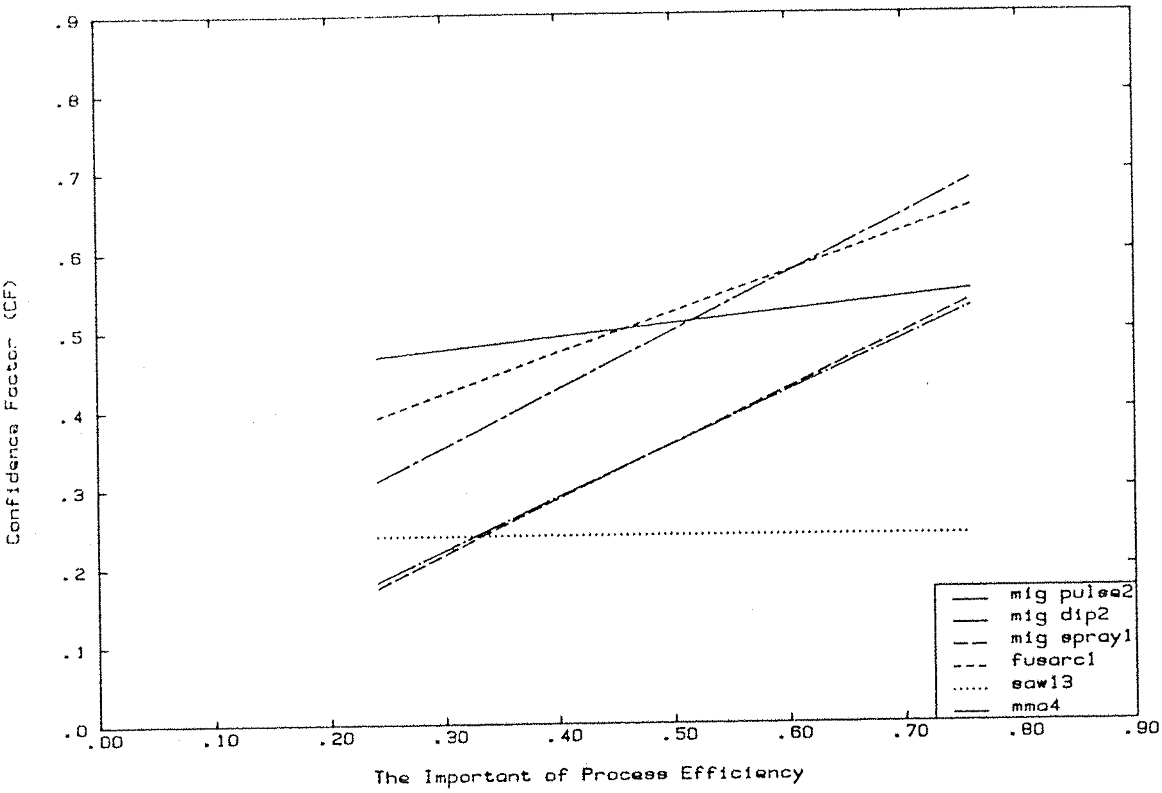


Figure E.39 Outdoors Welding Processes, Speed 75% and Cost 25%

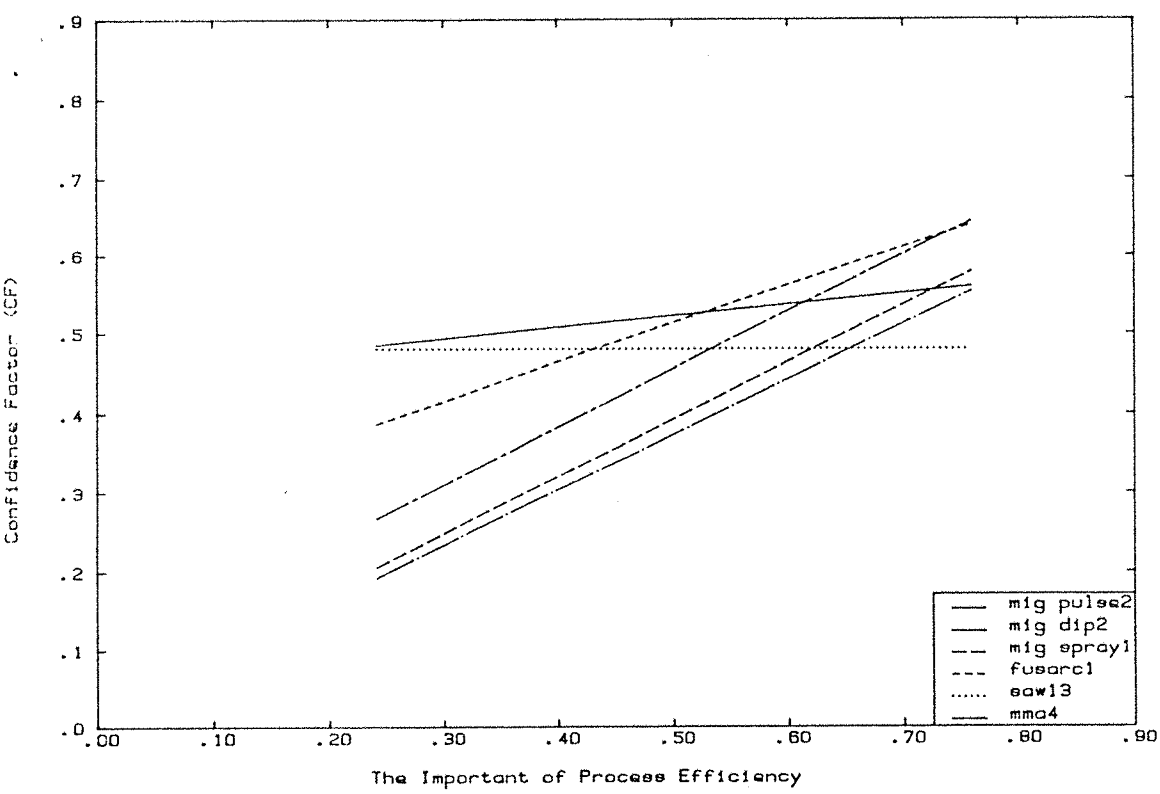


Figure E.40 Outdoors Welding Processes, Speed 25% and Cost 50%

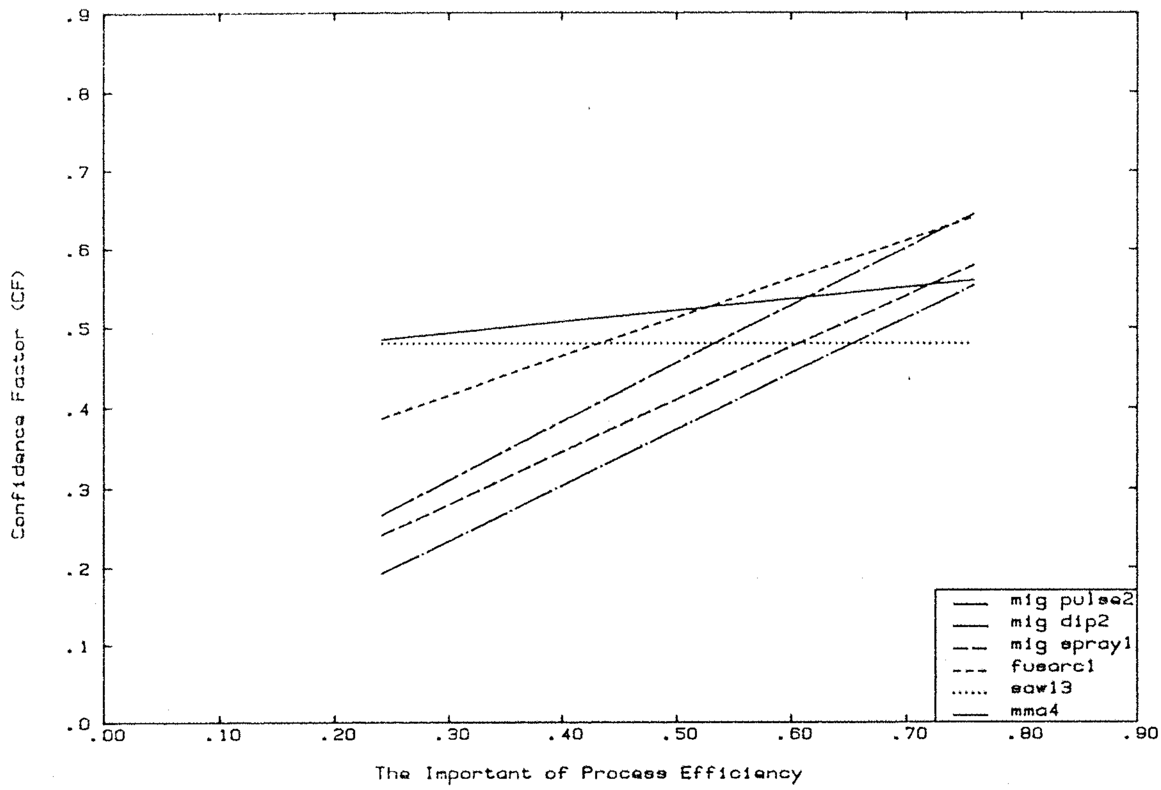


Figure E.41 Outdoors Welding Processes, Speed 50% and Cost 50%

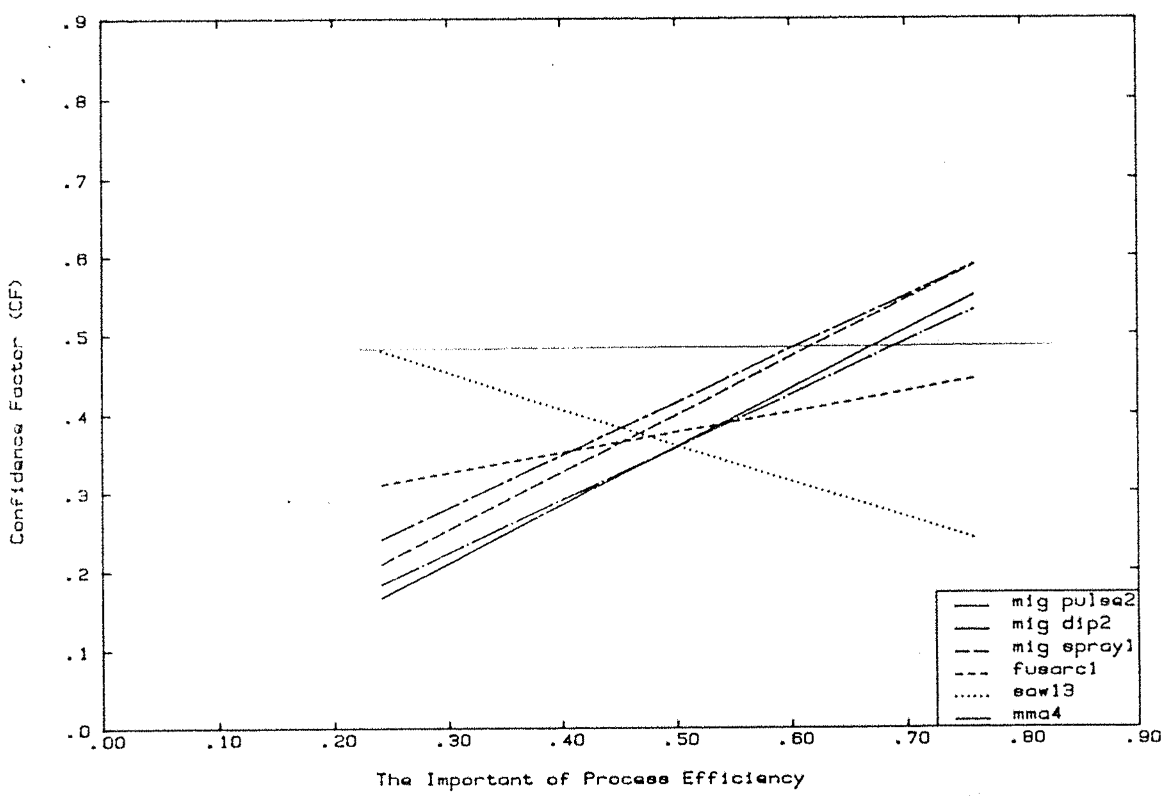


Figure E.42 Outdoors Welding Processes, Speed 75% and Cost 50%

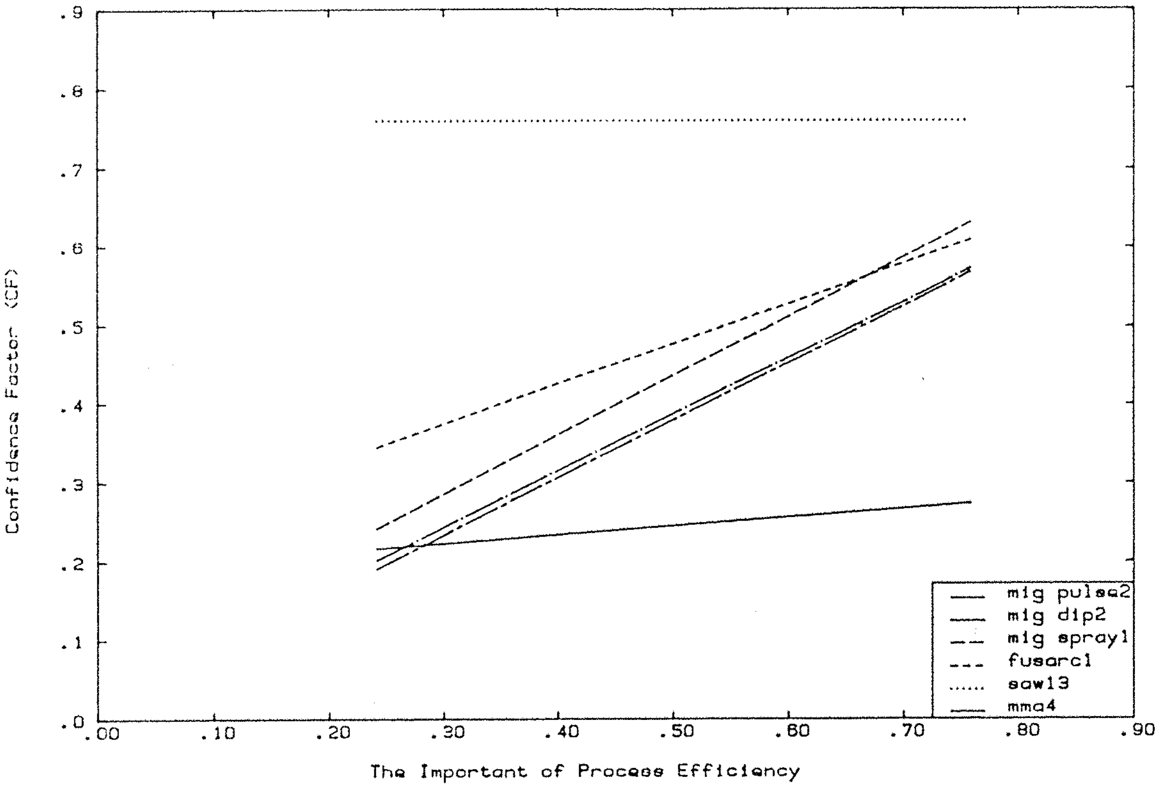


Figure E.43 Outdoors Welding Processes, Speed 25% and Cost 75%

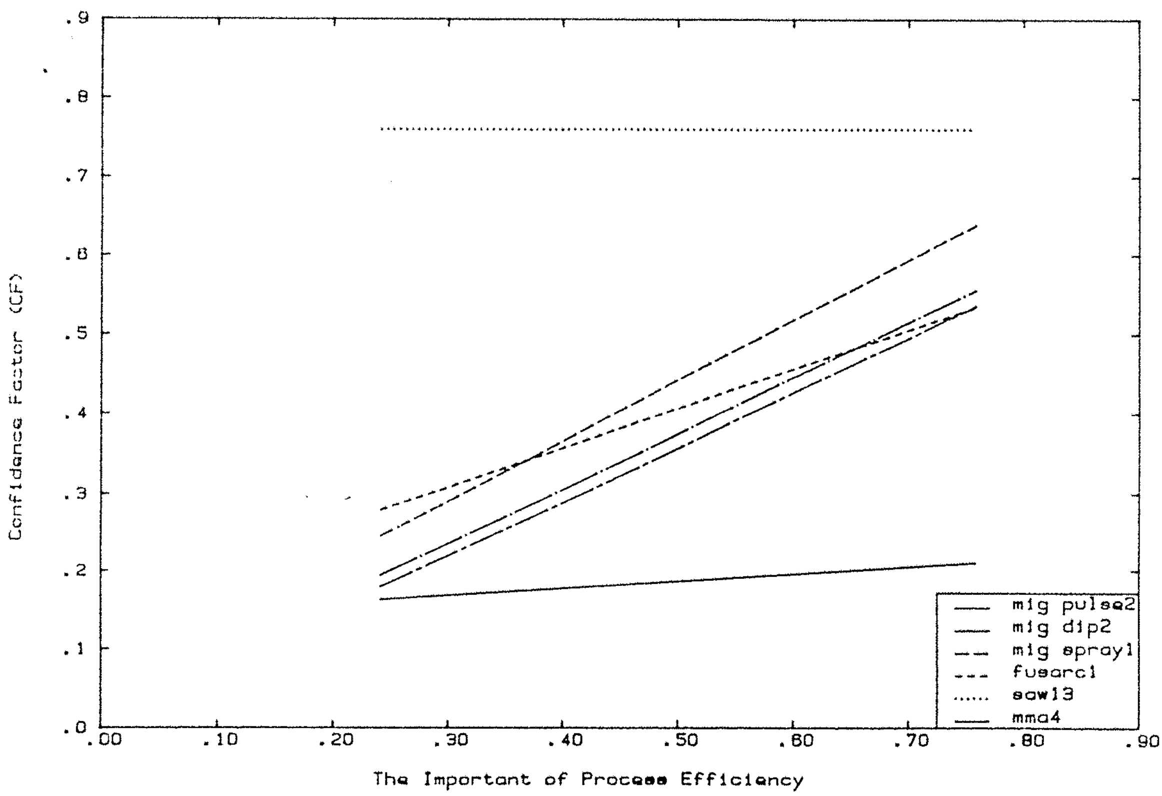


Figure E.44 Outdoors Welding Processes, Speed 50% and Cost 75%

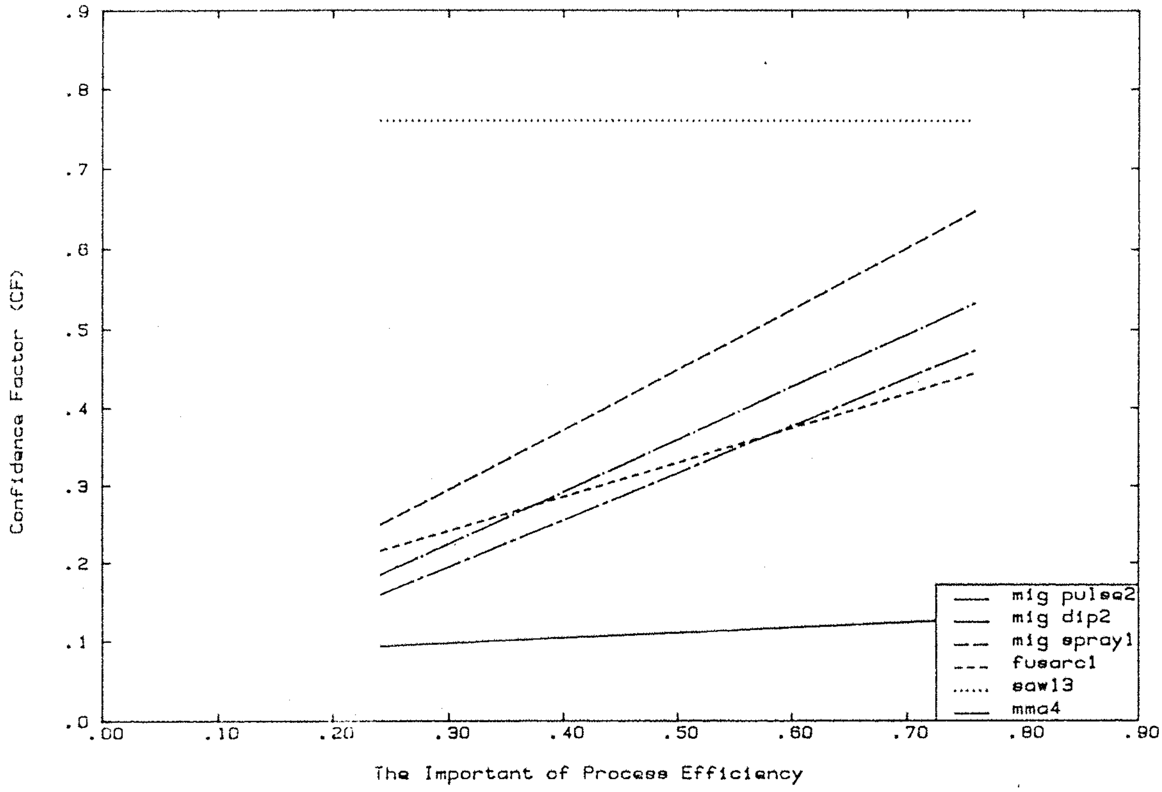


Figure E.45 Outdoors Welding Processes, Speed 75% and Cost 75%

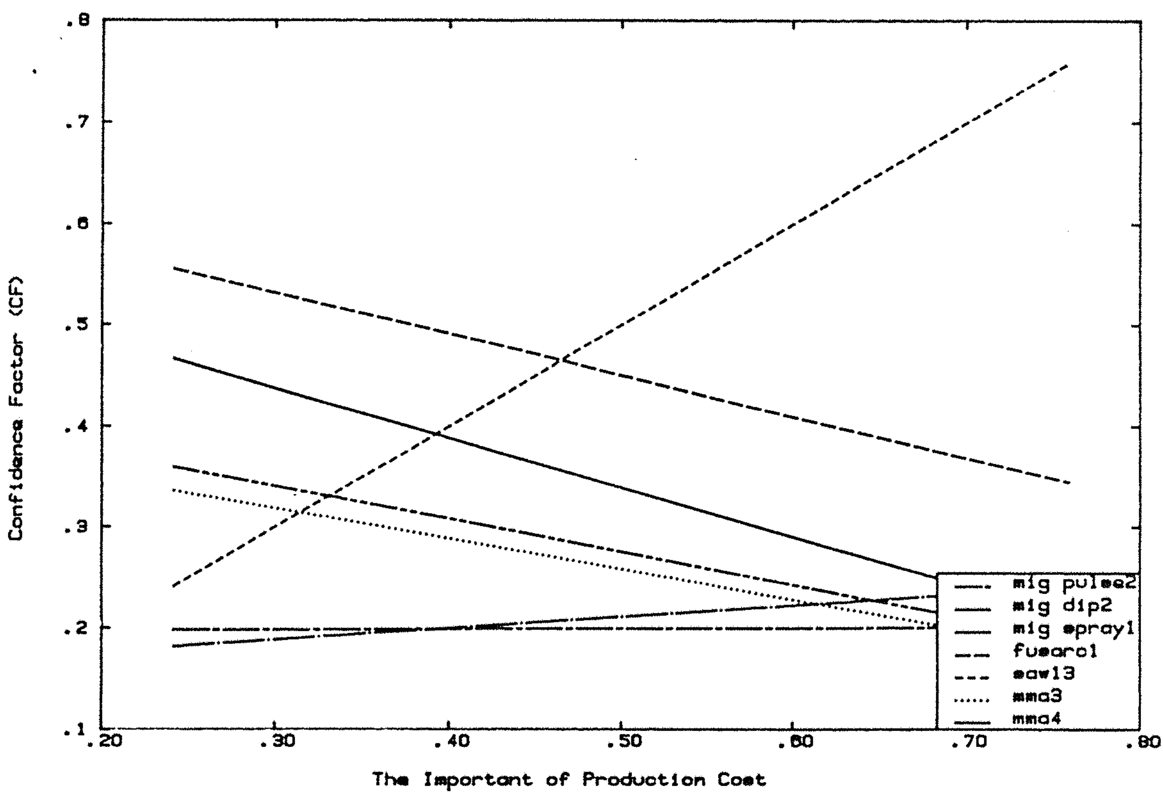


Figure E.46 Outdoors Welding Processes, Speed 25% and Eff. 25%

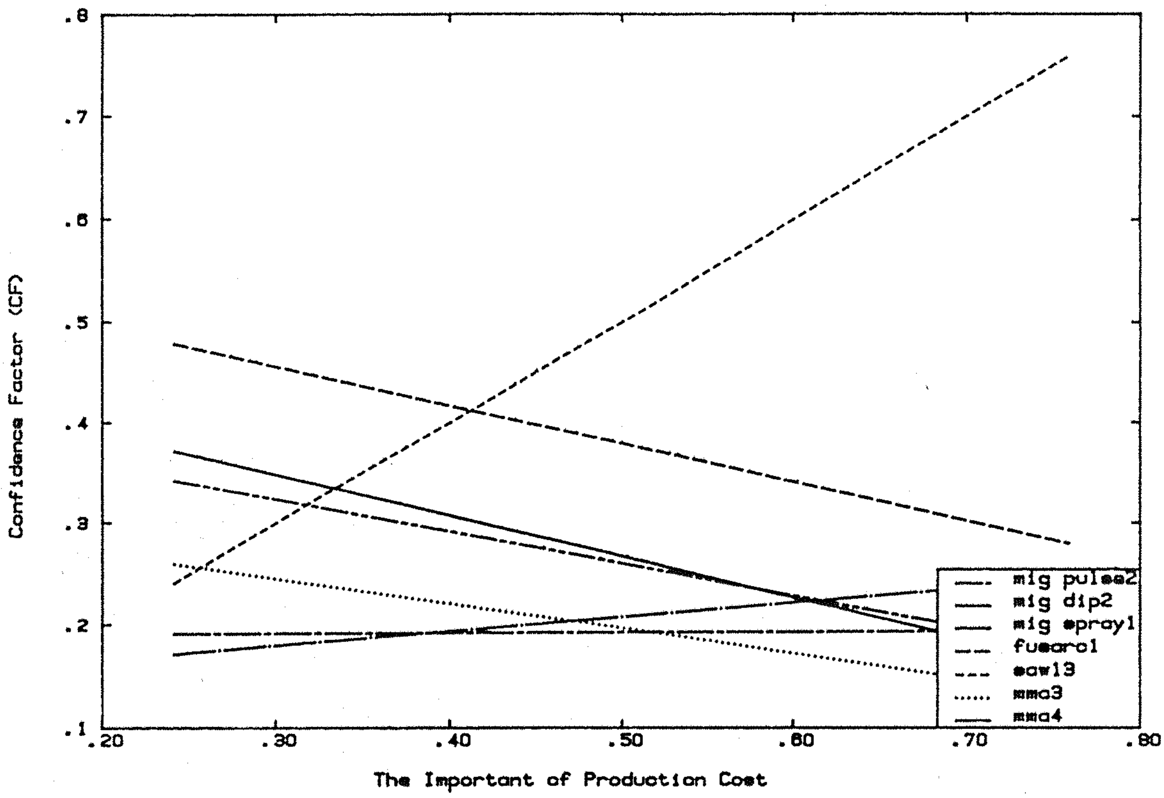


Figure E.47 Outdoors Welding Processes, Speed 50% and Eff. 25%

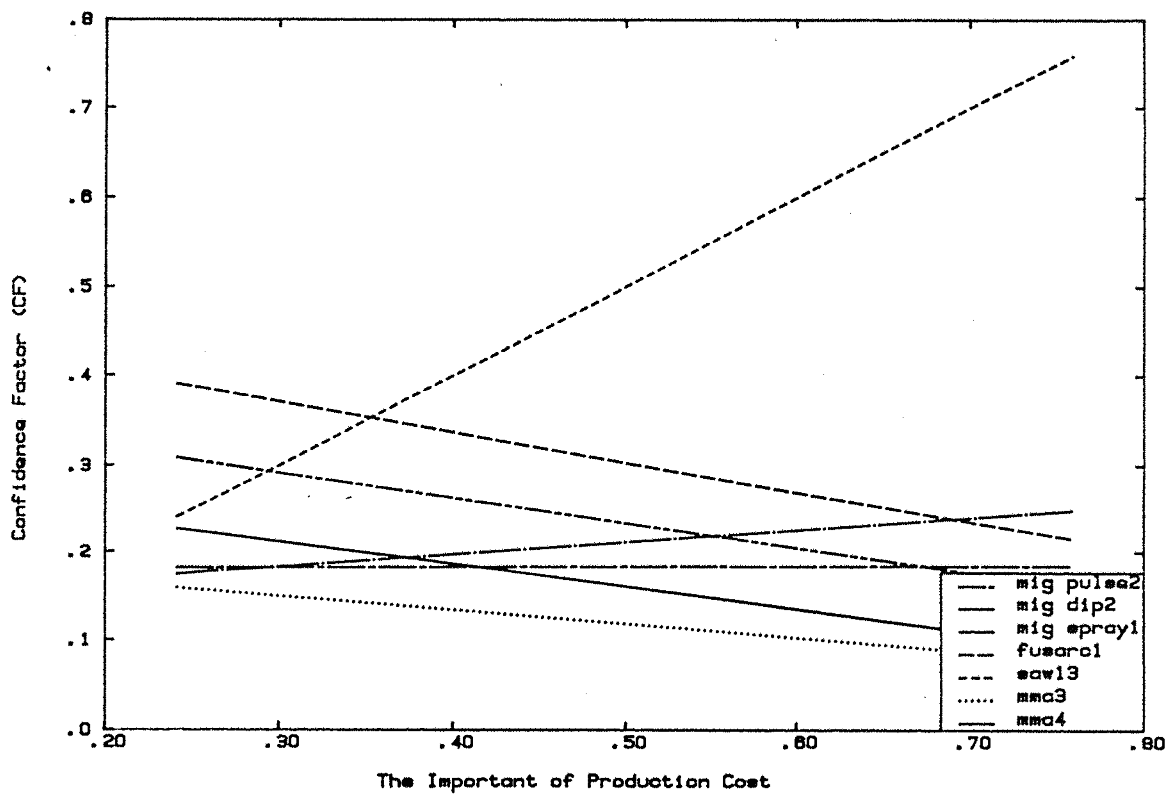


Figure E.48 Outdoors Welding Processes, Speed 75% and Eff. 25%

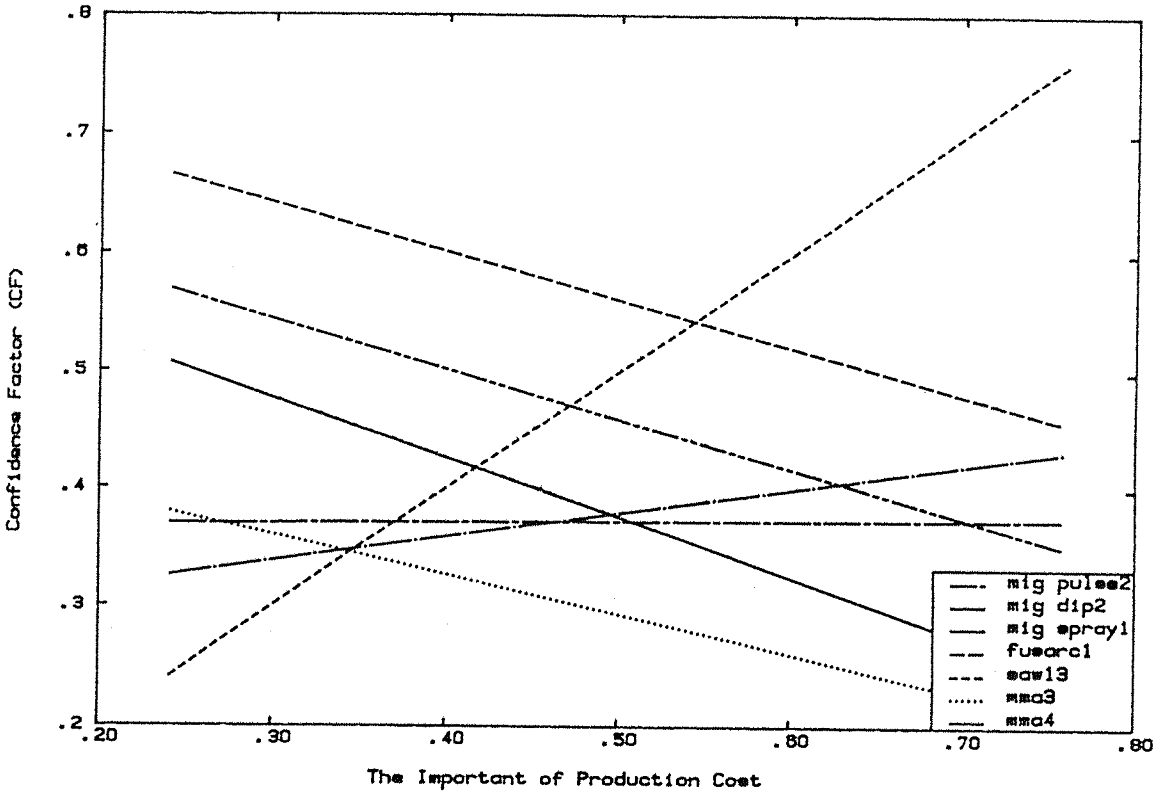


Figure E.49 Outdoors Welding Processes, Speed 25% and Eff. 50%

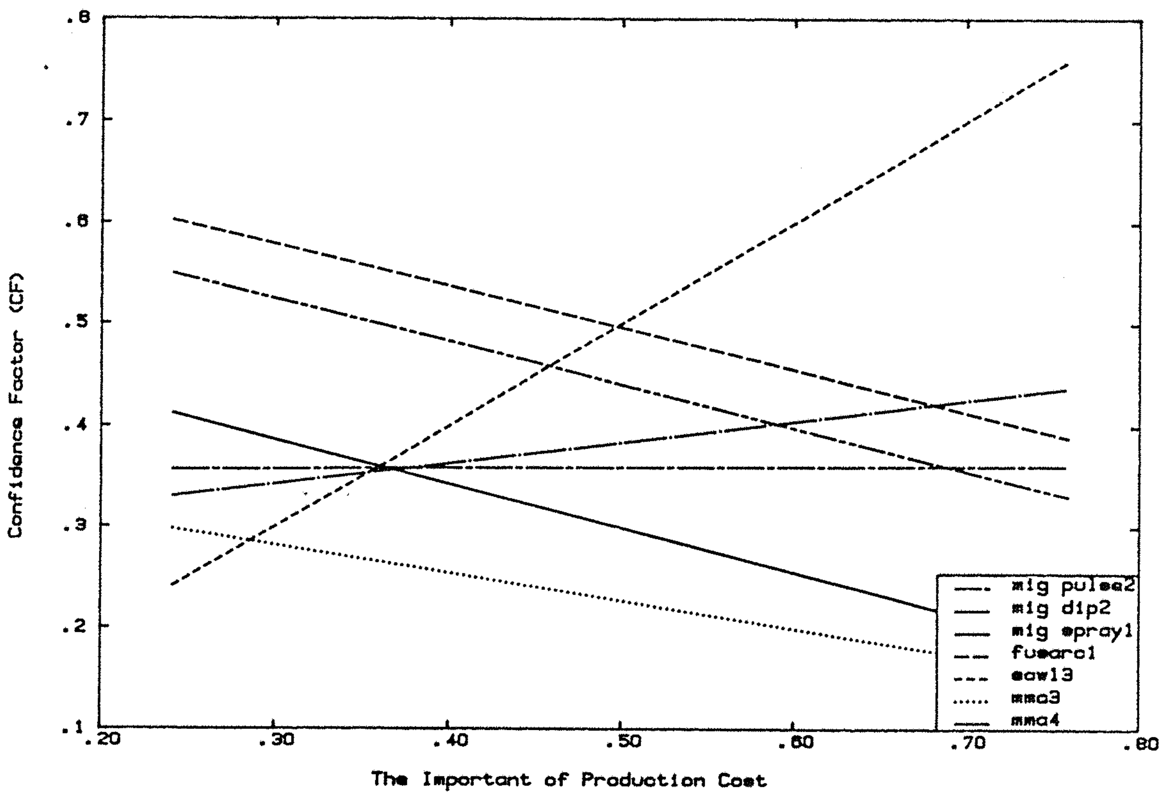


Figure E.50 Outdoors Welding Processes, Speed 50% and Eff. 50%

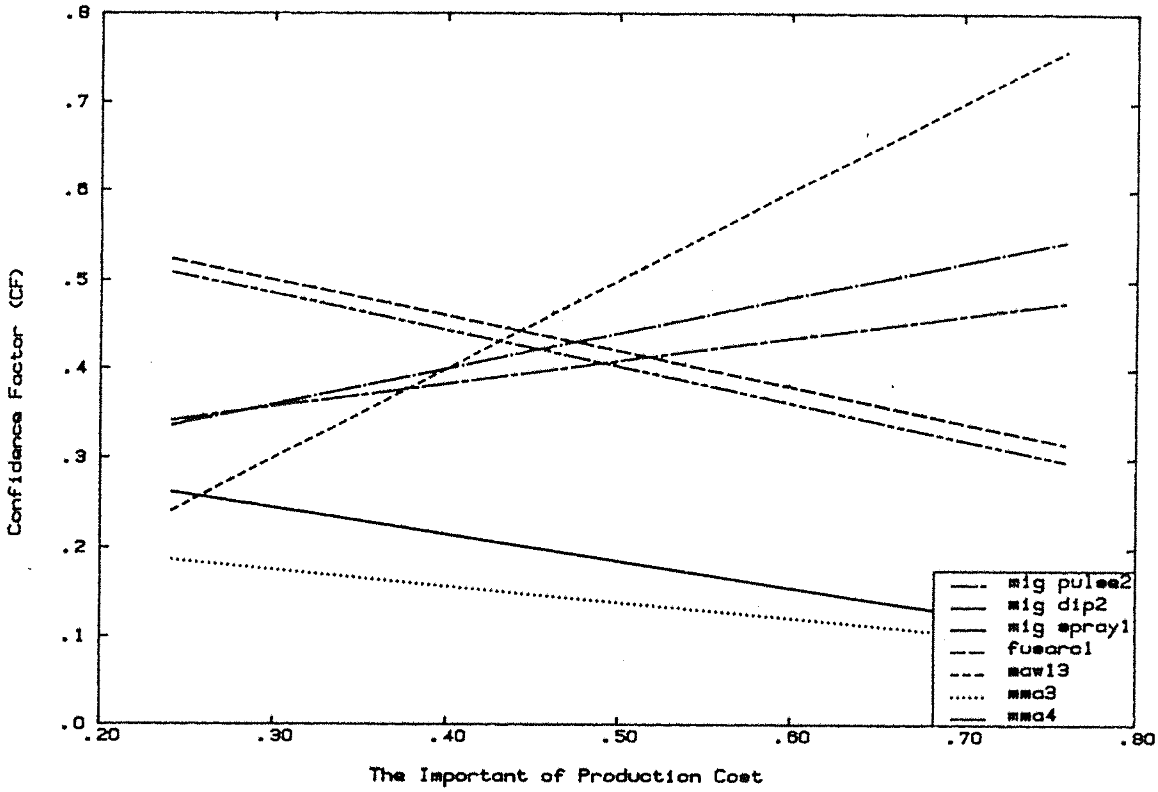


Figure E.51 Outdoors Welding Processes, Speed 75% and Eff. 50%

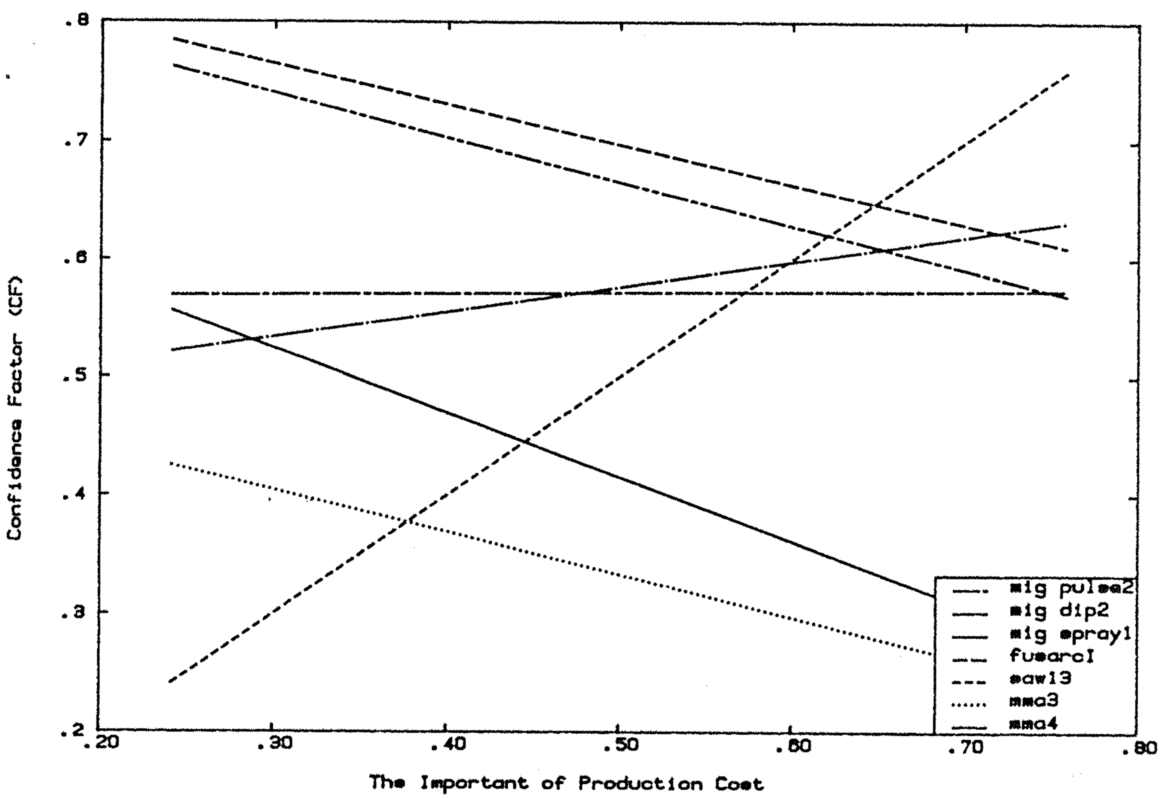


Figure E.52 Outdoors Welding Processes, Speed 25% and Eff. 75%

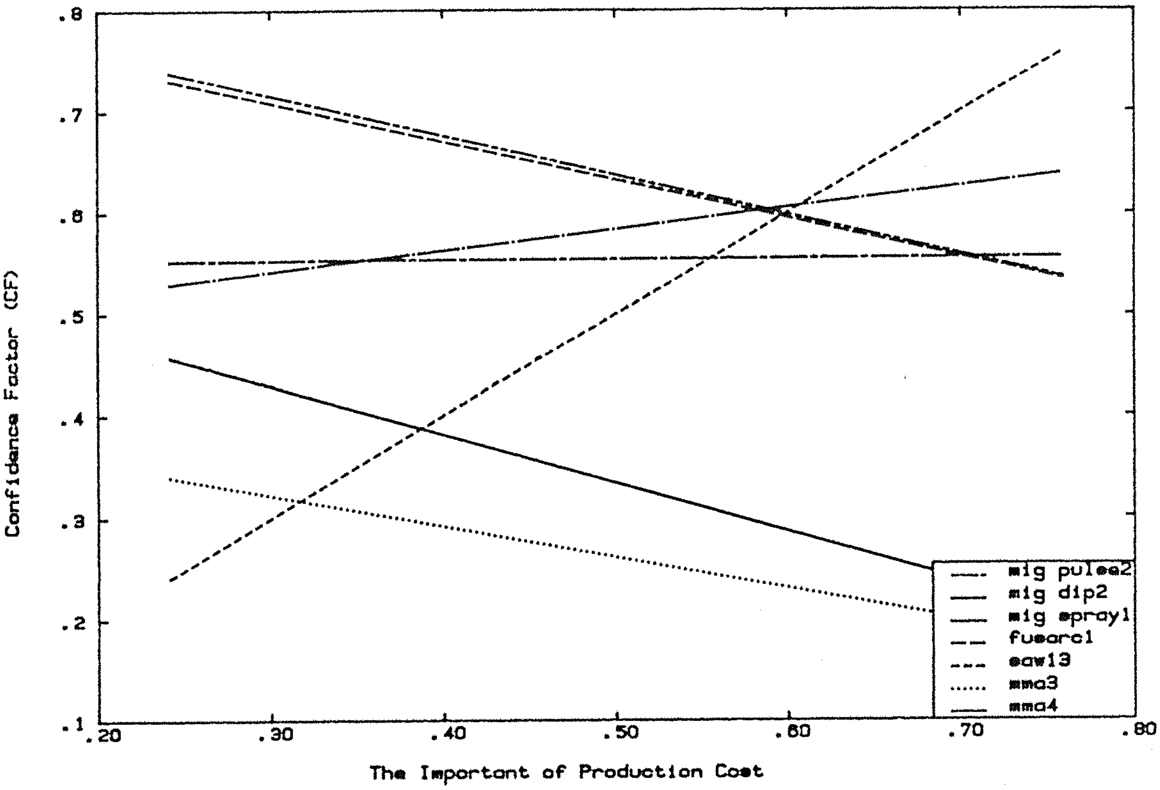


Figure E.53 Outdoors Welding Processes, Speed 50% and Eff. 75%

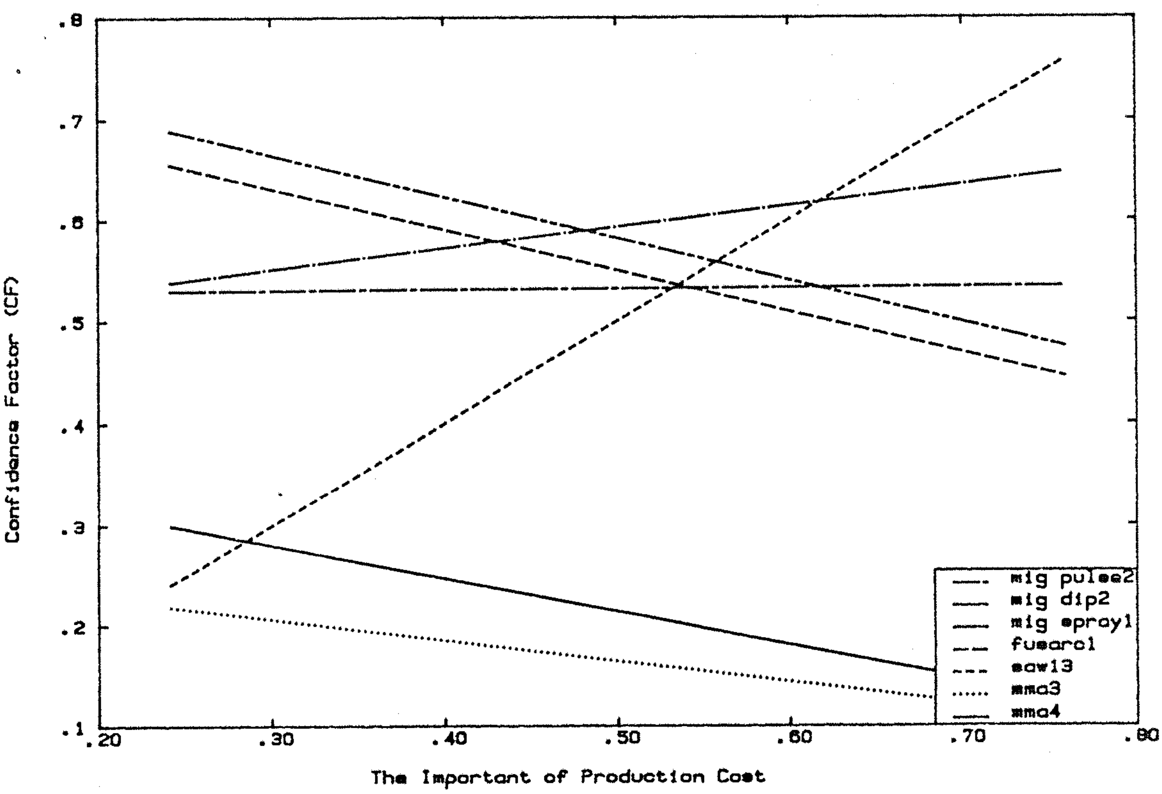


Figure E.54 Outdoors Welding Processes, Speed 75% and Eff. 75%

Appendix F : DETAILED RESULTS OF THE GRILLAGES ANALYSIS

As mentioned in Chapter 5, the program has been applied on the five structurally equivalent grillage panels which are shown in Figure 5.14. A set of detailed results of these five grillages can be seen in Figures F.1 to F.5 below.

PRODUCTION COST PREDICTION

FOR

A GRILLAGE PANEL

Susanto Sukardi
Ship Science dept.

GRILLAGE PANEL NO: 1

Length	:	10.70	meters
Width	:	9.50	meters
Plate thickness	:	11	mm

Transverse stiffeners :

Main stiffener			Web stiffener		
web height	:	150 mm	web height	:	0 mm
web thickness	:	11 mm	web thickness	:	0 mm
flange height	:	0 mm	flange height	:	0 mm
flange thickness	:	0 mm	flange thickness	:	0 mm
no's of stiffener	:	14	no's of stiffener	:	0

Longitudinals stiffeners :

Main stiffener			Web stiffener		
web height	:	1200 mm	web height	:	870 mm
web thickness	:	12 mm	web thickness	:	12 mm
flange height	:	400 mm	flange height	:	360 mm
flange thickness	:	30 mm	flange thickness	:	30 mm
no's of stiffener	:	1	no's of stiffener	:	4

Plate size :

Length	:	6.00
Width	:	2.00

Figure F.1 The Results of Grillage no: 1

List of input rates (in pound sterling) :

Skill labour rate	:	15.00
Unskill labour rate	:	12.00
Steel plate rate	:	250.00
Steel profile rate	:	250.00
Welding electrode rate	:	500.00

Welding process	Reject rate
MMA	20.0 %
MIG spray	10.0 %
MIG dip	10.0 %
MIG pulse	10.0 %
SAW	15.0 %
Fusarc	20.0 %

Rewelding factor is 5.0

The suggested processes Butt

Subjective conditions
Improtant of weld speed Very important 76.0 % important
Important of weld eff. Very important 76.0 % important
Important of prod. cost Not important 24.0 % important

Weld processes	Confidence factor
mig pulse2	0.7671
mig dip2	0.6962
fusarc1	0.6835
mig spray1	0.6659
mma3	0.5732
mma4	0.5516
saw13	0.2400

Figure F.1 (continued) The Results of Grillage no: 1

The selected welding process for :

Butt joint is

mig pulse2

The suggested processes Trans main stiff.

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig pulse2	0.7671
	mig dip2	0.6962
	fusarc1	0.6835
Important of weld eff. Very important 76.0 % important	mig spray1	0.6659
	mma3	0.5732
Important of prod. cost Not important 24.0 % important	mma4	0.5516
	saw13	0.2400

The selected welding process for :

Trans main stiff. joint is

mig pulse2

Suggested welding process for

Long'l Web stiff. joint is mma3

Suggested welding process for

Long'l main stiff. joint is mma3

Figure F.1 (continued) The Results of Grillage no: 1

Resume of chosen welding processes :

Butt joint	mig pulse2
Trans. Web stiffener to plate	--
Trans. Main stiffener to plate	mig pulse2
Long'l Web stiffener to plate	mma3
Long'l Main stiffener to plate	mma3
Stiffener connection	--

Resume of 'Direct production time' :

Fair & Tack	Butt joint	11.023
	Tee joint	28.721
	Sub-total	39.744
Weld Time	Butt joint	10.018
	Tee joint	143.751
	Sub-total	153.769
	Total direct production time	193.513

Resume of 'Direct cost calculation' (in pound sterling) :

Material cost	3159.16
Direct labour cost	4760.29
Welding material cost	140.95
Total direct cost	8060.40

	(in tones)
Structure weight	12.64
Cost Equivalent Relative Weight	23.09

Figure F.1 (continued) The Results of Grillage no: 1

GRILLAGE PANEL NO: 2

Length	:	10.70	meters
Width	:	9.50	meters
Plate thickness	:	21	mm

Transverse stiffeners :

Main stiffener			Web stiffener		
web height	:	200 mm	web height	:	0 mm
web thickness	:	8 mm	web thickness	:	0 mm
flange height	:	0 mm	flange height	:	0 mm
flange thickness	:	0 mm	flange thickness	:	0 mm
no's of stiffener	:	6	no's of stiffener	:	0

Longitudinals stiffeners :

Main stiffener			Web stiffener		
web height	:	700 mm	web height	:	900 mm
web thickness	:	10 mm	web thickness	:	10 mm
flange height	:	250 mm	flange height	:	400 mm
flange thickness	:	30 mm	flange thickness	:	30 mm
no's of stiffener	:	4	no's of stiffener	:	1

Plate size :

Length	:	6.00
Width	:	2.00

The suggested processes Butt

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig spray2	0.7271
	fusarc2	0.6658
	sawi3	0.5600
Important of weld eff. Very important 76.0 % important	mma5	0.4609
	mma4	0.4004
Important of prod. cost Important 56.0 % important		0.0000
		0.0000

Figure F.2 The Results of Grillage no: 2

The selected welding process for :

Butt joint is

mig spray2

The suggested processes Trans main stiff.

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig dip1	0.6842
	mig pulse2	0.6609
Important of weld eff. Very important 76.0 % important	saw12	0.5600
	mma3	0.3825
		0.0000
Important of prod. cost Important 56.0 % important		0.0000
		0.0000

The selected welding process for :

Trans main stiff. joint is

mig dip1

Suggested welding process for

Long'l Web stiff. joint is mma2

Suggested welding process for

Long'l main stiff. joint is mma2

Resume of chosen welding processes :

Butt joint	mig spray2
Trans. Web stiffener to plate	--
Trans. Main stiffener to plate	mig dip1
Long'l Web stiffener to plate	mma2
Long'l Main stiffener to plate	mma2
Stiffener connection	--

Figure F.2 (continued) The Results of Grillage no: 2

Resume of 'Direct production time' :

Fair & Tack	Butt joint	13.882
	Tee joint	17.017
	Sub-total	30.899
Weld Time	Butt joint	15.027
	Tee joint	92.301
	Sub-total	107.328
	Total direct production time	138.226

Resume of 'Direct cost calculation' (in pound sterling) :

Material cost	5550.58
Direct labour cost	3419.84
Welding material cost	112.99
Total direct cost	9083.41

	(in tones)
Structure weight	22.20
Cost Equivalent Relative Weight	29.67

Figure F.2 (continued) The Results of Grillage no: 2

GRILLAGE PANEL NO: 3

Length	:	10.70	meters
Width	:	9.50	meters
Plate thickness	:	8	mm

Transverse stiffeners :

Main stiffener			Web stiffener		
web height	:	600 mm	web height	:	0 mm
web thickness	:	6 mm	web thickness	:	0 mm
flange height	:	150 mm	flange height	:	0 mm
flange thickness	:	8 mm	flange thickness	:	0 mm
no's of stiffener	:	6	no's of stiffener	:	0

Longitudinals stiffeners :

Main stiffener			Web stiffener		
web height	:	114 mm	web height	:	600 mm
web thickness	:	10 mm	web thickness	:	6 mm
flange height	:	0 mm	flange height	:	200 mm
flange thickness	:	0 mm	flange thickness	:	8 mm
no's of stiffener	:	36	no's of stiffener	:	5

Plate size :

Length	:	6.00
Width	:	2.00

The suggested processes Butt

Subjective conditions
Improtant of weld speed Very important 76.0 % important
Important of weld eff. Very important 76.0 % important
Important of prod. cost Important 56.0 % important

Weld processes	Confidence factor
mig dip1	0.6842
mig pulse2	0.6609
saw12	0.5600
mma3	0.3825
	0.0000
	0.0000
	0.0000

Figure F.3 The Results of Grillage no: 3

The selected welding process for :

Butt joint is

mig dip1

Suggested welding process for

Trans main stiff. joint is mma2

The suggested processes Long'l Web stiff.

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig dip1	0.6842
	mig pulse2	0.6609
	saw12	0.5600
Important of weld eff. Very important 76.0 % important	mma3	0.3825
		0.0000
Important of prod. cost Important 56.0 % important		0.0000
		0.0000

The selected welding process for :

Long'l Web stiff. joint is

mig dip1

The suggested processes Long'l main stiff.

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig dip1	0.6842
	mig pulse2	0.6609
	saw12	0.5600
Important of weld eff. Very important 76.0 % important	mma3	0.3825
		0.0000
Important of prod. cost Important 56.0 % important		0.0000
		0.0000

Figure F.3 (continued) The Results of Grillage no: 3

The selected welding process for :

Long'l main stiff. joint is

mig dip1

Resume of chosen welding processes :

Butt joint	mig dip1
Trans. Web stiffener to plate	--
Trans. Main stiffener to plate	mma2
Long'l Web stiffener to plate	mig dip1
Long'l Main stiffener to plate	mig dip1
Stiffener connection	--

Resume of 'Direct production time' :

Fair & Tack	Butt joint	11.023
	Tee joint	76.338
	Sub-total	87.360
Weld Time	Butt joint	2.327
	Tee joint	459.981
	Sub-total	462.308
	Total direct production time	549.668

Resume of 'Direct cost calculation' (in pound sterling) :

Material cost	2975.56
Direct labour cost	11568.07
Welding material cost	236.60
Total direct cost	14780.23

	(in tones)
Structure weight	11.90
Cost Equivalent Relative Weight	41.58

Figure F.3 (continued) The Results of Grillage no: 3

GRILLAGE PANEL NO: 4

Length	:	10.70	meters
Width	:	9.50	meters
Plate thickness	:	11	mm

Transverse stiffeners :

Main stiffener			Web stiffener		
web height	:	600 mm	web height	:	0 mm
web thickness	:	10 mm	web thickness	:	0 mm
flange height	:	250 mm	flange height	:	0 mm
flange thickness	:	20 mm	flange thickness	:	0 mm
no's of stiffener	:	14	no's of stiffener	:	0

Longitudinals stiffeners :

Main stiffener			Web stiffener		
web height	:	250 mm	web height	:	0 mm
web thickness	:	8 mm	web thickness	:	0 mm
flange height	:	150 mm	flange height	:	0 mm
flange thickness	:	15 mm	flange thickness	:	0 mm
no's of stiffener	:	1	no's of stiffener	:	0

Plate size :

Length	:	6.00
Width	:	2.00

The suggested processes Butt

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig spray1	0.7285
	mig dip2	0.7040
	mig pulse2	0.6528
Important of weld eff. Very important 76.0 % important	saw13	0.5600
	fusarc1	0.5093
Important of prod. cost Important 56.0 % important	mma4	0.4004
	mma3	0.3849

Figure F.4 The Results of Grillage no: 4

The selected welding process for :

Butt joint is

mig spray1

The suggested processes Trans main stiff.

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig dip1	0.6842
	mig pulse2	0.6609
	saw12	0.5600
Important of weld eff. Very important 76.0 % important	mma3	0.3825
		0.0000
Important of prod. cost Important 56.0 % important		0.0000
		0.0000

The selected welding process for :

Trans main stiff. joint is

mig dip1

Suggested welding process for

Long'l main stiff. joint is mma2

Resume of chosen welding processes :

Butt joint	mig spray1
Trans. Web stiffener to plate	--
Trans. Main stiffener to plate	mig dip1
Long'l Web stiffener to plate	--
Long'l Main stiffener to plate	mma2
Stiffener connection	--

Figure F.4 (continued) The Results of Grillage no: 4

Resume of 'Direct production time' :

Fair & Tack	Butt joint	11.023
	Tee joint	22.130
	Sub-total	33.152
Weld Time	Butt joint	4.894
	Tee joint	46.154
	Sub-total	51.048
	Total direct production time	84.200

Resume of 'Direct cost calculation' (in pound sterling) :

Material cost	5121.92
Direct labour cost	1678.67
Welding material cost	96.15
Total direct cost	6896.74

	(in tones)
Structure weight	20.49
Cost Equivalent Relative Weight	25.03

Figure F.4 (continued) The Results of Grillage no: 4

GRILLAGE PANEL NO: 5

Length	:	10.70	meters
Width	:	9.50	meters
Plate thickness	:	11	mm

Transverse stiffeners :

Main stiffener			Web stiffener		
web height	:	0 mm	web height	:	0 mm
web thickness	:	0 mm	web thickness	:	0 mm
flange height	:	0 mm	flange height	:	0 mm
flange thickness	:	0 mm	flange thickness	:	0 mm
no's of stiffener	:	0	no's of stiffener	:	0

Longitudinals stiffeners :

Main stiffener			Web stiffener		
web height	:	550 mm	web height	:	1200 mm
web thickness	:	10 mm	web thickness	:	12 mm
flange height	:	250 mm	flange height	:	400 mm
flange thickness	:	20 mm	flange thickness	:	30 mm
no's of stiffener	:	10	no's of stiffener	:	1

Plate size :

Length	:	6.00
Width	:	2.00

The suggested processes Butt

Subjective conditions .	Weld processes	Confidence factor
Improtant of weld speed Very important 76.0 % important	mig spray1	0.7285
	mig dip2	0.7040
	mig pulse2	0.6528
Important of weld eff. Very important 76.0 % important	saw13	0.5600
	fusarc1	0.5093
Important of prod. cost Important 56.0 % important	mma4	0.4004
	mma3	0.3849

Figure F.5 The Results of Grillage no: 5

The selected welding process for :

Butt joint is

mig spray1

The suggested processes Long'l Web stiff.

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed	mig spray1	0.7285
Very important 76.0 % important	mig dip2	0.7040
	mig pulse2	0.6528
Important of weld eff.	saw13	0.5600
Very important 76.0 % important	fusarc1	0.5093
Important of prod. cost	mma4	0.4004
Important 56.0 % important	mma3	0.3849

The selected welding process for :

Long'l Web stiff. joint is

mig spray1

The suggested processes Long'l main stiff.

Subjective conditions	Weld processes	Confidence factor
Improtant of weld speed	saw12	0.6880
Very important 76.0 % important	mig dip1	0.6712
	mig pulse2	0.6426
Important of weld eff.	mma3	0.3878
Very important 76.0 % important		0.0000
Important of prod. cost		0.0000
Important 56.0 % important		0.0000

Figure F.5 (continued) The Results of Grillage no: 5

Butt joint	mig dip2
Trans. Web stiffener to plate	--
Trans. Main stiffener to plate	-
Long'l Web stiffener to plate	mig dip2
Long'l Main stiffener to plate	mig dip1
Stiffener connection	--

Resume of 'Direct production time' :

Fair & Tack	Butt joint	11.022
	Tee joint	18.126
	Sub-total	29.148
Weld Time	Butt joint	5.837
	Tee joint	53.879
	Sub-total	59.716
	Total direct production time	88.864

Resume of 'Direct cost calculation' (in pound sterling) :

Material cost	3649.59
Direct labour cost	1737.11
Welding material cost	84.70
Total direct cost	5471.40

	(in tones)
Structure weight	15.40
Cost Equivalent Relative Weight	[illegible]

Figure F.5 (continued) The Results of Grillage no: 5