ASPECTS OF DEVELOPING FOUNDRY CLASSIFICATION SCHEMES PARTICULARLY FOR COST-ESTIMATING

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No part of the work described in my thesis was done in collaboration, except where otherwise stated. The thesis is being submitted for the degree of Master of Philosophy at the University of Aston in Birmingham and for no other award.

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SUMMARY

Vital to a manufacturer's success is the ability to make accurate estimates of production costs.

The foundry industry presents particular problems in cost estimation because of a number of unquantifiable variables.

Cost-estimating in the foundry industry involves a degree of guesswork, and inevitably inaccuracy.

It is believed that the ability to classify castings into categories will result in more accurate and efficient cost-estimating for the foundry industry. Some classification systems have been developed, but they either have limited application or have yet to be shown to work.

The classification system developed in co-operation with a foundry* and described in this thesis will, it is believed, produce an accurate method of cost-estimating.

Subsequent analysis of the classification system has validated the parameters of the classification system and resulted in a simple equation which predicts the cost of any casting with an

* Footnote: Johnson Radley in Pudsey, Yorkshire.

accuracy which is at least equivalent to a cost-estimator's accuracy, and is much quicker. The variables inserted in the cost equation are the digits of the classification numbers which define a particular casting.

The approach used in developing the system has potentially broad applications within the foundry industry, not only in cost-estimating, but as a tool for organising the total foundry operation.

The research is in three parts:

(i) To develop a cost-estimating system for Johnson Radley.

(ii) To develop a cost equation using the Company's data and the classification system.

(iii) To describe how the approach used in developing the system could have widespread application.

Key words: 'Foundry classifications schemes'

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Sincerely,

T. D. NEWMAN

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CHAPTER 1

INTRODUCTION

Although the casting process came into existence during the bronze age, it is certainly not outdated, in fact it is one of the production processes essential to providing the goods necessary for modern society.

Virtually all metal products go through a casting stage, some are cast to complex shape and may even be used in the as cast form, others pass through the cast state during the production sequence, for instance metal bar and sheet is usually cast into ingots early in the production sequence.

There has been considerable technological development within the foundry industry, i.e. that part of the metal industry which casts finished or semi-finished components. Developments such as new alloys, better furnaces, more efficient materials handling equipment and better moulding materials have all been an aid to the casting process.

However, while the technology has developed, the Foundry Industry has been slow to adopt scientific management techniques. Largely as a result of poor quality management this essentially capital intensive industry, provides a low return on investment - compared to most industries it is in an unhealthy condition.

It is believed that the industry's efficiency could be greatly increased by a more sophisticated approach to such factors as production scheduling, development of accurate cost centres and improved cost-estimating procedures.

Although the problems are different, a lot can be learned from manufacturing industries* where there has been considerable work done on developing systems which lead to better use of plant, labour and raw materials.

The term "Group Technology" has been used to describe a method whereby components can be classified into groups, enabling the many variables associated with manufacture to be significantly reduced in number, hence simplifying analysis.

Classification of products into groups could also lead to widespread benefits for the foundry industry. Whilst problems and approach may be different the principle of reducing the number of variables to simplify analysis is the same.

This thesis is concerned with looking at a "typical" foundry in a competitive economy with the aim of developing a classification system to be used as an aid in one of the problem areas of the foundry industry, namely cost-estimating.

Footnote: For the purposes of this thesis a process industry is defined as one in which no discrete items can be identified at some point during the production, in contrast to a manufacturing industry where the production processes always act on discrete items.

The approach to the development of the classification scheme is believed to be original. Subsequent to its development, the scheme underwent a critical statistical analysis in order to validate the parameters on which it is based.

The problem of accurate cost-estimating is discussed and existing classification schemes studied with a view to adopting those features that could be used to solve the particular problem in question. Then having given the reader some of the company's background, the development of the classification scheme, in collaboration with the company, and the subsequent analysis are discussed in considerable detail.

The lessons learnt from this approach are discussed in order to lay the guidelines for other companies wishing to develop classification systems to help solve their problems.

Finally some ideas for further applications of classification systems in foundries are outlined and it is hoped that this will lead to further research.

CHAPTER 2

THE VALUE OF CLASSIFICATION IN CASTINGS PRODUCTION

To set this work in perspective it is necessary to look at the Foundry Industry, as a process industry and consider why the ability to classify castings into groups is helpful in solving some of the problems facing the industry.

The casting process has not fundamentally changed for centuries, but the variety of metals and the process variables have become increasingly more sophisticated.

"A casting may be defined as a metal object obtained by allowing molten metal to solidify in a mould, the shape of the object being determined by the mould cavity" (1)

Versatility, economics and metallurgical properties may all be reasons for casting instead of using another metal-shaping process such as forging or machining from solid.

To understand the many variables which must be considered when producing a casting, the process will be discussed in more detail.

2.1 The Foundry

Foundries work either in ferrous or non-ferrous metal, but basically the process is the same in both.

Foundries are categorised by the nature of their work and their organisational structure, for example:

2.1.1 The Jobbing Foundry has a plant which usually contracts to produce a casting, or a small number of castings of a given kind.

2.1.2 The Production Foundry is a highly mechanised shop which can produce large numbers of a given casting at a relatively low cost.

2.1.3 The Semi-Production Foundry is one in which a portion of the work is of a jobbing nature and the rest is production castings.

2.2 The Casting Process

A mould is made of some readily formed material, such as moulding sand, around a pattern. The pattern is removed and its imprint forms the mould cavity into which the molten metal is poured.

Hollows or cavities in a casting are formed by putting cores in a mould.

There is generally a strong relationship between the number of cores in a mould and the complexity, in terms of production difficulty of the casting.

Moulding consists of all operations necessary to prepare the mould for receiving the molten metal, including setting the cores in the mould.

When the metal has solidified the sand is separated from the casting by a process known as "shake-out". The casting is then cleaned by removing any burnt-on sand and fettled. This involves removing all extraneous metal - including the runners which are the solidified metal in the holes leading into the mould, and the metal which has formed in imperfections in the mould. Fettling can be a lengthy process, depending on the quality of the mould, the complexity of the casting, and the properties of the metal.

The casting may then need to be surface treated, heat treated, or both.

The casting process is, in principle, simple, but there are many factors involved in the manufacture of castings, which can produce problems.

2.3 Problems Encountered in Founding

2.3.1 Marketing

Due to the flexibility of the process, the large variety of shapes and sizes of castings often make it difficult to determine the relative value of particular product types, hence the problem of defining the most profitable markets.

2.3.2 Pricing

Many of the factors involved in casting are difficult to assess in monetary terms. Pattern costs, scrap rates and fettling times must all be taken into account in the cost-estimate. An apparently simple job may end up being complex and expensive.

2.3.3 Molten Metal Preparation

The metallurgical properties of metals change according to the rate at which they cool and foundry's customer will often specify the properties he requires. Also the initial temperature, the rate at which it is allowed to cool and the composition of the metal, all affect the quality of the casting. In order to reduce scrap to a minimum the

Foundry must carefully control the temperatures and rates of cooling.

Another problem is that there must always be a sufficient supply of molten metal, while a surplus will waste expensive energy.

2.3.4 Methoding

Methoding plays a major part in the "art" founding. It involves:

(i) Choosing the correct material for the cores and mould;

(ii) Deciding what can be moulded and what should be cored;

(iii) Considering the way in which the pattern should be designed to make core-setting and fettling inexpensive;

(iv) Ensuring that the mould will fill rapidly and completely;

(v) Maximising the yield per casting, i.e. minimising the difference in weight between the metal used in making the casting and the finished casting;

(vi) Attempting to forecast problems that may occur during casting and then taking corrective action e.g. core misplacement can occur if the patterns and hence the moulds are not designed to locate the cores positively. The methods engineer will consider this before the pattern is manufactured.

2.3.5 Moulding

Production must be as continuous as possible so that the plant is fully utilised. To ensure this the patterns and cores must be ready when needed, the moulds must be made and the cores set, so that the metal can be poured without delay.

2.3.6 Knockout and Fettling

It is important that the knockout and fettling areas keep up with the flow of work. It is particularly in the fettling department that the bottle-necks often occur. (2)

2.3.7 Inspection

The casting must be inspected to make sure that there are no voids in the metal, and that they are within specified tolerance limits.

The problems of marketing, pricing, reducing scrap rates, scheduling and dimensional tolerance must all be considered, not only in isolation, but also in relation to each other. For example, methoding and scheduling will affect fettling; marketing (determining the type of casting to be made) may affect the demands of the core and fettling departments.

2.4 An Approach to Solving Problems Encountered by the Foundry

Considerable work has been done on solving the problems a manufacturing industry encounters by the development of an approach called "Group Technology". This approach has had considerable success in both the industrial West, and in Eastern European countries.

Group Technology is based on the principle "that many problems are similar and that by grouping them by their similarity and separating them by their differences, the number of problems are significantly reduced. [3]

A number of articles have been written about the application of Group Technology to various companies. [4, 5, 6, 7, 8]

The success of Group Technology derives from the ability to classify components. A number of different classification systems are used in the manufacturing industry, [9, 10, 11] some have to be "tailor made" to fit the company's individual requirements, others may be adapted from a common basis.

Classification schemes do not always rely on describing the workpiece in quantitative terms. The method of Production Flow Analysis, for example, considers the manufacturing operations performed on the workpiece. (10)

It is only by using a classification scheme that a large number of variables, in terms of machines and components, can be grouped into a smaller and more workable number.

Having established groups, each facet of the company's operation can be studied. This covers buying of raw-materials, semi-finished and finished parts; the production processes which should lead to a group or flow-line layout; the sales and marketing areas, leading to the establishment of the most profitable products; the cost centres, leading to the exposition of the expensive areas in the company; and the utilisation of worker incentive schemes.

The term Group Technology is generally used to refer to manufacturing industry rather than a process industry such as the foundry industry, however, the application of classification systems could lead to widespread benefits in the foundry industry.

Many of the problems discussed earlier in this chapter could be greatly simplified if castings could be classified.

This thesis is concerned with the development of a classification scheme to make estimating the cost of jobs more accurate. Other areas of a foundry's operation, where classification could also be used, will be discussed briefly. The classification system which has been developed adds some original ideas to existing systems, in adapting to a particular foundry's requirements.

To set this classification scheme in perspective the work already done in this field will be reviewed.

CHAPTER 3

A LITERATURE SURVEY OF CLASSIFICATION SCHEMES FOR THE FOUNDRY INDUSTRY

Apparently classification schemes for the foundry industry have only been developed in Eastern Europe and Britain.

The Eastern European schemes have been developed for large sectors, if not all, of the foundry industries in the countries concerned. This is hardly surprising as it reflects the nationalised character of their industrial system.

Hence the classification systems aim to be extremely broad, although not necessarily at the expense of detail, so that the large steel foundry can use the system as effectively as the small cast iron foundry.

The British Classification schemes have been developed on a company basis, although it is hoped that in future some of the research associations connected with the foundry industry (such as the British Cast Iron Research Association) may work on classification for use in whole sectors of the foundry industry.

The difference in the approach of British and Eastern European schemes will become apparent in the ensuing literature review.

3.1 The Eastern European Classification Schemes for the Foundry Industry

Mitrofanov, well known for his contribution to Group Technology,[12] led other researchers to consider classification in the foundry industry. The papers published were not available in English until 1971-1972, when T. J. Grayson and T. A. Sparrow translated descriptions of a considerable number of classification schemes for the foundry industry.

Rosenberger, an East German, reviewed the possibilities of applying Mitrofanov's approach to the Foundry Industry. He said that increased foundry productivity is possible by utilising reserve capacity which is "....created by radical standardisation of pattern making and moulding practice, perfecting techniques, the most efficient utilisation of production capacity and improved organisation of labour"[13] He explained that efficient production planning in the minumum amount of time called for the grouping and classifying of castings according to "...design or technical characteristics...". Rosenberger gives examples of standardisation in the machine moulding shop, core shop, and fettling shop. He continued the development of a classification scheme for rationalisation of the production processes and in 1963 published a paper with Mattner and Kuhne outlining a classification scheme.[14] The authors explain in this paper that unlike the machine tool industry, the foundry industry "had little influence on the overall assortment of castings" which are generally requisitioned by the mechanical engineering industry, without much regard for "foundry technical matters". Perhaps the most relevant point they make is that in design of classification schemes for the foundry industry it is not geometrical similarity which is considered the main attribute, since it is all the same whether cylindrical or prismatic castings are made in a moulding box".

The scheme which Rosenberger and his colleagues propose (see Appendix 1A) considers three primary features:

- Complexity in moulding
- Complexity in core making
- Basic Geometric shape

These three features are divided into "main group", "group" and "sub-group" respectively.

The secondary characteristics are:

- Moulding box size and number of castings per moulding box;
- The wall thickness;
- The manufacturing process (dry sand casting, shell moulded castings, etc.);
- The type of production; (manual, machine, etc.);
- Material;
- Special conditions for the quality of the casting;

- Batch size;
- Delivery requirements;
- Technical requirements of the pattern;
- Machines used in the process.

The abovementioned scheme is designed to sort a wide variety of castings into groups, and whilst it certainly considers the most important parameters, without more detailed information on the system (which is unavailable) it is not possible to determine whether Rosenberger and his colleagues have been successful in delineating the various sections in the secondary classes. For example, when considering the wall thickness of a casting, how does one know which walls are important and thus, should be classified.

Perhaps the greatest contribution to the art of classification of castings in Eastern Europe has come from Malek and his co-worker, Burda [15]. They argue "that shape and size of a casting are the main indicators of technological similarity according to which the castings are classified". Furthermore, the shape of a casting is classified according to technological complexity, dimensional tolerance, and physical and chemical properties. The size of the casting is specified in terms of its weight.

The first component of the classification scheme comprises five categories.

For each "group" there are ten "classes" specifying more detailed geometry of the shape of castings from purely prismatic to complex combinations of various different shapes. Each class is further divided into "sub-groups" which are defined by drawings.

Thus there are 5 groups, 50 classes, and 500 sub-groups. In essence the process of classification involves assigning a weight and complexity digit, deciding which geometric shape the casting describes and then comparing it with 500 sketches to assign a sub-class. It should be noted that individual sub-groups are given names according to their visual impression, e.g. a cover, a gear wheel etc.

Malek continued his work and in 1965 published another paper [16], in which he comes to terms with the inability of foundries to adopt technical innovation. A particularly relevant quote of Malek's for Britan's ailing industries is, "In spite of numerous steps towards extended information and education we still make castings by means of outdated methods and we are not able to use the achievements of science quickly and effectively". As an example he mentions that foundries are not using sand mixes that have been found, by research, to be more effective than the "traditional mixings .... Our National Economy thus suffers great losses which each of us feel in our own pocket".

More information of Malek's classification scheme is published in this paper.[16] It divides castings into classes (as shown in Appendix 1B). It is a more detailed classification scheme. Although it is self-explanatory a few points are worthy of mention.

The "shape analysis of a casting" indicates the complexity of production. The shape "class" is a quantitative description of the geometry of the castings, with carefully defined ratios which specify the boundaries between one class and another, e.g. the ratio of the width to the length defines whether or not a casting is "longitudinal"; a "flat" casting is defined by $H \leqslant (L + W)/4$, where:

H is the height of the casting
W is the width of the casting
L is the length of the casting.

Digit six defines a "type of shape", it specifies one of nine, 10 x 10 matrices whose axes are digits 7 and 8. These matrices contain pictures. Classifying a new casting involves choosing the matrix and then comparing pictures with the drawing of the new job to establish the horizontal and vertical axes of the matrix.

H. Pacyna[17] contributed some interesting ideas to classification of castings. He regarded the existing classification schemes as being limited in their application because the "classes selected from a technological point of view are only related in a loose sort of way with the quantity and time structure so they can serve as a means of sorting factors for separating out a family of more or less similar parts for cost investigations but they cannot be considered as parameters in the mathematical sense".

Pacyna developed an extremely complex classification system based on the ratios of various dimensions of castings. Coding with this system is lengthy and involved and a computer will have to be used.

However it may have application in the area of computer-aided design of castings (see Chapter 8).

It is not intended to discuss Pacyna's work in detail because it is so complex, that it is unlikely to be relevant to this work. However, Pacyna makes some interesting suggestions, particularly the following quote; "In many cases a price has to be got out for a casting in a very short time. For this, price or manufacturing costs can help when they are tabulated against the weight per casting and classes of difficulty ..... The negotiating of the difficulty class (in East Germany) is the focal point of the sales talk since with insufficiently precise definitions it leaves a lot of room for bargaining".

Pacyna plots graphs of weight and manufacturing difficulty against cost per casting for about a hundred castings. He suggests that "knowing the weight of the casting and the production cost per unit weight, the difficulty class may be established".

Furthermore, Pacyna proposes that the classification data can be correlated directly with the cost data to obtain a "Total Manufacturing Cost per casting" using regression analysis and this will lead to much quicker calculation of costs.

3.2 The British Classification Schemes Developed for the Foundry Industry.

To the author's knowledge there is only one classification scheme actually being used in a foundry in Britain. Two other schemes are in the process of development and implementation.

A successful classification system exists at Leys Malleable Casting Company Limited of Derby. Leys is the largest producer of malleable iron castings in the United Kingdom, the vast majority of their production being for the Automobile Industry.

The requirement of the system is to assist in costing new jobs, and it was decided that a basis of comparison between existing and potential jobs would be the best solution.

One of the problems to be overcome was two customers referring to a very similar job by two different names.

The system has a seven digit code, which covers complexity, shape, size and material specification. Like Malek's system (Ley's system is based on Malek's system), the basic complexity/ shape coding takes the form of pictorial matrices of castings. Due to the vast majority of their output being supplied to one industry it is a relatively simple matter to use a matrix of "standards" which compares new jobs with existing jobs.

There are five 10 x 10 matrices; by assigning a "complexity" digit a matrix is chosen and the position on the row and column of similarly shaped casting provides values for the other two shape digits.

Having developed the system, which took one man two years, the cost-estimating department reorganised all of their files, which were in alphabetical order of customers, to one of numerical order of classification digits.

When a new job requires a quote, it is coded and compared, by means of the code, with an existing job, and a price will either be determined immediately if the two jobs are sufficiently similar, or else the existing record will act as a guide to calculating the new cost. If a job does not fall into any of the categories designated, provision has been made to insert more pictures, however, in practice, there is rarely a need to add pictures to the matrix.

The development of the classification system has not only been effective as a reference system for the estimating department but it has also been adopted by the production department so now they refer to the coded number, rather than the customer's name for the component. Furthermore, they envisage being able to use the system for production scheduling in the near future.

Catton and Company, of Leeds, is an independent foundry, producing sizeable batches of steel castings in a large, partially mechanised foundry. They have been working on a cost-estimating system based on classification for some months, and the details of the proposed scheme have been made available.(18)

Having already managed to establish a rate per lb. for each process in the foundry, they are now trying to apply it to estimating and job costing. The parameters they consider important for a good estimating system are:

1. It should take into account inflation.
2. It should be simple.
3. It should reflect changes in costs and process routes and highlight low margin job.

"The basic concept of the system is to list each process route in the plant and establish a rate for each, for simplicity only three types of rates are proposed, these are:-

(i) A rate per lb. of liquid steel

(ii) A rate per shell, mould or box.

(iii) A rate per lb. of casting.

Each process involved in the manufacture of a casting is then marked, i.e. a process route is established".

By multiplying these rates by the estimated or actual quantities a rough estimate is arrived at. However, if the complexity of the castings is taken into account the estimate becomes more accurate. Thus each process has been allocated five grades of difficulty from easy to complex, these are based on operation times.

This information can provide a cost by the following procedure:

(i) Establish a process route.

(ii) Establish the complexity level for each process.

(iii) Take the product of complexity factor rate per lb. and base rate to give a cost per process.

(iv) Sum the process costs.

(v) Adjust for percentage scrap.

(vi) Adjust for ON cost.

(vii) Adjust for overheads.

(viii) Add on profit margin.

The rates may be updated when necessary and it is proposed to use a computer to do the calculation. Thus one will merely indicate the process route, the liquid weight, number of castings per box and the net weight of the casting, the computer will then calculate the final estimate.

The last classification scheme to be discussed in this chapter was proposed by J. N. Anstie for use at Johnson Radley, a cast iron foundry in Pudsey, Yorkshire [19]. Intended as a general classification to be used "as a model to optimise the profitability of each department's operation, as a marketing tool, as a pricing tool and eventually as an aid to production scheduling".

Anstie considered it important to concentrate on the design features of castings rather than process variables. The factors taken into consideration are shape, complexity, size, material, and patterns per board.

The proposed scheme is largely based on Malek's original classification system [15, 16, 20]. Although he puts the digits specifying weight and material type first, followed by three more categories representing: (refer to Appendix 1C).

The Shape Group

The Shape Group refers to the moulding and coring requirements of the casting.

(i) "A cavity is a hole in a casting which may either be enclosed or may simply be a central bore open at both ends. A simple cavity is of relatively regular and easily mouldable proportions, whilst a complex cavity is diversely shaped, under-going several changes in cross section and direction throughout the space it occupies."

(ii) "An opening is a hole whose cross-sectional area in the plane perpendicular to its axis is negligible compared with the projected area in the same plane. Both holes are considered to be 'openings' whether they are actually cast or whether provision is made for them to be machined".

(iii) "A facet defines all those irregular features on the surface of the casting, such as lugs, bosses, and ribs, which could possibly lead to difficulties in their production but not necessarily so. It is effectively descriptive".

The Shape Class

The shape class conforms almost exactly to Malek's system except that it includes three "rotational" classes to cater for the large number of these castings at Johnson Radley. The ratios of the important dimensions as well as the appearance (e.g. a combination of round and flat shapes) define the categories.

The Sub-Groups

This is a descriptive class which refers to internal as well as external features.

The final digit in the classification scheme gives the patterns per board as shown in Appendix 1C.

Anstie intended to use six 9 x 10 matrices. Choosing the code for the shape group defines a matrix, then the shape class and sub-group are defined by selecting codes on the horizontal and vertical axes respectively.

3.3 Discussion of Existing Classification Schemes

Perhaps one of the most discouraging aspects of trying to adopt a classification into foundries is that although a considerable amount of research has been done on classification, particularly in the Eastern European countries, there is very little information on the implementation and operation of classification systems. Malek, 1965 (16), talks of distributing his system to foundries the following year. Yet there does not appear to be a paper written giving the details of the effectiveness of Malek's scheme after its introduction (if indeed it was ever introduced).

Thus any assessment of the classification schemes must be based on the writer's experience in trying to develop and implement a system.

The parameters used to classify a casting must reflect requirements of the system. For example, classification for the purpose of production scheduling must take into account the steps involved in the manufacture of a casting, namely the liquid metal, cores, moulding, fettling and perhaps others.

Furthermore, both type and quantity of output tend to vary enormously from one foundry to the next, thus a classification scheme that is suitable in one set of circumstances may be unsuitable in other circumstances.

To overcome the two abovementioned problems either an extremely broad classification scheme must be developed, and then a foundry selects the relevant sections, or else a classification scheme must be developed to suit a particular company.

The Eastern Europeans have attempted to do the former while the British have tried the latter. This is hardly surprising as the economic structure of the Eastern European industry is somewhat different from British Industry "it's (Eastern European) nationalised character lends itself more readily to larger scale macro-organisation of standards for castings production" (19).

Rosenberger (13, 14) has certainly brought out the salient parameters for a successful classification scheme. Furthermore, his observation regarding the problems of classifying castings, namely that it does not matter whether a casting is "cylindrical or prismatic" is important and should be borne in mind.

The problem with Rosenberger's, and other, classification schemes is lack of definition. For instance, Rosenberger and his colleagues talk of "few contours". "Few" is very vague, it could mean less than three on a small casting and less than ten on a big casting, or it could mean less than five contours always. Without clear definition, "classifiers" will get inconsistent codes.

Malek and his colleagues made a substantial contribution to the art. The principle of considering matrices of digits is a useful concept, particularly for a system which is to be universally applied, but like Rosenberger his definitions tend to be "woolly". He talks of simple and complex castings. What is complex to the foundry methods engineer may seem simple to the foundry salesman. Also in his "shape class" there are ambiguities such as, at what point does a "flat frame casting" become a "flat square casting" with a square hole in the middle. Furthermore, why differentiate between the two when as far as the manufacturing is concerned they have the same requirements.

Pacyna sees this lack of definition in his predecessor's classification schemes and goes to the other extreme. The amount of measurement and calculation required to code with his classification would not, in most cases, warrant the time required.

The Ley's classification scheme is commendable, because although it is very basic it allows the vast majority of new jobs to be classified according to their system, and having done so the estimator has no trouble in locating a similar previously made job. Furthermore, although not designed to do so, the production department has been able to adopt the system and use it to indicate the type of work flowing through the foundry i.e. for the first time they can quantify their "job-mix".

However, Leys is in a fortunate position in as much as their range of shapes and sizes of castings is limited due to the fact that they are serving mainly one industry.

Cattons have a very rational approach to the problem and there is little doubt that once implemented the system will be effective. Care has been taken to define all the necessary terms and there is little room for argument. Furthermore, the basis of the system, namely the production routes should be useful in other areas of the foundry, in particular production scheduling.

Anstie's proposed system was found, during subsequent work, not to be definitive enough. Tests showed that with four people classifying a casting they were only all in agreement on any one of the three shape and complexity digits, in 20% of the cases.

Furthermore, in development of a coding system for Johnson Radley's requirements there was no need to specify the branch of material, as all castings are either made in grey iron, or vantage iron, thus one category rather than two is satisfactory.

The "weight" and "patterns per board" digits will be dealt with in a later chapter, as they were subjected to a detailed analysis.

It will be evident to the reader that a lot of work has been done on the development of classification schemes for the foundry industry, particularly in the Eastern European countries.

Before embarking on the development of a classification scheme it was considered important to review the existing schemes to make use of the advantages and try and overcome the weaknesses of the schemes. Firstly, the classification systems which operate so well in manufacturing industry such as the Opitz scheme[9] were considered. However, these were quickly dismissed as they were not versatile enough to cater for the large variety of shapes obtained in casting, they are designed to reflect the characteristics of the machine tools which manufacture the components - a classification system based on these parameters was not relevant to the foundry industry. Furthermore, there were a lot of factors involved in founding which were not accounted for by the classification systems in use in manufacturing industry e.g. the coring requirements of the casting.

In considering the classification systems developed for the foundry industry, there appeared to be one main problem, namely, the lack of information on the application or analytical verification of any of the classification systems (with the exception of the Ley's system).

The author's aim was to develop a classification scheme to a stage whereby it could be applied to serve a useful function in a company and furthermore, develop a method of analysing the classes used in the classification scheme to test their significance in contributing to the overall objectives of the scheme. Also it was hoped that in doing this it would be possible to outline an approach which could be applied to classification systems in other companies.

Partly because Johnson Radley had already invested some time and money in Anstie's scheme and also because his literature review had been thorough and critical, the author, in collaboration with some of the employees at Johnson Radley, decided to use Anstie's scheme as the basis for further development of a system to be used as a reference base in the cost-estimating department.

Before detailing the development and validation of the scheme developed it is important that the reader have some knowledge of the environment in which the system was developed.

CHAPTER 4

JOHNSON RADLEY - THE COMPANY

4.1 A History of the Company

Johnson Radley came into existence in 1919 in Hunslet, Yorkshire, having been established to supply moulds to the glass industry. In its early days it was producing moulds at the rate of only a few dozen a month.

Yorkshire proved to be a wise choice geographically, the area had long been an established centre of glass making and many of the leading manufacturers were based in the vicinity. Furthermore, automatic bottle moulding machines were developed soon after the First World War and this greatly encouraged the use of glass containers. With this growth in glass containers, Johnson Radley managed to manufacture moulds to the small tolerances necessary for glass moulding machines.

Within a few years Johnson Radley was the only glass mould manufacturer remaining in the area and in 1925 the company had to move to larger premises.

Growth continued with annual outputs of 100 tons in 1948, 450 tons in 1956 and 1300 tons in 1969. This growth was greatly assisted by the development of export markets, until today Johnson Radley is one of the largest exporters of glass mould equipment in the world, to such diverse places as Australia and Bolivia.

In 1964 Johnson Radley was sold to United Glass Limited, and a number of small engineering businesses, also acquired by United Glass, came under Johnson Radley Administration.(21)

During 1971 work began on a new foundry at Grangefield Industrial Estate, Pudsey, which was officially opened on May 10, 1973.

The large capital investment involved in building a modern, mechanical foundry, could only be justified if the foundry had a greater capacity than required for the glass mould market, it was decided to fill the excess capacity by manufacturing general engineering castings.

The new foundry has a potential annual capacity of 5000 tonnes, although at present the annual output is about 4200 tonnes. This appears to be for technical rather than marketing reasons. When the author first made his acquaintance with the company early in November 1974 there was little doubt that the market for general engineering castings was bouyant.

Recently there has been a fall in demand for glass moulds and thus considerable effort has been made to develop the general engineering sector of the business. At present general engineering comprises over 40% of tonnage sold.

4.2 Present Production Facilities

The company is equipped to manufacture wood and resin patterns, aluminium patterns must be sub-contracted. Lack of capacity requires some wood and resin patterns to be sub-contracted. Two induction furnaces operate on an alternate melting and supply cycle. At each tapping metal is first transferred to 750 kg. receivers and subsequently to 250 kg. ladles. The transport of these ladles to the pouring stations is achieved by rack and pinion hoists suspended from a monorail.

Cores made from oil and CO_2 sands, as well as shell moulded cores, can be manufactured. Heavy cores are undesirable because all cores must be lifted and set manually. Small intricate cores and large numbers of cores per casting are considered unfavourably by production personnel as they tend to slow the rate at which boxes are produced.

The foundry is equipped with three jolt-squeeze pin-lift, and one job-squeeze roll-over, moulding machines, although the roll-over machine may be replaced by another pin-lift machine. Each moulding machines is supplied by a hopper fed by the sand plant.

There is only one moulding box size, namely 30 inches x 20 inches by a 9 inch top and a 9 inch bottom.

After moulding and closure the boxes are stacked on tracks awaiting transport to the pouring platform. There is capacity to store one and a half hour's production prior to pouring and the same during cooling.

After cooling the boxes travel along the roller conveyor to the automatic shake-out unit. Then runners, risers and gates are knocked off.

The fettling shop has a number of high speed grinders, a hand grinder and a surface grinder. This is not enough to cater for the volume of castings and at the time of writing there is a lot of work in progress as well as some fettling being sub-contracted.

Although there is a well equipped machine shop only glass moulds are machined, the company will not supply any machined general engineering castings.

This resumé of Johnson Radley's production facilities should help the reader when looking at the problems of cost-estimating.

4.3 The Problem of Cost-Estimating a General Engineering Casting

Due to Johnson Radley's inexperience in making general engineering castings, they have difficulty in establishing a correct casting cost-estimate. Although many of the cost elements may be calculated, there is a certain "art" to founding. A job which may appear easy could in fact cause manufacturing difficulties and similarly an apparently difficult job may cause no problems whatsoever.

Furthermore, because they are doing contract work, Johnson Radley have a large variety of jobs, from automative clutch plates, to pump bodies.

So not only does lack of experience make it difficult to estimate the cost of a casting accurately, but it is difficult to gain the experience when every job is different and there does not appear to be any basis for comparison.

The need to obtain more accurate costs, efficiently, was recognised by the Foundry Sales Manager (i.e. the manager in charge of General Engineering Sales), and it was at his instigation that Anstie [19] spent some time at Johnson Radley. Some months after Anstie's departure, the researcher was employed to adapt Anstie's system to be used for cost-estimating and then to implement the scheme.

Before giving details of an improved cost-estimating system it is necessary to review the existing system.

4.4 The Existing Cost-Estimating System for General Engineering Castings

There are three people concerned in the preparation of an estimate, namely:

- The Foundry Sales Manager
- The Foundry Estimator, who is a member of the Foundry Sales Department.
- The Methods Engineer who is in the Production Department.

The customer (or potential customer) sends a drawing to Johnson Radley with a request to quote. The drawing is studied by the abovementioned three people and they decide by somewhat subjective means, on ease of manufacturing and the profitability of the job.

At this stage it may be decided not to quote for the job because either:

- It can not be manufactured by Johnson Radley for technological reasons, e.g. the castings are too big.
- The job would not be profitable e.g. because the quantity required by the customer does not warrant a production run.

If the decision is to quote, there is some discussion regarding the methoding of the job, then the estimator fills out the "Casting Estimate" sheet shown in Appendix 2. At this stage the estimator must make a number of "guestimates". It is important to consider these in some detail.

The estimator is required to quote for pattern costs. Whether the patterns are sub-contracted or made at Johnson Radley he must estimate the cost, as there is not enough time to obtain quotes from pattern-makers.

Other "guestimates" that must be established are as follows:

(i) The scrap rate
(ii) The yield per casting
(iii) All the cost centres
(iv) The reject reserve

It should be noted that the reject reserve is the castings rejected by the customer because of unsatisfactory manufacture, whereas the scrap is rejected by the production department. (There is no quality control department).

Once the Estimator has completed the "Casting Estimate" form the Foundry Sales Manager calculates the ratio of £1/ton and £1/box, as this gives an indication of competitiveness of the estimate. He then sends out a quoted price which is equal to or above the estimated price.

To establish the figures the estimator requires, there appear to be three sources of information:

(i) Any experience the estimator had prior to joining his present employment.

(ii) Second hand knowledge of past scrap and reject rates, and yield. He is never actually supplied with this information.

(iii) Relying on his memory of past pattern costs in order to establish existing pattern costs. Similarly for the cost centres, if by chance he remembers a similar job previously he can refer to the estimated times to establish new estimated times*.

Whilst the estimator is expected to use his experience to establish a cost, he is not provided with any new information to allow him to make more accurate estimates.

Thus there are two requirements for more accurate estimates:

(i) The information must be received by the estimator.

(ii) The estimator must have some way of being able to compare incoming quotes with records of similar existing jobs.

* Footnote: The company is at present establishing actual times for the cost centres and already has many actual times for coremaking, but none as yet for the other cost centres.

To fulfill these two aims an improved cost-estimating system has been proposed. Its development and operation are described in the next chapter.

CHAPTER 5

THE DEVELOPMENT OF AN IMPROVED COST-ESTIMATING SYSTEM

The developmental work that had to be undertaken before Anstie's classification could be implemented, will be described in some detail as the approach is effective and efficient.

5.1 Development of the Classification Scheme

Having established the inconsistency in coding with Anstie's "Group", "Class" and "Sub-Group", attention was given to modifying these three categories. A team comprised of the Foundry Sales Manager, Foundry Salesman, The Estimator, and the author studied the parameters and constraints of the system.

The team met weekly for six months although some meetings had to be cancelled. The scheme was finalised after fifteen meetings.

A high level of co-operation, both within the team, and from others whose advice had to be sought, greatly contributed to the scheme's rapid development.

As well as a consistent classification scheme to assist in cost-estimating, the team wanted the system to describe the casting pictorially, i.e. by referring to the digits, some idea of the appearance of the casting should be apparent.

Furthermore, it was agreed that it would be advantageous if increasing classification digits indicated increased difficulty in manufacture.

During the week members of the team studied modifications to the scheme and coded castings, from drawings. Towards the end of the week, the team met and inconsistencies were discussed. Then the researcher modified the scheme and made a new proposal the following week.

It became apparent after some weeks of this trial and error approach that it is impossible to develop a purely objective scheme that could be used without some training. The solution was for the meetings to be conducted so that while the inconsistencies of the system were being eliminated, people were also being "brain-washed" into thinking along the same lines. When something could be described by two digits within the same class, discussion led to a decision as to whether the code could be tightened up, so the categories were mutually exclusive, and if not, the particular way in which that type of casting should be classified. Then the precedent was set if the same problems re-appeared.

Although all were studied simultaneously, each of the "three problem digits" has its own characteristics and will be discussed independently.

5.1.1 The Feature Class (See Figure 1)

This class caused considerable problems and had to undergo significant changes.

The biggest problem was the parameters in Anstie's "shape group" (Figure 1) were not definitive enough. The code was meant to describe the coring requirements of a casting without actually mentioning cores. This has the advantage of being broad enough to accommodate changes in methoding without having to reclassify. However, by doing this, consistency is being sacrificed for versatility. Anstie says "this digit does not purport to indicate moulding requirements", [19] but at the same time it defines cavities, holes and facets, which in many cases are moulded.

It was finally decided that the only way to use this class was to establish how the casting was to be manufactured and describe it in terms of its moulding and coring requirements.

While facets and cavities are descriptive names, they make little difference as far as manufacture is concerned, they are equally likely to be moulded or cored.

CLASSIFICATION OF SHAPE AND COMPLEXITY

Shape Group	Shape Class	Sub-Group	Coding
With one or more Simple Cavities, without Facets of Openings	Longitudinal	Symmetric in 3 Dimensions	0
With one or more Simple Cavities, with Openings	Rotational (Flat)	Symmetric in 2 Dimensions	1
Without Cavities, with or without Facets or Openings	Rotational	Symmetric in 1 Dimension	2
With one or more Simple Cavities, with Facets	Rotatonal (Voluminous)	Graduated	3
Without Cavities, with Facets and Openings	Flat Angular	Concaved	4
With one or more Simple Cavities, with Facets and Openings	Flat Frame	Ribbed	5
With one or more Complex Cavities, or without Facets and/or Openings	Flat Combined	Diversified	6
-	Voluminous Angular	Spatial	7
-	Voluminous Frame	Tapered	8
-	Voluminous Combined	-	9

Figure 1

Anstie's definition of a hole was modified, as it was pointless to classify a machined hole (i.e. a hole which is not cored) as this was of no interest to the Foundry. It was however, important to distinguish between a simple casting with a number of small holes (e.g. bolt holes) which required a number of cores being "popped" in to the mould and a casting with complex cores.

It took three meetings from the time it was decided to redefine the parameters until all the problems had been eliminated and the result was a more definitive and descriptive class. This is advantageous in cost-estimating as well as other areas of the foundry.

The drawbacks of coding in terms of manufacturing requirements are:

(i) It must be ascertained how the product is to be made.
(ii) If the method of manufacture changes the code may change.

However, a system that does not consider the method of manufacture is unlikely to be effective as an aid to costing. Furthermore, provided the estimator gets the required feedback he can make the necessary changes to the classification number.

From being the least precise of the "problem digits" the feature class became the most precise, and the easiest to use.

5.1.2 The Geometric Class

This class indicates the moulding difficulty and assists in the pictorial representation of the casting.

"There are a large number of cylindrical castings"[19] and these are separated into categories, hence the first three digits.

There was no further need for a frame castings as this is a rectangular casting with either a moulded or a cored cavity.

Some of the terms had to be defined more specifically and an "integrated" category had to be defined, i.e. a number of combined shapes.

One problem that arose was "all the definitions involving the height (H), depth (D) and length (L) presuppose that H, D and L are obvious dimensions and it has become apparent that .... (we) don't always agree on what is the height or length of a casting".[22] To overcome this problem the following rule was used, "length is greater than width which is greater than height". (23)

5.1.3 The Descriptive Class

This contributes very little to the costing scheme, but does help in providing descriptive details.

A number of changes to Anstie's sub-group have been made. The symmetry categories were eliminated because it was an inherent inconsistency that a casting could be symmetrical in one, two or three dimensions or graduated, tapered, etc. These factors are not mutually exclusive. It was decided to dispense with the symmetry details, as this is of no importance to the foundry and insert some more descriptive categories.

The definition of spatial required a ratio such as the surface area to volume and that is too complex to calculate each time, so it had to be discarded.

The other digits of the classification schemes did not undergo a detailed analysis and will be discussed briefly.

5.1.4. The Weight Class

Anstie studied the castings produced at Johnson Radley in some detail so it was decided to adopt his weight categories. This was further substantiated by the Foundry Sales Manager's assurance that the weight classes would be satisfactory.

5.1.5 The Patterns per Board Class

To simplify the estimator's job Anstie decided to omit code 0 and so one pattern per board would correspond to code 1, etc. Anstie's detailed analysis of the categories lead to a decision to adopt his proposal.

5.1.6 The Material Type Class

As mentioned previously one class is satisfactory to describe the four types of material Johnson Radley uses. However, provision has been made to insert a grade lower than 14 in code 0 and grades higher than 20 in codes 4 and 5. Other material types may be inserted in codes 7 - 9 inclusive.

5.1.7 The Historical Snags Class

This class was designed to expose the inherent faults in the design of the casting which could lead to manufacturing difficulties. It is important to distinguish between weaknesses in design which will tend to lead to faulty manufacture and faulty manufacture which is independent of casting design.

The former can not be corrected by Johnson Radley, but extra care in production may overcome the design faults, the latter can and should be overcome by Johnson Radley. This class serves as a "red light" to the production department to try and ensure this "snag" does not appear in casting.

The development of this class based purely on the experience of the members of the team, and due to lack of time it's effectiveness has yet to be tested.

5.1.8 The Pattern Type Class

This class only has relevance as a record of the type of pattern that was used. It has no effect on the price of the job, as patterns are charged separately. However, future studies may indicate a relationship between pattern type and scrap rate but this is only likely on large run jobs where, for instance, warping may occur with wooden patterns.

5.1.9 Examples

The proposed classification scheme for Johnson Radley is shown in figures 2 and 3. To indicate how the classification operates two photographs of castings are shown Figure 4 and 5 and their classification numbers are as follows:

THE PROPOSED CLASSIFICATION SCHEME FOR CASTINGS

CODE	WEIGHT IN KG.	PATTERNS PER BOARD	MATERIAL TYPE	HISTORICAL SNAGS	PATTERN TYPE
	DIGIT ONE	DIGIT FIVE	DIGIT SIX	DIGIT SEVEN	DIGIT EIGHT
0	inclusive up to 0 - 3.00	-	-	NO SNAGS	wood on wood
1	3.00 - 6.00	ONE	GRADE 14	CORE MISPLACEMENT	resin on wood
2	6.00 - 10.00	TWO	GRADE 17	SURFACE DEFECTS	aluminium on wood
3	10.00 - 15.00	THREE	GRADE 20	DIMENSIONAL/TOLERANCE MISMATCH	resin on aluminium
4	15.00 - 20.00	FOUR	-	SHORT RUNNING	wood on aluminium
5	20.00 - 30.00	FIVE	-	SHRINKING/SINKING	aluminium on aluminium
6.	30.00 - 40.00	SIX - SEVEN	VANTAGE	CHILLING/METTALURGICAL	-
7.	40.00 - 50.00	EIGHT - NINE	-	-	-
8.	50.00 - 60.00	TEN - FOURTEEN	-	COMBINATION OF THE ABOVE	-
9.	over 60.00	FIFTEEN & OVER	-	OTHERS	others

Figure 2.

THE PROPOSED CLASSIFICATION SCHEME FOR CASTINGS

CODE	FEATURE CLASS	GEOMETRIC CLASS	DESCRIPTIVE CLASS
	DIGIT TWO	DIGIT THREE	DIGIT FOUR
0	BASIC (No cores, cavities or facets) WITHOUT OPENINGS	CYLINDRICAL $H/D \leq \frac{1}{4}$	PLAIN AND/OR SIMPLY LUGGED PLAIN - No obvious features
1	BASIC WITH OPENINGS	CYLINDRICAL $\frac{1}{4} < H/D \leq \frac{1}{2}$	TAPERED INTERNALLY AND/OR EXTERNALLY
2	SIMPLE (No cores, but has mouldable cavities and/or facets. No cavity cores) WITHOUT OPENINGS	CYLINDRICAL $\frac{1}{2} < H/D$	RIBBED INTERNALLY AND/OR EXTERNALLY
3	SIMPLE WITH OPENINGS	LONGITUDINAL $W \leq \frac{1}{4}L$ The length is greater than or equal to four times the largest cross-sectional dimensions	FLANGED
4	SEMI - COMPLEX (Two or less simple cores) WITHOUT OPENINGS	RECTANGULAR - THIN Rect refers to castings whose shape is predominantly rectangular in all three dimensions. Thin: W $\frac{1}{4}L$ H $\frac{L + W}{4}$	TAPERED AND RIBBED
5	SEMI - COMPLEX WITH OPENINGS	RECTANGULAR - THICK As above except Thick: $H > \frac{L + W}{4}$	DOMED INTERNALLY OR EXTERNALLY
6	COMPLEX Characteristics are: i) A core with a loose piece ii) A core which needs sticking together iii) Interlocking cores iv) A core which requires greater than a two piece moulding box v) Any casting with three or more cored cavities and/or facets. WITHOUT OPENINGS	COMBINED - THIN A combination of one or more rectangular shapes with one or more rotational shapes Flat $W \geq \frac{1}{4}L$ $H \leq \frac{L + W}{4}$	DOMED INTERNALLY AND EXTERNALLY
7	COMPLEX WITH OPENINGS	COMBINED - THICK As above except Thick: $H > \frac{L + W}{4}$	GRADUATED INTERNALLY OR EXTERNALLY
8	-	INTEGRATED A number of combined shapes some of which are predominant and, thus, cannot be defined by any of the above.	GRADUATED INTERNALLY AND EXTERNALLY
9	-	-	DIVERSIFIED. Two or more of the above classes with neither predominant

Figure 3

FIGURE 4

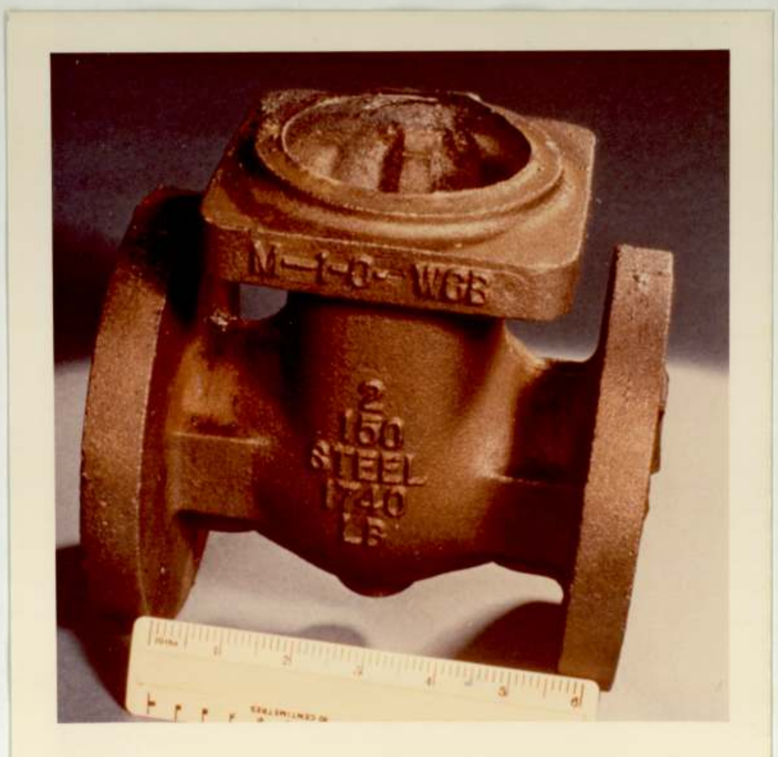


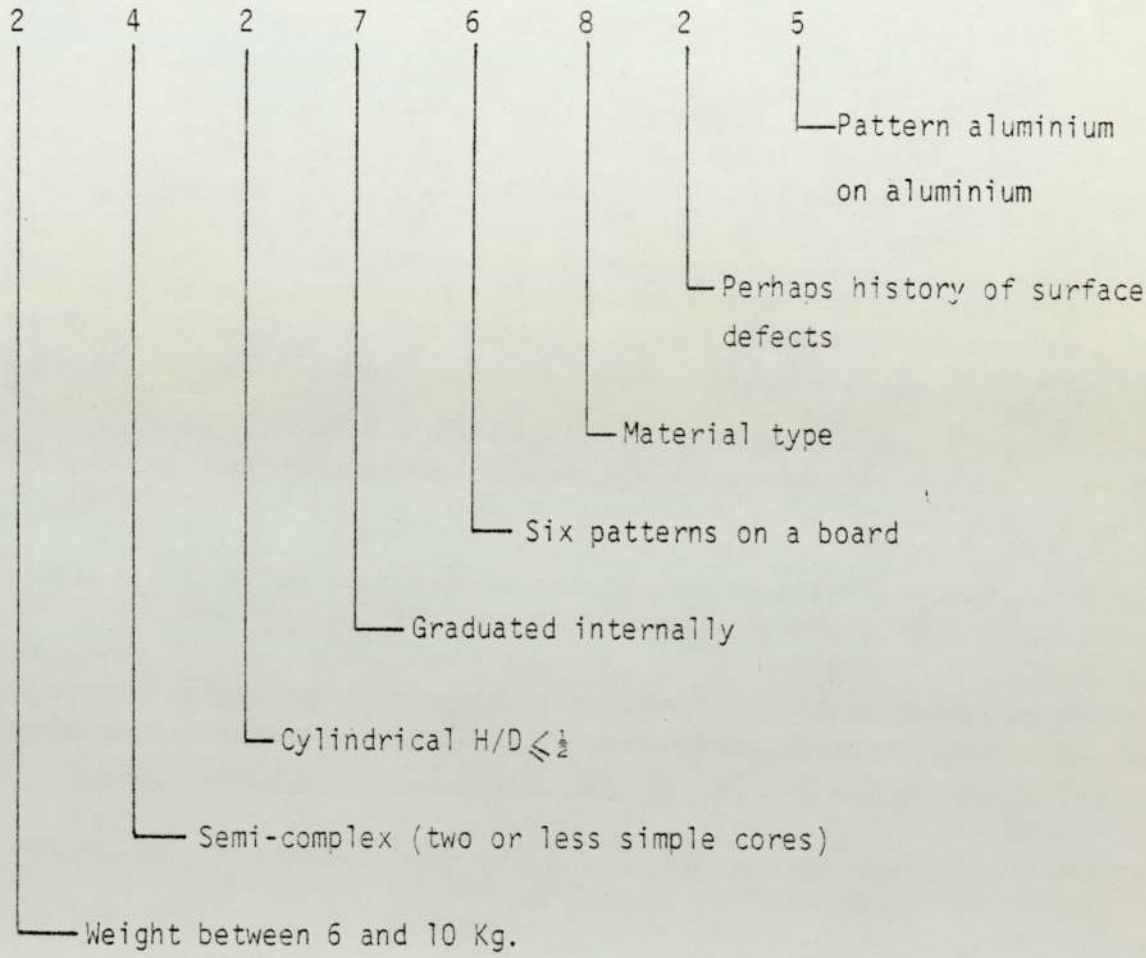
FIGURE 5

Figure 4

3 4 2 3 4 5 0 0

- 0 — Pattern, wood on wood
- 0 — No historical snags
- 5 — Material type
- 4 — Four patterns on a board
- 3 — A flanged casting
- 2 — Cylindrical with H/D ratio $\leq \frac{1}{2}$
- 4 — Semi-complex (one simple core, no cored holes).
- 3 — Weight between 10 and 15 Kg

Figure 5


2 4 2 7 6 8 2 5
Pattern aluminium on aluminium
Perhaps history of surface defects
Material type
Six patterns on a board
Graduated internally
Cylindrical H/D ≤ ½
Semi-complex (two or less simple cores)
Weight between 6 and 10 Kg.

5.2 Data Collection

The classification scheme is a reference base, but this is only of value if the required data is available. More specifically, to compare existing jobs with potential jobs, to obtain better estimates, the relevant data must be collected and updated.

In many industrial situations data exists either recorded or remembered by people, which should be made available to other people who can act on this information. For example the production controller may know that a job has a tendency to chill and extra care must be taken, but the estimator is not informed so if a new job is ordered which appears to have the same problem the estimator will not know, so he can not allow for it in calculating the scrap, nor can he warn the production controller.

The system envisaged will impose a discipline on the people concerned to make all the necessary data available to the estimator. The data that was considered important is listed in Figure 6 some of the items will be discussed in more detail later.

The best way of obtaining the data is to make the people responsible for a section to complete the related part of the form for each job. The form would then progress through the various

The Necessary Data for Cost-Estimating

- Classification Number
- Part Number
- Casting Weight in Kilogrammes
- Updated Cost
- Last quoted price
- Date of last quoted price
- Patterns per board
- Date of pattern manufacture
- Cores per Casting
- Coremaking SUVS
- Moulding SUVS
- Fettling SUVS
- Total quantity made
- Yield as a percentage
- Total quantity scrapped
- Scrap rate as a percentage
- Total quantity rejected
- Reject rate as a percentage

Figure 6

departments. The estimator would ensure that all forms were progressed and completed.

The estimator also needs a drawing for each job. It has been recommended that each drawing be copied onto A3 size paper and stored in a folder. This drawing should have the classification number and part number, designated by Johnson Radley, written on the drawing.

5.3 The Computer - an aid to System Operation

Johnson Radley is well endowed with computing facilities - this will be useful in processing the information.

The system must reflect changes in costs, the estimator can not refer to outdated costs when trying to compare existing and potential jobs. The comparison must be between the cost of an existing job at to-day's prices and the potential job.

The computer would be used to update costs of all Johnson Radley jobs at regular intervals. At present the costs are updated but this is done by adding a percentage increase to all castings and this fails to reflect the way these increases occur. If, for instance, a light casting with a lot of fettling is increased in price by the same percentage as a heavy casting with negligible fettling, while labour costs have increased 40%

and metal costs 10% then adding the same price increases will not give a true reflection of the cost increases.

Over a period of time some jobs will become over-priced, and others under-priced. Seeing repeat orders are quite common, it is important (even regardless of the new system) to provide more accurate updated costs.

An equation describing the calculation on the casting estimate form shown in Appendix 2, has been developed, and this could be used by the computer to re-cost all jobs. The equation is as follows:

$$S.P. = \left[\frac{W}{1000} \left\{ \frac{(1 + x)}{y} \; c_{1 \text{ or } 2} - \left(\frac{(1 + x)}{y} - \right) c_3 \right\} \right.$$

$$+ r_1 n_1 \; t_1 \; (1 + x) + \frac{(1 + x) r_2}{n_2} + (1 + x) t_3 \; r_3$$

$$\left. + \frac{W}{1000} (1 + x) r_4 + \frac{W}{1000} (1 + x) r_5 \right] (1 + z) \; (1 + p)$$

$$+ \frac{W}{1000} \; r_{6 \text{ or } 7}$$

WHERE:

w = Casting weight

x = Estimated Scrap rate

y = Yield

t_1 = Est. time to produce cores in fractions of an hour

t_2 = Est. time to produce moulding box.

t_3 = Est. time to fettle in fractions of an hour

n_1 = No. of cores per casting

n_2 = No. of castings per box

z = Estimated reject reserve

c_1 = Cost of Grades 14 & 17 iron

c_2 = Cost of Grades 20 iron

c_3 = Metal credited back to the company

r_1 = Core-making rate £/hour

r_2 = Moulding rate £/hour

r_3 = Fettling rate £/hour

r_4 = Heat treatment £/ton

r_5 = Shot Blast £/ton

r_6 = Delivery cost in £/ton for less than 100 miles

r_7 = Delivery cost in £/ton for greater than 100 miles

p = Profit

S.P. = The Estimated Selling Price of the casting, the actual selling price may be higher than the estimated selling price.

All the "variables" listed on the left hand side of the page are in fact semi-variable i.e., they will not change at regular intervals but may alter if, for instance, there is a change in methoding. The variables: x, t_1, t_2 and z should become increasingly accurate as more batches are produced.

The variables on the right hand side of the page are subject to inflation and hence will need to change periodically. However, they are independent of the type of casting and hence the computer may be programmed to update these rates and calculate new prices for each job.

The program should be run approximately every 2-3 months. Prior to running the Foundry Sales Manager and the Estimator should review all rates and the Estimator should provide the Computer Department with details of changes to existing castings and new jobs that must be added to the file.

5.4 The General Running of the System

Assuming a new Estimator is employed and must be taught the system, to ensure that he codes correctly and when in doubt conforms to convention, he will firstly be given an instruction manual which explains the purpose and process of coding. Secondly he will code castings of increasing complexity, and the errors will be discussed. This should be repeated until proficiency is achieved. Thirdly, he should be shown a written list of precedents that have been established and given illustrations of these precedents. He can now proceed with coding although the work should be checked until total proficiency is achieved.

When costing a new job the procedure is as follows:

(i) Classify the drawing received by the customer.

(ii) Refer to the latest computer print-out, which will have all jobs listed in classification number order, (see Appendix 3) and establish which jobs may be similar.

(iii) Ascertain the similar jobs by referring to the drawings, these will also be filed in classification number order.

(iv) Referring to the computer output, again, will give the required data of similar jobs. Any changes that should be made because the job is not exactly the same may be estimated.

(v) The casting estimate sheet is completed.

If the quote is successful the Estimator must warn the production controller if he has reason to believe that the job may have a snag, the computer output will have indicated this.

After the casting is produced the Estimator will receive the form giving deatils of the job. Comparisons should be made of actual versus estimated SUV rates and yield, if there is a marked discrepancy the reasons should be ascertained. This will improve the estimator's skill and also allow manufacturing problems to be brought to the attention of management. The estimator will also be responsible for setting and noting precedents when classifying.

To try and validate the parameters of the classification system described in this chapter a detailed statistical analysis of the scheme was carried out. The analysis and results are described in Chapter 6.

CHAPTER 6

ANALYSIS OF THE DATA

The empirical approach used to develop a classification scheme to solve Johnson Radley's cost-estimating problem appeared to be successful. However, to validate this assumption a statistical analysis was carried out, its main aim being to show which classes were significant indicators of cost, and their contribution to the total cost of the casting. As a result, it was possible to test Pacyna's [(17)] suggestion that classification digits could be used as variables in a cost-equation because the contribution to costs were given as coefficients in the output from the statistical analysis.

Data for 170 different types of castings was collected, the total number of castings being 60,850. A computer print-out listing the castings, in ascending order of the classification numbers, with the data was produced (see Appendix 3).

Note that the column marked "price" is the estimated cost. Core making SUVS are a measure of the time taken to make a core. (60SUVS = 100 seconds). When the data was collected a considerable amount of work-in-progress existed which accounts for the discrepency between the total quantity cast and the total quantities issued and scrapped.

Examination of the listing in classification order indicated some interesting trends so it was decided to pursue a statistical analysis.

6.1 The Type of Analysis

The analysis was carried out on a ICL 1905E computer using the ICL XDS3 statistical package [24]. To enable a quick turnaround of jobs it was decided to use MOP terminals (see Appendix 5).

The output from this analysis is in Appendix 4A. Some definitions of the more important results will be given.

6.1.1 The Correlation Matrix

The Correlation Matrix is a means of determining the degree of association of two variables. The correlation coefficient (r) has a range of $-1 \leqslant r \leqslant 1$. It will be positive if both variables increase together and negative if one variable decreases while the other increases. A value of zero indicates absolutely no correlation. It may only be used if the relationship is thought to be linear. To test if a particular value of r indicates a signficant correlation between two variables the following equation should be applied:

$$r = \frac{t}{\sqrt{\emptyset + t^2}} \quad \ldots\ldots\ldots\ldots \quad (6.1)$$

where $\emptyset$ = number of degrees of freedom

t = the t a statistic at a given confidence level.

The degrees of freedom (Ø) represents the number of independent comparisons that can be made among the total number of observations. The t- statistic gives a measure of the degree of confidence that a variable is included in the regression set.

6.1.2 Regression Analysis

Regression Analysis is "the problem of finding the most suitable.... equation to predict one variable from one, or more other variables".[25] In this case the aim was to predict an equation for cost using those classification digits that could be shown to have an effect on cost.

The computer output shows which independent variables are in the regression set at a given significance level (the significance level percentage is one hundred minus the confidence level and indicates the likelihood of the quoted result having arisen by purely accidental occurence. A significance level of 5% is usually considered acceptable for most industrial purposes). The following features of the computer output are of particular interest:

(i) The regression coefficient. This is the coeffecient of the independent variables in the regression equation e.g. for a three dimensional regression it would be the coefficients b_1 and b_2 in $y = a + b_1 x_1 + b_2 x_2$ where y is the dependent variable, x_1 and x_2 being independent.

(ii) The standard error. This is a measure of the error of the regression coefficient, i.e. a measure of the error in the slope of the line.

(iii) The t- statistic. As defined in 6.1.1. this is used to determine if a variable is included in the regression set at a given significance level (i.e. it tests the likelihood of an accidental inclusion).

(iv) The partial correlation coefficient gives a measure of the change in the dependent variable per unit change of an independent variable while keeping all the other independent variables constant.[26]

(v) The Multiple Correlation (also referred to as the "coefficient of determination" R) when squared gives the correlation coefficient. This is the sum of squares accounted for in the regression analysis i.e. a measure of the amount that the independent variables in the regression set account for the variation in the dependent variable.

(vi) The residual error is one minus the correlation coefficient i.e. the amount that the independent variables do not account for the variation in the dependent variable.

(vii) The intercept term. This is the constant in the regression equation as denoted by "a" in (i).

6.2 Analysis of Results

The aim was to investigate the direct significance of each variable on the cost of a casting and to develop a meaningful cost equation.

Before discussing the analysis it is important that any assumptions necessary to the analysis be stated. They are:

(i) That the costs obtained from the company were the actual costs of the casting when in fact they are only the estimated manufacturing costs, these estimated costs include overheads. Furthermore that updated costs were re-estimated and not just increased by a percentage as mentioned in Chapter 5.

(ii) That the data approximates a normal distribution.

(iii) The relationship between the independent variables and cost is linear.

The first output resulted in an equation with a negative intercept term, implying that if no castings were made there would be a negative cost i.e. a profit. This was unacceptable and the cause had to be investigated.

Plotting actual weights against weight digit (see Appendix 4B, graph 1) showed a parabolic curve, this resulted in the line of best fit having a negative intercept (i.e. a negative weight corresponds to weight digit 0). Graphs 2 and 3 show that while weight versus cost gives a positive intercept weight digit versus cost gives a negative intercept. The weight categories had not been defined to give a linear relationship hence an algebraic transformation had to be performed such that there was a "spreading out" effect as the digits increased. An exponential transformation was found to be too extreme so it was decided to raise the weight digit to a power. A number of exponents were tested and the results are tabulated. All tests are at 5% significance level and "yes" means the variables are in the regression set, "no" they were rejected from the set. The dependent variable is cost.

It will be seen from table 1 that by raising the weight digit to the power 1.75 the intercept was positive, there are at least as many independent variables in the regression set as in the other tests and the mutliple correlation is the highest. To further check that this transformation was satisfactory the weight digit to the power 1.75 was plotted against cost to establish that the relationship was linear (see Figure 7).

6.3 Discussion of Results

The results discussed are those obtained by raising the weight digit to the power 1.75. The output is shown in Appendix 4A parts of it will be quoted in the text to make reference easier.

EXPONENT	INTERCEPT	MULTIPLE CORRELATION	WEIGHT DIGIT	COMPLEXITY DIGIT	GEOMETRIC DIGIT	DESCRIPTIVE DIGIT	PATTERNS DIGIT	MATERIAL DIGIT
1.00	-1.047	0.921	YES	YES	YES	NO	NO	NO
1.25	-0.497	0.933	YES	YES	NO	NO	NO	YES
1.50	-0.040	0.937	YES	YES	NO	NO	NO	YES
1.75	+1.025	0.940	YES	YES	NO	NO	YES	YES
2.00	+1.505	0.938	YES	YES	NO	NO	YES	YES

Table 1

The residual error is 11.8% (multiple correlation 0.940) and the intercept term is 1.025. This implies that all castings cost at least £1.025 and as may be observed from the data this is incorrect. Thus further analysis should be done to obtain a lower intercept. However, seeing this study is merely an example of the approach, and the data is not satisfactory anyway, it was decided to accept this equation for the purposes of discussion.

Hence 88.2% of the costs of the casting are accounted for by the following equation:

$$\begin{aligned} \text{COST (£)} \quad = \quad & +0.311 \times (\text{WEIGHT DIGIT})^{1.75} \\ & +0.243 \times (\text{COMPLEXITY DIGIT}) \\ & -0.150 \times (\text{PATTERNS DIGIT}) \\ & +0.039 \times (\text{MATERIAL DIGIT}) \\ & +1.025 \end{aligned}$$

Graphs of each of these variables are plotted against cost and shown in Figures 7, 8, 9, 10.

It is important to establish how this equation compares in accuracy with the present estimating system.

Seeing actual costs are not monitored the answer to this question can only be an opinion.. The opinion of the Foundry Sales

Manager and the author is that he will be within 10% of the costs 80 - 85% of the time. (This opinion was expressed before the regression analysis).

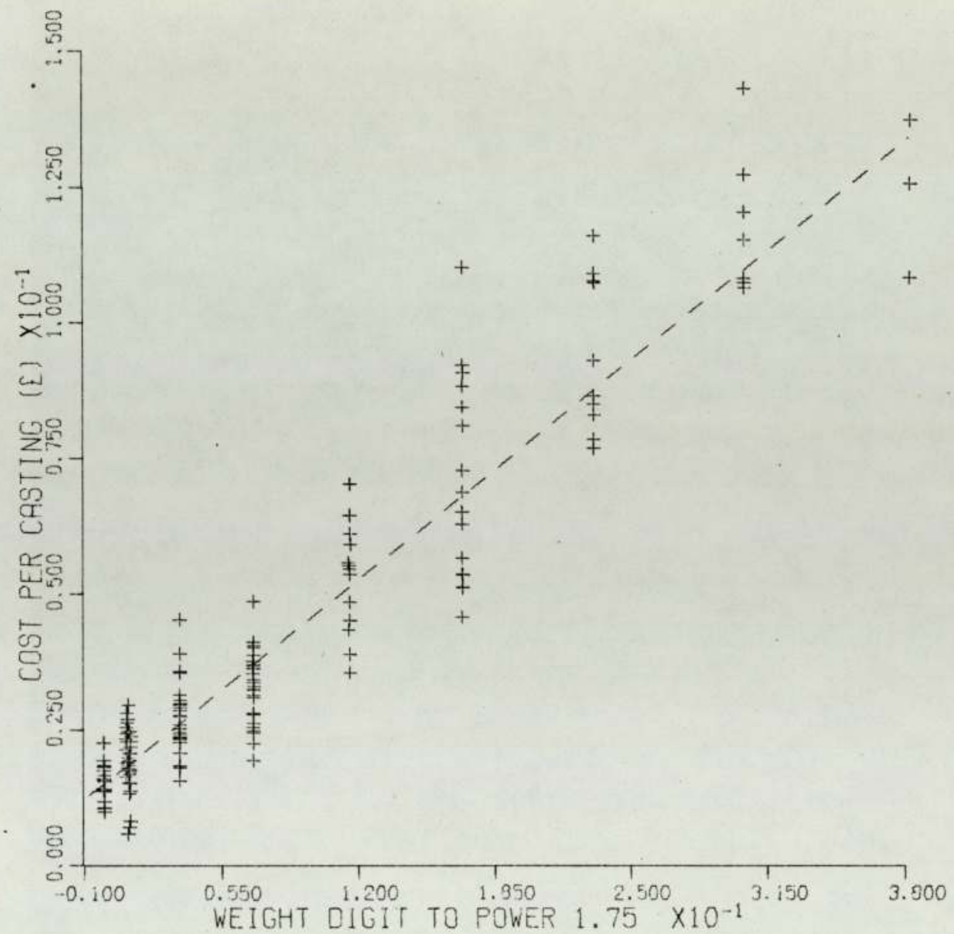
It is not possible to put an overall confidence level on the regression equation but the accuracy at particular values may be tested.

Table 2 considers the error in cost when the regression coefficients have one and then two standard errors added to them, also the error in cost will increase as values of digits further away from the mean values are substituted. Hence zero, one and two standard deviations of the digits is also considered at zero, one and two standard deviations of the coefficients. The intercept term was kept constant for these calculations.

It may be concluded that, in 97.7% of the cases, the error in cost will be at most $\pm$12.8%, if digits two standard deviations from their mean value are used. Furthermore, the error will be within 6.1% in 84% of the cases.

Hence it may be said that the costing procedure, is not only much simpler by using the regression equation, but also there is a considerable improvement in accuracy.

Referring to Figure 11 showing the relationship between observed and calculated values will indicate the accuracy of the equation.



GRAPH PLOTTING COST V WEIGHT DIGIT.

Figure 7

6.3.1 The Correlation Matrix

Applying equation 6.1 the values of the correlation coefficient are tabulated for three significant levels:

Significance Level	Correlation Coefficient (r)
1%	0.181
2.5%	0.152
5%	0.128

The results obtained from the analysis, displayed in a correlation matrix (see Appendix 4A) are as follows:

INDEPENDENT VARIABLE	COST
Weight Digit	0.928
Complexity Digit	0.377
Geometric Digit	0.167
Descriptive Digit	0.167
Patterns Digit	-0.607
Material Digit	0.206

At the 2.5% significance level all digits are correlated with cost, with weight digit being by far the most significant. The patterns digit is negatively correlated, which implies more patterns on a board result in cheaper castings.

The material digit may be expected to have a higher correlation. However, of the 170 castings being studied 167 were made of four types of iron, grades 14 and 17 which had the same price, and grade 20 which is 10% more expensive, the other three castings were made of vantage iron which is six times more expensive than grade 17. To approximate a linear relationship between material digit and the cost the vantage iron was reclassified from digit 6 to digit 44. However, there is not enough spread of samples to indicate a stronger correlation.

The correlation between weight digit, to the power 1.75, and weight is 0.989 (compared to 0.957 for weight digit to the power 1.0 and weight). This indicates that the transformed class is an improvement.

The above results indicate considerable correlation between the classes and the cost of a casting, however to determine the way in which the independent variables can be used to predict cost the technique of regression analysis must be used.

6.3.2. Regression Analysis

The regression analysis was carried out at a number of levels of significance and the optimum result was found to be at 2% significance level. The correlation coefficient is 0.940 compared to 0.941 at 20.0% when all the digits are included in the regression set. At 1% the material digit is rejected (although it would be accepted at 1½% but this could not be done with this statistical package). The results at 2% significance level are summarised as follows:

VARIABLE NAME	REGRESSION COEFFICIENT	STANDARD ERROR	T- STATISTIC
Weight Digit	0.311	±0.013	24.64
Complexity Digit	0.243	±0.070	3.49
Patterns Digit	-0.150	±0.046	3.24
Material Digit	0.039	±0.016	2.35

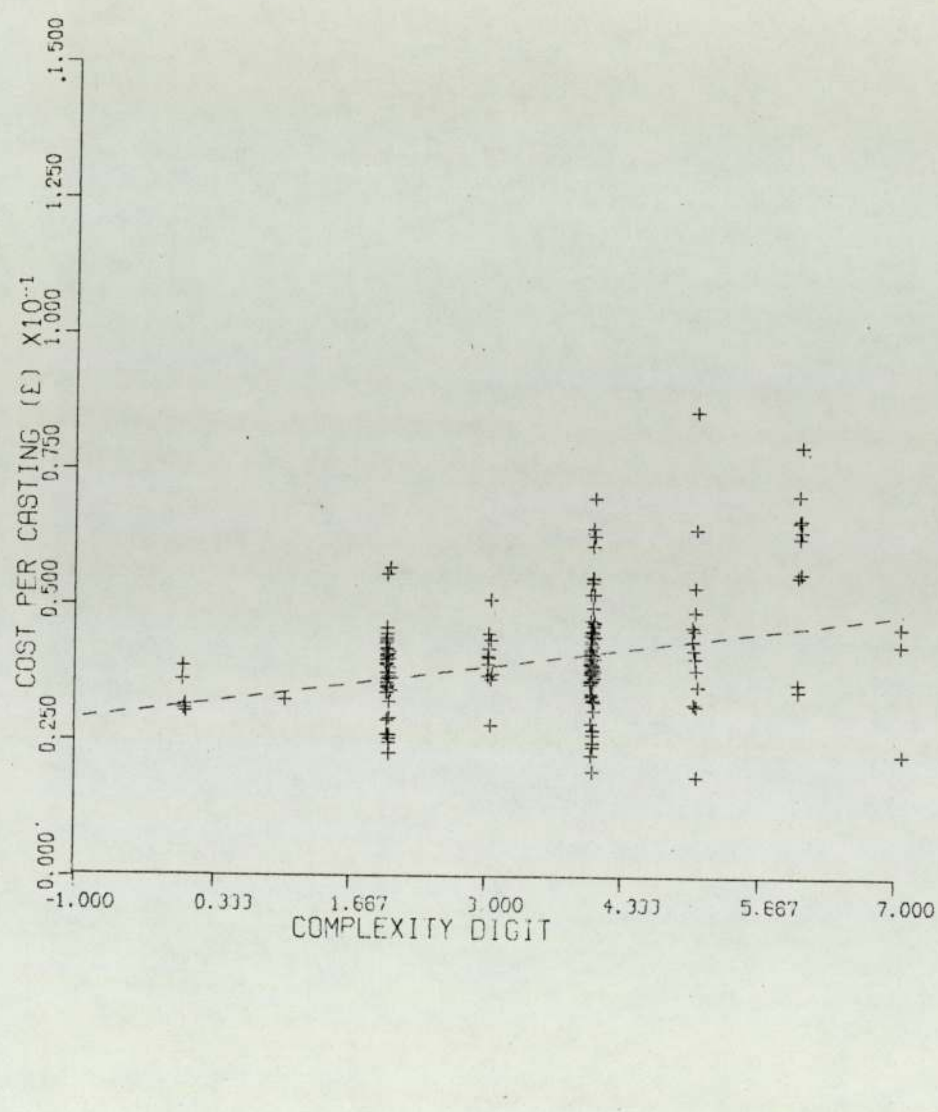

COST PER CASTING (£) X10⁻¹
0.000
0.250
0.500
0.750
1.000
1.250
1.500
-1.000
0.333
1.667
3.000
4.333
5.667
7.000
COMPLEXITY DIGIT
GRAPH PLOTTING COST V COMPLEXITY DIGIT

Figure 8

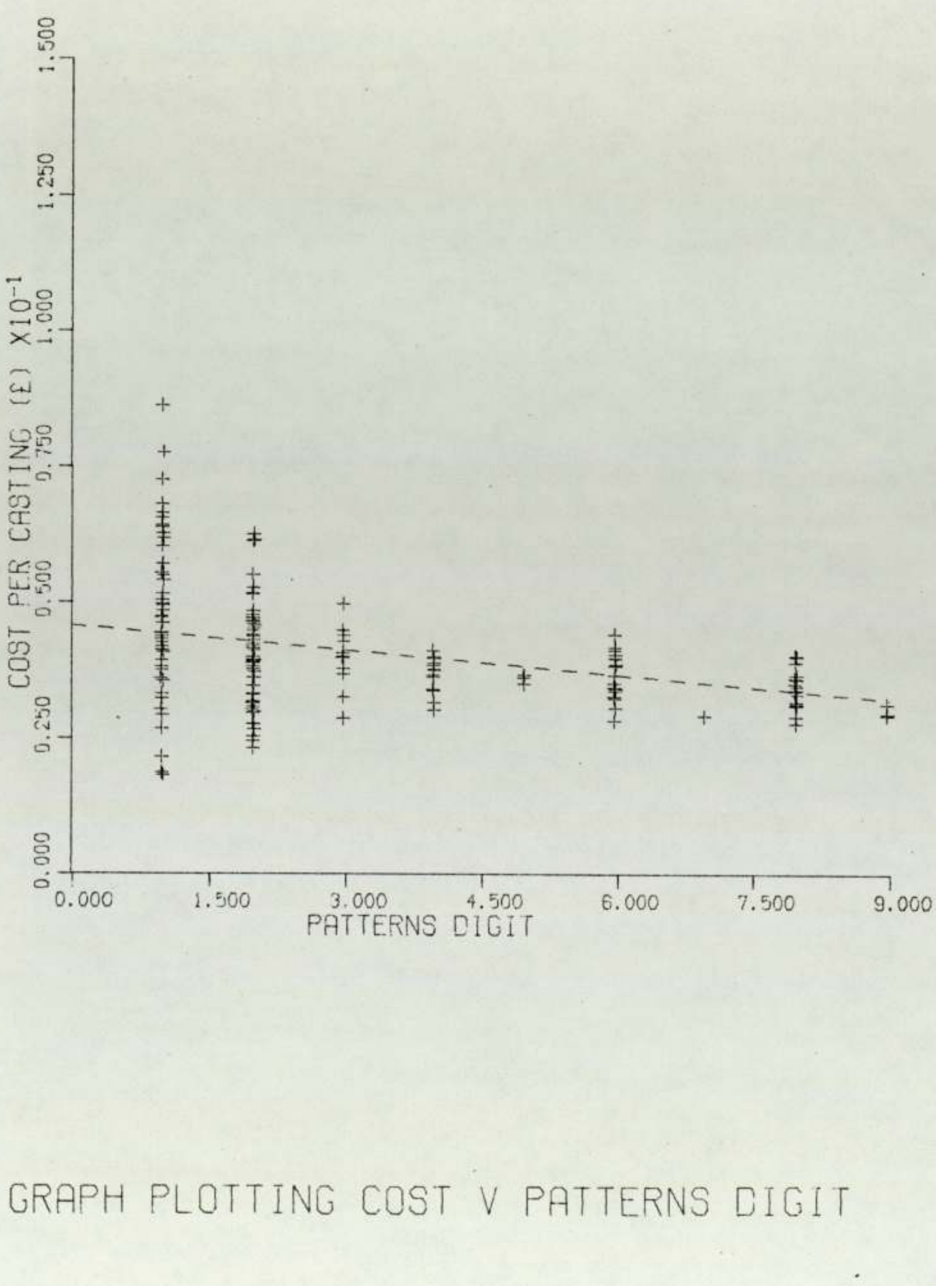
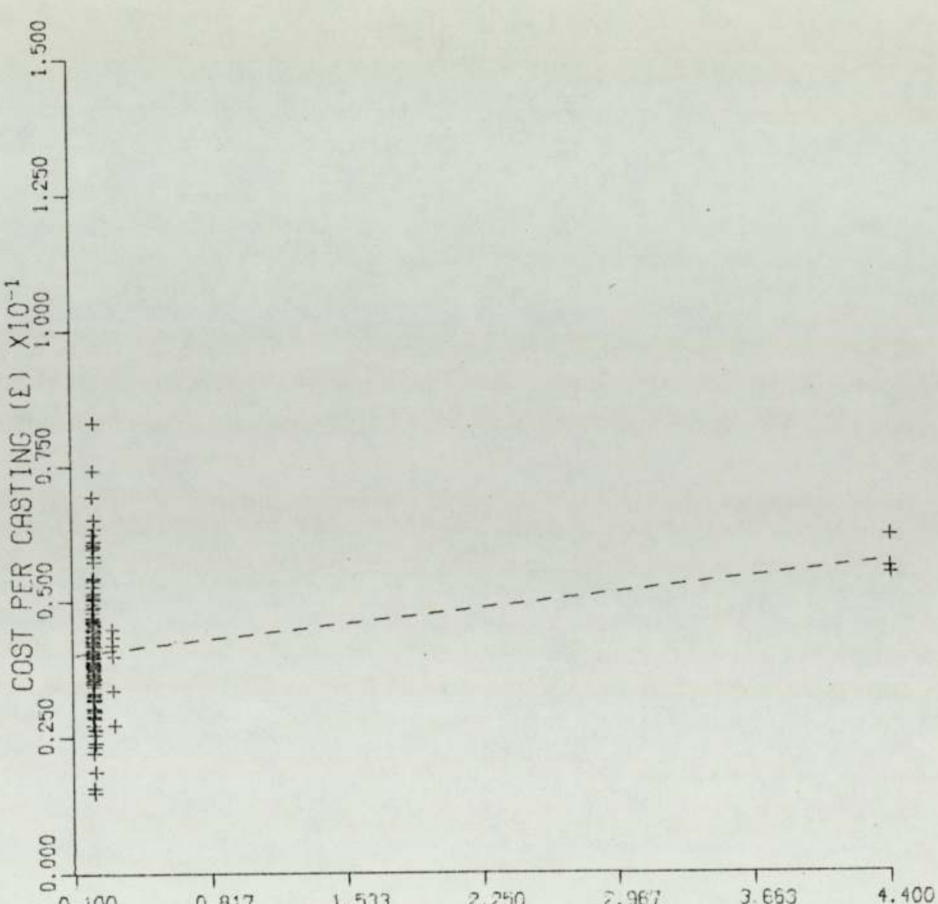

COST PER CASTING (£) X10^-1
0.000
0.250
0.500
0.750
1.000
1.250
1.500
0.000
1.500
3.000
4.500
6.000
7.500
9.000
PATTERNS DIGIT
GRAPH PLOTTING COST V PATTERNS DIGIT

Figure 9



GRAPH PLOTTING COST V MATERIAL DIGIT

Figure 10

TABLE SHOWING THE EFFECT OF ERRORS IN THE REGRESSION EQUATION AND VALUES WHICH DIVERGE FROM THE MEAN

	ZERO STANDARD DEVIATIONS IN DIGITS		ONE STANDARD DEVIATION IN DIGITS		TWO STANDARD DEVIATIONS IN DIGITS	
	COST (£)	% ERROR	COST (£)	% ERROR	COST (£)	% ERROR
ZERO STANDARD DEVIATIONS IN REGRESSION EQUATION	4.00	-	6.99	-	10.04	-
ONE STANDARD DEVIATIONS IN REGRESSION EQUATION	4.24	6.1%	7.43	6.2%	10.68	6.4%
TWO STANDARD DEVIATIONS IN REGRESSION EQUATION	4.49	12.2%	7.87	12.4%	11.33	12.8%

Table 2

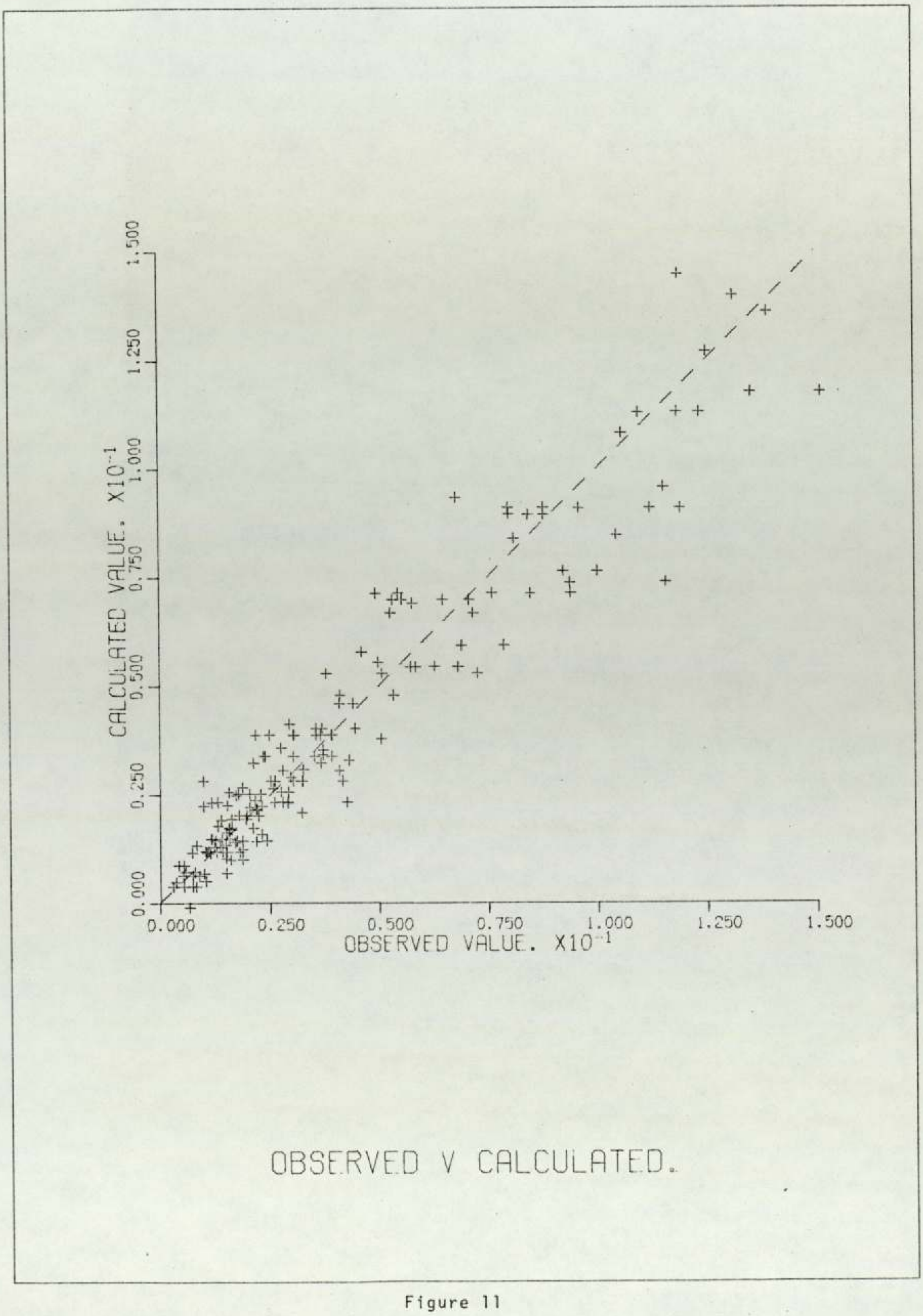

CALCULATED VALUE. X10^-1
0.000
0.250
0.500
0.750
1.000
1.250
1.500
OBSERVED VALUE. X10^-1
OBSERVED V CALCULATED.

Figure 11

6.4 Further Results

Cost was also regressed against weight patterns and cores and at a signficance level of 0.2% the following equation resulted

$$\text{COST } (£) = 0.229 \times \text{WEIGHT} - 0.107 \times \text{PATTERNS} + 0.294 \times \text{CORES} + 0.909$$

This equation accounts for 88.4% of the cost (multiple correlation 0.941). These results are illustrated graphically in Appendix 4C and reference to the observed versus calculated values shows the accuracy of the equation.

An attempt to determine a relationship between the actual scrap and the seven classes to determine if extra scrap allowance should be made for castings with, for instance, greater complexity.

At a significance level of 20% both weight digit and material digit appear to be predictors of scrap. The equation being:

$$\text{SCRAP } (\%) = 0.515 \times (\text{WEIGHT DIGIT})^{1.75} - 0.323 \times \text{MATERIAL DIGIT} + 8.72$$

This accounts for 9.5% of the total scrap. However at lower significance levels the material digit is not in the regression set and at a significance level of 0.1% the equation is:

$$SCRAP\ \% = 0.482 \times (WEIGHT\ DIGIT)^{1.75} + 8.09$$

The standard error is ± 0.12 and the multiple correlation is 0.286.

Hence Johnson Radley would be advised to allow for greater scrap rates for heavier castings. A table may be drawn up giving weighting factors for heavier castings, although there is a high residual error so there are other factors contributing to scrap rates.

The approach used was an effective way to test the significance of the classes chosen in fulfilling the aims of the classification system. It is hoped that this technique will be of assistance as a means of validating the parameters for future classification systems.

The experience gained in developing and analysing the system will be discussed in the following chapter so it may serve as a guideline for the development of future classification systems.

CHAPTER 7

THE RELEVANCE OF THIS WORK TO THE DEVELOPMENT OF A CLASSIFICATION SCHEME

The greatest contribution of this work will, it is hoped, be in providing an approach to the development of classification systems for the cast-metal and similar production industries (for example, the plastics moulding industry).

The approach adopted has been discussed in some detail and the purpose of this chapter is to use the experience gained in this work to improve upon the technique as a guide to future researchers.

7.1 The Team

Before work may begin a team must be formed. The team should consist of people who have some knowledge of the area for which the scheme is to be developed and preferably at least one person who is working in that area, for example, an estimator for a cost-estimating scheme. The team should be big enough to accommodate all the people who can offer some expertise but small enough that meetings will not get "bogged down" by too many people airing views. Between four and six people is probably the optimum number.

One of these people should be appointed team leader. It may be preferable if this person is appointed from outside the company otherwise he may have other duties; during the development stages he should be working full-time on the scheme.

It is important that the team knows the aims of the scheme. Once this is established all members can contribute but there is little value in having someone in the team who does not believe in the scheme as his useful contribution will be minimal and may, in fact, be destructive.

7.2 Defining the Problem

The team must define the problem - this is particularly important. It is suggested that the scheme be developed for one department in the company and then it may be modified for use in other areas at a later date, otherwise a scheme will result that is either too broad to solve any specific problems or its development will be too complex.

If the scheme is designed for the area of central importance in the company, usually production, the modifications for other areas may not be so great.

For example, if a classification scheme is developed for production scheduling in a foundry it will have to consider the various production departments. To further develop it for cost-estimating one may have to modify it to consider the costs of raw materials, delivery costs and profit margins but the basis of the scheme may be the same.

At Johnson Radley the problem was defined as "a need to develop a classification scheme which could be used to classify any casting that Johnson Radley may be requested to quote for, so that the scheme could be used as a reference in comparing existing with potential jobs for the purpose of achieving more accurate cost-estimates".

At times enthusiasts in the team prompted the reasearcher to go and talk to producton personnel about adopting the scheme for production scheduling.

This was resisted for two reasons:

(i) It was more important to satisfy the initial aim firstly as this would be the biggest "selling point" to other departments.

(ii) Because the problems of production scheduling had not been considered in the scheme's development, it probably would not have been applicable and failure would have lead to a loss in confidence in the scheme.

Ley's Malleable developed their scheme initially for cost-estimating. Not only has it been successful but the production department has been able to use the classification number to refer to jobs. However, much work is still required before the system may actually be used for production scheduling.

Defining the problem imposes a discipline on the team, ensuring that it concentrates on the problem and does not get side-tracked during the meetings.

7.3 The Approach

The approach used at Johnson Radley was effective. The researcher (team leader) made the suggestions, and the rest of the team criticised constructively so the researcher could present an improved proposal. Whilst this may appear somewhat harsh on the researcher, it should be remembered that a good team will comprise people who are experts in all areas of interest, hence with a positive attitude they can make a significant contribution.

Testing new proposals will vary depending on the scheme being developed. For the scheme at Johnson Radley testing consisted of getting the members of the team to classify castings and determining if:

(i) They arrived at the same code numbers, i.e. was the scheme consistent.

(ii) The codes were succeeding in delineating the different types of castings.

(iii) The codes were giving members of the team a "picture" of the casting.

The development of the scheme must have the approval of top management, and if possible the Managing Director. At Johnson Radley work was hindered by not having the full approval of the Sales and Marketing Director from the outset and some meetings had to be cancelled while this problem was overcome. When the meetings were reconvened people's memories had to be refreshed and this wasted a considerable amount of time.

7.4 Data Collection

When the team feels confident that the scheme is in a useable form, which is a subjective decision, the researcher should collect a sample of jobs and code them - ideally with the team. This sample must be a fair cross-section of the company's jobs. Faults may appear at this stage which need to be corrected.

7.5 Analysis

The data should be reviewed critically in conjunction with the classificaton scheme and may even need to be subjected to detailed analysis to validate the classification scheme.

It may involve determining if there is a spread of classification digits being used in each class. For example, if 85% of the weight class may be classified by the first four digits the weight classes possibly should be re-defined. In other cases histograms for each digit may have to be plotted or correlations between classes may need to be calculated. If two classes have an extremely high correlation it may be possible to dispense with one class.

Johnson Radley would be advised to redefine its weight class to achieve a linear relationship with cost. This weakness in the class was only discovered during subsequent analysis (see section 6.2).

Changes that need to be made should be discussed with the team so that they feel an integral part of the schemes development. Otherwise, support for the scheme may be lost at the very important stage of implementation.

7.6 Implementation

Due to management indecision at Johnson Radley, the scheme has not been implemented although they are convinced of the need for a classification scheme and are hoping to implement it.

However, some work was done in preparation for implementation. It was ensured that anyone who would be associated with the scheme's implementation and operation understood its aims and requirements. Meetings were held with the Financial Director and Computer Programmer to ensure that the computing facilities were satisfactory and available when required.

It is essential that people involved know about the scheme. It may be necessary to give a lecture about it. Furthermore, proposals may have to gain the approval of unions - overlooking this may be an expensive mistake.

Once the necessary approval is gained, a timetable for implementation must be constructed. The researcher should try and oversee the implementation whilst not becoming too involved otherwise his withdrawal from the company may cause the failure of the scheme.

7.7 Further Development

The successful operation of the scheme may lead to modification in order that it may be adopted by other departments. A new team will have to be formed and it is suggested that at least one person in the team should have been in the original team.

CHAPTER 8

FUTURE WORK

This thesis is concerned with a classification system for use in cost-estimating although mention has been made of the use of classification systems in other areas. It may be interesting to consider breifly how classification may be adopted by the foundry industry as a whole and then to suggest further developments at Johnson Radley.

8.1 Classification and the Foundry Industry

Classification may be used as the tool in solving many of the problems that the foundry industry encounters. Whilst this work will not discuss these proposals in detail it is hoped that someone will be sufficiently encouraged to pursue some of these ideas.

8.1.1 Classification for Cost-Estimating

The approach used at Johnson Radley in developing a cost-estimating system based on classification has potentially broad applications, particularly for foundries that have a large variety of castings. Although the classes may have to be redefined, the principle of using classification as a means of reference could be adopted by many foundries.

Furthermore, provided accurate data may be obtained it is believed that a regression equation of the kind suggested in Chapter 6 could be used for cost-estimating. However a more detailed analysis is suggested so that other factors may be included in the equation, for example, scrap rate, fettling costs which would somehow be related to classification numbers, inspection costs and overheads. In the analysis in Chapter 6 these costs were considered collectively, however, a more thorough analysis in which the costs are studied as separate entities is required.

A chart could be constructed for salesmen so that jobs could be quoted for immediately. It would have cost tabulated against classification numbers for each class. The salesman would classify, refer to his chart by selecting the required digits, add up the costs and quote. Provided the limitations of the system are made clear this would be efficient and accurate and undoubtedly would give the foundry an advantage in the market.

The equation may be changed as costs, rise by adding the appropriate percentage to each of the coefficients in the regression equations, and constructing a new chart. A programmable desk-top calculator could quite easily perform such a task.

8.1.2 Classification of Production Control

"Production Control has as its main objective improved productivity via the optimised use of scarce resources, labour, plant and raw materials". [27] Some of the problems associated with production control were discussed in sections 2.3.3 to 2.3.7 of this thesis.

One of the secrets to running a successful batch producing foundry is to obtain good product-mixes, this means organising production runs of castings which complement each other on their demand for the facilities. For example, mixing castings that require many cores with those that require few cores, castings that require much fettling with those that require little fettling, while ensuring that the furnace is working at full, or near full, capacity.

In most foundries production scheduling is determined by customer priority and experience but there is very little scientific decision-making. Work has been done on computerised production scheduling for foundries and computer programs are available, [28] however, the cheapest known system is only considered worth installing if the company has more than four-hundred live patterns (i.e. patterns that are used at least once every twelve months) and then the cost of running the system is over £1,500 per annum if the company owns a computer [29].

It is believed that classification could be used by the production scheduler to obtain a better product-mix. A very elementary solution , although probably an improvement on scheduling systems now operating in many foundries, would be to have a listing of jobs to be produced, say for the next week, perhaps in order of urgency and let the production scheduler construct a schedule which had low and high numbers alternately, hence their would be a mix of; heavy and light castings; many and few cores per casting; slow and fast to fettle and inspect; etc.

More sophistication could be achieved by deriving empirical fomulae based on the constraints of the foundry. For example, the maximum metal that may be poured each day may be 100 tonnes. A formulae such as:

$$\frac{Ax_1 + Bx_2 + Cx_3 + \dots\dots\dots}{M} < 100$$

where: A, B, C, etc. are the quantity of each casting to be produced.

x_1, x_2, x_3, etc. are weight classification digits.

M is a scaling factor.

The scheduler will know that he must obtain a mix which gives a value less than 100 but greater than say 93. Similarly, a formulae for core, fettling and inspection SUVS could be constructed.

Adopting this approach would be simple, quick and more efficient than many existing procedures. Perhaps it could be further enhanced by using a computer and feeding in the digits of all castings to be produced. The problem is essentially one of linear programming and an optimal solution could be produced daily, weekly or monthly.

8.1.3 Classification for Marketing

As mentioned previously the problem of analysing jobs on the basis of profitability and relating this to market segments is particularly complex for many foundries. This is further compounded by the fact that profitability is related to product-mix.

Using classification as a reference base for analysis it will be easier to establish the type and mix of castings that is most suitable for a particular foundry. Having done this salesmen may be directed to the most lucrative markets.

8.1.4 Computer Aided Design

Some work has been done on using computers to store specific shapes of castings (in the form of co-ordinatres on a grid) and then feeding in details, such as wall thickness, types of material and size, to obtain a cost and then let the computer give instructions to a numerically controlled machine which manufactures the pattern.(30)

If this program is further developed there will be a need to define classes of castings that have been programmed. It will be considerably easier to do this by means of a set of digits than by a descriptive term such as a "medium sized pump body".

8.2 Suggested Further Work At Johnson Radley

The scheme proposed for Johnson Radley has the full endorsement of the team and it is believed that implementation based on the guidelines set out in Chapter 5 should proceed with haste, while the concept is still fresh.

Furthermore, there is a need to establish the real costs involved in each job as quickly as possible and increase the company's fettling capacity.

Having solved these problems another regression analysis could be carried out and quite likely an accurate equation based on classification numbers could be achieved.

Johnson Radley would benefit greatly if the classification scheme could be extended for production control and marketing. Steps have been made to interest management in this field, see Appendix 6.

CONCLUSIONS

1. There are a number of factors that must be considered in the manufacture and marketing of castings and these could be greatly simplified by a more rational approach.

2. Classification schemes may provide a useful tool for adopting a systematic approach to the problems encountered by the foundry industry.

3. The Eastern European schemes are a useful guideline for the development of classification schemes, but there is no literature available on the success, or otherwise, of their application. With the exception of Pacyna's scheme, they all appear to lack precise definition.

4. Pacyna's classification is too complex for most industrial applications although his suggestion of using regression analysis, to obtain a cost-equation, is worthy of further investigation.

5. There is only one known castings classification system in operation in Britain, it is based on Malek's scheme and is successful - largely due to the company being involved in a very specific market.

6. Another scheme based on production routes is soon to go into operation and looks promising.

7. A classification scheme developed at Johnson Radley, by Anstie, was a useful guide but had to undergo a lot of modification in preparation for implementation

8. Johnson Radley is well equipped with production facilities and potential markets but lacks experience in general engineering castings and in particular requires an improved cost-estimating system.

9. A team of people comprising the author and a number of people from Johnson Radley worked to develop a classification system to achieve the following:

   (i) Consistency with different people classifying;
   (ii) Obtain some idea of the appearance of the casting by studying the code numbers;
   (iii) High classification numbers should indicate increased complexity of manufacture with the three "problem" digits.

10. The outcome of these meetings is a classification system which it is believed will be highly effective in being able to compare the cost of new jobs with the updated cost of old jobs.

11. It is believed that no casting classification schemes can be completely objective. At Johnson Radley this problem will be

overcome by making a set of decision rules when in doubt, i.e. precedents will be set that have to be followed.

12. The requirements for the proposed system at Johnson Radley are:

(i) The cost-estimator must be able to use the classification system to get accurate codes for casting.

(ii) There must be a computer print-out with all jobs listed in order of classification numbers and the data necessary for castings listed with these numbers.

(iii) This output must be produced at regular intervals so that changes in costs, method of manufacture and new jobs can be made available to the estimator.

(iv) The cost-estimator should make comparisons between the job to be quoted for and existing jobs by means of the code numbers.

(v) To further identify similarities the cost-estimator should have drawings of all jobs listed in the computer print-out, filed in order of the classification numbers.

(vi) Having read the relevant data from the computer print-out he should complete the "Casting Estimate" form .

(vii) The estimator should ensure that he receives a feedback of actual production data when the casting has been manufactured, for three reasons:

(a) To assess his accuracy and hence improve his ability to estimate.

(b) To allow the computer output to be updated.

(c) So that management can be notified of any apparent production problems.

13. To validate the classification scheme a statistical analysis which considers the correlations between variables and the contribution of the classes towards the cost of a casting, was carried out.

14. The analysis is useful as an approach to be adopted but it should be remembered that estimated and not actual costs were used, hence not too much importance should be placed on the values actually obtained.

15. The analysis indicated the relationship between weight class and cost could not be considered as linear and hence the weight class should be re-defined.

16. The correlation between cost and the six classes analysed showed they were all significant at the 2.5% significance level. The highest correlation with cost was the weight class ($r = 0.928$) followed by the patterns per board class ($r = -0.607$).

17. When the weight class was re-defined appropriately the regression analysis showed the following classes were included in the regression set at the 2% significance level: weight, complexity, patterns per board and material type. These four factors account for 88.2% of the cost of the casting.

18. Analysis indicates that using a cost equation obtained by regression analysis is likely to be at least as accurate as the present cost-estimating system. However, the limitations of the application of the equation must be clearly defined.

19. Further analysis shows that the scrap rate at Johnson Radley is dependent on the weight of a casting and possibly the type of material. This should be reflected in future estimates at Johnson Radley.

20. The approach used at Johnson Radley and the subsequent analysis is considered to be a good one, hence it is outlined for other companies to adopt.

21. Classification could be used as the tool to solve many of the problems that the foundry industry is facing, for example:

    (i) Accurate cost-estimating.
    (ii) Improving product-mix.
    (iii) Defining the market.

22. It may be useful to develop classification systems to define shapes of castings which are to be designed and manufactured with the aid of a computer.

23. Johnson Radley should implement the proposed cost-estimating scheme and when it is successful consider further development for production control and marketing.

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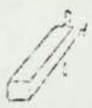
APPENDIX 1A

GROUP 0 Simple castings without cavities	Castings which can be formed naturally according to a solid pattern or according to a pattern with a flat or shaped parting plane. Cores can be used to pre-cast isolated openings. (an opening is a cavity, the cross section of which in the plane perpendicular to the axis is negligible compared with the area of the sectional view in the same plane).
GROUP I Complex castings without cavities	Castings demanding a multi-split pattern, or moulds formed from patterns with the multiple partings areas, losse parts or false cores. Cores can be also used to cast openings. (False cores are those which are parts of the active outer surface of a mould but do not come into contact with molten metal more than by one half of the perimeter of the largest cross-section perpendicular to the wall. It is not decisive whether the core is formed in a core box or in the mould itself).
GROUP 2 Simple hollow castings	Castings with a continuous cavity, the forming of which usually requires one main core. The outer surface of the casting can be moulded naturally. Pre-casting of openings can be done by means of additional cores.
GROUP 3 Complex hollow castings	Castings with a continuous cavity formed with one core or castings with several non-continuous cavities formed with cores. The outer surface of the casting cannot be moulded naturally. It must be moulded by means of a multiple split mould of pattern, loose parts of false cores.
GROUP 4 Hollow case castings	Hollow castings with a number of non-continuous or differentiated cavities formed by means of a number of core systems. Unfavourable diversification of the outer surface requires the use of false cores and complicated ways of splitting the mould and the pattern.

Bar Casting	A casting, the length of which is usually larger than five times the width or diameter and the width is the second largest dimension of the given casting.
Plate Casting	A casting of angular shape, the height of which is less than - or equal to - a half of its width (the second largest dimension).
Prism Casting	A prism-shaped casting, or a casting near to a prism; its height is more than a half of its width.
Frame Casting	A casting of angular shape bounded by straight or arched walls with angular or shaped non-rotational opening. The main inside dimensions are equal at least to one-third of the corresponding outside dimensions. Castings closed from at least three sides (horse-shoe shape) are considered as frame castings.
Rotational Castings	Castings of circular shape or of annular cross-section (or their parts -segments and sectors).
Combined Casting	A casting consisting of two or more basic shapes with none of them clearly prevailing, the shape being incomplete.
Lever Casting	Straight, cranked or a spider-shape castings with local reinforcement.
Pipe Casting	A hollow, lengthwise rotational casting the length of which is more than three-times the outside diameter. Included here are castings which are of indirect or crossing axis of rotation.
Armature Castings	Hollow castings for liquid or gas lines with a continuous cavity with projections for blocking the flow.

APPENDIX 1B

Shape Classes of Castings



Longitudinal Castings

Castings regardless of their geometrical shape, in the framework of the given group, provided that their $L \geq 4B$.

Flat Square Castings

Castings near to a circumscribed prism of which $L \leq 4\ B$ and $H \leq \frac{L + B}{4}$

Flat Rotational Castings

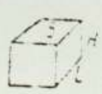
Circular castings the height of which $H \leq 0.5\ D$, and castings of cylindrical shape, the length (L) of which is $3\ D \leq L \leq 4\ D$.

Flat Frame Castings

Flat castings of angular shape $L \leq 4\ L$, $H \leq \frac{L + B}{4}$ with mass at least in its three periphery walls $L \geq 0.5\ L$; $b \geq 0.5\ B$;
area $f \geq 0.25F$.

Flat Combined Castings

Due to irregularities of their shape these cannot be classified among the 0-3 class castings. Theoretically they can be analysed as consisting of sections of the following shape $L \leq 4B$, $H \leq \frac{L + B}{4}$



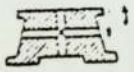
Voluminous Angular Castings

Castings near to a prism circumscribed to a casting $L \leq 4\ D$, $H > \frac{L + B}{4}$

Voluminous Rotational Castings

Circular castings the height (H) of which is $0.5\ D < H < 3\ D$.

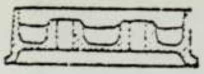
Shape Analysis of a Casting



Massive Castings

These are full of castings, the volume (V) of which is near to the volume of a circumscribed prism V. As a rule, the volume of a casting is $\geq 2/3$ of the volume of the prism. The thickness of the casting t is $\geq \frac{L + B}{12}$

Moulding may be difficult because grooves and bosses are smaller than the thickness of the adjacent wall.



Simple Castings without Cavities

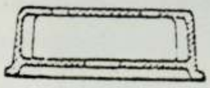
These are castings of ordinary thickness, without cavities, with a naturally moulded surface.

Complex Castings without Cavities

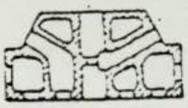
Castings without cavities, of ordinary thickness; their surface is not naturally moulded (i.e. use of cores).

Simple Hollow Castings

Castings of ordinary thickness (as 2) with a simple continuous cavity.

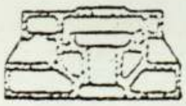


Complex Hollow Castings



Castings with a simple cavity which do not have naturally moulded surface (as 3). Castings with naturally moulded surface with a complex or a simple system of cavities.

Case Castings



Castings with a very complicated system of cavities with a diversified shaped surface that cannot be formed naturally because of the complexity of its internal cavities.

7, 8, 9 reserved for classification of castings not described here.

Voluminous Frame Castings

Voluminous angular castings $L \leq 4\ D,\ H > \frac{L + B}{4}$
with mass $l \geq 0.5\ L;\ b \geq 0.5\ B$
area $f \geq 0.25\ F$

Voluminous Combined Castings

Castings that cannot be classified as 0 - 7 due to their irregular shape. Theoretically they can be analysed as consisting of sections of the following shape: $L \leq 4\ B;\ H > \frac{L + E}{4}$

Voluminous Spheric Castings

Castings of spheric shape - L = D = H = D

Classification according to Weight

1.			Up to	8 kg.
2.	over	8 kg.		25 kg.
3.		25 kg.		80 kg.
4.		80 kg.		250 kg.
5.		250 kg.		800 kg.
6.		800 kg.		2,500 kg.
7.		2,500 kg.		8,000 kg.
8.		8,000 kg.		25,000 kg.
9.		25,000 kg.		

Classification according to Length

1.			up to	100 mm.
2.	over	100 mm.		160 mm.
3.		160 mm.		250 mm.
4.		250 mm.		400 mm.
5.		400 mm.		650 mm.
6.		650 mm.		1,000 mm.
7.		1,000 mm.		2,000 mm.
8.		2,000 mm.		4,000 mm.
9.		4,000 mm.		

Classification according to Thickness

Classification Degree	Shape Groups (7th Digit of a Code)	
	0	1 - 8
1.	$\frac{1}{8} L \leq B < \frac{1}{4} L$	$\frac{3}{4} L \leq B < L$
2. A	$1/16 L \leq B < \frac{1}{8} L$	$\frac{1}{2} L \leq B < \frac{3}{4} L$
3. Thin Wall Castings	$B < 1/16L$	$\frac{1}{4} L \leq B < \frac{1}{2} L$
4.	$\frac{1}{8} L \leq B < \frac{1}{4} L$	$\frac{3}{4} L \leq B < L$
5. B	$1/16 L \leq B < \frac{1}{8} L$	$\frac{1}{2} L \leq B < \frac{3}{4} L$
6. Ordinary Thickness	$B < 1/16L$	$\frac{1}{4} L \leq B < \frac{1}{2} L$
7.	$\frac{1}{8} L \leq B < \frac{1}{4} L$	$\frac{3}{4} L \leq B < L$
8. C	$1/16 L \leq B < \frac{1}{8} L$	$\frac{1}{2} L \leq B < \frac{3}{4} L$
9. Thick Wall Castings	$B < 1/16L$	$\frac{1}{4} L \leq B < \frac{1}{2} L$

Detailed Classification by Weight of
Castings up to 8 kg.

Castings of the weight

1.			up to	0.8 g.
2.	over	0.8 g.		2.5 g.
3.		2.5 g.		8 g.
4.		8 g.		25 g.
5.		25 g.		80 g.
6.		80 g.		250 g.
7.		250 g.		800 g.
8.		800 g.		2,500 g.
9.		2,500 g..		8,000 g.

Classification of Castings by Area
(Castings up to the weight of 8 kg.)

Area of a Casting

1.			up to	2.5 cm^2
2.	over	2.5 cm^2		10 cm^2
3.		10 cm^2		25 cm^2
4.		25 cm^2		50 cm^2
5.		50 cm^2		100 cm^2
6.		100 cm^2		200 cm^2
7.		200 cm^2		350 cm^2
8.		350 cm^2		800 cm^2
9.			over	800 cm^2

The area of a casting in its parting plane is determined as a product of two largest mutually perpendicular dimensions in the parting plane.

Classification by Tolerance

Castings	Quality		
	Ordinary	Sampled	Tested
Ordinary Tolerance	1	2	3
Increased Tolerance	4	5	6
Highest Tolerance	7	8	9
	Class of Tolerance		

Specification of Terms used for Castings of:

Ordinary Tolerance: degree of tolerance according to CSN (Standard No.) 01 4470 0.5

Increased Tolerance: CSN 01 4470 0.4, 0.3

Highest Tolerance: CSN 01 4470 0.2, 0.1

Ordinary Quality: Castings approved on the basis of visual check-up, faultless with regard to their serviceability.

Sampled Quality: besides visual check-up the material is tested by individual tests or by means of a system of tests.

Tested Quality: besides visual check-up and material tests, special tests are carried out to prove the homogeneity of a casting.

APPENDIX 1C

CLASSIFICATION OF SHAPE AND COMPLEXITY

Shape Group	Shape Class	Sub-Group	Coding
With one or more Simple Cavities, without Facets of Openings	Longitudinal	Symmetric in 3 Dimensions	0
With one or more Simple Cavities, with Openings	Rotational (Flat)	Symmetric in 2 Dimensions	1
Without Cavities, with or without Facets or Openings	Rotational	Symmetric in 1 Dimension	2
With one or more Simple Cavities, with Facets	Rotatonal (Voluminous)	Graduated	3
Without Cavities, with Facets and Openings	Flat Angular	Concaved	4
With one or more Simple Cavities, with Facets and Openings	Flat Frame	Ribbed	5
With one or more Complex Cavities, or without Facets and/or Openings	Flat Combined	Diversified	6
-	Voluminous Angular	Spatial	7
-	Voluminous Frame	Tapered	8
-	Voluminous Combined	-	9

CLASSIFICATION OF MATERIAL

Branch of Material	Coding	Specification of Material
-	0	Grade 14
Grey Iron	1	Grade 17
-	2	Grade 20
Vantage Iron	3	-
White Cast Iron	4	AP 202A
S.G. Iron - as cast	5	AP 202B
S.G. Iron - Pearlitic	6	-
S.G Iron - Ferritic	7	-
Malleable - Pearlitic	8	-
Malleable - Ferritic	9	-

CLASSIFICATION OF STYLE

Weight Range (Kg.)	Coding
0 - 3.0	0
3.1 - 6.0	1
6.1 - 10.0	2
10.1 - 15.0	3
15.1 - 20.0	4
20.1 - 30.0	5
30.1 - 40.0	6
40.1 - 50.0	7
50.1 - 60.0	8
Over 60	9

CLASSIFICATION OF PATTERNS PER BOARD

Patterns Per Board	Coding
1	1
2	2
3	3
4	4
5	5
6 - 7	6
8 - 9	7
10 - 14	8
15 - 24	9

APPENDIX 2

CASTING ESTIMATE

CUSTOMER	EST. NO.
DESCRIPTION	DATE
PART NO.	EST. WGT.
QTY.	METHOD
MATL. SPEC.	YIELD
SCRAP RATE	PATTERNS

METAL MELTING	QTY.	WGT.	RATE	VALUE	VALUE
GROSS					
SCRAP					
		SUB TOTAL			

COST CENTRES	DETAILS	RATES	VALUE	
COREMAKING				
MOULDING				
FETTLING				
HEAT TREATMENT				
	SUB TOTAL			

OTHER EXPENSES	DETAILS	RATES	VALUE	
REJECT RES.				
CONTRIBUTION				
DELIVERY				
	SUB TOTAL			

	EACH	£/T	£/BOX	
EST.				
QUOTE				

APPENDIX 3

CLASSIFICATION NUMBER	PART NUMBER	PRICE	WEIGHT (KG)	PATTERNS PER BOARD	CORES PER CASTING	CORE MAKING SUVS	TOTAL QUANTITY MADE	TOTAL QUANTITY SCRAPPED	SCRAP RATE %	TOTAL QUANTITY ISSUED
002381	1306	0.65	2,6	12	0	0.0	216	1	4.6	198
020061	2828	0.99	2,2	6	0	0.0	84	1	1.2	83
020082	2903	0.53	0,8	10 M	0	0.0	1080	80	7.4	963
020381	2708	0.72	1,3	8	0	0.0	512	14	2.7	459
021881	0302	0.80	2,9	8 R	0	0.0	1228	37	3.0	1194
024281	0802	0.29	1,3	8 -R	0	0.0	4330	37	0.9	4045
026011	2811	2.19	1,0	1 F	0	0.0	4	0	0.0	4
032381	2837	0.50	1,0	10	0	0.0	190	2	1.1	188
034281	2807	0.86	1,6	10	4	2.0	100	0	0.0	99
035281	2817	0.71	2,2	8	1	3.3	96	2	2.1	94
037491	2802	0.34	0,7	18	3	0.6	375	8	2.1	350
040361	1321	0.70	2,8	6	1	6.7	340	0	0.0	282
042091	2833	0.56	1,1	16	1/8	3.3	96	18	18.8	78
042381	2806	0.53	1,6	11	1	3.3	1177	0	0.0	1175
045091	1601	0.77	1,5	16	1	6.7	1280	73	5.7	1180
047068	0201	1.05	2,4	6 M	1	8.3	2502	216	8.7	2088
047682	0801	0.41	1,0	8	1	8.0	592	0	0.0	592
048211	2822	1.39	2,4	1	1	11.7	106	10	9.4	52
056211	2812	2.19	1,1	1 F	0	0.0	2	0	0.0	2
057361	0109	1.71	2,8	6 R	2	18.7	350	0	17.0	319
101361	1802	1.02	5,2	6 R	0	5.2	12	0	0.0	12
120021	2706	2.31	5,8	2	0	0.0	192	4	20.8	188
120031	2823	1.25	4,2	3	0	0.0	65	2	3.1	63
120331	1322	1.75	4,8	3 W	0	0.0	169	3	1.8	165
120332	2304	2.43	5,9	3 R	0	0.0	222	17	7.6	193
120341	2827	1.35	4,0	4	0	0.0	52	0	0.0	52
120041	2826	1.22	3,2	4	0	0.0	64	3	4.7	61
121362	1104	1.60	5,8	6 R	0	0.0	230	13	5.7	212
121363	1101	1.49	5,2	6 R	0	0.0	132	1	0.8	131
121381	2825	1.50	3,0	8	0	0.0	24	0	0.0	24
121651	1325	1.12	4,5	5	0	0.0	160	4	2.5	156
121761	2820	1.87	5,6	6	0	0.0	54	0	0.0	57
126343	1102	1.49	5,6	4 R	0	0.0	224	14	6.3	191
131662	0505	1.88	3,0	6 R	4	5.0	230	13	5.7	212
140821	2801	3.21	4,8	2	1	3.0	24	2	8.3	22
141311	0404	2.31	5,0	1 M	1	5.0	332	16	4.8	316
141311	2835	0.97	3,0	3	1	8.3	149	2	1.3	147
141331	2805	1.95	5,0	3	2	1.3	48	3	6.3	45
141331	2813	1.62	4,8	3	2	13.3	87	10	11.5	89
141381	2810	1.03	5,0	10	1	5.0	110	1	0.9	95
141582	1323	1.10	4,3	8	0	0.0	2616	82	3.1	2328
142161	2816	1.59	5,8	6	1	8.3	144	8	5.6	136
142381	2824	1.82	4,0	8	1	5.0	24	3	12.5	21
142771	2705	0.83	4,0	8	1	3.3	550	6	10.9	542
142861	1801	1.16	4,8	6 M	1	6.0	653	94	14.2	552
145382	1003	1.43	4,2	8 R	1	4.0	3159	498	15.7	1795
145382	1004	1.30	3,0	8 R	1	5.0	16	4	25.0	9
146341	1602	1.32	4,6	4 R	1	13.3	636	101	15.9	564
147382	0104	1.54	4,2	8 R	2	19.0	2527	214	8.5	2296
148362	1001	1.19	3,3	6 R	1	5.4	12	0	0.0	12
148362	1002	1.43	4,0	6 R	1	6.0	1847	117	6.3	1497
151062	2901	1.60	4,7	6 R	2	11.0	1384	12	0.9	1249
157621	2839	1.19	4,6	6	2	13.3	156	5	3.2	135
157941	0105	2.26	4,3	4	4	4.2	1850	66	3.6	176
204031	1907	1.65	7,6	3 W	0	0.0	166	38	22.9	120
211351	1304	1.53	6,5	5	1	3.3	344	4	10.0	341
220041	2821	1.82	7,6	4	0	0.0	76	2	2.6	73
221042	2902	2.00	8,2	4 M	0	0.0	1124	84	7.5	959
220311	1315	1.75	7,3	1	0	0.0	40	0	0.0	40

221332	0601	2.22	8.0	3		0	0.0	105	22	94.5	6
223221	1401	2.63	8.0	2		1	11.7	222	46	20.7	176
224021	1903	1.33	6.6	2		0	0.0	93	0	0.0	93
224022	2603	4.28	7.7	2	W	0	0.0	38	6	15.8	28
224062	1501	1.58	7.4	6	R	1	3.0	138	11	8.0	110
225761	1502	2.12	9.0	6		0	0.0	288	6	20.8	261
230922	0510	2.76	6.8	2		1	33.3	12	6	50.0	6
234421	2819	2.92	8.6	2		1	2.5	66	0	0.0	57
240321	1318	2.63	7.4	2		1	8.7	102	9	8.8	91
240321	1319	2.63	7.6	2		1	6.0	102	2	2.0	100
240321	2858	2.53	7.0	2		1	1.6	40	14	35.0	22
240332	0602	1.89	6.8	3		0	0.0	355	2	0.6	123
240741	2809	1.79	6.2	4		1	1.7	32	4	12.5	28
241321	0401	3.24	8.8	2	R	1	10.0	593	31	5.2	457
241321	0403	3.24	7.6	2	R	1	5.2	713	43	6.0	7
241321	2832	3.02	9.0	2		2	16.6	22	0	0.0	22
241321	2836	0.96	7.6	2		1	18.7	65	2	3.1	63
241361	2830	2.02	8.2	6		1	5.0	30	0	0.0	30
242341	0901	2.02	6.4	4	M	1	5.5	1480	483	32.6	779
242341	0902	2.27	7.2	4	M	1	8.6	164	91	55.4	113
242363	1301	1.51	6.4	6	M	1	5.0	1079	99	9.1	708
244221	2503	4.14	8.6	2	M	2	25.0	350	2	0.6	3
247051	2103	2.15	7.8	5		2	6.2	290	22	7.6	257
252122	0509	4.05	9.6	2		2	14.0	20	4	20.0	1
252621	0502	2.76	6.8	2		1	33.3	12	6	50.0	6
254621	2814	2.87	8.6	2		1	8.3	74	3	4.1	70
266922	2302	4.27	9.4	2	M	2	19.0	848	113	13.3	696
267921	0103	1.54	3.2	2		6	13.0	138	14	10.1	120
300321	2815	2.94	13.2	2		0	0.0	36	3	8.3	20
305043	2101	2.55	12.0	4		0	0.0	36	10	27.8	26
320011	1805	3.68	14.0	1		0	0.0	14	3	21.4	11
320021	1803	2.32	12.4	2	R	0	12.4	3087	37	1.2	2900
320031	2707	2.10	10.2	3		0	0.0	363	17	4.7	290
320321	1302	3.88	10.2	2		1	8.7	116	8	7.0	108
320322	1103	3.00	12.2	2	R	0	0.0	370	16	4.3	350
320822	1904	3.47	10.2	2		0	0.0	89	0	0.0	89
322741	2703	3.23	14.5	4		0	0.0	810	37	4.6	528
324223	0702	3.68	10.4	2		1	7.5	1042	96	9.2	883
326332	0607	3.63	13.6	2	W	0	0.0	173	73	42.2	90
331310	2501	5.02	14.2	1		1	2.0	11	7	63.7	4
340311	2834	3.65	12.4	1		2	33.3	10	0	0.0	10
340321	1312	3.87	14.2	2		1	7.0	632	12	2.0	497
341021	1314	3.61	11.0	2		1	18.7	161	8	5.0	142
340321	1317	3.86	12.6	2		1	4.8	110	11	10.0	84
341041	1905	2.72	11.0	4		1	3.5	12	0	0.0	12
341311	0406	3.53	10.2	1	R	1	6.0	28	5	17.9	23
341321	0402	3.53	10.0	2	R	1	25.0	66	0	0.0	66
341321	1310	3.01	14.5	2		2	8.8	750	15	2.0	553
341321	1806	2.16	11.2	2	R	2	3.0	88	10	11.4	78
342612	0303	4.42	13.2	1		2	33.3	9	3	33.3	6
341621	1307	2.47	10.2	2		1	5.4	242	2	0.8	216
341622	2201	3.03	14.6	2		1	4.0	178	2	1.1	171
354221	2818	2.92	10.0	2		4	16.6	48	1	2.1	47
372322	0604	4.36	12.9	2		1	10.9	146	13	8.9	65
376922	3001	4.06	10.2	2		3	10.2	6	2	33.3	4
420321	0112	2.37	8.6	2	W	0	0.0	64	0	0.0	64
420321	1303	5.32	19.1	2		1	9.0	112	25	22.3	91
420322	0603	4.08	17.5	2		0	0.0	256	103	39.7	92
434426	1202	7.15	17.8	2	R	1	1.8	136	4	2.9	125
440311	0405	5.84	17.8	1		1	5.0	276	65	23.6	206
440611	2504	8.48	20.8	1		3	25.0	90	[illegible]	[illegible]	82
441321	1906	7.25	18.6	2		1	25.0	12	1	[illegible]	12
441621	1508	3.77	17.0	2		1	5.6	348	13	2.9	298

[illegible]	[illegible]	[illegible]	19.4	1	R	1	18.7	346	104	30.6	203
447321	0301	5.06	18.2	2	AL	2	33.3	200	9	4.0	135
448611	2808	6.27	17.8	1		1	33.3	53	2	5.8	37
457221	2831	4.97	18.2	2		2	33.3	17	0	0.0	17
462922	2301	4.59	19.0	2	R	1	5.0	660	20	4.4	633
468311	0111	7.87	17.8	1		1	33.3	117	8	6.8	109
524213	0701	5.28	22.5	1		0	3.5	577	58	6.6	424
534426	1201	8.11	26.6	2	R	2	4.0	206	14	6.8	104
536211	2804	5.77	27.0	1	W	3	19.0	52	6	11.5	45
540021	1326	7.08	29.6	1		1	19.0	324	32	9.9	7
541312	1316	4.92	20.0	1		1	5.0	26	1	3.8	25
541321	1311	5.31	23.0	2		2	4.0	92	28	30.4	62
541611	2302	5.45	23.6	1		1	9.0	146	11	7.5	133
542321	0106	5.54	24.0	2	R	1	6.5	150	10	7.7	115
542612	0304	9.41	20.6	1		2	40.3	106	3	2.8	79
547012	1701	7.61	26.2	1		1	18.0	437	54	22.8	344
547322	0606	6.49	24.4	2	W	2	15.0	129	10	7.8	56
552412	0308	9.41	29.2	1		2	40.3	97	51	52.6	32
554612	2001	11.60	24.0	1		2	50.0	4	0	0.0	4
565212	2701	10.04	24.0	1		5	18.2	187	86	46.0	49
565912	2702	9.26	20.2	1		2	15.6	4	0	0.0	4
625221	1305	10.47	39.3	2		0	0.0	20	9	45.0	11
641012	0605	8.82	36.1	1		0	0.0	207	87	42.0	77
641311	1804	8.01	38.6	1	R	1	8.0	158	60	38.0	83
641321	1908	8.02	30.6	2		1	19.0	52	18	34.6	31
642021	2829	8.47	35.2	2		1	16.6	56	38	64.3	18
642021	1902	8.82	33.4	2	W	1	19.0	28	4	14.3	24
642412	0306	9.63	36.6	1		2.5	18.7	1276	48	3.8	740
644612	2602	11.94	35.8	1		1	10.0	37	7	18.9	26
645011	2803	1.24	30.2	1		2	33.3	75	18	24.0	51
650611	2305	6.80	31.4	1	AL	1	2.1	28	4	14.3	24
668311	0102	11.55	30.3	1		2	20.0	95	6	6.3	63
724011	1320	10.59	47.0	1	W	0	0.0	27	4	14.8	23
734416	1203	12.54	42.4	1		2	3.2	202	8	4.0	191
741211	2704	11.86	42.6	1		1	22.0	162	11	6.8	148
741311	1324	12.38	49.4	1		1	18.7	100	15	15.0	85
742412	0301	10.97	45.0	1	R	2.5	21.7	644	80	12.4	519
764412	2601	13.55	47.8	1		6	8.2	34	2	5.9	32
767911	0107	6.93	16.8	1		5	35.0	236	73	30.9	154
767911	0101	15.13	46.8	1	W	4	40.0	96	19	19.8	78
841022	1901	13.91	58.0	2		1	33.0	32	19	59.3	13
855811	2102	13.14	57.2	1		5	175.0	12	3	25.0	9
877911	0108	11.89	50.5	1		2	52.0	597	38	6.3	562

ALL PRICES ARE JANUARY 1975 MANY HAVE JUST HAD A PERCENTAGE INCREASE ADDED ON

THERE ARE 170 CASTINGS LISTED

APPENDIX 4A

	MEAN	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION
CONST	1.000			
WEIGTD	7.997	0.000	38.055	9.029
CMPLXD	3.518	0.000	7.000	1.381
GEOMED	2.629	0.000	8.000	2.521
DESCRD	3.353	0.000	9.000	2.470
PTTNSD	3.182	1.000	9.000	2.395
MATRLD	2.776	2.000	44.000	5.545
COST	3.999	0.290	15.150	3.394
WEIGHT	13.633	0.700	58.000	12.616
PATTNS	3.441	1.000	18.000	3.083
CORES	1.154	0.000	6.000	1.185
CRESUV	10.527	0.000	175.000	16.941
SCRAP	11.951	0.000	94.300	15.209

CORRELATION MATRIX

	WEIGTD	CMPLXD	GEOMED	DESCRD	PTTNSD	MATRLD	COST	WEIGHT	PATTNS	CORES
WEIGTD	1.000	0.308	0.113	0.091	- 0.568	0.168	0.928	0.980	- 0.519	0.310
CMPLXD	0.308	1.000	0.349	0.380	- 0.258	- 0.057	0.377	0.288	- 0.211	0.617
GEOMED	0.113	0.349	1.000	0.138	0.029	0.076	0.167	0.100	0.061	0.382
DESCRD	0.091	0.380	0.138	1.000	- 0.104	0.032	0.167	0.077	- 0.110	0.359
PTTNSD	- 0.568	- 0.258	0.029	- 0.104	1.000	- 0.083	- 0.607	- 0.568	0.939	- 0.196
MATRLD	0.168	- 0.057	0.076	0.032	- 0.083	1.000	0.206	0.161	- 0.077	0.054
COST	0.928	0.377	0.167	0.167	- 0.607	0.206	1.000	0.932	- 0.559	0.367
WEIGHT	0.980	0.288	0.100	0.077	- 0.568	0.161	0.932	1.000	- 0.526	0.294
PATTNS	- 0.519	- 0.211	0.061	- 0.110	0.939	- 0.077	- 0.559	- 0.526	1.000	- 0.139
CORES	0.310	0.617	0.382	0.359	- 0.196	0.054	0.367	0.294	- 0.139	1.000
CRESUV	0.493	0.423	0.253	0.267	- 0.309	- 0.063	0.498	0.485	- 0.275	0.493
SCRAP	0.286	0.065	0.011	- 0.011	- 0.218	- 0.066	0.286	0.313	- 0.210	0.053

	CRESUV	SCRAP
WEIGTD	0.493	0.286
CMPLXD	0.423	0.065
GEOMED	0.253	0.011
DESCRD	0.267	- 0.011
PTTNSD	- 0.309	- 0.218
MATRLD	- 0.063	- 0.066
COST	0.498	0.286
WEIGHT	0.485	0.313
PATTNS	- 0.275	- 0.210
CORES	0.493	0.053
CRESUV	1.000	0.159
SCRAP	0.159	1.000

REGRESSION ANALYSIS

DEPENDENT VARIABLE COST DEGREES OF FREEDOM 165

INDEPENDENT VARIABLES AT SIGNIFICANT LEVEL 2,00 %

WEIGTD CMPLXD GEUMFD DESCRD PTTNSD MATRLD

VARIABLES IN THE REGRESSIUN SET

VAR NAME	REGRESSIUN COEFF	STANDARD ERROR	CONFIDENCE INTERVAL	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
WEIGTD	0,3108988	.126185E- 1	.295905E- 1	24,64	0,89	0,672	.106836E 4
CMPLXD	0,2434275	.697044E- 1	.163457E 0	3,49	0,20	0,935	.245178E 3
PTTNSD -	0,1497220	.461817E- 1	.108296E 0	3,24	-0,24	0,936	.242873E 3
MATRLD	0,0391681	.166693E- 1	.390894E- 1	2,35	0,18	0,937	.235969E 3

VARIABLES NOT IN THE REGRESSIUN SET

VAR NAME	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
GEOMED	1,54	0,12	0,940	.225053E 3
DESCRD	1,70	0,15	0,941	.224365E 3
WEIGHT	4,08	0,30	0,945	.207285E 3
PATTNS	0,52	-0,04	0,940	.227947E 3
CORES	1,23	0,10	0,940	.226243E 3
CRESUV	0,90	0,07	0,940	.227202E 3
SCRAP	0,95	0,07	0,940	.227085E 3

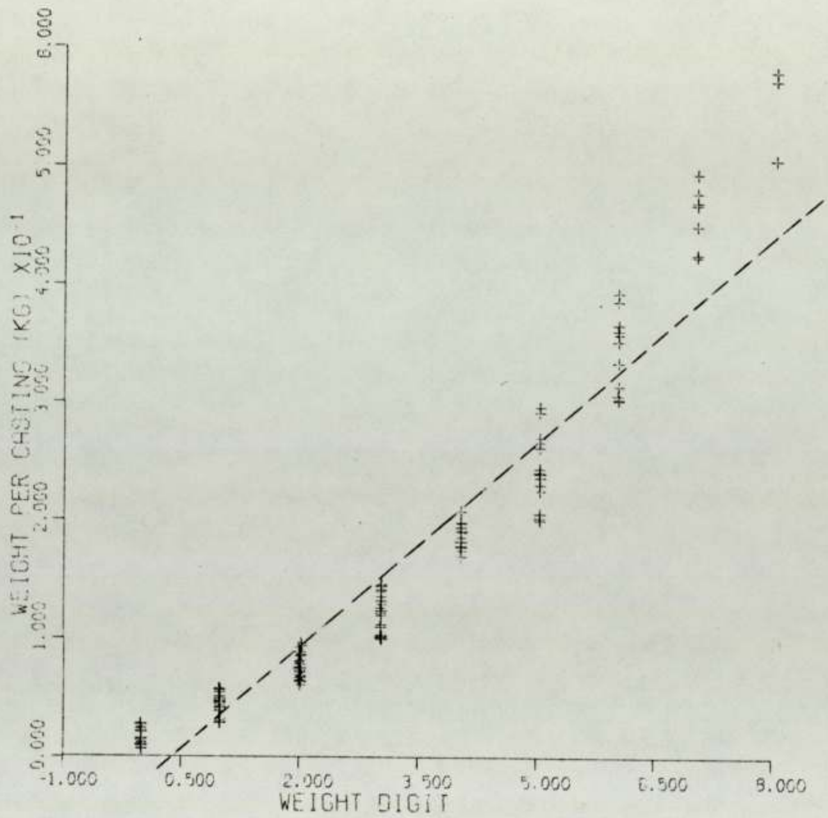
E.S.S. .228328E 3

RESIDUAL ERROR .117635E 1

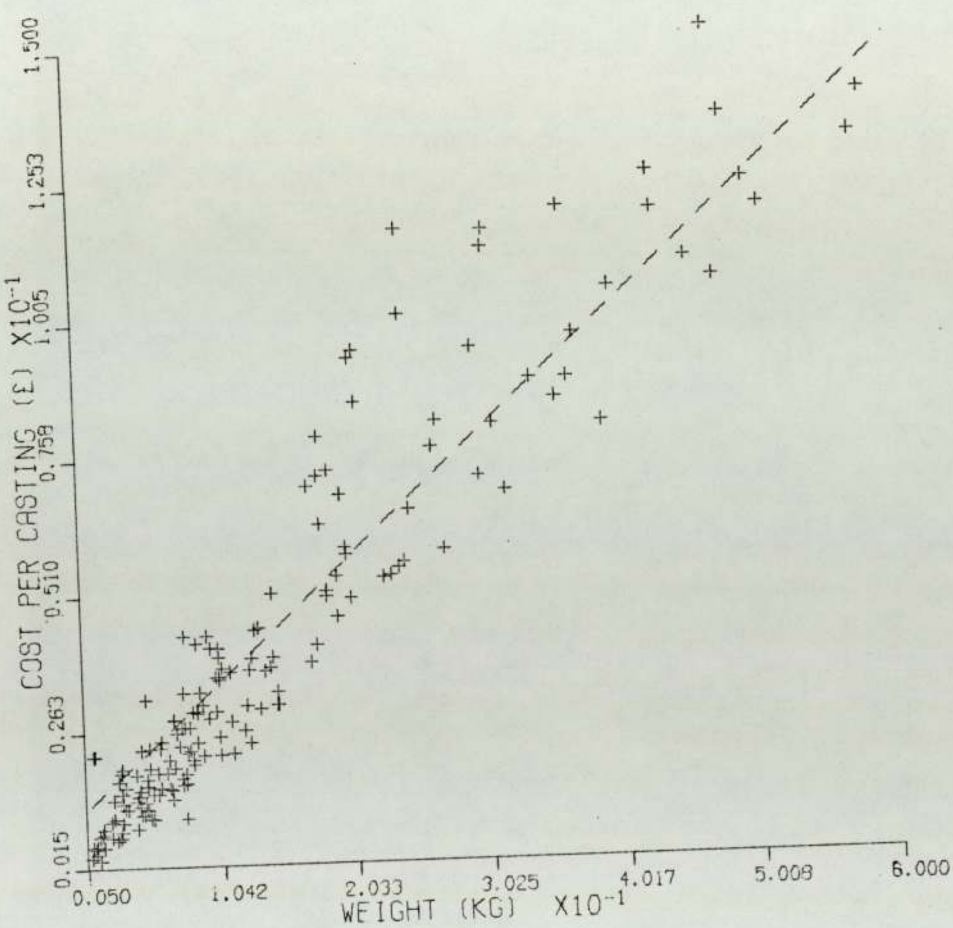
MULT CORR 0,940

INTERCEPT TERM 1.0246880

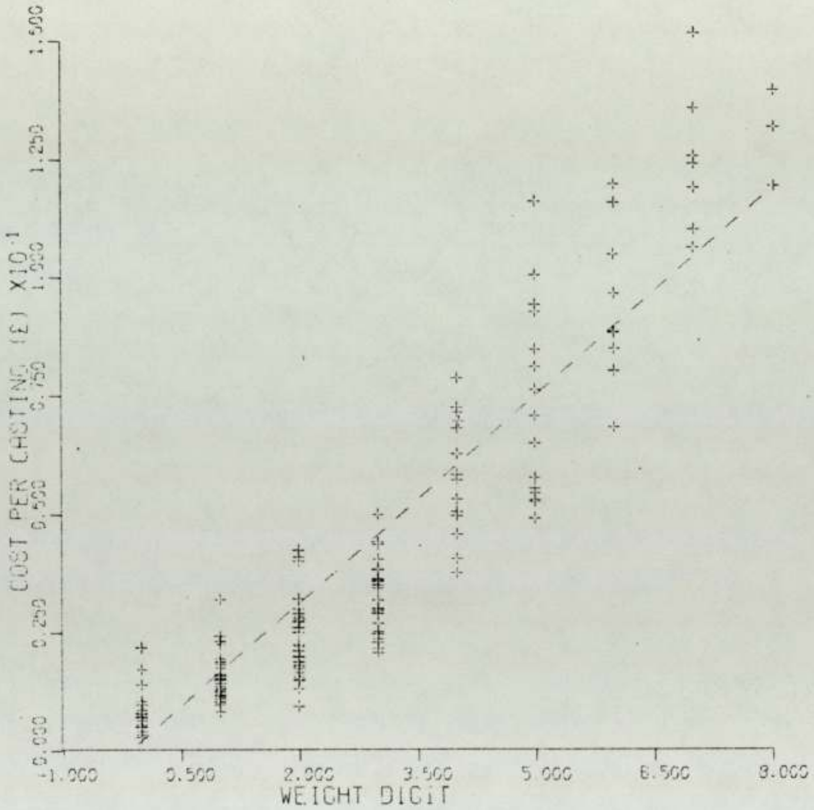
APPENDIX 4B



GRAPH PLOTTING WEIGHT DIGIT V WEIGHT



GRAPH PLOTTING COST V WEIGHT



GRAPH PLOTTING COST V WEIGHT DIGIT

APPENDIX 4C

REGRESSION ANALYSIS

DEPENDENT VARIABLE COST DEGREES OF FREEDOM 169

INDEPENDENT VARIABLES AT SIGNIFICANT LEVEL 5,00 %

WEIGHT PATTNS CORES

VARIABLES IN THE REGRESSION SET

VAR NAME	REGRESSION COEFF	STANDARD ERROR	CONFIDENCE INTERVAL	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
WEIGHT	0.2288619	.861302E- 2	.169947E- 1	26,56	0,90	0.630	.117272E 4
PATTNS -	0.1072959	.340373E- 1	.671216E- 1	3,15	-0,24	0,937	.236819E 3
CORES	0.2936824	.783295E- 1	.155452E 0	3,73	0,28	0,936	.242126E 3

VARIABLES NOT IN THE REGRESSION SET

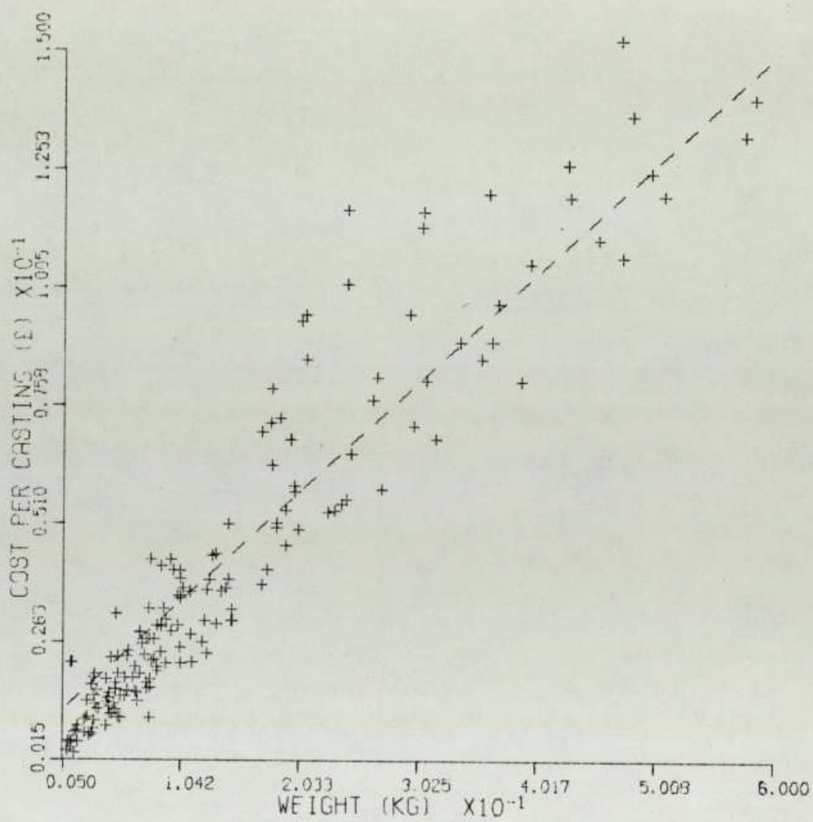
VAR NAME	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
WEIGTD	1,26	0,10	0,941	.221329E 3
CMPLXD	2,38	0,18	0,943	.216036E 3
GEOMED	2,06	0,16	0,942	.217821E 3
DESCRD	2,25	0,17	0,943	.216783E 3
PTTNSD	1,39	-0,11	0,942	.220872E 3
MATRLD	2,18	0,17	0,943	.217106E 3
CRESUV	0,37	0,03	0,941	.223253E 3
SCRAP	0,25	-0,02	0,941	.223356E 3

E.S.S. .223443E 3

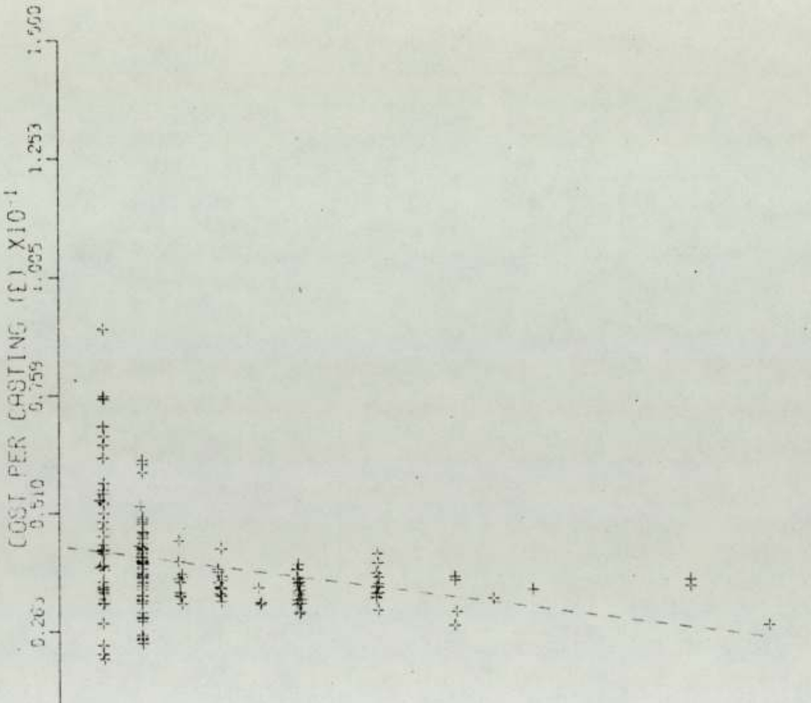
RESIDUAL ERROR .116019E 1

MULT CORR 0,941

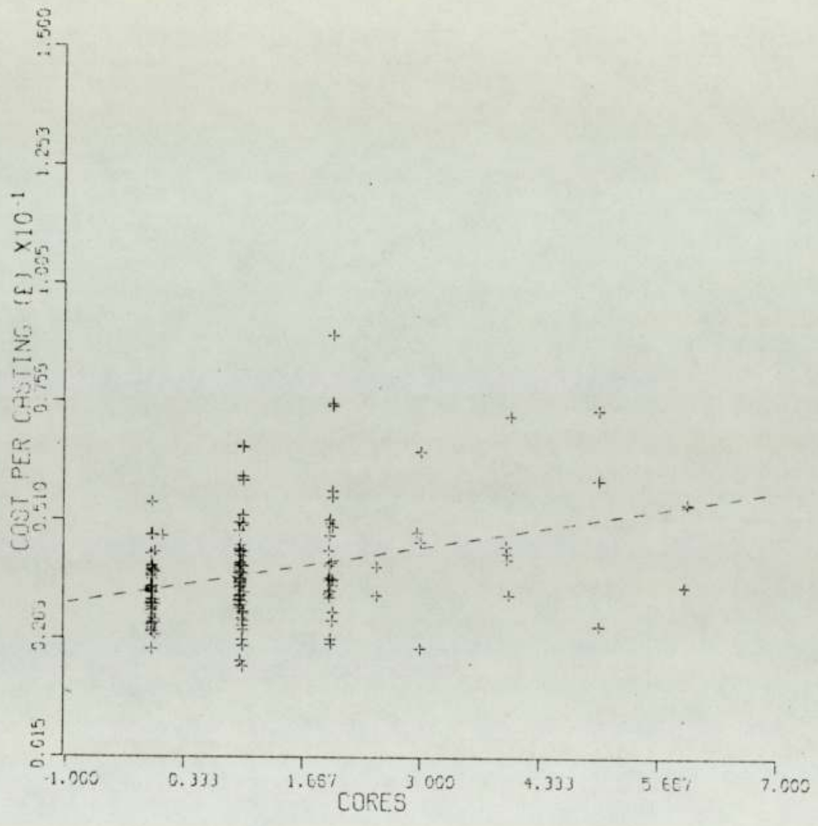
INTERCEPT TERM 0,9091226



GRAPH PLOTTING COST V WEIGHT



GRAPH PLOTTING COST V PATTERNS



GRAPH PLOTTING COST V NUMBER OF CORES

REGRESSION ANALYSIS

DEPENDENT VARIABLE SCRAP DEGREES OF FREEDOM 167

INDEPENDENT VARIABLES AT SIGNIFICANT LEVEL 20,00 %

WEIGTD CMPLXD GEOMED DESCRD PTTNSD MATRLD COST

VARIABLES IN THE REGRESSION SET

VAR NAME	REGRESSION COEFF	STANDARD ERROR	CONFIDENCE INTERVAL	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
WEIGTD	0.5154810	.125764E 0	.161732E 0	4,10	0.30	0.066	.382213E 5
MATRLD -	0.3225408	.204303E 0	.263376E 0	1,57	-0,14	0,286	.358889E 5

VARIABLES NOT IN THE REGRESSION SET

VAR NAME	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
CMPLXD	0,51	-0.04	0.311	.353082E 5
GEOMED	0,20	-0.02	0.309	.353552E 5
DESCRD	0,48	-0.04	0.311	.353155E 5
PTTNSD	0,89	-0,07	0.316	.351976E 5
COST	0,96	0.07	0.317	.351670E 5
WEIGHT	2,75	0,21	0,367	.338225E 5
PATTNS	0,95	-0.07	0.317	.351717E 5
CORES	0,50	-0.04	0.311	.353099E 5
CRESUV	0,01	0.00	0.309	.353637E 5

E.S.S. .353637E 5

RESIDUAL ERROR .145519E 2

MULT CORR 0.309

INTERCEPT TERM 8.7244800

REGRESSION ANALYSIS

DEPENDENT VARIABLE SCRAP DEGREES OF FREEDOM 168

INDEPENDENT VARIABLES AT SIGNIFICANT LEVEL 5.00 %

WEIGTD CMPLXD GEOMED DESCRD PTTNSD MATRLD COST

VARIABLES IN THE REGRESSION SET

VAR NAME	REGRESSION COEFF	STANDARD ERROR	CONFIDENCE INTERVAL	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
WEIGTD	0.4821744	.124518E 0	.245549E 0	3.87	0.29	0.00[illegible]	.390922E 5

VARIABLES NOT IN THE REGRESSION SET

VAR NAME	T STAT	PART CORR	MULTIPLE CORRELATION	F S S
CMPLXD	0.32	-0.02	0.287	.358645E 5
GEOMED	0.29	-0.02	0.287	.358709E 5
DESCRD	0.50	-0.04	0.289	.358351E 5
PTTNSD	0.90	-0.07	0.294	.357138E 5
MATRLD	1.57	-0.12	0.309	.353637E 5
COST	0.74	0.06	0.291	.357732E 5
WEIGHT	2.79	0.21	0.351	.342801E 5
PATTNS	0.97	-0.07	0.295	.356889E 5
CORES	0.50	-0.04	0.289	.358345E 5
CRESUV	0.27	0.02	0.287	.358729E 5

E.S.S. .358889E 5

RESIDUAL ERROR .146159E 2

MULT CORR 0.286

INTERCEPT TERM 8.0953026

APPENDIX 5

THE USE OF MOP FOR STATISTICAL ANALYSIS

This is not intended as a users guide to the MOP terminals as there are many publications which are satisfactory for the purpose (31, 32). However, it may help the reader to know the way in which the statistics and graph plotting packages may be used with MOP terminals.

There is considerable time to be saved by using MOP, it is possible to get many outputs per day compared with perhaps two, using cards.

At the time of writing anybody who has a user number at the Aston University Computer Centre is free to use MOP and direct access to core is available from 800 and 2000 hours for jobs under 40K provided they are already compiled. (Both the packages are in binary form). Jobs over 40K may be put ON LINE and will usually be run during the night.

For both packages a file must be generated in which every line on a listing of the file is exactly as would be punched on cards if the job was submitted on cards. The only exceptions to this is there will not be a line equivalent to the job card.

It is suggested that all data required in the analyses be punched on cards as described in Statistics Package Handbook. It may also be adviseable to punch the instruction cards for the package.

Within 15 minutes of submission of the cards the file should be stored on disk and MOP may now be used to run the programme. If core on MOP is being used the steps for the ICL statistics package log in and:

(i) MZ 25000 (This assigns the computer's core, 25000 should be large enough for most jobs).

(ii) UASTATSXDS3 DATA filename.

The job will now run and if there is a mistake in the file one of the standard error messages will be typed on the terminal. The operator may edit the file and try again i.e. repeat (i) and (ii).

When using MOP for the "Multiple Regression Presentation Programme" the graphs will usually be plotted during the night.

Like the statistical package, the file must first be established.

This program takes longer and requires more core than the statistics package, the instructions after logging in will be:

(i) MZ 32000

(ii) UAAP UA13 DATA filename, TIME 200,*GP

During the running of this programme a file will be created in the users director called UAGRAPHPLOT (abcd) where abcd is the generation number. This file may be erased once the graph has been plotted. Furthermore, a second copy of this graph may be plotted by submitting one card punched with the users number starting in column 13, and UAGRAPHPLOT (abcd) starting in column 25. The word "REPLOT" should also be written on the card.

APPENDIX 6

PROPOSALS FOR FURTHER DEVELOPMENT OF THE CLASSIFICATION SCHEME

The classification scheme has now been developed to the point where one can foresee in the near future a useable system for cost estimating jobs and providing a data base which will allow effective decision making regarding the type of work which will best satisfy Johnson Radley's needs, i.e. it will provide a marketing tool.

To finalise the scheme the following still need to be done:-

(i) The necessary data needs to be collected.

(ii) A system for collecting new data on a regular basis needs to be instituted.

(iii) For a fully effective system the information should be put on computer so that periodic changes can be automatically processed.

The opinion of those who have worked on the development of this system is that it has great potential, not only in the relatively small area for which it was developed, but as a total system throughout the foundry.

Having learnt something of Johnson Radley's problems on the general engineering side during my visits to the company, I am of the opinion that the classification scheme could do a great deal in finding solutions.

In particular, with further development work the classification could be used effectively for the following:-

(i) To close the 'gap' between Production and Sales, because a classification scheme gives a basis for decisions; it will allow Production to define the more preferable type of jobs and the job mix. It will allow Sales to define the type of jobs it needs and can get. The result will be a more satisfactory job mix as far as the whole company is concerned.

(ii) Classification as a production scheduling tool appears to be a simple, empirical way of optimising the many variables that go into the production of castings, for example, the core shop, the moulding machines, the core setting, pouring and the biggest bottle-neck of all, fettling.

The growing confidence that the people working on this project have gained leads me to the conclusion that with proper support from the top management of the company further development will reap substantial benefits throughout the company. It is important, however, to act quickly to optimise on the present enthusiasm as it will undoubtedly wane with time.

T. D. NEWMAN — *10 April, 1975*