COUNCIL for NATIONAL ACADEMIC AWARDS

"THE EFFICIENT UTILISATION OF RAW MATERIALS IN SPECIAL STEELMAKING"

A thesis submitted for the degree of

MASTER OF PHILOSOPHY

BY

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SHEFFIELD POLYTECHNIC

CONTENTS

Appendices

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Chapter 1

"Background to the Project"

The author was sponsored by British Steel Corporation to carry out a programme of research into the efficient utilisation of raw materials in special steelmaking. The experimental studies were carried out at River Don Works, Sheffield and most of the models developed relate to the methods of operation at this plant. Prior to nationalisation this works was a part of English Steel Corporation Limited. River Don Works operates as an integrated organisation for the manufacture of special steel products, with production facilities for steelmaking, forging, casting and machining. The works produces Forgings and Castings in the weight range 0-250 Tons. The following is a sample of the product range: Turbine Rotors for power stations, marine propulsion shafts, chemical reaction chambers, high pressure vessels, locomotive crankshafts, automobile components, etc. The steel qualities required for such items are mainly alloy steels. The main steelmaking facilities of the company are electric arc melting furnaces, for which the major raw material is steel scrap. This research project has been concerned with scrap as a raw material in the production of special steels.

The initial phases of the research programme were concerned with the development of a model to represent the decision making systems for the efficient blending of raw materials. Appraisal of the results from experimental studies using the model indicated the need to examine associated problem areas within the broader framework of the company as a whole, with particular reference to scrap flow.

In addition to considerations of physical inter-actions, the sociological aspects of human reactions within the organisation have been studied with particular reference to the resistance to change or innovation. Coverage of this aspect has been regarded as being relevant and important, because industrial systems are usually sensitive to human involvement or interference.

The results of a Literature survey of previous and contemporary work on this topic are included in this thesis. The discussions include an appraisal of these contributions and an assessment of originality in this thesis in relation to work by others.

During the course of this project the author was awarded a Travel Scholarship by British Steel Corporation, to study computer applications in Electric Steelmaking Plants in North America. This study has enabled the inclusion in this thesis of an appreciation of contemporary approaches in the field of raw material allocation in North American Steelplants.

The thesis terminates with proposals for further work in associated problem areas.

It is anticipated that the subject matter presented herein will be of interest to both academic and industrial readers.

Chapter 2

2.(i) Introduction to the Research Topic

The topic of research is - "The Efficient Utilisation of Raw Materials in Special Steelmaking". The object of this chapter is to outline the principles of special steelmaking and to define the problem areas associated with this process which have been studied in this project.

"Special Steels" is a term used to denote steels which have chemical compositions within the categories of alloy steels, stainless steels, enhanced Carbon Steels and steels for specialist applications. These steels tend to have significant amounts of Nickel, Chromium and Molybdenum which promote favourable physical properties in steel. These elements from virgin sources command high market prices and hence special steels are priced very much higher than "mild steels". Special steels are produced mainly in electric arc melting furnaces. Steel scrap constitutes the major raw material for electric arc furnaces.

The requirements of a particular steel at the melting stage are stipulated by a specification of chemical composition. This chemical specification constitutes the production objective of the melting shop for that order. The furnace accepts a charge of steel scrap which is melted by the arc struck between three graphite electrodes and the scrap. A furnace may require several charges of scrap before it achieves its nominal capacity of molten metal. The "melt-down" phase is deemed to be complete when all the charge in the furnace is fully melted. A sample is drawn from the furnace and the chemical composition determined by spectrographic means. The level of each chemical element at this stage is referred to as the "melt-out" value. The next production phase is "refining", during which attempts are made to adjust the "melt-out" values, to converge towards the specification. The levels of some elements can be controlled by altering the chemical condition of the slag (a non-metallic floating layer) to promote slag-metal reactions. Some elements can be oxidised by injecting oxygen into the bath. Positive adjustments for most elements can be made by adding these elements in the virgin form. Some elements are termed "stable elements" by virtue of their resistance to reduction, i.e. stable elements cannot be removed from the bath. The refining period terminates with all element values within the bounds of the specification. The molten metal is tapped into a ladle and cast into ingot moulds. The furnace is then prepared for the next melt.

The cost objective in selecting a charge of scrap is to select the cheapest blend of scrap which will provide the required melt-out values of the major elements included in the specification. The elements usually included in special steel specifications are Carbon, Silicon, Manganese, Sulphur, Phosphorus, Nickel, Chromium, Molybdenum, Copper and Tin. An upper and lower bound is normally specified for most of these elements. The scrap required to "make-up" furnace charges is acquired and stocked in bunkers or rail wagons, according to a scrap classification code. A typical scrap classification system is indicated on the next page.

Scrap Type	Attributes			
Carbon Scrap				
05 Carbon	Sulphur and Phosphorus .05% MAX			
04 "	" " " .04% "			
Basic Carbon	Unspecified			
Alloy Scrap	**Nickel**	**Chromium**	**Molybdenum**	**(%)**
1.CR.MO	0/.5	.8/1.8	.1/.4	
3.CR.MO	0/.3	2.5/3.5	.3/1.2	
1.NCM	.5/1.2	.3/.9	.15/.35	
2.NCM	1.2/2.2	.5/1.7	.2/.4	
3.NCM	2.3/3.5	.5/.8	.4/.7	
CP	.5/1.0	1.0/1.8	.3/.5	
Mixed	Unspecified			

The content of other elements such as Si, Mn, Cu, Sn, etc., in the scrap is not usually known. Where the levels of these values are stringent in the specification as is the case for certain steels, it is often necessary to use special grades of scrap with guaranteed specifications, which are usually expensive. The scrap classification code is designed to cater more to the problems concerning scrap collection, where due to space problems the segregation of scrap from a wide variety of steels, has to be based on a limited number of scrap codes. Therefore, the scrap codes tend to have a wider range for each element, than the steel qualities for which they cater. The typical specifications for some well known steels are indicated on the next page.

Steel Quality	Acceptable % Range for each element											
	C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	Sn	
35/40. CARBON	.35/.40	.15/.30	.7/.9	0/.05	0/.04	0/.3	0/.2	0/.1				
CP	.27/.3	0/.3	.5/.7	0/.02	0/.015	.6/.8	1.4/1.6	.35/.4				
1 NCM	.48/.53	0/.35	.9/1.0	.02/.05	0/.04	1.0/1.2	1.0/1.2	.5/.6	.03/07			
EN.24	.35/.45	.1/.35	.4/.7	.0/.02	0/.02	1.5/1.8	.9/1.1	.2/.28				
3 NCMV	.34/.37	.15/.3	.6/.7	0/.012	0/.012	3.0/3.2	.7/.8	.33/.38	.04/.08	0/.2	0/.02	

The scrap charge selected for the production of a given steel quality should fulfil the following conditions.

i) It should provide melt-out values of all relevant elements at levels which provide the feasibility of convergence towards the bounds stipulated for the steel quality being made.

ii) The scrap density of the charge should not result in an excessive number of charges.

iii) As far as possible the melt out values of cost sensitive elements such as Nickel, Chromium and Molybdenum should be near or within the specified bounds.

iv) For commercial reasons it is highly desirable to select the cheapest blend of scrap and virgin alloys which will fulfil the steel quality requirements.

v) It should be possible to supply the requirements from the scrap stocks.

Let us now consider how this list of requirements are accounted for by the scrap-mix planner in melting shops.

<u>Fulfilling requirements i, iii and iv</u>

The specified bounds for the control elements are considered and by a recursive process of "trial and error", a blend of scrap is determined, which should provide a feasible "melt-out", based on anticipated yields of the elements as indicated by the scrap code.

<u>Fulfilling requirements ii and v</u>

Using the solutions determined above and with reference to the scrap inventory record, the scrap charge directive is prepared. During the assignment procedure attempts are made to ensure satisfactory charge densities by judicious selection of heavy and light scrap. In cases where it is infeasible to meet the requirements of a particular blend due to shortages or "run-out" situations in scrap stocks it will be necessary to determine alternative solutions which are feasible in terms of stock levels.

Although in principle a planner should try to fulfil requirement iv), he usually does not have the time to consider more than a few alternative solutions. It is hence reasonable to assume that the solutions obtained by manual procedures as described above, will in most cases be non-optimal in terms of cost.

The development of systems which will assist in the search for optimality in this decision making process and the examination of the problem areas associated with such decision making, constitute the remit for this programme of research.

2. (ii) Literature Survey

A survey of published work indicates that the steel industry has sponsored a number of research teams to examine the scope for cost reduction in the field of raw material usage. The common answer to this problem has been to develop a Linear Programming model (L.P.) for the blending of furnace charges. During 1959 HILTY, TAYLOR and GILLESPIE[20] reported the development of an L.P. model in investigations of stainless steel melting practice with reference to the use of FERRO-CHROME additives. This work was sponsored by UNION CARBIDE CORPORATION, a major supplier of FERRO-CHROME. This was followed in 1961 by the development of an L.P. model for blending CUPOLA furnace charges at a General Motors foundry by METZGER and SCHWARZBEK[37]. The first L.P. model for the blending of electric furnace charges was developed by BERNACCHI and DUDLEY[4], on behalf of the United States Steel Corporation in 1964. Shortly afterwards GLOVEN, LONG and WEINHEIMER[29, 47] had also implemented a Least Cost Mix system for the blending of electric furnace charges at LUKENS STEEL, USA. The charge blending system was only a small segment of the computer control structure that had been established at the LUKENS melt-shop. In recent years a number of melt-shops in North America have implemented L.P. systems for charge blending using time sharing facilities at commercial computer bureaux. Details of these developments are included in the author's review[35, 36] of L.P. projects in North American Steelplants which is included in the appendices.

In the U.K. both British Steel Corporation and the private sector steel industry have been developing Least Cost Mix systems. The British Steel contributions were reported by the author[32,33] and HOLLOCKS[21]. The private steel industry contributions have been reported by HEMMING and PAYNE[18].

Published information in this field has tended to concentrate on the advantages of using L.P. models for furnace charge blending. There is very little information on the numerous limitations of such systems in practice. Although some authors[1,18,21,30,47] have acknowledged briefly the limitations imposed on blend planning by scrap uncertainty, they do not appear to have made any serious attempt to analyse this important problem area. In terms of originality the author's thesis provides a comprehensive analysis of the charge blending problem, which includes considerations of the effects of scrap uncertainty, methods of improving scrap segregation and a sociological analysis of human resistance to change.

Chapter 3

Development of an Efficient Material Allocation System

The Scope for Improvement

It was shown in the preceding chapter that the manual system could not be expected to produce Least Cost blends for furnace charges because of the large solution space and the constraint on time available for blend evaluation. If the decision rules involved in the blend calculation can be incorporated into a model, which can be solved readily to provide Least Cost Blends, then the scope for improvement does exist and should be examined.

An efficient system for Least Cost furnace charge blending should include facilities to appraise optimality in terms of the following:

a) To provide a blend of raw materials which will "melt-out" with the specified attributes at least cost, without involving operational problems.

b) To ensure that the collective demands of a group of casts are both feasible and optimal within the inventory level for the relevant raw materials.

The evolution of an improved system would involve the following stages of development:

i) Representation of the basic features of the allocation problem in a model.

ii) Examination of the methods for manipulating the model to determine optimal solutions.

iii) Evaluation of the savings potential, from the use of new methods, using historic situations for comparison.

iv) Appraisal of the limitations associated with the new system based on experimental experience, leading to an examination of the scope for overcoming the limitations.

Stages i) and ii) are outlined in this chapter, whilst iii) and iv) are considered in subsequent chapters.

Development of a Charge Blending Model

The basic features of this problem are similar to optimum blending in other industries, viz: blending of:- ores, diets, petroleum etc. The optimal blends in these cases have been evaluated by Linear Programming, normally referred to as L.P. Linear Programming is well known as an iterative optimisation procedure and there are numerous publications devoted exclusively to this topic.[6, 11, 13, 15, 39, 46]

We now consider the formulation of the furnace charge allocation problem in terms of an L.P. model.

Let,

a_{ij} = (The coefficient representing the yield of attribute i, from resource j (raw material)

x_j = (The resource variable representing the quantity of resource j that is included in a particular solution.

b_i = (The desired level of attribute i in a particular solution.

c_j = The unit cost of each resource j.

We will initially formulate the model for the single furnace situation which will provide the basis for extending the formulation to the multi-furnace situation.

Single furnace charge blending with n resources

$$\text{Minimise } Z = \sum_{j=1}^{n} c_j \; x_j \quad \text{——— (1)}$$

subject to:

BLEND ATTRIBUTES

$$\sum_{j=1}^{n} a_{ij} x_j \leqslant (b_u)_i \text{, for } i = 1, \ldots\ldots\ m^1$$

(u represents upper limit)

$$\sum_{j=1}^{n} a_{ij} x_j \geqslant (b_L)_i \text{ for } i = 1, \ldots\ldots\ m^{11}$$

(L represents lower limit)

where constraints 1, ... m^1 and 1, ... m^{11} are sub sets of the complete set of constraints 1, ... m.

CHARGE DENSITY

$$\sum_{j=t_1}^{t_n} x_j \leqslant b_{tmax.},$$

$$\sum_{j=t_1}^{t_n} x_j \geqslant b_{tmin.},$$

where $b_{tmax.}$ and $b_{tmin.}$ represent the acceptable limits of low density raw materials in each furnace charge. The resource set $t_1 \ldots\ldots\ t_n$ includes all low density raw materials from the total set of n.

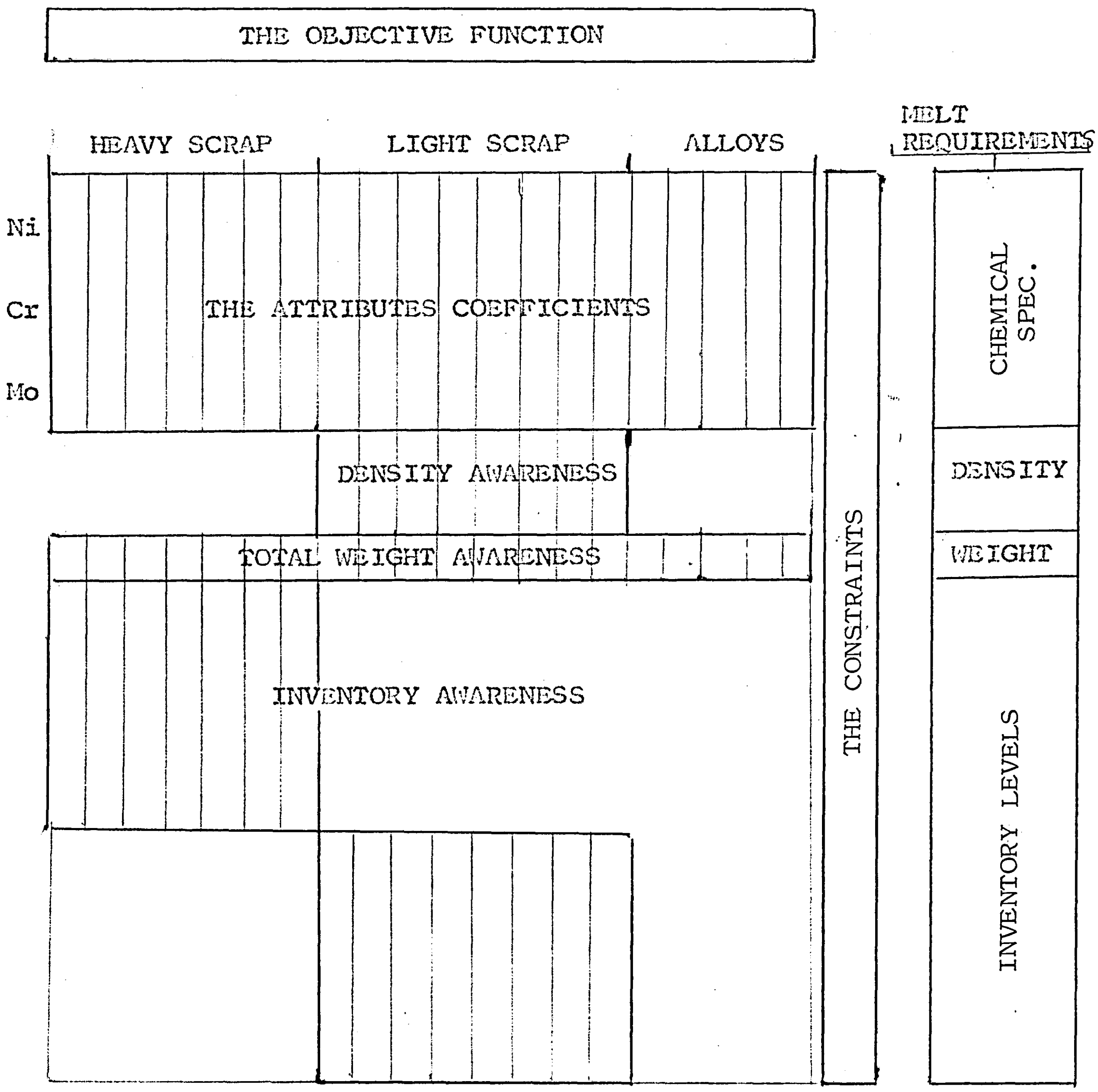
TOTAL WEIGHT EQUALITY*

$$\sum_{j=1}^{n} x_j = b_w$$, the total weight of the charge.

INVENTORY CONSTRAINTS $x_j \leqslant b_{stock_j}$, for $j = 1, \ldots\ldots\ n$.

* In severely constrained circumstances feasibility may be more easily attained by replacing this constraint by a range using two inequality constraints.

The single furnace model thus formulated can be represented schematically as shown below.



The columns represent candidates for a particular blend whilst the rows represent attributes and controls. The inclusion of virgin alloys as candidates assists in reducing the occurence of infeasibility at lower bounds of the chemical requirements. Inventory awareness for alloys will usually be redundant and hence they are not included in the above representation. We now consider extending the single furnace charge blending model to the multi-furnace model, which will enable optimisation on a broader scale and reduce the chances of sub-optimisation.

Let, X_i = (Column Vector representing resource variables for (cast i.

C_i = (Row vector representing the segment of the objective function for cast i.

B_i = Requirements vector for cast i.

A_i = (Matrix representing attributes, and controls for (density and weight for cast i.

I_i = (Identity matrix representing the controls for (Inventory awareness

B_I = Raw Material Inventory

The relation : represents the set of equalities and inequalities, where the relation can be converted to an equality by the introduction of slack variables for inequalities.

The multi-cast L.P. model is represented below:

$$\begin{bmatrix} C_1 & C_2 & C_3 & \cdots & C_n \\ A_1 & & & & \\ & A_2 & & & \\ & & A_3 & & \\ & & & \ddots & \\ & & & & A_n \\ I_1 & I_2 & I_3 & \cdots & I_n \end{bmatrix} \cdot \begin{bmatrix} \\ X_1 \\ X_2 \\ X_3 \\ \\ X_n \\ \\ \end{bmatrix} : \begin{bmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \\ \\ B_n \\ B_I \end{bmatrix}$$

Minimise B_0

Obtaining Solutions from L.P. Models

Solutions to L.P. Models are usually obtained from Simplex algorithms. A number of alternative versions exist and are largely based on the pioneering work done in this field by G. B. Dantzig. It is reasonable to assume that most practical applications of Linear Programming rely on digital computers for evaluating solutions. Computer software for L.P. is usually based on the Two Phase Revised Simplex algorithm. The original developments on the computational aspects of the Two Phase Revised Simplex were carried out by G. B. Dantzig and W. Orchard-Hays[39]. A brief outline of this method follows: The initial phase is concerned with reducing all artificial variables (arising from $\geqslant$ constraints) to zero. This is achieved by assigning a price of -1 to all artificial variables $x_{i'}$, zero to all other variables and maximising a secondary objective function $Z^* = \sum_{i'=1}^{s} (-1)\, x_{i'}$, where s = number of artificial variables. The maximum value of Z^* is zero which is reached when all artificial variables are zero. If max $Z^* < 0$ then the artificial variables cannot be reduced to zero and the problem is infeasible. During phase two the actual objective function is optimised, commencing from a basic feasible solution, any artificial variables present being at zero level.

An outstanding feature of the Revised Simplex Method is that during the transition from one basic feasible solution to the next, the amount of tableau updating is kept to a minimum. This is mainly because the following useful relationship is utilised: Given the associated elementary matrices the inverse of the p^{th} basis can be computed as

$E_p^{\ell} \cdot E_{p-1}^{\ell} \cdot \cdot \cdot \cdot \cdot E_1^{\ell} \cdot E_o = B_p^{-1}$

where the elementary matrices E, are Identity matrices except for one column, and ℓ is the index which corresponds to the index of the column in the preceding basis that is being replaced. The inverse of the original basis B_o is an Identity Matrix, i.e. $B_o^{-1} = I = E_o$

The above outline is extremely brief and interested readers are directed to publications by Orchard-Hays[39], G. Hadley[13] and S. I. Gass[1] for detailed expositions. In using the computer for industrial applications in Linear Programming there are a number of considerations which demand attention, outlined as follows.

i) Turnround Time: The time required for a computer to calculate optimal solutions to an L.P. problem is dependent on the problem size, matrix density, core store availability and ancilliary file store media. In addition to actual elapsed time on the computer there is the time required to obtain the data for the run from various sources to the data preparation centre and the punching of this data for computer input. Operating in this conventional off-line mode there will be an expected turn-round time for an L.P. run, which may or may not be compatible with the speed of response that is required at the melt-shop for the receipt of charge-blending information. Where the speed of response from off-line operations is not satisfactory, the justification for on-line access using remote terminals should be considered.

ii) Assessment of the number of casts that should be considered jointly in a Multi Cast Model: Ideally, the chances of sub-optimisation can be avoided by using a Multi Cast Model which considers all casts to be made, over a long time period. But such an ideal faces a number of practical limitations which are outlined below:

The computing time becomes prohibitive and impractical within industrial computer centres if more than about 15 casts are included in the L.P. model. The usefulness of solutions from large models is further limited by frequent changes of the cast schedule and replenishments to the resource inventory which could introduce the scope for more optimal blends than previously obtained. Furthermore, it is likely that after the melting of the initial casts in a solution set, new information on the prevailing yield levels from particular scrap types, may become known. The availability of up to date information on replenished inventory levels and current attribute yields could necessitate a new L.P. run, deleting the casts already made. If this situation is recurrent, then we are seldom utilising the many solutions to each cast that we are continually generating at great expense owing to the large model size. It would be sensible to select a model which only considers as many casts that are likely to be unaffected by the above considerations. In practice the associated time scale will usually be between one shift of 8 hours and a 24 hour day, depending on the standard cycle times for particular meltshop furnaces, operating on given steel qualities.

iii) <u>The use of Solution Libraries</u>

This system could be regarded as an alternative to the method of obtaining fresh solutions at each planning stage for a given set of casts. The case for considering the solutions library would be strong provided it can be shown that the Inventory constraints are redundant most of the time due to the relative abundance of the resources that are required. The Library of Solutions would consist of blends that have been evaluated from single cast models. When the blends for a given set of casts are required they are obtained by consultation from the standard optimal blends in the library file and a feasibility test for aggregate resource demands against available stocks is carried out. If feasible then it is equivalent to solutions that would be obtained from a multi-cast model. If there is infeasibility it is reasonable to consider either of the following second stage operations.

a) To initiate a multi-cast L.P. run to examine the scope for feasible optimality at the current stock levels.

b) To identify the particular solution or solutions from the library set which cause the infeasibility and determine alternative solutions to just those casts which are feasible. These solutions can be added to the library file for use in similar situations in future.

The advantage of this Library system is that it minimises the number of computer runs for generating L.P. solutions with consequent cost savings and reduction in response time for obtaining solutions.

iv) Mode of Operations and Communications Interface

The software that is normally available for L.P. requires that data be presented in a strict format with numerous control parameters which organise input, monitor and direct the L.P. run and print results in standard formats. This structure is suited more to the needs of trained users rather than production staff whose knowledge in such fields is limited. It is hence necessary and desirable to design software systems which will assist in producing a satisfactory interface between the central L.P. and the simplified input/output for the production staff. The input segment would consist of a matrix generator which will produce the necessary input from brief and essential information provided by the melt shop staff. In its generation process the matrix generator will have provisions to consider a number of relevant rules in formulating the L.P. model. Similarly the output segment will translate the L.P. solutions into a lucid form for use by melt shop staff at various levels. The structure of the Matrix Generator and Report Writer are detailed in the following section.

The Matrix Generator

The matrix generator consists of the following routines:

a) Validation of input data and merging with standard information from backing store to amplify the coded input data.

b) Candidate Selection.

c) Attribute Estimation.

Routine a

This routine carries out checks to test for errors that may have been introduced at some stage of data input preparation. Using the codes for steel quality and other markers for special restrictions, the routine amplifies the details of the steel specification and aim points for each element from a file in backing store. The backing store information would also provide the information required for the operation of the routines b and c.

Routine b - Candidate Selection

The aim of this routine is to prevent the inclusion of certain types of scrap in blends for the production of particular steel qualities. The eligibility of each scrap type for blends to produce particular steel qualities are usually stipulated by the management, based on their experience of "material credibility" and the associated yield variance of control elements. For purposes of illustration a small sample of the reasons for candidate selection are outlined as follows:

i) Some steel qualities have stringent requirements on the permissible maximum of 'residual' or 'tramp' elements such as Copper, Tin, Arsenic, etc. The standard scrap classification code does not acknowledge the levels of these elements. As such the yield of these elements from samples within the standard code will tend to be unpredictable. However there could exist within the standard code scrap stocks, some sub-sets of consignments which have identified levels of residual elements. This situation requires that where residual element levels are a significant consideration, eligibility of scrap should be restricted to the identified sub-sets.

ii) Some scrap types have a wider range of element yields and should therefore be either excluded or have a usage limit imposed, to reduce the chances of violating specified bounds.

iii) In certain melt shops the layout of the scrap bunkers, the railway supply lines to the shop and disposition of overhead cranes, are relevant considerations in terms of feasibility for executing particular solutions from the total scrap inventory. The candidate selection routine will incorporate such limitations.

It is important that the L.P. system should incorporate rules to deal with the numerous practical problems which the manual planning system deals with in the same situation.

The candidate selection routine can be operated using a library reference for each steel quality which defines the approved scrap eligibility in relation to the full range of resources that could be selected.

Routine c - Attribute Estimation

Each a_{ij} in the L.P. model represents the exact yield of attribute i from resource j. However, resource j could have a range of yields for attribute i, due to the "range" structure in steel specifications and the scrap code, as well as poor scrap segregation. All planning is based on the "expected" yield of various attributes from a particular raw material. With a knowledge of the "expected" yield and the variance, it is possible to assign a value for a_{ij} which is biased to give a greater chance of either positive or negative errors at "melt-out". The desired bias will usually be stipulated by management within the framework of their operating strategy for each steel quality and particular melt shop configurations. It is not uncommon for the expected value and the variance for element yield to drift at random intervals. It is desirable that such trends are identified and appropriate updating of the reference matrix should be carried out to ensure that the model adapts to changes in the real system.

The Report Writer

The purpose of the report writer is to express the solutions from the L.P. run in a readily understood and sensible form for direct use by melt shop staff. In some ways its role is similar to a translator, in that it reads the brief solutions from the L.P. package and expands the description of the variable names. Some of the major functions of the report writer are outlined below.

i) Variable Names - These are usually required to be less than 8 characters in length in most L.P. packages. Such a brief identification does not permit adequate description of most scrap resources and hence the report writer extends the description using a reference file.

ii) Numerical Quantities - The L.P. solution for a particular furnace charge could consist of a number of raw materials. The matrix generator should examine if the quantities involved are "significant" and carry out minor rounding off with monitoring of the effects of such corrections. This procedure is vulnerable to criticism from some schools of thought, on the grounds that Integer programming is the correct procedure. Whilst their arguments are certainly valid, it should be noted that on large problems, Integer programming extensions tend to demand a prohibitive amount of computing time, hence the justification for a well designed report writer routine to assist in this particular aspect of using the solutions from the L.P. package.

Experimental Studies

The experimental studies were carried out in two stages. The first stage consisted of an evaluation of potential savings from the use of a Least Cost Mix system for furnace charge blending, based on the historic records of a sample of casts. The results of this evaluation were submitted to the melt shop management which stimulated discussions on the merits and possible limitations of Least Cost Mix Systems. It was agreed that historic comparisons fail to account for various practical problems which may have been in force during the actual execution of the sample casts. In view of this it was decided to carry out the second stage of the experimental studies which consisted of plant trials on live casts.

Stage I

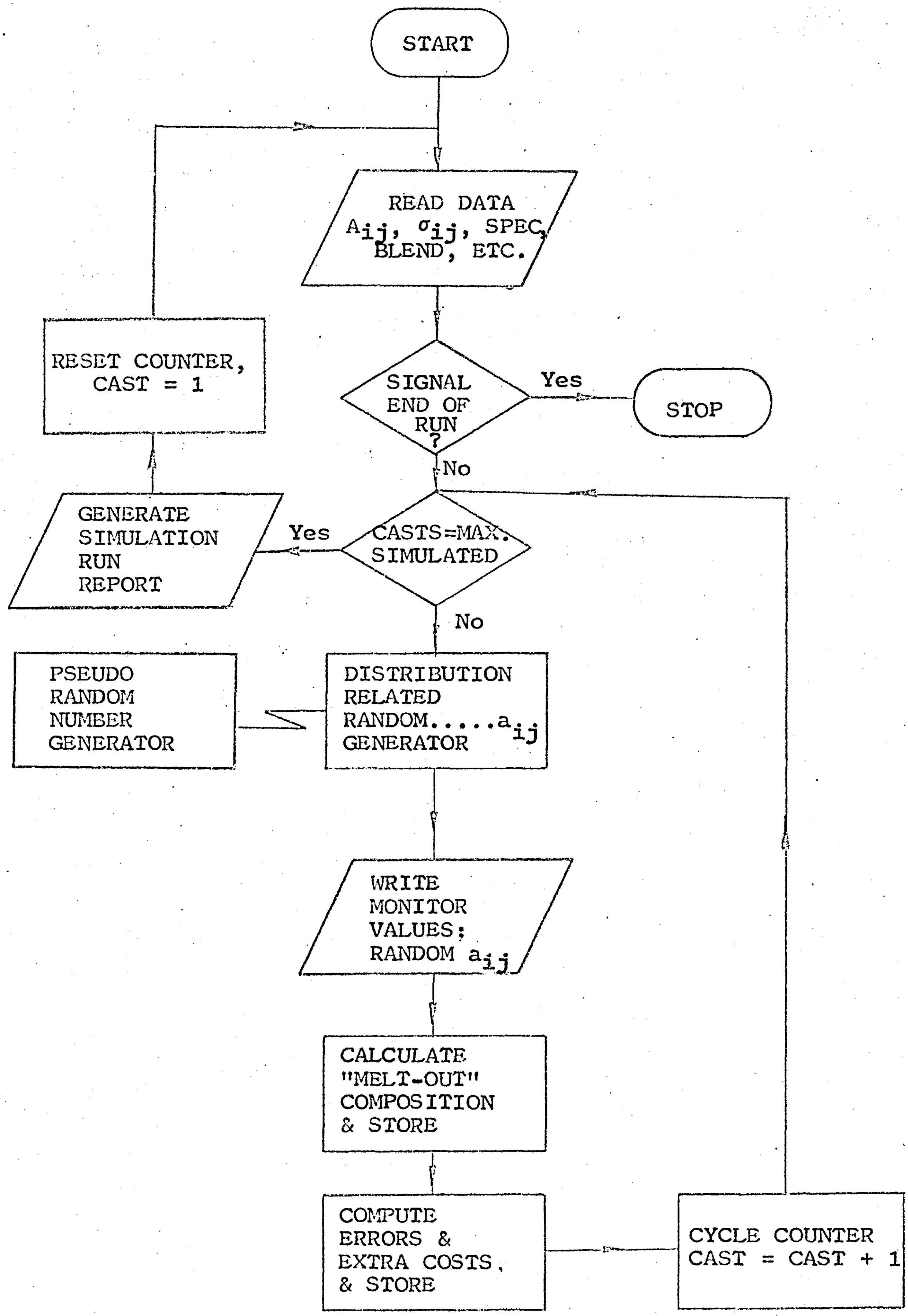
Experimental Procedure The aim of this study was to obtain an assessment of the scope for cost savings from the use of a Least Cost Mix system for the blending of furnace charges. The historic records of all alloy steel casts melted in one week (14th to 21st December, 1969) and the inventory records for raw materials in stock during that week were retrieved. The Least Cost Blends of scrap and alloys for each of these casts which were feasible within inventory constraints were evaluated using a 5 cast L.P. model. It was decided that to ensure a realistic basis for comparison of costs, the L.P. costs should be corrected to include an estimated "extra-cost" due to fluctuating yields of scrap attributes. The "extra-cost" so incurred can be estimated either from a simulation model of steel "melt-out" or from an analytical model of attribute behaviour. The formulation of each of these models follows.

The Simulation Model for estimating "Extra Cost"

The simulation consists of reading each L.P. solution and generating a pseudo-random sample of attribute yields for each raw material in the blend. The extra cost during each simulated cast is obtained by calculating the cost of virgin alloys necessary to bridge the gap (if one exists) between the simulated melt-out value of a particular element and the specified lower bound for that element. A MACRO-LEVEL flow diagram of the Simulation program which was written in FORTRAN is shown on the following page. The estimate of the expected extra cost during execution of a particular Least Cost blend is the average value from all the simulated melt-outs of the blend. A specimen copy of the print-out from this program is presented in the appendices(III).

"SIMULATION MODEL: TO ESTIMATE EXTRA COSTS DUE TO VARIABLE ELEMENT YIELDS FROM SCRAP"

MACRO LEVEL FLOW DIAGRAM



Analytical Model for the evaluation of "extra-cost"

Consider a particular solution from the Least Cost Mix evaluation. This solution would be a blend of n constituents, which can be represented by x_j, $j = 1, \ldots\ldots n$.

The attributes i in each resource j are represented by a_{ij}. Suppose standard deviations of the attributes are estimated to be σ_{ij} and are assumed to be independent of the constituent size x_j.

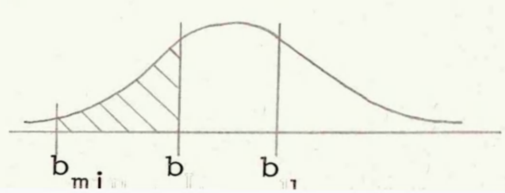
The mean yield of each attribute i from the Least Cost Blend

$$\mu_i = \sum_{j=1}^{n} a_{ij} \cdot x_j \quad , \text{ where } \sum_{j=1}^{n} x_j = 1$$

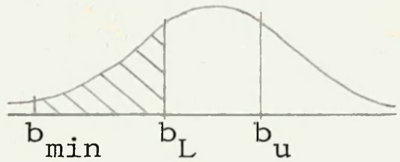
The estimated standard deviation of yields for each attribute i from above blend

$$\sigma_i = \left[\frac{\sum_{j=1}^{n} x_j^2 \cdot \sigma_{ij}^2}{\sum_{j=1}^{n} x_j^2} \right]^{\frac{1}{2}}$$

Let the probability density function defining the attribute variations be f(y). The blend is required to provide a "melt-out" with attribute i within the lower bound b_L and upper bound b_u. We consider the cases where this requirement is not satisfied by the blend, i.e. all melts with $A_i < b_L$, where corrective additions from virgin sources are required. The cost of such additions is linearly proportional to the magnitude of the correction for stable elements. In the distribution shown below the shaded area represents the probability of incurring extra cost for additions. The values b_L and b_u represent the stipulated lower and upper bounds for i, whilst b_{min} represents the cut-off at the absolute minimum yield. Let C_v be the unit cost of providing



virgin alloys for corrections between b_{min} and b_L.



Then, Expected Extra Cost for virgin alloys, E_1 $= \displaystyle\int_{b_{min}}^{b_L} C_v \cdot (b_L - y) \cdot f(y) \cdot dy$

For a normal distribution; $f(y) = \dfrac{1}{\sigma\sqrt{2\Pi}} \cdot e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2}$

$$\therefore E_1 = \frac{C_v}{\sigma\sqrt{2\Pi}} \cdot \int_{b_{min}}^{b_L} (b_L - y) \cdot e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2} \cdot dy \quad \ldots\ldots\ldots\ldots \text{(i)}$$

Expression (i) can be computed either by numerical integration methods or, if reduced to the standardised Normal form N(0, 1), by reference to published tables of the standardised Normal distribution.

Standardising expression (i) to the Normal N(0, 1) form as follows:

The standardised Normal p.d.f.; $\phi(t) = \dfrac{1}{\sqrt{2\Pi}} \cdot e^{-\frac{1}{2}t^2}$

where $t = \dfrac{y - \mu}{\sigma}$

Replacing limits of integration b with Z, where $Z = \dfrac{b - \mu}{\sigma}$,

and y with $(\sigma t + \mu)$.

$$E_1 = \frac{C_v}{\sqrt{2\Pi}} \cdot \int_{Z_{min}}^{Z_L} (b_L - \mu - \sigma t) \cdot e^{-\frac{1}{2}t^2} \cdot dt$$

Let $\Phi(Z)$ be the normal distribution function,

i.e. $\Phi(Z) = \displaystyle\int_{-\infty}^{Z} \phi(t) \cdot dt$

$$E_1 = C_v \cdot \sigma \cdot \Big\{ Z_L \big[\Phi(Z_L) - \Phi(Z_{min}) \big]$$

$$- \int_{Z_{min}}^{Z_L} t \cdot e^{-\frac{1}{2}t^2} \cdot dt \Big\}$$

continued

Thus,

$$E = \sigma \cdot C_v \cdot \left\{ Z_L \left[\Phi(Z_L) - \Phi(Z_{min}) \right] + \left[\phi(Z_L) - \phi(Z_{min}) \right] \right\} \qquad \text{........ (ii)}$$

Using expression (ii), E_1 can be computed using tables of the standard Normal distribution function and density function.

Experimental Results from Stage I

The findings from this study are summarised below. The breakdown of costs used in the comparisons between manual blends and L.P. blends is presented on the next page.

Casts from Week Ending: 20th December, 1969

Number of Casts: 26

Type of Steels : Alloy

Furnaces Concerned: F, J, K and X, of RIVER DON WORKS, British Steel Corporation

Mixture Cost	Total	Average per Ton
	£	£
Manual Blends:	23,995.16	19.93
Least Cost Blends:	17,675.85	14.68
Estimated "Extra Cost" for Least Cost Blends:	1,425.40	1.18
Potential for Cost Reduction:	4,893.91	4.07

Total Production Volume = 1,204 Tons

% Cost Reduction Potential on Manual Blends = 20%

TABULATED SUMMARY - PHASE I EXPERIMENTAL STUDY

F'CE No.	STEEL QUALITY	WEIGHT TONS	INCURRED COST OF MANUAL BLEND	COST OF L.P. BLEND	ESTIMATED EXTRA COST ON L.P. BLEND	POTENTIAL COST REDUCTION GAIN (+) LOSS (-)
			£	£	£	£
F1	3NCMV	12.66	491.67	347.22	23.14	121.31
J1	Cr.Mo	36.88	398.36	417.19	8.94	- 27.77
K1	CP	35.45	545.60	420.77	44.22	80.61
X1	CP	95.45	1,668.90	1,132.93	119.09	416.88
X2	SA8620	102.26	1,397.47	1,185.27	102.54	109.66
F2	3NCM	13.85	479.72	278.85	24.42	176.45
F3	EN34	13.00	235.84	264.75	15.57	-44.48
J4	EN40A	34.77	864.64	436.95	26.84	400.85
K3	EN24	27.11	578.86	391.73	33.67	153.46
K4	CP	35.40	644.65	420.18	44.19	180.28
J5	EN19C	33.33	519.56	372.10	11.13	136.33
K5	3NCMV	32.73	1,062.56	741.56	59.81	261.19
K6	3NCMV	35.34	1,117.48	800.57	64.62	252.29
X6	SA8822	102.48	1,839.47	1,270.17	108.73	460.57
X7	SA8822	102.66	1,582.22	1,271.66	109.33	201.23
F10	1NCMV	11.70	247.73	167.45	17.67	62.61
J6	1NCMV	34.08	705.16	494.98	53.69	156.49
K7	3NCMV	32.55	1,060.23	737.47	59.48	263.28
X8	SA8822	102.15	1,636.64	1,290.05	104.80	241.79
X9	EN24	77.18	2,028.20	1,212.18	108.60	707.42
F11	3NCM	14.21	439.76	286.03	25.08	128.65
F12	EN34	11.79	322.02	240.16	14.12	67.74
J7	EN27	32.88	1,140.17	861.81	60.09	218.27
J8	CP	36.01	582.10	514.60	40.15	27.35
J10	EN24	33.36	762.71	503.38	39.24	220.09
X15	EN353	104.28	1,643.44	1,615.84	106.24	- 78.64
TOTAL		1,204	23,995.16	17,675.85	1,425.40	4,893.91
COSTS/TON			£19.93/TON	£14.68/TON	£1.18/TON	£4.07/TON (GAIN)

Discussion on the Results of Stage I

The results obtained were submitted to the melt shop management, with explanations of the methods used in producing the cost comparisons. Whilst they accepted in principle the scope for savings from L.P. systems, it was suggested that the level of savings shown by the experimental study was unrealistic for the following reasons.

i) The bounds used for each element in the L.P. runs were the limits from the steel specification. This practice would be unacceptable because of the dangers of violating upper bound constraints. The bounds that are normally used are below the steel specification limits, the margin between the two, provides a safety buffer against upper bound violations.

ii) Whilst the cost comparisons did include considerations of "extra-cost" due to yield fluctuations from scrap, it was suggested that the variations in practice are greater due to poor scrap segregation from sources of supply.

iii) The study, although accounting for inventory levels of raw materials, could not possibly acknowledge the numerous practical constraints that are imposed on the handling of raw materials within the shop at various times during a week.

iv) The model does not take into account the loss of some chromium during melt down which occurs because it is only partially stable. It is acknowledged, however, that this does not seriously affect the cost figures because chrome is comparitively cheap in relation to the other elements, Nickel and Molybdenum.

Some of the weaknesses outlined on the previous page, were corrected in the model and the effect examined from a sample of 9 live casts. The results from this study indicated a potential for cost reduction of 9%, which is considerably less than the 20% cost reduction shown in the previous study. The tabulated results from this study follow.

Comparison of Costs - Manual and L.P. furnace charges using the updated L.P. model

9 Casts from week-ending 7.2.70

Furnace and Cast Number	Steel Quality	Manual Blend	Corrected L.P. Blend	Potential Savings	Cast Size Tons
		£	£	£	
J1	1% Cr.Mo	446.16	438.79	+ 7.37	35
J5	Mn.Cr.Mo	476.12	431.80	+ 44.32	37
J6	1% Cr.Mo	353.95	431.79	- 77.84	31
K3	C.Cr.Mo	458.52	410.89	+ 47.63	30
X7	EN353	1,951.15	1,646.80	+304.35	100
X8	EN36B	3,359.25	3,566.65	-207.40	100
X10 & X11	SAE8822H	1,697.25	1,261.25	+436.00	100
X13	EN351	1,716.72	1,338.95	+377.77	100
TOTAL		10,459.12	9,526.92	932.2	533

Observations

i) The savings potential of £932.2, representing a 9% cost reduction was obtained from the L.P. model which was updated for Chrome yields and the aim point criteria.

ii) Some of the potential savings are shown to be negative because the "actual furnace charges" obtained the benefit of positive errors in the yield of Nickel and Molybdenum from scrap charged.

iii) These results were discussed with the melt shop management which led to plant trials on 22 casts the findings from which follow.

Stage II Experimental Studies - Plant Trials

During the three week period from 6th to 27th September, 1970, the furnace charges for 24 casts were allocated using Linear Programming. The procedure used was to carry out an L.P. run at the start of each week using data supplied by the melt-shop planner. The data consisted of the specifications, and quantities for a set of planned casts, as well as the scrap allocation for these casts based on the prevailing inventory of bunkered stocks. It was necessary to carry out the L.P. run during the preceding week-end because the computer at the works was fully committed to commercial duties during the working week. Operating in this mode, meant that there were no options to take advantage of fresh information which becomes available during the working week.

The summary of costs incurred are tabulated on the following pages. The tabulated results are followed by a discussion of the findings from this study.

MIXTURE COSTS INCURRED BY L.P. BLENDS

SET	STEEL QUALITY	CAST NUMBER	WEIGHT TONS	MIXTURE COST (SCRAP + ALLOYS)	
				TOTAL £	£/TON
A	C.Cr.Mo	SJ 4580	34.29	625.67	18.25
	"	SJ 4592	29.07	504.42	17.35
	"	SJ 4593	35.82	593.75	16.58
	"	VJ 4604	34.08	641.12	18.81
	Cr.Mo	FH 6908	12.56	191.28	15.23
B	CP	FJ 4583	26.02	542.20	20.84
	"	FK 4015	26.06	545.63	20.94
	L.NCM	FH 6910	13.05	254.23	19.48
	"	VJ 4589	34.25	663.83	19.38
	"	FK 4030	30.50	507.20	16.63
	"	VJ 4602	32.61	715.08	21.93
	"	VJ 4579	32.52	637.87	19.61
	1 NCMV	VX 3517	93.13	2,333.01	25.32
C	2 NCMV	VK 4011	32.55	982.26	30.18
	EN 25	VK 4012	30.31	1,128.36	37.22
	"	VK 4014	35.45	1,257.17	35.46
	"	VK 4021	32.78	1,501.56	45.81
	"	VK 4029	30.33	1,249.00	41.18
D	3 NCMV	FK 4013	33.97	1,665.06	49.02
	"	FK 4019	34.38	1,800.64	52.37
	"	FK 4028	33.81	1,436.39	42.48
	"	VK 4022	35.32	2,259.43	63.97
E	HYKRO	VJ 4600	32.37	809.16	24.99
	"	VJ 4601	34.81	932.69	26.79

TOTAL	800.04	23,847.01	

COMPARISON OF MIXTURE COSTS

L.P. BLENDS - MANUAL BLENDS

SET	CAST NUMBER	WEIGHT TONS	MIXTURE COST (SCRAP + ALLOYS)			
			L.P. BLEND		AVERAGE MANUAL BLEND	
			TOTAL £	£/TON	£/TON	TOTAL £
A	SJ 4580	34.29	625.67	18.25	18.00	617.22
	SJ 4592	29.07	504.42	17.35	18.00	523.26
	SJ 4593	35.82	593.75	16.58	18.00	644.76
	VJ 4604	34.08	641.12	18.81	18.00	613.44
	FH 6908	12.56	191.28	15.23	17.10	214.78
SUB-TOTAL		145.82	2,556.24			2,613.46
B	FJ 4583	26.02	542.20	20.84	23.40	608.87
	FK 4015	26.06	545.63	20.94	23.40	609.80
	FH 6910	13.05	254.23	19.48	20.47	267.13
	VJ 4589	34.25	663.83	19.38	20.47	701.10
	FK 4030	30.50	507.20	16.63	20.47	624.34
	VJ 4602	32.61	715.08	21.93	20.47	667.53
	VJ 4579	32.52	637.87	19.61	20.47	665.68
	VX 3517	93.13	2,333.01	25.32	24.30	2,358.05
SUB-TOTAL		288.14	6,199.05			6,502.50
C	VK 4011	32.55	982.26	30.18	34.42	1,120.37
	VK 4012	30.31	1,128.36	37.22	37.80	1,145.72
	VK 4014	35.45	1,257.17	35.46	37.80	1,340.01
	VK 4021	32.78	1,501.56	45.81	37.80	1,239.08
	VK 4029	30.33	1,249.00	41.18	37.80	1,146.47
SUB-TOTAL		161.42	6,118.35			5,991.65
D	FK 4013	33.97	1,665.06	49.02	41.17	1,398.55
	FK 4019	34.38	1,800.64	52.37	41.17	1,415.42
	FK 4028	33.81	1,436.39	42.48	41.17	1,391.96
	VK 4022	35.32	2,259.43	63.97	51.68	1,825.34
SUB-TOTAL		137.48	7,161.52			6,031.27
E	VJ 4600	32.37	809.16	24.99	25.65	830.29
	VJ 4601	34.81	932.69	26.79	25.65	892.88
SUB-TOTAL		67.18	1,741.85			1,723.17
TOTAL		800.04	23,847.01			22,862.05

EXTRA COSTS INCURRED DUE TO ATTRIBUTE UNCERTAINTY

% ERROR INCURRED in the % of element = (Actual % Melt-out - Expected % Melt-out).

EXTRA COST = (NEGATIVE ERROR INCURRED) x COST OF VIRGIN ADDITIONS.

SET	CAST NUMBER	% ERROR INCURRED in the % of element			TOTAL EXTRA-COST £	
		Ni	Cr	Mo		
A	SJ 4580	0	- .10	- .01	14.06	
	SJ 4592	0	+ .03	- .05	15.99	
	SJ 4593	0	- .10	- .06	34.39	
	VJ 4604	0	- .29	- .06	52.14	
	FH 6908	0	+ .40	- .02	2.76	
					119.34	SUB-TOTAL
B	FJ 4583	- .16	+ .17	+ .11	45.80	
	FK 4015	+ .13	+ .42	+ .11	0	
	FH 6910	0	+ .16	- .02	2.87	
	VJ 4589	- .20	- .06	+ .01	81.52	
	FK 4030	+ .08	+ .27	+ .04	0	
	VJ 4602	- .20	- .15	- .03	97.18	
	VJ 4579	- .20	- .18	0	89.10	
	VX 3517	- .14	- .26	- .15	369.73	
					686.20	SUB-TOTAL
C	VK 4011	+ .05	+ .03	- .02	7.16	
	VK 4012	- .63	+ .20	- .03	220.05	
	VK 4014	0	+ .41	+ .02	0	
	VK 4021	- .80	+ .01	- .12	331.73	
	VK 4029	- .75	+ .32	- .07	273.58	
					832.52	SUB-TOTAL
D	FK 4013	- .63	+ .09	- .08	265.31	
	FK 4019	- .55	0	- .17	272.29	
	FK 4028	0	+ .40	- .07	26.03	
	VK 4022	- 1.27	- .19	- .16	575.72	
					1,139.35	SUB-TOTAL
E	VJ 4600	0	- .67	- .04	79.31	
	VJ 4601	0	- .83	- .16	147.94	
					227.25	SUB-TOTAL

£3,004.66	TOTAL

SUMMARISED MIXTURE COST COMPARISON

SET	STEEL QUALITY	WEIGHT TONS	COST IN £		
			L.P. BLENDS	MANUAL BLENDS	GAIN (+) OR LOSS (-)
A	Cr.Mo	145.82	2,556.24	2,613.46	+ 57.22
B	L.NCM	288.14	6,199.05	6,502.50	+ 303.45
C	2 NCM	161.42	6,188.35	5,991.65	- 196.70
D	3 NCM	137.48	7,161.52	6,031.27	- 1,130.25
E	HYKRO	67.18	1,741.85	1,723.17	- 18.68
TOTAL		800.04	23,847.01	22,862.05	- 984.96

LOSS OF £1.23/TON

TOTAL EXTRA-COST SUFFERED

SET	£
A	119.34
B	686.20
C	832.52
D	1,139.35
E	227.25
	3,004.66

EXTRA COST INCURRED)
BY ATTRIBUTE UNCERTAINTY) = £3.76/TON

Discussion on the Results of Stage II

The results obtained from these plant trials suggest that the L.P. blends have incurred a higher cost than the average cost of manual blends. This does not however mean that charge blending by the L.P. method is less efficient than the manual method. To appreciate the basis of this claim consider the following observations on the results obtained.

The sets of casts A and B have produced some cost reduction whilst sets C and D have suffered substantial losses. The losses were induced, firstly because during the experimental period, no supplies were available of a highly desirable resource - 3 NCM scrap, and secondly because the casts within sets C and D suffered exceptionally high negative errors in the yields of Nickel from scrap.

The effect of the inventory constraint for 3 NCM scrap being at Zero, is that the blends in sets C and D have to be made up with 2 NCM with a 1% difference in Nickel Yield, which has to be met from expensive virgin additions. If in addition to this, the yields of Nickel from 2 NCM suffer large negative errors, then the total mixture cost can be expected to be high in relation to blends which have not suffered such severe constraints. The effects of negative errors on these results have been measured by computing the "Extra Costs Suffered". The Extra Costs during these trials have been of the order of £3.76/TON (Comparable value during stage I studies being £1.18/TON). Since the level of extra costs suffered is independent of the methods used for blend planning, its effect can be misleading within the context of comparison, between alternative methods of blend planning using small sample sizes. Above all else, this study provided an indication to the steelplant management that scrap segregation has been extremely poor and it was recommended that scrap segregation and control within the company should be investigated to examine the scope for improvements. This recommendation was authorised by the General Manager of the company and led to the development of improved systems for scrap identification and segregation. The author's contribution in this project is outlined in a British Steel Corporation report a copy of which is included in the appendices (II).

The experimental studies have thus led to an examination of the problems in associated areas within the broader framework of the company, with reference to scrap circulation and control. The results of this study are outlined in the chapter - "Analysis of Scrap Circulation in Steelplants" (chapter 7).

Chapter 5

A Review of benefits and limitations associated with Least Cost Mix Systems

The use of a Least Cost Mix System for special steel production offers a number of benefits. However the system is far from being perfect and suffers from a number of limitations. The benefits and limitations are listed below followed by discussions.

The Benefits

i) Mixture Cost optimisation.

ii) Ability to generate alternative blends.

iii) Options for the control of stocks.

iv) Guidance on Purchasing policies.

v) Appreciation of penalty costs from constraints.

vi) Accuracy of Blend Evaluation.

The Limitations

a) The effects of randomness in element yields from scrap.

b) Effects of "Pick-Up" from Furnace Linings.

c) Problems arising from Residual Elements.

d) "Integer programming" problems.

e) Infeasibility.

f) The "Mixed Scrap" problem.

g) L.P. software problems with respect to computer configuration.

h) The anomalies of resource costs within the objective function.

Discussion of Benefits

i) Mixture Cost Optimisation

The blends obtained from a Least Cost Mix system are evaluated using an objective function minimising costs for particular levels of resource availability. The user thus has the assurance that in planning blends, mixture cost is always being optimised, based on information available at the time. The same assurance cannot be given with respect to the manual system because the human planner does not have the time to evaluate several alternative blends in seeking the optimal blend. In any case the planner cannot cope with problems of multi-cast blend evaluations by manual calculations.

ii) Rapid generation of Alternative Blends

The need for the evaluation of alternative blends to the ones planned can arise from any of the following events: Changes in the production schedule, short term restrictions on the supply routes to some furnaces, detected trends in the yield of elements from some scrap consignments, changes in the stock levels of scarce resources, etc. The Least Cost Mix system can rapidly generate new solutions that are optimal under the revised conditions and can be regarded as being invaluable for its contributions in this role. The speed of response and turnround from the computer will depend on the access queue and the L.P. run time. Least Cost Mix systems operating via on-line terminals are more suited to provide an adequate service in this role.

iii) Options for the control of stocks

The Inventory constraints of the L.P. model allow the user to restrict or force the usage of particular resources. The user may wish to restrict the usage levels of some resources because they are scarce, with infrequent supply. Conversely, some resources reach stocking limits and the user can force the usage of such resources to assist in physical problems of stocking.

The use of a computer based Least Cost Mix system makes it easier to update inventory records for scrap and alloys on the computer file. Whilst it is true that such a system could be implemented separately without the existence of a Least Cost Mix system, it is reasonable to suggest a steelplant using computerised charge blending will be more motivated to consider the use of an on-line inventory updating system.

iv) <u>Guidance on Purchasing policies</u>

The interpretation of the Dual Solution (which is available from each L.P. run) with reference to the stock constraint rows provides a useful measure of the current "worth" of each resource and indicates the potential for cost reduction by further acquisitions of particular resources. The Dual solution is expressed in sensitivity units in relation to the current solution, i.e. the cost effect per unit change in constraint level. This information provides valuable feedback to the purchasing function in negotiating with suppliers for deliveries of scarce resources.

In addition to the above it is possible to formulate a separate L.P. model which considers long term policies for supply and demand of resources based on forecasts of production plans and market conditions.

v) <u>Appreciation of penalty costs from Constraints</u>

The interpretation of the Dual solution in relation to attribute constraints, provides an indication of cost sensitivity for changes in the level of constraints. We illustrate the usefulness of this information as follows: Supposing a customer requires steel with Molybdenum specification 0.10% max. The L.P. model would include the constraint,

$$\sum_{j=1}^{n} a_{ij} x_j \leq 10 \quad , \text{ for } i = \text{Molybdenum}$$

where $\sum_{j=1}^{n} x_j = 100$, and a_{ij} = % yield of i from j (resource) Supposing the dual solution for the Molybdenum constraint is δ, then δ is the cost reduction that would result from a unit increase in the level of the constraint which in this case is $(0.10 \longrightarrow 0.11)\%$. When δ is sufficiently large the user can consider liaison with the customer for a relaxation of the constraint.

The Dual solution also indicates the penalties if any, of forcing the usage of certain resources which may have been introduced to prevent stock congestion. The usefulness of this facility was demonstrated to the melt-shop management in relation to the forced usage of "Mixed Scrap" in all Ni-Cr-Mo heats. "Mixed Scrap" as a scrap code is designed to accept unusual steel qualities which are not acceptable within the other authorised scrap codes. However processing departments often ignore the authorised interpretation for "Mixed Scrap" and use the following interpretation - ("Mixed Scrap" is the code which will accept all steel qualities, and hence will allow us to have simple arrangements for scrap collection and disposal). As a result of this unauthorised interpretation the processing departments despatch an unjustified amount of "Mixed Scrap" to the melt shop with consequent problems of physical stocking. To alleviate such problems the melt shop is reluctantly forced into using a policy of compelling the use of "Mixed Scrap" on all feasible heats which happen to be the Ni-Cr-Mo group. The Dual solution interpretation of the "Mixed-Scrap" forcing constraint provided management with a quantified measure of the penalty suffered from the usage policy, which initiated a review of the problem, leading to improved alternative policies. Some further anomalies associated with "mixed scrap" are discussed under limitations.

vi) <u>Accuracy of Blend Evaluation</u>

The blends obtained from a computer based system can be expected to be more reliable in terms of accuracy of evaluation, than the manual system. It is accepted that in most cases minor errors of evaluation do not have any significant effect on the "melt-out" owing to the permitted truncation during the weighing of furnace charges. However it is well known that accurate calculation of virgin alloy additives can contribute to cost reductions by avoiding "wasted" additions arising from approximate manual calculations.

Discussion of Limitations

a) <u>The effects of randomness in element yields from scrap</u>

In an L.P. model, the a_{ij} values are constant coefficients representing the contribution of attribute i from resource j. The a_{ij} in the Least Cost Mix model represent the <u>expected</u> yield of element i from scrap type j. In theory the yield of stable elements from well segregated scrap will be constant. But in practice steel scrap is not segregated properly which introduces randomness into the actual yields from scrap. At "melt-out", if the error is negative, extra cost is incurred for the provision of virgin alloy additives and if the error is positive it could violate upper limits which cannot be corrected and usually introduces a production crisis.

The designer of a Least Cost Mix system has to accept this problem and attempt to reduce the adverse effects by a suitable combination of a_{ij} estimation and safety margins on the requirements limit b_i. If the a_{ij} estimates are biased towards the upper limits then the chances of upper bound violations will be lower whilst that of lower bound violations will be higher. In a similar way the bounds used for the L.P. run could include a safety margin, providing the magnitude of the safety margin does not introduce infeasibility.

Let us examine the case for using a probabilistic model which accounts for the randomness of scrap yield. Supposing the probability distribution for a randomness is normal and defined as

$$f(y) = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{y-\mu}{\sigma}\right)^2}$$

or in the standardised form $\phi(t) = \frac{1}{\sqrt{2\pi}} \cdot e^{-\frac{t^2}{2}}$.

The attribute requirements for each i can be expressed as follows:

$$\left[\sum_{j=1}^{n} a_{ij} \quad x_j\right] - \Psi_L\left[\sum_{j=1}^{n} x_j^2 \quad \sigma_{ij}^2\right]^{\frac{1}{2}} \geqslant b_L$$

$$\left[\sum_{j=1}^{n} a_{ij} \quad x_j\right] + \Psi_u\left[\sum_{j=1}^{n} x_j^2 \quad \sigma_{ij}^2\right]^{\frac{1}{2}} \leqslant b_u$$

where Ψ_L is the normal deviate corresponding to the required probability P_L that the lower bound is not violated.

$$P_L = 1 - \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\Psi_L} e^{-t^2/2} \, dt$$

Similarly Ψ_u is the normal deviate corresponding to the required probability P_u that the upper bound is not violated.

$$P_u = 1 - \frac{1}{\sqrt{2\pi}} \int_{\Psi_u}^{\infty} e^{-t^2/2} \, dt.$$

This type of formulation has been used by Van der Panne and Popp for minimum cost cattle feed under probabilistic protein constraints (Management Science, April, '63, pp 405 -430). Their probabilistic requirement was limited to just the single protein constraint which was of type "$\leq$". The method of solution used for the formulation was ZOUTENDIJK'S[40] method of feasible directions. No attempt has been made within the author's research programme to use the non-linear formulation for furnace charge blending, mainly because the development of suitable computer software would not have been possible within the limited time period for this research. The run time for non-linear optimisation would in any case appear to be prohibitive for multi-furnace charge blending models. A further limitation arises from the assumption that σ_{ij} is independent of x_j, the quantity used. It is suggested that this assumption will not be valid in most instances when applied to scrap because supplies of scrap are not homogeneous. As a result σ_{ij} will tend to be a function of the "lot size" used in the evaluation procedure. Until these limitations can be dealt with adequately, it would appear that the case for considering non-linear formulations of the type considered, for multi-furnace charge blending, should be deferred.

In examining the solutions to deal with a_{ij} uncertainty we find ourselves attempting to "cope" with the effects. If we examine the physical causes which produce the effects, then we may discover means of reducing the effects to acceptable levels. This philosophy has been adopted with success, as outlined in the chapter - "Analysis of Scrap Circulation in Steelplants" (Chapter 7).

b) The effects of "Pick-up" from Furnace Linings

When a cast of steel is tapped from the furnace some of the molten metal adheres to the refractory linings and certain elements are absorbed into the linings. The concentration of the absorbed elements can be quite high, particularly if the furnace has been producing Stainless Steels which are rich in Nickel and Chromium. This residue can remain dormant for a period and usually re-enters the molten bath during one of the subsequent heats. This can result in a positive error on the expected values of the relevant element in the melt. The standard Least Cost Mix model does not have facilities which will cater for "pick-up". Providing planned schedules are adhered to, it would be possible to introduce a correction to the b_i vector in anticipation of "pick-up" from preceding heats in the planned set for a given furnace. The weakness of such a correction lies in the fact that very little is known about the dormant life of "pick-up" residues, i.e. If "pick-up" occurred in heat j, we do not know the likelihood of re-entry for the next n heats.

The "pick-up" problem is most significant in melt shops where operating policies include the "switching" of widely differing qualities on the schedule for each furnace.

The "pick-up" problem affects all methods of blend planning.

c) Problems arising from Residual Elements

The residual elements of concern in special steelmaking are Copper, Tin, Arsenic and Antimony. The removal of these elements from the bath is not possible and hence it is essential to aim for "melt-out" values below the upper bounds. The problem of residual elements with reference to the Least Cost Mix L.P. model is that information on residuals for scrap resources is known in some cases and not known in others. The level of residual elements is usually an unknown factor in scrap supplies under the general classification code. However some scrap stocks have further identity with reference to residual elements. To prevent the harmful effects of scrap from the general category which may enter solutions for low residual steels, it is necessary to either use the controls for candidate selection within the matrix generator or to assign upper percentile estimates of residual element yield for the scrap types in the general classification. Under conditions of low stock for the known residual scrap group, the chances of the L.P. run terminating due to infeasibility can be greater, which could be overcome by lowering the estimates of residual yield for the general scrap group within acceptable risk levels. The cost savings from coping effectively with the low residual problem can be high, if there are facilities for on-line access to the Least Cost Mix system, which enables the user to take advantage of new opportunities from changing stock levels and fresh information on residual levels.

d) "Integer programming" problems

The solutions from an L.P. model are usually continuous values. However some scrap consignments can be used only in integer units because of physical structure, the most common example being "ingot scrap". In principle this problem can be overcome by utilising the integer programming extensions to the L.P. package, if available at a given computer installation. The constraint on the use of this facility at present is one of run time, which can be prohibitive on large problems like the multi-furnace charge blending model. It is usually more practical, though less optimal, to utilise routines in the report writer program to convert the continuous values to feasible units for particular resources.

e) Infeasibility

Infeasibility refers to the condition which arises when it is impossible to find any feasible solution for a given requirement vector from the attributes and stock levels described in the L.P. model. When this conditon arises in the computer run of a Least Cost Mix system, the user is initially concerned with identifying the cause of infeasibility to examine the scope for "forcing" feasibility. The identification process is not always straightforward and in this respect some L.P. packages offer more helpful post-mortem information than others. The method usually adopted is to examine the constraints in relation to the a_{ij} matrix - we could for example find that we have specified a maximum chrome requirement of 0.3% and in the a_{ij} matrix the lowest possible chrome yield is 0.5%. In this situation it is probable that the 0.5% yield refers to the upper percentile yield catering for a scrap code accepting both 0.3% and 0.5% scrap types. In this instance the user will be justified to use a temporary update to the a_{ij} for chrome assigning it 0.3% yield and including suitable "variable descriptions" which stipulate the need for "selective" charging of 0.3% chrome scrap.

On many occassions infeasibility can be attributed to data punching errors, which when identified and corrected resolves the deadlock.

If the cause of infeasibility relates to a stock constraint, then the search for feasible solutions for the cast concerned will need to be deferred until the stock level improves to permit feasibility.

f) <u>The "Mixed Scrap" Problem</u>

Mixed scrap is a resource which has far more variance in attribute yield than any other scrap type. As the mixing process is not homogeneous the variance is a function of sample size. In the L.P. model the attribute yields for mixed scrap are usually based on the long term expectations from moderate sample sizes. The only reliable method of reducing the risk from mixed scrap is to include suitable usage constraints during the matrix generation procedure. In spite of the risk to the user from the inclusion of mixed scrap in a blend, the resource price for mixed scrap is rather high, contrary to rational expectation of compensation in view of risks to the user.

g) <u>L.P. Software problems with respect to computer configuration</u>

Most computer manufacturers will supply well tested software packages for Linear programming. The L.P. package selected for use in a Least Cost Mix system should have options for efficient interfacing with the users matrix generator and report writer. The interface problem can arise in certain computer installations with reference to the peripheral devices that are available. For example consider a user with an ICL 1902 A computer, 32K words of core store, four disc drives, card reader, card punch and line printer. For the Least Cost Mix system they use the ICL-L.P. package XDL2 which will accept input data from cards, paper tape or magnetic tape. This user cannot have an efficient interface for the matrix generator/L.P. package XDL2, because the only feasible transfer medium for his installation is via the card punch for re-input to the card reader. This problem will not exist now because ICL now provide an enhanced L.P. package-XDLA, which will accept input from any named peripheral device.

The L.P. package within a Least Cost Mix system should provide turnround within the time allocations that is assigned for the system by the Computer Centre. The iteration time to reach optimality is governed by the problem size and matrix density, as well as the control parameters for multiple column selection, frequency of inversion, Eta vector file dumping and the core store allocation. Some typical run times for Least Cost Mix systems using ICL software are indicated below.

	Rows	Cols	Minutes of Elapsed Time (XDL2 & George II)
One cast model	30	20	2-3
Five cast model	60	100	5-10
Ten cast model	110	220	15-25

The run times quoted are based on the XDL2 package, which can be less on XDLA, which has iteration time optimisation facilities, for switching automatically between inversion and eta-vector file scan as iteration time from one procedure exceeds that of the other.

h) <u>Anomalies of resource costs within the objective function</u>

The L.P. model in a Least Cost Mix system optimises an objective function which represents the resource costs. It is reasonable to stipulate that the resource costs used in the objective function should represent the "true" cost incurred to the user and be based on a consistent standard of reference. It will be apparent from the ensuing discussion that conventional standards of resource cost such as market price alone does not provide a realistic basis of true cost for use in a Least Cost Mix system.

Consider the following criteria of resource costs, relating to scrap.

i) The cost of a resource is the amount which the user has to pay for supplies from the market.

ii) The cost of a resource is the amount which the user actually pays for procurement from a particular source.

iii) The cost of a resource is the sum of source related procurement cost, expected penalties during use (+), and expected advantage during use (-).

The use of each of the above for the objective function has both advantages and limitations. The use of market price has the advantage that the values are readily obtained by reference to published prices. However the real validity of market price does not extend to supplies procured from non-market sources, viz. internal supplies. The market price is not a realistic measure for internal revert scrap because it is unwittingly subsidised by the customer who purchases the product from which the scrap arose. The only significant costs of internal scrap are for cutting and handling, which are usually quite small in relation to the market price of scrap. The limitation to the separate costing of internal and external scrap is that the physical controls for inventory and bunkering resources, may not be amenable to this form of segregation.

The use of procurement cost alone as the resource cost for scrap has the weakness that it ignores the extra costs or special advantages which can be attributed to the resource during melting. The expected extra costs will be a function of attribute variance and scrap density. The special advantage contributed by certain resources are low residual properties, ease of handling, and guaranteed yield from scrap of known analysis. Resource cost which accounts for penalties, advantages and procurement can be regarded as being realistic and more suited for use in the objective function rather than the market price.

Development of a model to evaluate the expected cost to the user arising from attribute uncertainty

The Need for the Model

The purpose of developing this model is to provide a means of assessing the cost damage to the user which is directly related to the level of attribute uncertainty from steel scrap. The need for such an assessment becomes necessary in cost-benefit consideration of schemes to reduce the level of uncertainty affecting scrap supplies. In addition to this role it is conceivable that the model could be of use to the purchasing function in the evaluation of break-even purchase price for scrap supplies with declared margins of uncertainty.

Formulation of the Model

We assume that the probability density function defining the yield of particular attributes from given blends of scrap is known. In any steel specification for which the blend is used, there exists an upper and lower bound stipulating the acceptable level of each chemical attribute. In general it is accepted that on the basis of a least cost objective, it is desirable for attribute yields to converge towards their respective lower bounds. The lack of compliance with this objective, results in extra costs to the user due to one of the following reasons.

i) If the attribute yield is below the lower bound, expensive virgin additives have to be provided.

ii) If the attribute yield is within the specified bounds, but not at the lower bound, then a "lost opportunity" cost can be regarded as being incurred. The "lost opportunity" being a reference to the fact that we could have used the difference between the lower bound and the actual yield, to fulfil the lower bound requirements of some future order. Since this future correction will quite likely be made using virgin alloys, it is reasonable to evaluate the lost opportunity cost using the price of the requisite virgin additions. Where the aim point (planned yield) is above the lower bound, the range of the opportunity cost applies only between the aim point value and the upper bound.

iii) If the attribute yield falls above the upper bound, then a production crisis is invoked which is resolved either by re-scheduling if a feasible alternative order exists or by deciding to abort the melt. The election of either option incurs extra cost to cover the cost of melting, any re-setting of differing mould sizes, the priority usage of scarce resources, the standby running of vacuum tanks, etc. The extra cost for this type of upper bound violation is constant and not directly related to the magnitude of the error.

From the above discussion we can consider three cost zones. The operating practices used in various companies varies a great deal and hence only some of the three costs may be active in certain steelplants. The validity of the model in these situations will depend on suitable re-structuring of the model to reflect any such variations.

The disposition of the cost zones in relation to a typical probability distribution is shown on the next page.

Let: b_E = Aimpoint yield for the attribute

b_L = Stipulated lower bound for the attribute

b_u = Stipulated upper bound for the attribute

b_{max} = Absolute maximum yield

b_{min} = Absolute minimum yield

C_v = Unit Cost of virgin additives

C_p = Penalty Cost for each upper bound violation

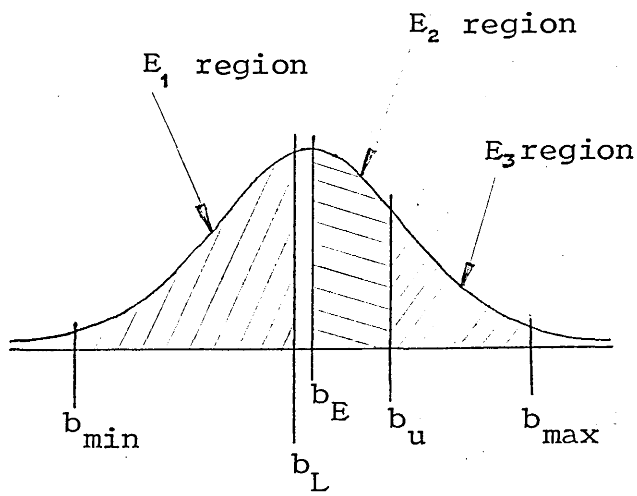
E_c = Total Expected Cost to user due to uncertainty of attribute yield

E_1 = Expected Extra Cost due to lower bound violations

E_2 = Expected Lost Opportunity Cost

E_3 = Expected Penalty Cost due to upper bound violations

Distribution of attribute yield



$$E_1 = \int_{b_{min}}^{b_L} C_v \cdot (b_L - y) \cdot f(y) \cdot dy \ ;$$ where $f(y)$ is the probability density function of attribute variable y.

$$E_2 = \int_{b_E}^{b_u} C_v \cdot (y - b_E) \cdot f(y) \cdot dy.$$

$$E_3 = \int_{b_u}^{b_{max}} C_p \cdot f(y) \cdot dy$$

$E_c = E_1 + E_2 + E_3$, The general case where all costs are assumed to be operative.

$$= \int_{b_{min}}^{b_L} C_v \cdot (b_L - y) \cdot f(y) \cdot dy + \int_{b_E}^{b_u} C_v \cdot (y - b_E) \cdot f(y) \cdot dy + \int_{b_u}^{b_{max}} C_p \cdot f(y) \cdot dy \qquad \text{........ (i)}$$

Providing the p.d.f., f(y) is known the above expression can be evaluated. We consider the case where the distribution is normal and the p.d.f. is

$$f(y) = \frac{1}{\sigma.\sqrt{2\Pi}} \cdot e^{-\frac{1}{2}\left(\frac{y - \mu}{\sigma}\right)^2}$$

$$E_c = \int_{b_{min}}^{b_L} C_v \cdot (b_L - y) \cdot \frac{1}{\sigma.\sqrt{2\Pi}} \cdot e^{-\frac{1}{2}\left(\frac{y - \mu}{\sigma}\right)^2} \cdot dy$$

$$+ \int_{b_E}^{b_u} C_v \cdot (y - b_E) \cdot \frac{1}{\sigma.\sqrt{2\Pi}} \cdot e^{-\frac{1}{2}\left(\frac{y - \mu}{\sigma}\right)^2} \cdot dy$$

$$+ \int_{b_u}^{b_{max}} C_p \cdot \frac{1}{\sigma\sqrt{2\Pi}} \cdot e^{-\frac{1}{2}\left(\frac{y - \mu}{\sigma}\right)^2} \cdot dy \qquad \ldots\ldots \text{(ii)}$$

Expression (ii) can be computed either by numerical integration or by reference to published tables of the normal distribution providing the expression is reduced to the standardised normal form N (0, 1).

<u>Standardising expression (ii) as follows</u>

The standardised normal p.d.f., $\phi(t) = \frac{1}{\sqrt{2\Pi}} \cdot e^{-\frac{1}{2}t^2}$

where $t = \frac{y - \mu}{\sigma}$.

In expression (ii) we replace the p.d.f., f(y) with $\phi(t)$, the variable y with $(\sigma t + \mu)$ and the limits of integration b with Z, where $Z = \left(\frac{b - \mu}{\sigma}\right)$

$$\text{Thus, } E_c = C_v \int_{Z_{min}}^{Z_L} (b_L - \mu - \sigma t) \cdot \phi(t) \cdot dt + C_v \cdot \int_{Z_E}^{Z_u} (\sigma t + \mu$$

$$- b_E)\ \phi(t) \cdot dt + C_p \cdot \int_{Z_u}^{Z_{max}} \phi(t) \cdot dt.$$

$$= C_v \cdot \sigma \cdot \int_{Z_{min}}^{Z_L} (Z_L - t) \cdot \phi(t) \cdot dt + C_v \cdot \sigma \cdot$$

Continued

$$\int_{Z_E}^{Z_u} (t - Z_E) \cdot \phi(t) \cdot dt + C_p \cdot \int_{Z_u}^{max} \phi(t) \cdot dt \quad \text{.....(iii)}$$

Now substituting the Normal distribution function

$$\Phi(Z) = \int_{-\infty}^{Z} \phi(t) . dt,$$ and the integral

$$\int_{Z_1}^{Z_2} t \cdot \phi(t) \cdot dt = \Big[- \phi(t) \Big]_{Z_1}^{Z_2}$$ in expression (iii), reduces the expression to a form consistent with published tables of $\Phi(Z)$ and $\phi(Z)$, as follows:

$$E_c = \sigma . C_v . \{ Z_L \left[\Phi(Z_L) - \Phi(Z_{min}) \right] + \left[\phi(Z_L) - \phi(Z_{min}) \right] \}$$
$$+ \sigma . C_v . \{ \left[\phi(Z_E) - \phi(Z_u) \right] - Z_E \left[\Phi(Z_u) - \Phi(Z_E) \right] \}$$
$$+ C_p . \{ \Phi(Z_{max}) - \Phi(Z_u) \} \quad \text{.....(iv)}$$

Expression (iv) reduces further for particular cases of the aim point (planned yield from a blend) and the disposition of the bounds in relation the distribution mean μ .

Consider the following cases for illustration.

<u>Case (i)</u> $Z_E = Z_L$

$$E_c = \sigma . C_v . \{ Z_L \; 2 \left[\Phi(Z_L) - \Phi(Z_{min}) - \Phi(Z_u) \right]$$
$$+ \left[2\phi(Z_L) - \phi(Z_{min}) - \phi(Z_u) \right] \}$$
$$+ C_p \{ \Phi(Z_{max}) - \Phi(Z_u) \} \quad \text{.....(v)}$$

<u>Case (ii)</u> $Z_E = Z_L$ and $b_L = \mu$

$$E_c = C_v . \sigma . \{ 2 \phi(Z_L) - \phi(Z_{min}) - \phi(Z_u) \}$$
$$+ C_p \{ \Phi(Z_{max}) - \Phi(Z_u) \} \quad \text{.....(vi)}$$

<u>Case (iii)</u> $Z_E = Z_u$

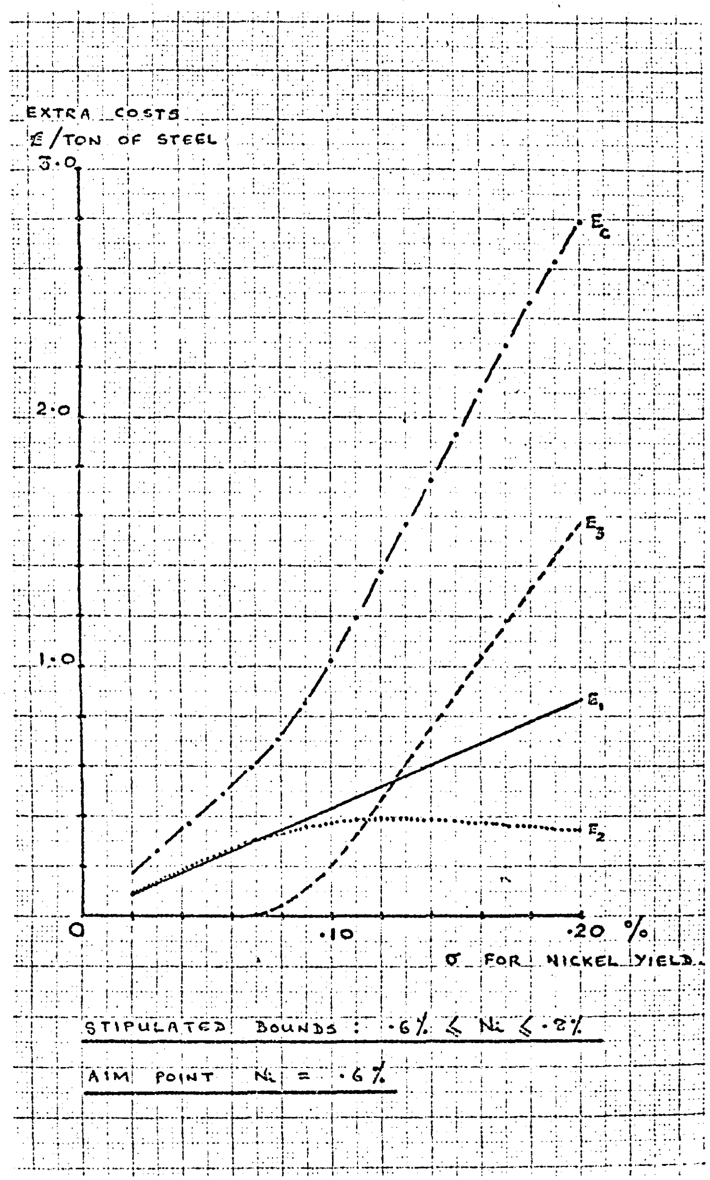
$$E_c = \sigma . C_v . \{ Z_L \left[\Phi(Z_L) - \Phi(Z_{min}) \right] + \left[\phi(Z_L) - \phi(Z_{min}) \right] \}$$
$$+ C_p . \{ \Phi(Z_{max}) - \Phi(Z_u) \} \quad \text{.....(vii)}$$

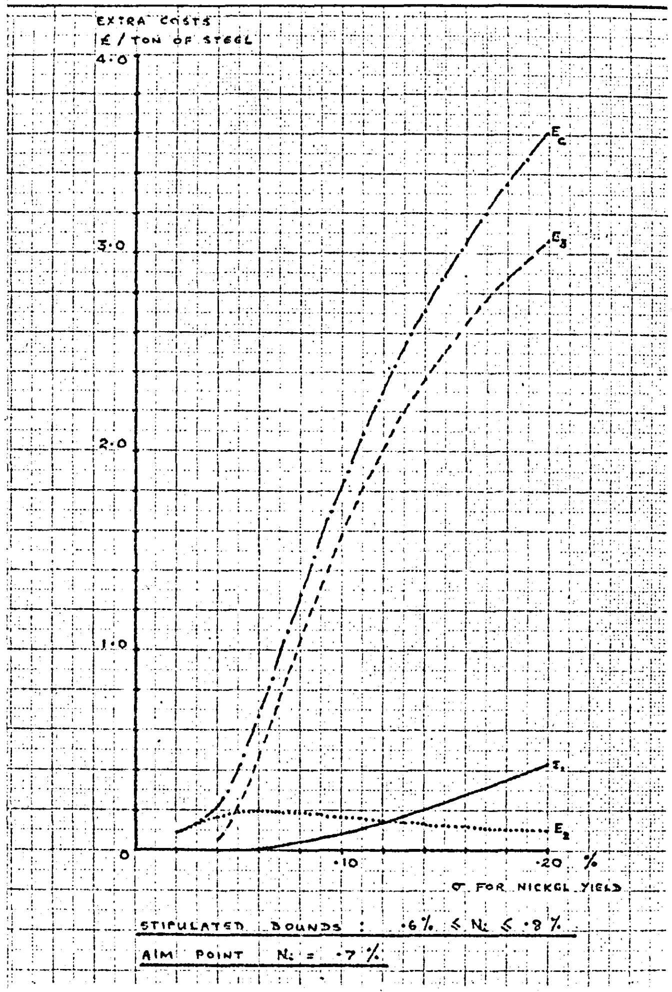
Study of expected cost due to attribute uncertainty

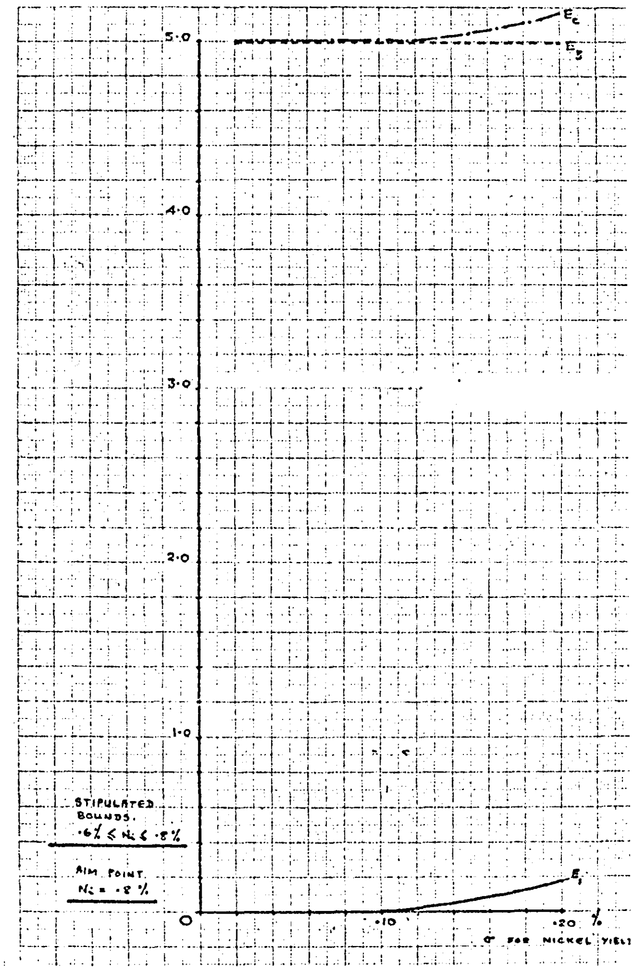
The model developed in this chapter can be of use in evaluating the cost to the steelplant arising from attribute uncertainty. This information could be useful to management in considering the scope for improvements and in cost benefit assessments of schemes which offer to decrease attribute variance of expensive elements. The model could also be of use in strategic studies to establish the aim points in relation to the bounds for each steel quality, which will fulfil stipulations concerning the acceptable probabilities of upper or lower bound violations.

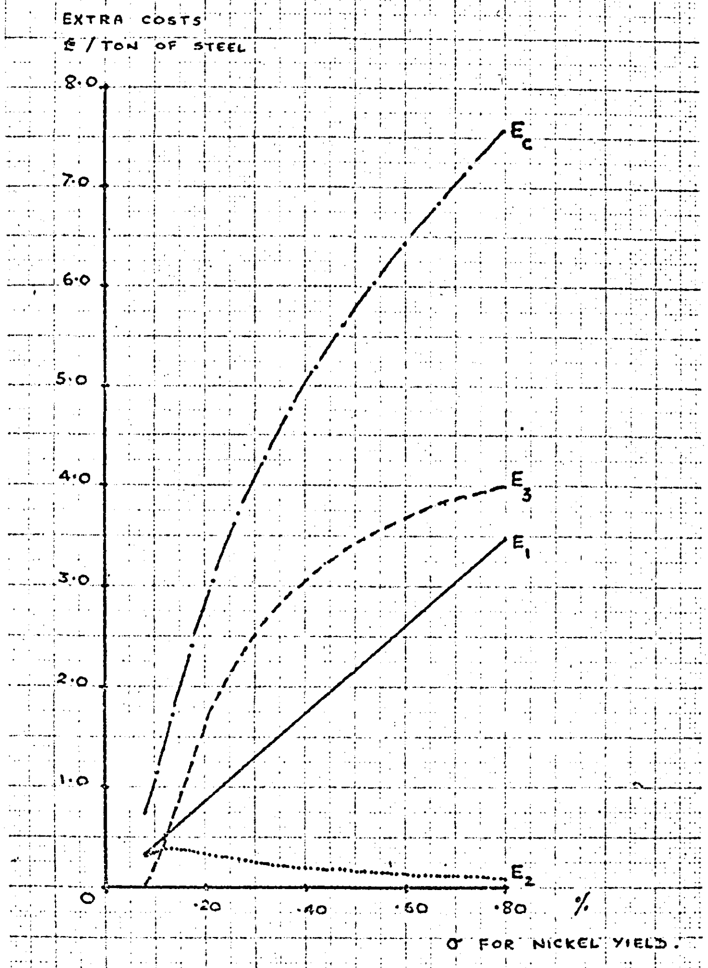
For illustration consider a steelplant which produces just three steel qualities; L.NCM, 2½ NCM and 3 NCM. The Nickel specification for these steels are .6-.8%, 2.5-2.7% and 3.0-3.2% respectively. Virgin Nickel with a yield of 100% is priced at £1,100/Ton. Upper bound violations incur a cost of £10/Ton of steel to cover for expenses incurred: Electric power, Oxygen, plant services, labour, etc. It is regarded as being reasonable to assume that the min and max values for the Nickel yield population are ($\mu - 3\sigma$) and ($\mu + 3\sigma$) respectively, where μ is the aim point and σ the standard deviation of the blend, conforming to the Normal probability distribution. Based on this information we can use the model to compute extra costs expected for various aim points relative to the bounds for given levels of σ. The extra costs for the above steels were computed using the expressions derived earlier. The results have been plotted on the following graphs indicating extra costs E_1, E_2, E_3 and E_C for a typical range of σ, for each of three cases of the aim point at the lower bound, mid range and upper bound.

The graphs are followed by a discussion of the significant relationships evident from this study.


EXTRA COSTS
£/TON OF STEEL
3.0
2.0
1.0
0
E_c
E_3
E_1
E_2
·10
·20 %
σ FOR NICKEL YIELD.
STIPULATED BOUNDS : ·6% ≤ Ni ≤ ·8%
AIM POINT Ni = ·6%

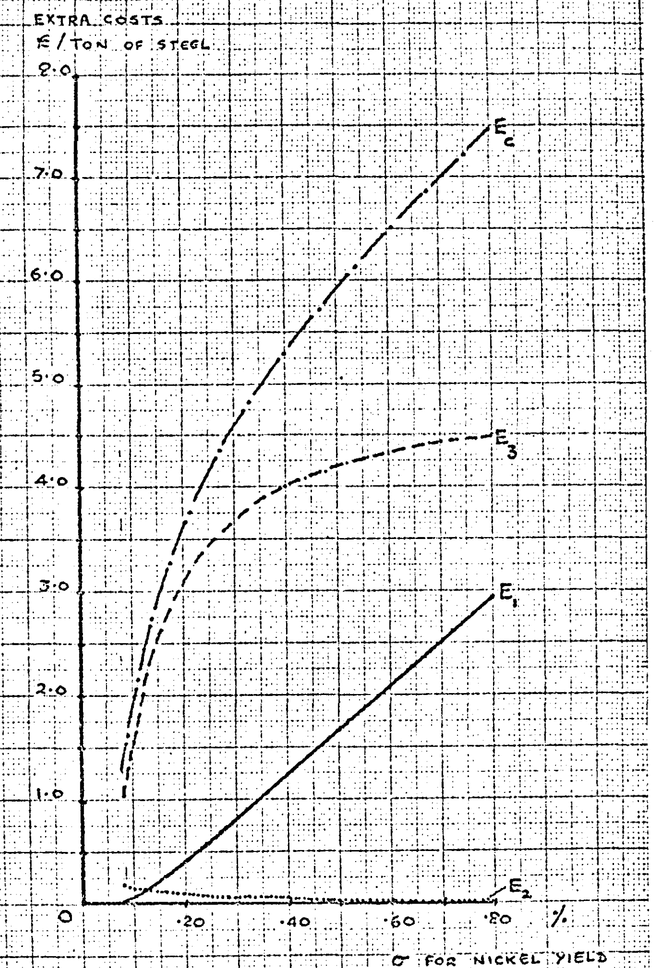

EXTRA COSTS
£ / TON OF STEEL
4.0
3.0
2.0
1.0
0
E_c
E_3
E_1
E_2
·10
·20 %
σ FOR NICKEL YIELD
STIPULATED BOUNDS : ·6% ≤ Ni ≤ ·8%
AIM POINT Ni = ·7%


5.0
4.0
3.0
2.0
1.0
0
E_c
E_3
E_1
·10
·20 %
σ FOR NICKEL YIELD
STIPULATED BOUNDS. ·6% ≤ Ni ≤ ·8%
AIM POINT. Ni = ·8%



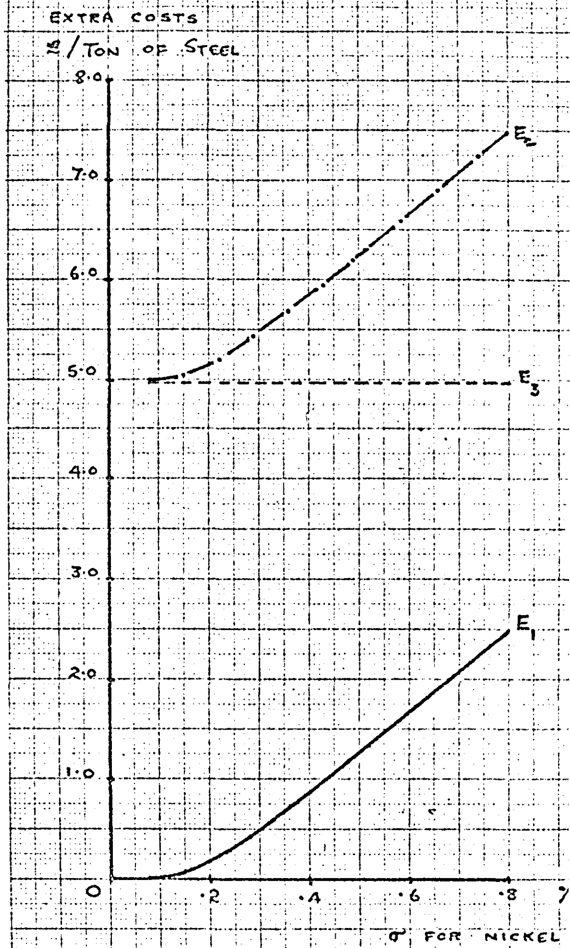
STIPULATED BOUNDS : 2.5 % ≤ Ni ≤ 2.7 %

AIM POINT Ni = 2.5 %



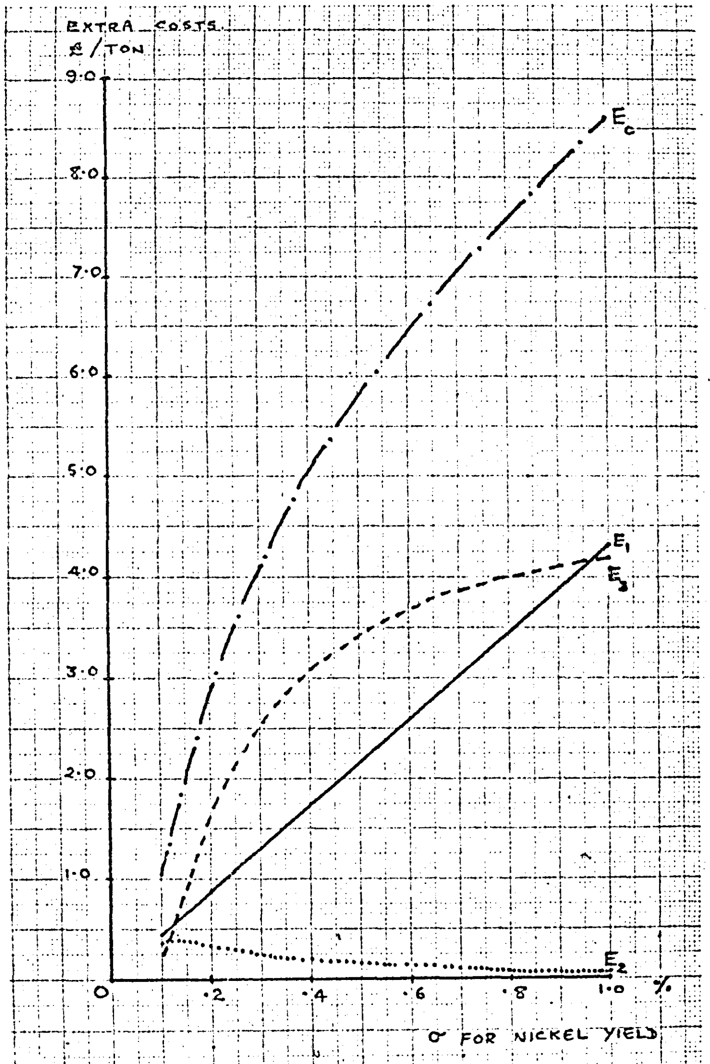
STIPULATED BOUNDS : 2.5 % ≤ Ni ≤ 2.7 %

AIM POINT Ni = 2.6 %



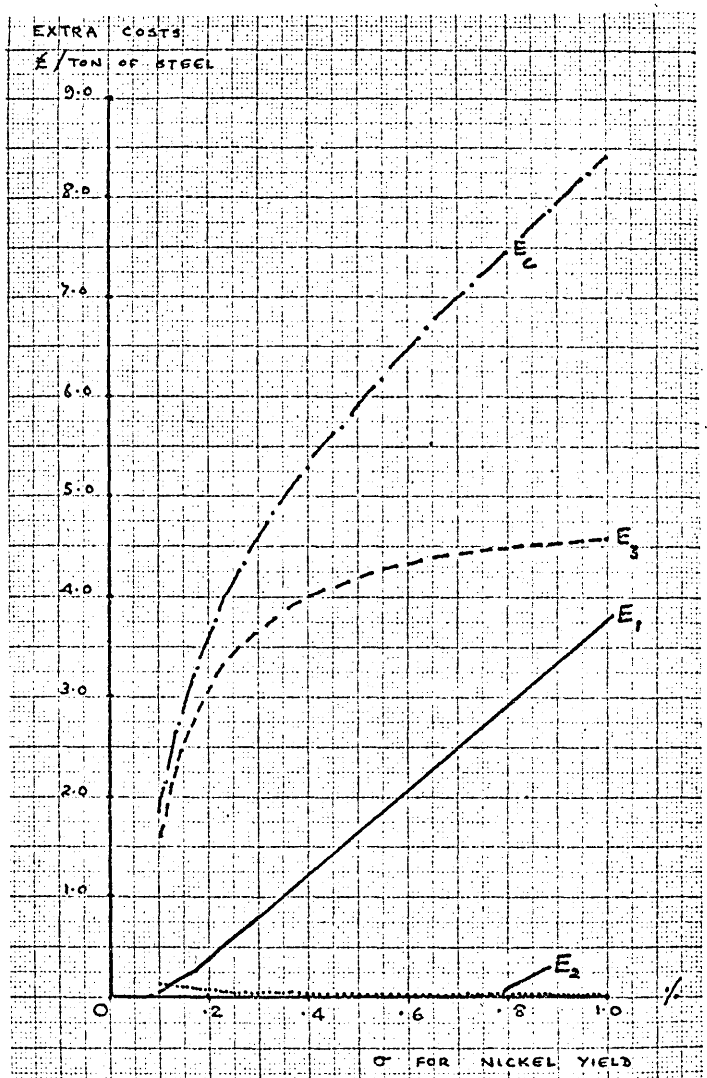
STIPULATED BOUNDS : 2.5% ≤ Ni ≤ 2

AIM POINT Ni = 2.7 %



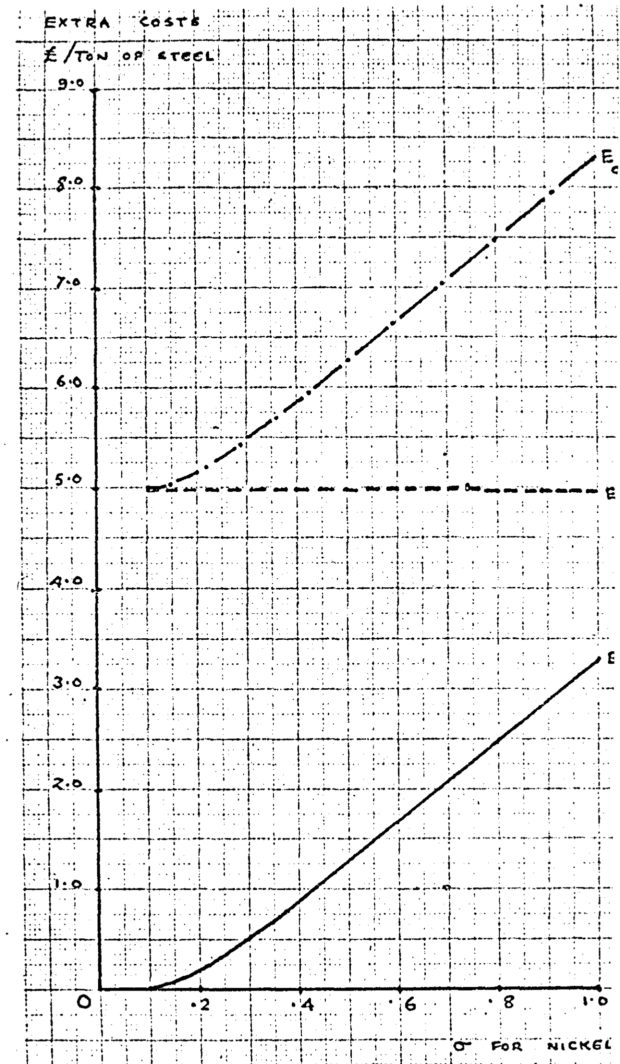
STIPULATED BOUNDS : 3·0 % ≤ Ni ≤ 3·2 %

AIM POINT Ni = 3·0 %



STIPULATED BOUNDS 3·0 % ≤ Ni ≤ 3·2 %

AIM POINT Ni = 3·1 %



STIPULATED BOUNDS 3·0 % ≤ Ni ≤ 3·

AIM POINT Ni = 3·2 %

Discussion

An examination of the graphs of Extra Cost expectations indicates the following.

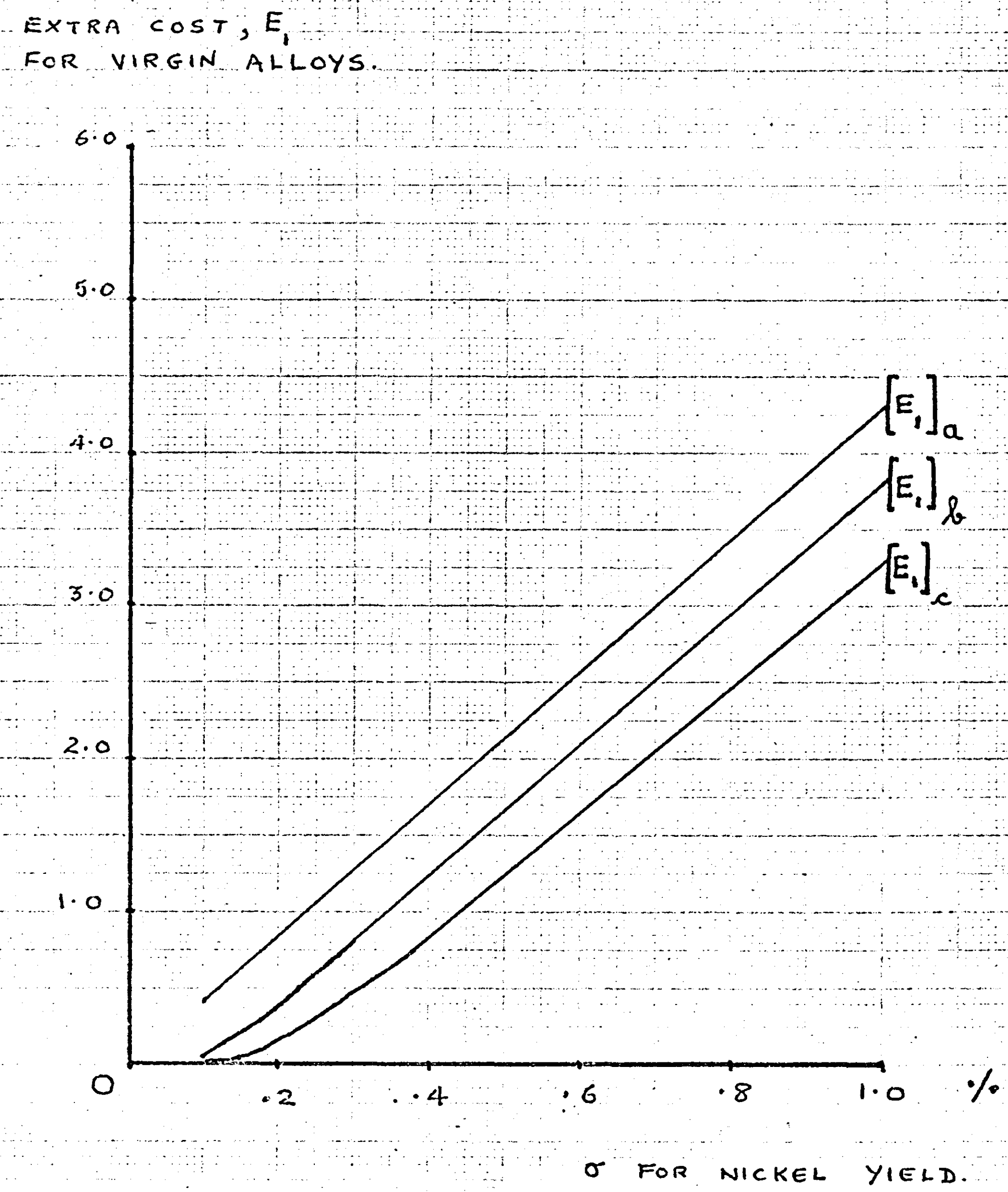
i) The extra costs for lower and upper bound violations (E_1 and E_3) tend to increase as the standard deviation of the blend σ becomes larger, where increasing σ represents increasing attribute uncertainty.

The curve for "opportunity cost" (E_2) which is incurred within the range of the bounds has a point of inflexion.

ii) For steels with identical distributions and magnitudes of stipulated attribute range, the extra costs incurred will be the same, providing the aim point disposition in relation to the bounds is similar. Under such conditions the extra cost is a function of σ and independent of μ. The validity of this argument is confirmed by expression (vi) for the case of a lower bound aim point and expression (vii) for the upper bound case. (Both expressions were presented earlier in this chapter). The significance of this fact to the user is that he can compute expected extra costs due to attribute uncertainty from general tables for given attribute ranges and aim point strategies, independent of steel quality.

iii) In this analysis of extra cost due to attribute uncertainty we have included E_1, E_2 and E_3. In practice the management of steelplants producing special steels will be interested mainly in E_1. They will usually be willing to ignore E_2 as this expected extra cost arises from feasible and "trouble free" casts. As far as E_3 is concerned they will be interested primarily in avioding upper bound violations because of the numerous practical difficulties that are invoked at each incidence of upper bound violations. As the user is most interested in E_4, the cost of extra virgin additions, we present a comparison of E_4 that is incurred for aim points at the upper bound, mid range or lower bound. The comparison is presented on the following graph, which indicates that E_4 increases as the aim point is lowered. It is clear that this increase in cost will continue as the aim point falls below the lower bound and serves as an indicator to management that using "safe" aim points with negligible risks of upper bound violations, may not always promote overall economies. The recommended aim point should be based on the joint consideration of E_4 and the acceptable probability of upper bound violations.

GRAPH OF RELATIONSHIP BETWEEN E1 (COST OF EXTRA VIRGIN) , AIMPOINT & BOUNDS .



RANGE BETWEEN UPPER & LOWER BOUND = 0·2%

$[E_1]_a$ OCCURS WHEN AIMPOINT IS AT LOWER BOUND

$[E_1]_b$ OCCURS WHEN AIMPOINT IS AT MID-RANGE

$[E_1]_c$ OCCURS WHEN AIMPOINT IS AT UPPER BOUND.

Analysis of Scrap Circulation in Steelplants

The production procedures used in steel shaping processes usually result in some proportion of source material being shed as scrap discards. These discards constitute a ready source of raw material for the melting process. However, its value to the melting process is considerably reduced if the discards have not been segregated properly, according to the authorised scrap classification code. Poor scrap segregation results in uncertainty of scrap attributes for supplies from such sources. The expensive consequence of poor scrap segregation on raw material cost has been demonstrated in earlier chapters. The object of this chapter is to discuss some of the approaches that could be used in a study of the "cause-effect" aspects of scrap segregation. Such a study could identify the problem areas associated with scrap segregation and lead to the development of better policies for scrap segregation.

A simplified material flow diagram is shown below* for a steelplant where the processing units are open-die forging presses and machine shops.

* diagram on next page

MATERIAL FLOW DIAGRAM

British Steel Corp., River Don Works

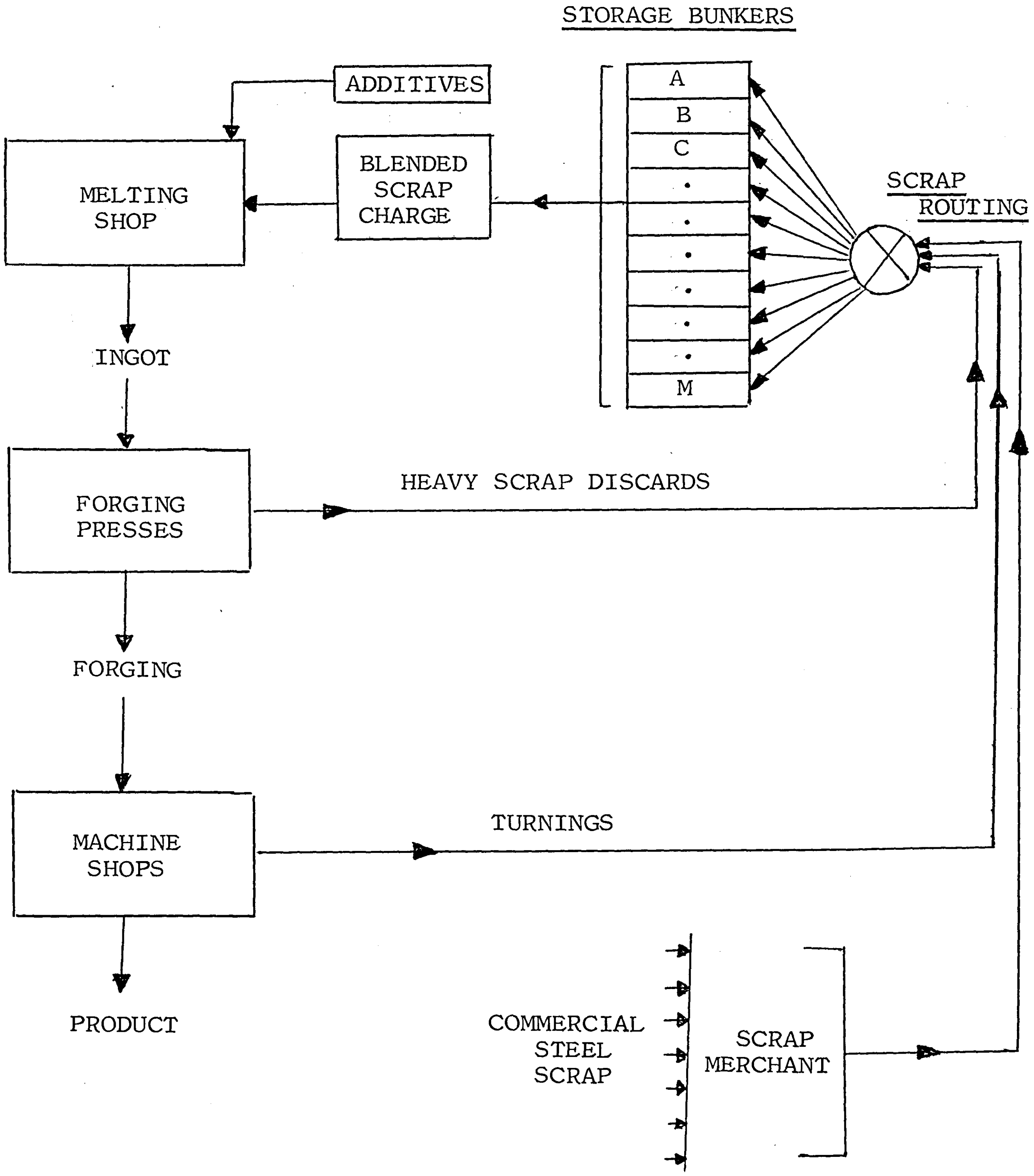


Fig. 1

The approaches that have been considered for a study of the scrap segregation problem during this research programme are as follows.

<u>Method I</u> Analysis of historic production data to ascertain the expected proportions of scrap arising in each scrap type for comparison with proportions that were actually registered in each type respectively. The discrepancies can be expressed in terms of cost.

<u>Method II</u> A study of the effects that will occur from the adoption of various scrap segregation policies, using a computer based simulation model which attempts to emulate the operational practices of the real system.

<u>Method III</u> An examination of the scope for modeling the system on an analytic basis, resorting to simplifications where necessary.

A detailed presentation of each of these methods and discussions on the results as well as limitations of each approach follow.

<u>Method I</u>

The reason for our examining the segregation system is because we suspect that a particular steel processing department is not conforming to the stipulated scrap segregation disciplines. The object of this exercise is to validate this statement and attempt to quantify the lack of discipline in money terms so that a case for improved control can be presented.

Suppose we consider a particular time interval. Then during that period the processing department will have executed a production schedule consisting of several orders. The products that constitute these orders will usually be of various steel qualities. The discards from each order should have made a contribution to the scrap stocks within each scrap category defined by the scrap code. The amounts generated within each code will, in an error-free system, be equal to the amounts actually received into the system as indicated by the scrap inventory for the department. In an error-prone system significant differences between amounts generated and amounts received are likely. The object of this exercise is to determine these differences during a sample interval and express the errors in monetary terms. The monetary unit that is most readily usable in this form of analysis is the market value of each scrap type defined by code. The losses incurred by the error prone system can then be expressed as devaluation or overvaluation of the scrap stocks.

The quantities of scrap generated within each code can be evaluated as follows.

Let I_i = Weight of i^{th} ingot (raw material)

F_i = Weight of i^{th} forging (processed product)

S = Weight of Scrap received during time interval $t_o \longrightarrow t_m$.

R = Weight of Recoverable Scrap generated during time interval $t_o \longrightarrow t_m$.

P = Proportion of Scrap recovered relative to total metal removed in processing.

t_o and t_m; Time markers to define the start of a production schedule and its termination having made m forgings.

Ω = Quality Code to identify scrap types 1, 2, ... n.

Total Metal Removed in producing m forgings $= \sum_{i=1}^{m} (I_i - F_i)$

$$P = \left[\frac{S}{\sum_{i=1}^{m} (I_i - F_i)} \right]$$

Recoverable Scrap generated in each scrap quality Ω. $\quad R_\Omega = P . \sum_{i=1}^{m'} (I_i - F_i)_\Omega$

where the range $i = 1, \ldots\ldots m'$, excludes all sets of (I_i, F_i) which do not belong to the particular category Ω, and as such is a sub-set of complete range $i = 1, \ldots\ldots m$ covering all qualities, $\Omega = 1, \ldots\ldots n$.

To evaluate the errors in the system we determine the differences between the amounts of scrap generated in each quality Ω and the amounts actually "received" under the corresponding quality code Ω.

Let the range of qualities in the system be $\Omega = 1, 2, \ldots\ldots n$.
Let the unit price for each quality Ω be C_Ω.
Then for each scrap quality Ω, the devaluation or overvaluation, can be evaluated as;

Valuation Error $= (R_\Omega . C_\Omega) - (S_\Omega . C_\Omega)$

$= \left[(R - S) . C \right]_\Omega$

If the valuation error is positive then it is a devaluation, but if negative it is overvaluation.

The sum of the Valuation error for all qualities $\Omega = 1, 2, \ldots\ldots n$, represents the overall error of the system, using the value of stock as a monetary measure, for a given time period, when segregation is assumed to be at a particular level of "ineffective control" - sic.

$$\text{Overall Valuation Error} = \sum_{\Omega=1}^{n} \Big[(R - S) \, . \, C \Big]_{\Omega}$$

The results of such an analysis carried out on the forge for a 16 week sample schedule (29th March 1970 to 25th July 1970) are presented below.

Scrap Type Ω	Price C £/Ton	Recoverable Scrap Arising		Scrap Received	
		Tons	Value £	Tons	Value £
Carbon	12.85	2,528	32,484.8	3,495	44,910.75
1 CR.MO	14.75	1,513	22,316.75	1,105	16,298.75
3 CR.MO	13.45	129	1,735.05	70	941.5
1 N_i.CR	17.9	12	214.8		
2 N_i.CR	20.6	191	3,934.6		
3 N_i.CR	25.2	52	1,310.4		
L/NCM	17.1	286	4,890.6	207	3,539.7
1 NCM	18.4	96	1,766.4		
2 NCM	21.15	594	12,563.1	705	14,910.75
3 NCM	25.7	573	14,726.1	10	257.0
Miscellaneous	14.2-30.4			118	2,274.5
Mixed	8.0	233	1,864.0	497	3,976.0
TOTAL		6,207	97,806.6	6,207	87,108.95

Devaluation = £97,806.6 - £87,108.95

= <u>£10,697.65, in 16 weeks</u>

Average Weekly Devaluation = <u>£668.6/WEEK</u>

Devaluation/Ton = £10,697.65/6207

= £1.75/Ton

Observations on the Results from Method I

The results from this study suggest that the scrap segregation system in force is not satisfactory. Further investigations were carried out to identify the weaknesses of the existing system. It was found that poor scrap segregation arises when scrap discards are not adequately identified or when the storage space for scrap becomes congested. The existing method of scrap identification was to hand-stamp the scrap code, using single dies. The code is stamped when the discard is hot which results in the indentation being vulnerable to erasure by surface scaling. The operative responsible for segregating scrap and routing it to respective storage areas, often finds difficulty in locating the identity on the discard and all too often the information required is illegible or incomplete. In such cases he routes the discard to a storage area which may or may not be the correct one. To overcome this problem the HILTI identification was developed which utilises an electric embossing machine to print the identity code on a metal plate, which is nailed on the discard using a HILTI power tool. This system is now in operation and the results so far have been satisfactory. To avoid the problems arising from insufficient storage areas, the plant management authorised the allocation of new areas for scrap bunkers.

The details of this study were published in a British Steel report a copy of which is included in the appendices (II).

Method II The Simulation Model

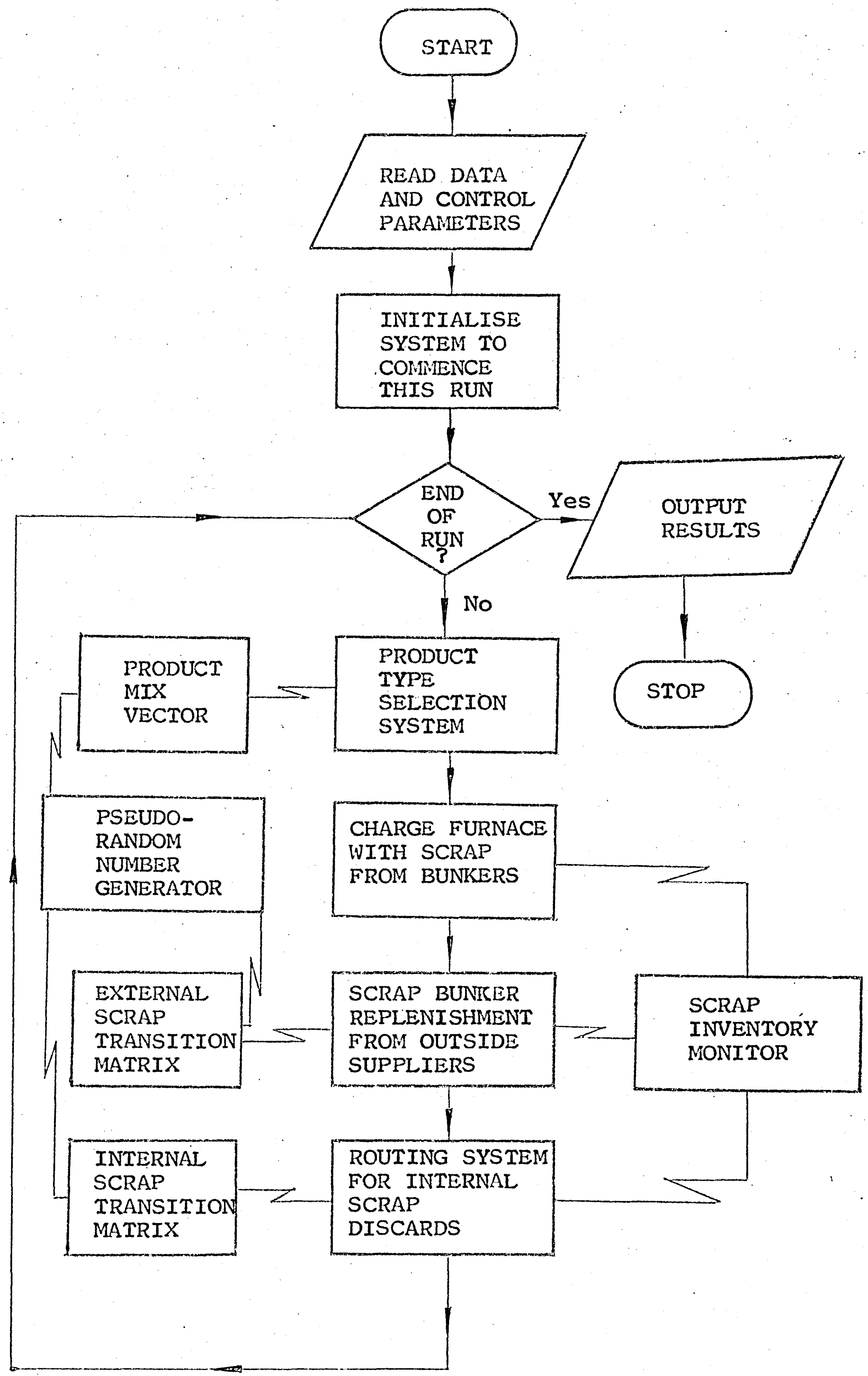
It is generally accepted that the quality of scrap segregation can have significant effects on the raw material costs for special steel production. However, the scrap segregation disciplines in force within steelplants and commercial scrap companies are usually unsatisfactory. The Simulation model of scrap flow could serve as an aid to management in appraising the relative advantages of various control policies to improve scrap segregation. The development of a scrap flow simulation model and the results obtained from running this model are outlined below.

The model is structured on an idealised representation of scrap flow within a steelplant. The scrap segregation discipline at each control node is represented by a Transition Matrix, which describes the probabilities of material transition into correct or incorrect bunkers. Material flow within the system commences at the melt-shop with the production of an ingot from scrap, which proceeds to a processing unit where it is converted to a product which leaves the system. The scrap discards arising at the processing unit proceed to a control node which routes it to a bunker. To maintain the material balance of the system, scrap supplies are purchased from outside sources whose segregation policies are also assumed to be imperfect. The model also includes facilities for the inclusion of product mix considerations and sequencing of product types within the production schedule.

The computer programming related to the development of this model was assigned as an undergraduate computing project to Miss P. J. DOHERTY, a student at Sheffield Polytechnic. The macro-level flow diagram of the simulation model is presented on the following page.

COMPUTER SIMULATION MODEL OF SCRAP FLOW:

MACRO-LEVEL FLOW DIAGRAM



Results from the Simulation Model

The results presented here were obtained using the following data.

The plant produces four types of steel with a product mix ratio of (1 : 2 : 4 : 3).

The Transition Matrix at the internal control node for scrap routing to bunkers is as follows.

SCRAP TYPES ↓ / → BUNKERS	1	2	3	4
1	.5	.25	.15	.1
2	.2	.5	.2	.1
3	.1	.2	.5	.2
4	.1	.15	.25	.5

Element (i, j) represents the probability of scrap type i being routed to bunker j.

The ingot size is assumed to be 10 units, which is processed into a product of size 7 units and scrap discards of size 3 units. Scrap is purchased from the external supplier in consignments of 7 units whose constituents are assumed to be distributed according to the above transition matrix normalised on columns. The initial states of the bunkers are stated on the print-out as the situation at cycle 0.

An extract from the computer print-out for a 2000 cycle run of the simulation model is presented on the following pages.

RESULTS FROM 2000 OPERATIONS OF STEEL PROCESS SIMULATION

0 CYCLES

		SCRAP TYPE 1	2	3	4
BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		50.000	20.000	10.000	10.000
2		25.000	50.000	20.000	15.000
3		15.000	20.000	50.000	25.000
4		10.000	10.000	20.000	50.000
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	160.000	50.000	40.000	40.000	30.000
2	250.000	25.000	100.000	80.000	45.000
3	330.000	15.000	40.000	200.000	75.000
4	260.000	10.000	20.000	80.000	150.000

100 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		39.305	21.547	23.606	15.852
2		14.822	40.989	27.025	17.162
3		8.104	16.379	51.200	24.231
4		4.271	9.938	29.093	56.839
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	190.000	74.680	40.940	44.852	30.120
2	259.000	38.390	106.162	69.995	44.450
3	300.000	24.312	49.137	153.601	72.695
4	251.000	10.722	24.945	73.024	142.668

150 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		43.352	21.020	21.393	14.510
2		15.309	43.186	25.192	16.311
3		7.742	18.949	48.310	24.942
4		8.278	9.401	24.067	58.307
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	193.000	83.669	40.568	41.290	28.004
2	259.000	39.651	111.853	65.249	42.245
3	306.000	23.692	57.986	147.829	76.323
4	242.000	20.034	22.752	58.243	141.104

200 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		40.792	22.794	21.860	14.737
2		17.572	42.099	23.404	16.923
3		8.153	17.014	46.945	27.852
4		10.890	8.748	19.683	60.702
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	211.000	86.072	48.095	46.125	31.095
2	262.000	46.040	110.301	61.318	44.338
3	300.000	24.459	51.042	140.837	83.558
4	227.000	24.721	19.859	44.682	137.793

500 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		45.420	24.167	19.426	11.029
2		16.568	44.026	24.327	15.077
3		9.789	19.999	52.283	17.927
4		7.704	8.345	26.407	57.543
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	277.000	125.815	66.943	53.812	30.551
2	292.000	48.380	128.558	71.036	44.024
3	228.000	22.319	45.598	119.206	40.874
4	203.000	15.640	16.940	53.607	116.812

1000 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		44.312	25.384	16.423	13.885
2		21.151	39.734	23.025	16.087
3		9.108	12.816	58.550	19.524
4		8.107	11.317	26.261	54.313
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	364.000	161.297	92.401	59.782	50.544
2	352.000	74.454	139.865	81.049	56.628
3	102.000	9.290	13.072	59.721	19.915
4	182.000	14.756	20.597	47.795	98.850

1250 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		42.690	26.178	17.326	13.808
2		20.977	41.976	23.225	13.820
3		15.207	3.217	55.282	26.292
4		8.397	11.081	23.839	56.681
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	436.000	186.128	114.139	75.543	60.204
2	367.000	76.988	154.054	85.236	50.720
3	15.000	2.281	0.482	8.292	3.943
4	182.000	15.284	20.167	43.387	103.160

REFILLED BUNKER NUMBER 3

1500 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		39.006	25.107	19.964	15.923
2		18.339	45.886	22.018	13.755
3		14.223	12.167	51.470	22.138
4		7.325	8.367	27.052	57.254
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	493.000	192.301	123.779	98.426	78.502
2	406.000	74.457	186.299	89.395	55.845
3	258.000	36.696	31.391	132.795	57.116
4	164.000	12.013	13.723	44.365	93.897

2000 CYCLES

BUNKER		PERCENTAGES OF CONTENTS OF BUNKER			
1		44.628	22.212	16.634	16.525
2		17.768	45.468	23.657	13.105
3		12.261	16.376	50.108	21.254
4		10.521	11.945	21.788	55.743
BUNKER	TOTAL	DIVISION OF TOTAL CONTENTS OF BUNKER			
1	577.000	257.504	128.164	95.983	95.349
2	439.000	78.003	199.606	103.857	57.531
3	156.000	19.127	25.547	78.168	33.156
4	149.000	15.677	17.798	32.465	83.058

BUNKER NUMBER	1	2	3	4
NUMBER OF EXTRACTIONS FROM EACH BUNKER	186	435	808	571
NUMBER OF ADDITIONS TO EACH BUNKER	325	498	643	534
PURCHASES INTO EACH BUNKER	186	435	808	571
AVERAGE PERCENTAGE OF PURE STEEL TYPE	42.74	43.81	50.28	55.06

Observations on the Simulation Results

The results indicate that the inter-action between the product mix ratio and the flow pattern for internal scrap discards, results in a nett gain of material into bunkers 1 and 2, whilst bunkers 3 and 4 suffer a nett loss. The effect of this on purchasing requirements is that the plant has to procure a greater tonnage of scrap types 3 and 4 than is actually produced within these steel qualities within a given operating period.

The composition of the bunkers at various stages of the simulation run provide a guide to the yields that could be expected in a steelplant operating under the stated conditions.

Where the market price of each scrap type is different, it would also be possible to evaluate the monetary devaluation or over-valuation of stock, using the concepts outlined in method 1 of this chapter.

Method III

Examination of the scope for Analytical Models

Model I

Consider the system which produces product types A, B, C, ... M. Let the scrap segregation system operate on the same basis with bunkers for the collection of discards from each type A, B, C, ... M. If the system is error-free then discard 'A' is routed to bin 'A' and under such conditions the probability of the transition discard $A \rightarrow$ Bunker A will be unity.

i.e. $P_{AA} = 1.0$

However, in an error prone system the scope for the transitions $A \rightarrow B$, $A \rightarrow C$, ... $A \rightarrow M$, are likely to exist.

Hence in an error-prone system

$P_{AA} < 1.0$

Supposing $P_{AA} = N$,

then the probability of not routing $A \rightarrow A$ will be,

$$q_{AA} = 1 - N$$
$$= P_{AB} + P_{AC} + \ldots\ldots + P_{AM}$$

These arguments can be repeated for each of the other product types B, C, D, ... M. These transition probabilities for the system can be represented by a matrix, where the row number represents products and the column number the bunkers, as indicated below.

$$\text{Transition Matrix } T = \begin{array}{l} \xrightarrow{\quad} \text{SCRAP BUNKERS} \\ \text{SCRAP TYPES} \downarrow \begin{bmatrix} P_{AA} & P_{AB} & P_{AC} & \cdots\cdots & P_{AM} \\ P_{BA} & P_{BB} & P_{BC} & \cdots\cdots & P_{BM} \\ P_{CA} & P_{CB} & P_{CC} & \cdots\cdots & P_{CM} \\ \vdots & & & & \\ P_{MA} & P_{MB} & P_{MC} & \cdots\cdots & P_{MM} \end{bmatrix} \end{array}$$

At a given time t, we find the system in a particular state S, where S has a matrix of similar structure to T and represents the quantities of each scrap type in each bunker. In this matrix let a_{ij} be the quantity of type i in bunker j.

$$\text{State Matrix } S = \begin{bmatrix} a_{AA} & a_{AB} & a_{AC} \cdots\cdots & a_{AM} \\ a_{BA} & a_{BB} & a_{BC} \cdots\cdots & a_{BM} \\ a_{CA} & a_{CB} & a_{CC} \cdots\cdots & a_{CM} \\ \\ a_{MA} & a_{MB} & \cdots\cdots\cdots\cdots & a_{MM} \end{bmatrix}$$

Using the information on the state of the system at a given stage, S_i, we should be able to predict the state of the system at some future stage S_n. The transformation of the system from one state to the next is governed by the relationship;

$$S_{j+1} = T \cdot S_j$$

We could then extend this argument to considerations of long run properties of the system.

In many ways the representation discussed so far resembles a Markov Process model. If it can be assumed that the model considered here fulfils the requirements of a Markov Process, then we can readily determine the steady state transition matrix T_∞, which can be used to compute the resultant steady state S_∞ from a system commencing with an initial state S_1.

i.e. $S_\infty = T_\infty \cdot S_1$

For illustration consider the following example.

Let the initial state be S_1,

$$S_1 = \begin{bmatrix} 50 & 30 & 20 \\ 10 & 50 & 40 \\ 5 & 45 & 50 \end{bmatrix}$$

The transition matrix for the system is as stated below.

$$T = \begin{bmatrix} .5 & .3 & .2 \\ .1 & .5 & .4 \\ .2 & .2 & .6 \end{bmatrix}$$

Now consider the transformations of the system.

$$S_2 = T \cdot S_1 = \begin{bmatrix} 29 & 39 & 32 \\ 12 & 46 & 42 \\ 15 & 43 & 42 \end{bmatrix}$$

$$S_3 = T \cdot S_2 = \begin{bmatrix} 21 & 42 & 37 \\ 15 & 44 & 41 \\ 17 & 43 & 40 \end{bmatrix}$$

$$S_4 = T \cdot S_3 = \begin{bmatrix} 18 & 43 & 39 \\ 16 & 44 & 40 \\ 17 & 43 & 40 \end{bmatrix}$$

$$S_5 = T \cdot S_4 = \begin{bmatrix} 17 & 43 & 40 \\ 17 & 43 & 40 \\ 17 & 43 & 40 \end{bmatrix}$$

The column convergence of all a_{ij}, in each column j, suggests that the steady state has been reached.

ie. $$S_6 = T \cdot S_5 = \begin{bmatrix} 17 & 43 & 40 \\ 17 & 43 & 40 \\ 17 & 43 & 40 \end{bmatrix} = S_5 = S_\infty$$

S_∞ can alternatively be determined from $S_\infty = T_\infty \cdot S_1$, where T_∞, can be determined from the one step transition matrix T.

$$T = \begin{bmatrix} .5 & .3 & .2 \\ .1 & .5 & .4 \\ .2 & .2 & .6 \end{bmatrix}$$

$$T_\infty = \begin{bmatrix} \Pi_1 & \Pi_2 & \Pi_3 \\ \Pi_1 & \Pi_2 & \Pi_3 \\ \Pi_1 & \Pi_2 & \Pi_3 \end{bmatrix}$$

where Π can be evaluated either from successive transformations of T in the form $T_{2i} = T_i \cdot T_i$, until convergence or by solving for Π from equations below.

$$\Pi_1 = .5\Pi_1 + .1\Pi_2 + .2\Pi_3 \qquad (1)$$
$$\Pi_2 = .3\Pi_1 + .5\Pi_2 + .2\Pi_3 \qquad (2)$$
$$\Pi_3 = .2\Pi_1 + .4\Pi_2 + .6\Pi_3 \qquad (3)$$
$$\Pi_1 + \Pi_2 + \Pi_3 = 1 \qquad (4)$$

In solving for Π, one of the equations is redundant, but the redundant equation should not be (4).

Solving the equations we find

$\Pi_1 = .24$, $\Pi_2 = .32$, $\Pi_3 = .44$

$\therefore \quad S_\infty = T_\infty \cdot S_1$

$$S_\infty = \begin{matrix} .24 & .32 & .44 \\ .24 & .32 & .44 \\ .24 & .32 & .44 \end{matrix} \qquad \begin{matrix} 50 & 30 & 20 \\ 10 & 50 & 40 \\ 5 & 45 & 50 \end{matrix}$$

$$= \begin{matrix} 17.4 & 43 & 39.6 \\ 17.4 & 43 & 39.6 \\ 17.4 & 43 & 39.6 \end{matrix}$$

Which is the same result as before, the fractional differences in Π_1 and Π_3 being due to rounding off at each transformation in the earlier evaluation.

<u>Limitations of the Markov Model</u>

i) The model considers a particular state and all transformations to predict future states are based on the assumption that all members of the initial set remain in the system and maintain their identity, whilst remaining as an integer unit.

ii) The real system takes a particular amount from a bunker i, melts it down and if the result differs from the expected attributes of i then it corrects it and its output is then i, whereas the input may have consisted of i and various forms of "not i" members. However, at the end of the process the "not i" members no longer exist and discards from the output 'i' return as 'i'. The model is incapable of representing this complex transformation.

iii) The model is a true representation only if we consider it analogous to the "coloured balls in URNS" type of situation; where we label the URNS with particular colours, load the URNS initially with mixtures of balls and then continue to transfer random sets of balls from URN to URN. In this situation the members of the ball population are able to maintain their identity both in type (colour), unity of existence, and members of the population do not leave the system.

<u>Model II</u>

In this model we will attempt to represent the flow of material within the system, identifying each physical transformation separately.

The basis of this model is the State Matrix, wherein we represent the amounts of each grade in a particular bunker at any stage of the process. The structure of the state matrix is exactly as proposed in Model I.

The major physical transformations that constitute the process are as follows.

(a) The charging of the furnace with scrap from a bunker, which at a given point in time contains some known combination of scrap types. By completing the charging process we deplete the contents of a bunker.

(b) The production of an ingot which is then processed, resulting in the creation of scrap discards which can be routed correctly or incorrectly to the bunkers as defined by a Transition matrix.

(c) For the system to remain in equilibrium it is necessary to balance the weight of products leaving the system by an equivalent amount of raw material from outside suppliers. The quality of supplies from this source will also be defined by a Transition matrix, where in this case it represents the behaviour of the outside sources from which the supplier obtains his stock.

We propose the following models to represent each of these phases.

Charging phase

Let S = State Matrix prior to charge

C = The charge matrix, where each column represents the depletion from each bunker, the row elements being the amounts of each scrap type expected from each bunker

The elements of the charge matrix C_{ij} are computed as:

$C_{ij} = \left[q_j \cdot P'_{ij} \right]$, for all i

where P'_{ij} is the transition matrix for supplies into the bunkers normalised on columns.

and q_j = quantity charged from bunker j.

The state of the bunker after charging, $S' = S - C$, where S', S and C are m x m matrices.

<u>The Internal and External Scrap Supplies</u>

The scrap replenishment will be represented by the matrix R_K, (K = I or E, where subscripts I and E represent internal and external supplies respectively).

The elements of the matrix R_K are r_{ij}, which represent the constituent contents i within each supplied scrap type j.

R_K can be computed as follows.

$R_K = \left[r_{ij} \right]_K = \left[q_i \cdot P_{ij} \right]_K$, for all j.

where,

P_{ij} = the transition probability of routing to j for any consignment supplied as type i.

and,

q_i = the quantity supplied as type i.

<u>The Total System Model</u>

The separate phases of material flow described so far can be combined to give the following total system representation.

$S_{i+1} = S'_i + R_I + R_E$

<u>Applications of Model II in studies of System Behaviour</u>

The model can be used to:

i) Monitor the stage by stage changes that are likely to occur using sampling techniques to simulate the behaviour of various parts of the system under particular sets of operating conditions.

ii) Predict the "expected behaviour" of the system using considerations of product mix.

Let us consider the latter case and illustrate using a numerical example.

Given a system whose long term product mix is defined by the ratio Ω_K; (A : B : C : D) : (10 : 20 : 40 : 30)

and the Transition Matrix being,

$$T = \begin{bmatrix} .5 & .25 & .15 & .1 \\ .2 & .5 & .2 & .1 \\ .1 & .2 & .5 & .2 \\ .1 & .15 & .25 & .5 \end{bmatrix}$$

For convenience, let $T = T_I = T_S$

Let scrap to product ratio $(\Omega_I : \Omega_E) = (0.3 : 0.7)$

Let the total quantity supplied $\Omega_S = \Omega_K$

$\Omega_I = 0.3\Omega_S = (3, 6, 12, 9)$

$$R_I = \begin{bmatrix} 1.5 & .75 & .45 & .3 \\ 1.2 & 3.0 & 1.2 & .6 \\ 1.2 & 2.4 & 6.0 & 2.4 \\ .9 & 1.35 & 2.25 & 4.5 \end{bmatrix}$$

$\Omega_E = 0.7\Omega_S = (7, 14, 28, 21)$

$$R_E = \begin{bmatrix} 3.5 & 1.75 & 1.05 & .7 \\ 2.8 & 7.0 & 2.8 & 1.4 \\ 2.8 & 5.6 & 14.0 & 5.6 \\ 2.1 & 3.15 & 5.25 & 10.5 \end{bmatrix}$$

Now the state change of the total system was shown to be,

$$S_{i+1} = S_i' + R_I + R_E ,$$

where $S_i' = S_i - C$

Let the total system contain 1,000 units at the initial state as follows.

$$S_i = \begin{bmatrix} 50 & 25 & 15 & 10 \\ 40 & 100 & 40 & 20 \\ 40 & 80 & 200 & 80 \\ 30 & 45 & 75 & 150 \end{bmatrix}$$

To evaluate C we consider furnace charges of 10 units each, with demand being consistent with the product mix ratio. i.e. the average charges of the four types will be (q_j) = (10, 20, 40, 30) during each production cycle.

$$C = C_{ij} = q_j \cdot P_{ij} \text{ , for all i.}$$

where P_{ij}' is the original transition matrix T normalised on columns.

Thus,

$$T' = \begin{bmatrix} .55 & .23 & .14 & .115 \\ .22 & .45 & .18 & .115 \\ .115 & .18 & .45 & .22 \\ .115 & .14 & .23 & .55 \end{bmatrix}$$

and

$$C = \begin{bmatrix} 5.5 & 4.6 & 5.6 & 3.45 \\ 2.2 & 9.0 & 7.2 & 3.45 \\ 1.15 & 3.6 & 18.0 & 6.6 \\ 1.15 & 2.8 & 9.2 & 16.5 \end{bmatrix}$$

Combining each of these,

$$S_{i+1} = \begin{bmatrix} 50 & 25 & 15 & 10 \\ 40 & 100 & 40 & 20 \\ 40 & 80 & 200 & 80 \\ 30 & 45 & 75 & 150 \end{bmatrix} - \begin{bmatrix} 5.5 & 4.6 & 5.6 & 3.45 \\ 2.2 & 9.0 & 7.2 & 3.45 \\ 1.15 & 3.6 & 18.0 & 6.6 \\ 1.15 & 2.8 & 9.2 & 16.5 \end{bmatrix} +$$

continued

$$
+\begin{bmatrix} 1.5 & .75 & .45 & .3 \\ 1.2 & 3.0 & 1.2 & .6 \\ 1.2 & 2.4 & 6.0 & 2.4 \\ 0.9 & 1.35 & 2.25 & 4.5 \end{bmatrix} + \begin{bmatrix} 3.5 & 1.75 & 1.05 & .7 \\ 2.8 & 7.0 & 2.8 & 1.4 \\ 2.8 & 5.6 & 14.0 & 5.6 \\ 2.1 & 3.15 & 5.25 & 10.5 \end{bmatrix}
$$

Thus,

$$
S_{i+\bar{\bar{1}}} \quad \begin{bmatrix} 49.5 & 22.9 & 10.9 & 7.55 \\ 41.8 & 101.0 & 36.8 & 18.55 \\ 42.85 & 84.4 & 202.0 & 81.4 \\ 31.85 & 46.7 & 73.3 & 148.5 \end{bmatrix}
$$

The state change for one complete production cycle is thus computed. This procedure could be repeated to observe the effects over a given range of repetitive production.

<u>Appraisal of the three alternative methods for scrap flow analysis</u>

<u>Method 1</u>: Analysis of plant data

This method is the simplest approach and can be regarded as being the most expedient in practice. The results obtained relate to the actual operations of the plant. The major limitation of the approach is that the validity of the results depend on the credibility of plant data. The analysis is restricted to considerations on a macro scale of material flow, i.e. the results are in terms of the aggregate quantities in a given material code and not in terms of its constituent population identified by attribute.

<u>Method 2</u>: The Simulation Model

This method is perhaps the most flexible of the three approaches considered here. The user has the option to build either or simple models if expediency is important or develop a highly sophisticated model which is an almost total emulation of the real system. The system can thus monitor any number of attributes or characteristics of interest, in a particular plant. The only constraints in this context are the time scale for model development, the computer configuration required and the cost of such a project. The validity of the results from a simulation model depend on the accuracy of probability distributions that are used to represent any real system. The results obtained from a simulation are experimental and as such cannot be proclaimed in any absolute terms. It is often true that large simulation models can have errors in logic which are not easily identified and could in some situations give false results. In spite of these limitations it appears that this approach is at present, superior to the other two considered here, for the study of material flow in steelplants.

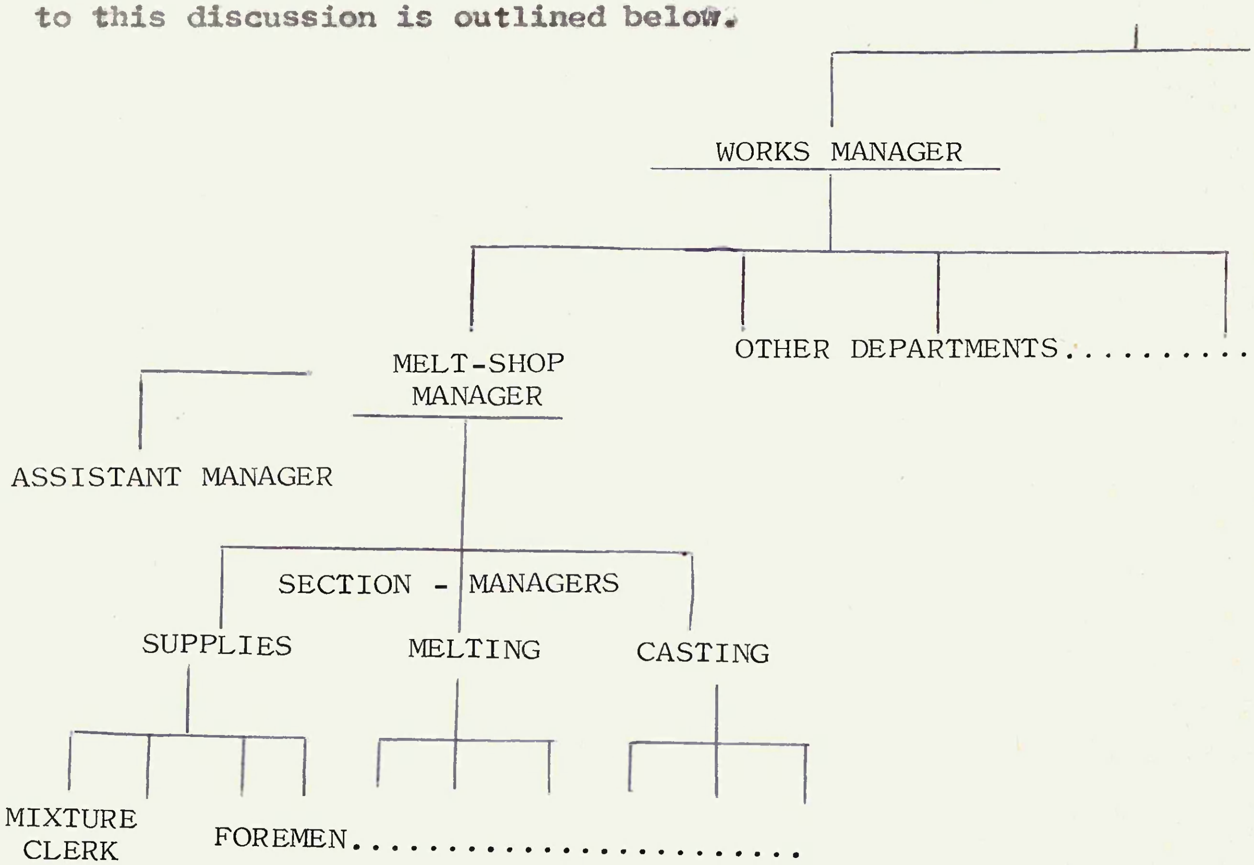
Method 3: The analytical approach

The superiority of analytical models to other approaches rests on the fact that solutions obtained from them are absolute and readily applied. The models developed by the author are only simplified representations and are subject to a number of limitations which have been stated. Within the limited time scale of this research programme, it has not been possible to develop a satisfactory analytical model of this problem. It is suggested that the challenge presented by this problem, merits attention as a separate and exclusive research project.

Analysis of human reactions towards change

The Situation

The Technical Management of the company decided to sponsor a research student to examine the scope for improvements in methods used for furnace charge blending. The project was initiated with the approval of the senior Production Management. The section of the organisational hierarchy relevant to this discussion is outlined below.



The author believed that successful transition in a process of change will depend on the co-operation that is received from those people affected by the change. In line with this reasoning every attempt was made to keep these people fully informed of the motives for this project and notified of the results obtained at each stage of development. The level of enthusiasm for the project ranged from strong support at the Works Manager level to strong resistance at the Mixture Clerk level.

The person most knowledgeable on the existing manual system happened to be the Mixture Clerk. In spite of repeated assurances to the contrary, from the author and the management, the Mixture Clerk appeared to hold the conviction that the instigation of this project has been motivated by a lack of confidence in the quality of his work and that the success of this project will have consequences on his job security and status in relation to other members of this working environment. The argument used to assure him to the contrary was that the new system is intended to be a more efficient tool within his control, to assist him in a similar but more sophisticated manner to the electric calculator that he has been using. As far as job security was concerned he was assured that the new system will be totally dependent on him as the day to day controller of the system usage. As far as job status was concerned it was pointed out that generally users of sophisticated systems are accorded greater status by fellow members in the company. It was conceded however that the system does tend to take over some of the powers of decision making which previously were vested in the Mixture Clerk. Although it was felt highly desirable to win the confidence and co-operation of the Mixture Clerk, this goal was not achieved. A request was made to the management that the Mixture Clerk or someone with comparable expertise on the practical aspects of charge blending be seconded to work on the Least Cost Mix project. This request was not granted. In retrospect the author feels that more pressure ought to have been applied on management to insist on the secondment of a suitable member of staff from the melt-shop, to assist in the modeling of practical details and more important to overcome the resistance to change by those on whom there is some dependence for accurate input data and reliable implementation of solutions from the system.

The Reactions observed during the Major Stages of Development

i) The Feasibility Studies

This stage consisted of experimental work in developing the models for the Least Cost Mix system and testing of the models using historic data. The results obtained were discussed at various levels of management and staff, in descending order from the senior levels. It was observed during these discussions that the concern for cost reduction was very much greater at Works Manager level than in the lower echelons of the hierarchy. In consequence the support for the project was greatest at the executive level. Members of line management and supervisory staff tended to be more concerned with maintaining productive operations using feasibility criteria and almost apathetic to objectives relating to cost optimality.

During the discussions that were held with various members of the organisational hierarchy a peculiar interaction was observed at each interface between managers at one level and their subordinate staff. In this context the Melt-Shop Manager is a subordinate of the Works Manager, the Section Manager is a subordinate of the Melt-Shop Manager, etc. The interaction observed is described as follows: The manager at a particular level in the hierarchy is presented with the case for considering the use of a new system. The merits and limitations of the system were discussed with him, which lead to his finally accepting the case for considering the proposal subject to minor alterations. He then invites his subordinate to discuss the procedure for action on the proposal. At this meeting the subordinate initially expresses misgivings on the scope for the new system and argues the case for a status quo. During this meeting the senior manager defends the case for the new system using the arguments made to him earlier by the proposers of the system. This usually leads to a conditional acceptance of the system by the subordinate. This cycle of events tended to repeat itself as the consideration of the new system percolated through each manager/subordinate interface. Where the discussion involved more than two members of the hierarchy the interaction was between the most senior manager against the collective set of his subordinates from various levels. The collective set often included particular members who individually had once accepted the system but now comply with the disposition of the group.

These interface reponses point to the hypothesis that within the framework of an organisational hierarchy, the junior members adopt a defensive role in relation to proposals for change within their areas of responsibility, particularly if they suspect that the motive for such change is an implied judgement on their organisational effectiveness.

ii) The Plant Trials

The commencement of plant trials was delayed for a long period after they were authorised. The delay was induced by members in the lower echelons of the hierarchy by utilising the conditions which they had imposed on the acceptance of the directive to commence plant trials. The trials were eventually commenced by the issue of an ultimatum by the Works Manager. In this hostile environment such a move constituted "overcoming resistance by executive force". It was fully realised that this was a measure of last resort, but there seemed to be no alternative course of action which was suitable at that time. In effect it was a case of the controlling executive asserting his authority over subordinates who were effectively procrastinating his directive to satisfy their own goals.

In consequence, the plant trials took place in an atmosphere of reluctant co-operation from the melt-shop staff. The results of the plant trials indicated the need to examine the sources of raw material supply to the melt-shop, to consider improvements in the control procedures used. From this stage onwards the support and co-operation from the melt-shop staff began to improve, because they saw the extensions to the project as being something they themselves had felt to be necessary for a long time but remained powerless to motivate action.

iii) Extensions to the Project - Examination of Scrap Control from sources of supply

This phase of the project was an investigation to determine the prevailing state of "ineffective control - sic" on the control of scrap arising in processing departments. The investigations revealed that the scope for improvements was substantial. The method proposed to improve the control of scrap segregation was to introduce a new method of identification for scrap discards. The new method was to emboss the identification on a metal plate using an electric embossing machine and to nail the plate on to the solid scrap using a power tool. The old method was to indent manually the identification using single alpha-numeric dies. The old method was slow, laborious, and needed two operatives to stand fairly close to the red hot discard. In contrast the proposed method was quick, relatively effortless, needed only one operator, and reduced the "hot proximity" time. The proposal to adopt this method was not resisted in the least and met with strong support from the operatives concerned. The reason for this response could be attributed to the fact that the change in this case was one which endowed a great deal of immediate benefit to those affected by the change without any adverse threats to their work roles or group relationships.

Discussion

A review of social science publications indicates that the field of human resistance to change has received considerable attention as a research topic. As early as 1948 COCH and FRENCH[7] had established that a participation strategy can overcome resistance to change. This approach is supported by JUDSON[24] and SCHEIN[42] based on their experiences in a number of successful changes within organisations. However, LAWRENCE[28] warns that participation does not assist in overcoming resistance, if it is treated purely as a device which makes people accept changes. He maintains that participation can only be successful, if the participant can feel that his contribution is essential and hence commands respect from those motivating the change. The level of participation in the author's project did not extend to the lower echelons of the melt shop hierarchy. It would appear that more effort should have been directed towards securing the involvement and contributory participation of the Mixture Clerk and to a lesser extent other melt-shop staff.

The motives for resistance observed by the author have been fear of redundancy, loss of status, objections to a threat on the status quo and lack of confidence in the proposed change. LAWRENCE[28] has suggested that such fears are usual in a situation where some technical change threatens the social fabric of a working group.

The levels of enthusiasm observed by the author indicated strong support by top management, with the opposite reaction at lower levels of the hierarchy. JUDSON[24] has reported that this is quite typical in most situations of industrial change.

The environment of a company can be regarded as being a relevant consideration in terms of whether it is conducive to change. The general disposition of the melt-shop staff was one which favoured a status quo. They had accepted an environment where change was not normal and hence it is natural for them to resist change to the best of their ability. JUDSON[24] and SCHEIN[42] confirm that the resistance to change is usually strongest in an environment where change is a rare event.

In concluding this discussion the author adds ROBUSTNESS as a relevant consideration to the survival of an innovation. If an innovation does not have to rely on employee co-operation for its survival and success, then it can be regarded as being "robust". If however an innovation is totally dependent on employee co-operation for its survival, then it can be regarded as being "fragile". Some hardware innovations which offer immediate benefit tend to be more robust than software innovations where benefits are usually long term. In the author's project the Least Cost Mix system falls within the fragile category, whilst the scrap identification system was quite robust in comparison.

Thus, it is clear that the sociological aspects concerning the introduction of new systems, merit more attention than is usually accorded within most organisations.

Conclusions

It is apparent from this study that the considerations of efficiency in the usage of materials for special steelmaking, extend beyond the domain of melt-shops, owing to the problems of scrap uncertainty which are induced from external sources.

The findings of this research have indicated that the major problem area in relation to the usage of steel scrap in steelmaking is one of attribute uncertainty. The methods developed by the author for the evaluation of the cost arising from attribute uncertainty in scrap, will be of use to steel-plant management, as an aid to assess the scope for improvement.

It is encouraging that an increasing number of companies are now considering the use of Least Cost Mix systems for their melt-shops. It is suggested that such companies will find this thesis to be a comprehensive guide on this topic, at the present time.

In concluding this research programme the author suggests that there is scope for further research in the following areas:

i) A study of scrap uncertainty affecting steelplants with reference to the identification of probability distributions and an examination of the relationships between variance and sample size. Sample size is a relevant parameter in this context because scrap populations are generally non-homogeneous.

ii) The development of a satisfactory analytical model to solve the control problems relating to scrap circulation and segregation.

iii) The development of an efficient computer package for the solution of non-linear representations of the charge blending problem.

REFERENCES

1. B. T. BERNACCHI AND E. F. DUDLEY, JR., Materials usage optimisation in Electric Furnace Steel Production. Metals Engr. Quarterly, November, 1964.

2. R. N. BRASWELL AND F. M. ALLEN, Non-PARAMETRIC SENSITIVITY Analysis in L.P. A.I.I.E. Transactions, March, 1969.

3. T. BURNS AND G. M. STALKER, The Management of INNOVATION, TAVISTOCK, 1961.

4. E. CALANOG AND G. H. GEIGER, OPTIMISATION of stainless steel melting practice by DYNAMIC PROGRAMMING, JNL. of METALS, July, 1967.

5. S. R. CALHOUN, L. HILL AND D. HINDS, Discussion on the LUKENS L.P. model for charge blending, COATESVILLE. PA., August, 1971.

6. A. CHUNG, Linear Programming, MERRILL, 1966.

7. L. COCH AND J. R. P. FRENCH, JR., Overcoming resistance to change, Human Relations, Vol. 1 1948.

8. G. B. DANTZIG, Linear Programming under uncertainty, Management Science, April-July, 1955.

9. J. W. DUNCAN, OPTIMISATION of Blast Furnace operation through L.P., Blast Furnace and Steel Plant, April, 1963.

10 S. E. ELMAGHRABY, The design of production systems, REINHOLD, 1966.

11. S. I. GASS, Linear Programming, McGraw-Hill, 1969.

12. L. E. GREINER, Patterns of organisation change, HARVARD BUSINESS REVIEW, May-June, 1967.

13. G. HADLEY, Linear Programming.

14. K. B. HALEY, Industrial applications of Linear Programming, Ph.D. Thesis Birmingham University, 1962.

15. K. B. HALEY, Mathematical Programming for business and industry, MACMILLAN, 1967.

16. H. J. HALSTEAD, Introduction to Statistical Methods, MACMILLAN, 1966.

17. P. HATIN AND R. KORTNER, Discussions on the Atlas Steels Least Cost Mix system, WELLAND, ONT. CANADA, August, 1971.

18. J. H. HEMMING AND D. R. PAYNE, Least Cost Mix, PROCEEDINGS of O.R. SOCIETY CONFERENCE - 1971, also STEEL TIMES, October, 1971.

19. F. S. HILLIER AND G. J. LIEBERMANN, INTRODUCTION to Operations Research, HOLDEN-DAY, 1968.

20. D. C. HILTY, R. W. TAYLOR AND R. H. GILLESPIE, PREDICTING MINIMUM MATERIALS COST FOR STAINLESS STEELS, JNL. of METALS, July, 1959.

21. B. W. HOLLOCKS, The application of Least Cost Mix, British Steel Corporation - CYBOR HOUSE REPORT M176/OR49/1, January, 1972.

22. I.S.I. - Control of composition in Steelmaking, Publication 99 - The Iron and Steel Institute, May, 1966.

23. A. JACKSON, Modern Steelmaking for steelmakers, NEWNES, 1967.

24. A. S. JUDSON, A managers guide to making changes, WILEY, 1966.

25. E. KAY AND E. DUCKWORTH, L.P. in practice, Applied Statistics, Vol. 6, 1957.

26. E. KAY AND G. MORTON, An L.P. application to SWARF recovery in a Foundry, METAL WORKING PRODUCTION, December 30th 1955.

27. J. R. LAWRENCE AND A. D. J. FLOWERDEW, Economic models for production planning, Operational Res. Quarterly, March, 1963.

28. P. R. LAWRENCE, How to deal with resistance to change, HARVARD BUSINESS REVIEW, January-February, 1969.

29. S. M. LONG AND D. O. GLOVEN, Application of Computer Process Control in Electric Arc Furnace Steelmaking, LUKENS STEEL CO., PENNSYLVANIA.

30. I. K. MACLEAN, R. B. R. STEPHENS AND J. WERNER, Proposal for Arc Furnace control at the Tinsley Park Melt Shop, IBM publication, May, 1968.

31. A. MADANSKY, Linear Programming Under uncertainty - Recent advances in Math Progr. - eds. R. L. GRAVES AND P. WOLFE, McGRAW-HILL, 1963.

32. U. MENON, Development of Systems for the efficient utilisation of Raw Materials in Special Steelmaking, Sheffield Polytechnic Research Report, 1971.

33. U. MENON, Efficient utilisation of scrap - Scrap control in the Heavy Forge, O.R./WORK STUDY REPORT - RIVER DON WORKS, British Steel Corporation, January, 1971.

34. U. MENON, Reactions of the organisation towards innovation, Research Seminar - Sheffield Polytechnic Management Centre, June, 1971.

35. U. MENON, A study of computer applications in Electric Steelmaking plants in U.S.A. and Canada, British Steel Corporation, Special Steels Travel Award Report, October, 1971.

36. U. MENON, Computer Control of Arc Furnace operations, 4th Special Steels Steelmakers Conference, HARROGATE, March, 1972.

37. R. W. METZGER AND R. SCHWARZBEK, An L.P. application to CUPOLA Charging, Journal of Ind. Engr., March-April, 1961.

38. T. H. NAYLOR, J. L. BALINTFY, D. S. BURDICK AND K. CHU, Computer Simulation Techniques, JOHN WILEY, 1967.

39. W. ORCHARD-HAYS, Advanced Linear Programming Computing Techniques, McGRAW-HILL, 1968.

40. C. VAN de PANNE AND W. POPP, Minimum cost cattle feed under probabilistic protein constraints, Management Science, April, 1963.

41. K. ROESSING, R. B. SHAW AND D. C. THOMPSON, Discussions on the furnace charge and alloy additions blending system at ALLEGHENY-LUDLUM STEEL PITTSBURGH, Pa., August, 1971.

42. E. H. SCHEIN, Organisation Psychology, Prentice-Hall, 1965.

43. J. F. STENHOUSE AND D. F. BOYD, Application of a digital computer to melt-shop control, Iron and Steel Engineer, March, 1971.

44. S. M. T. TARKOWSKI, Some human problems, O.R. in management, E.U.P., 1962.

45. S. VAJDA, Planning by mathematics, Pitman, 1968.

46. S. VAJDA, L.P. and the theory of games, METHUEN, 1960.

47. F. E. WEINHEIMER, The computer in Electric Furnace Melting, Proceedings of the Electric Furnace Conference, U.S.A., 1968.

48. A. C. WILLIAMS, On Stochastic L.P., JNL. S.I.A.M., December, 1965.

49. N. WILLIAMS, An application of L.P. to the selection of raw materials, Applied Statistics, Vol. IV, No. 1, 1955.

Appendix I

A Review of Least Cost Mix Projects in North American Steelplants

Appendix I

"A review of Least Cost Mix projects in North American Steelplants"

The author was awarded a travel scholarship by British Steel Corporation, to carry out a study of computer applications in North American Steelplants, during July-August, 1971. The findings of this study were presented in a detailed report, copies which have been distributed within British Steel Corporation. The author has also presented a paper on this topic at the fourth Steelmaker's Conference, Harrogate, March, 1972. The information presented here is a summary of this study, with reference to Least Cost Mix systems.

Atlas Steels System, WELLAND, ONTARIO, CANADA

Atlas Steels have recently installed Least Cost Mix systems using remote time-sharing facilities from a commercial Computer Bureau. The company has an in-house computer on data processing duties, which could run the Least Cost Mix system. However, the company decided against using the in-house data processing computer, on the grounds that the scope for making full use of a Least Cost Mix system is often inhibited by the constraints of job access queue and turnround time. The system is operated from remote teletype terminals at the melt shop, linked by normal telephone lines to the Computer Bureau at Toronto, 80 miles away. There are two systems which are used in sequence, to minimise raw material costs. The first system evaluates the cheapest blend of scrap to fulfil a given chemical composition for each steel quality. The second system is used to calculate the cheapest blend of alloy additions which will bridge the gap between the actual "melt-out" and the stipulated final composition.

Both systems are based on L.P. models and have matrix generators and report writers. They decided to use single cast models for the L.P. in each case, because the overriding priority was one of rapid response from the system in producing solutions at the melt shop, where delays on furnace operations are not acceptable. They were aware of the sub-optimisation which results from single cast models and have attempted to reduce the effects from this source by utilising a cast sequencing routine within the matrix generator of the scrap blending system.

It is understood that similar systems are in use at the following companies in North America: Carpenter Steel, Reading, Pa, U.S.A., CRUCIBLE Steel, SYRACUSE, N.Y., U.S.A. TIMKEN Steel, CANTON, OHIO, U.S.A. Standard software packages for this application are now being marketed by a number of suppliers in U.S.A.

The LUKENS STEEL SYSTEM, COATESVILLE, Pa., U.S.A.

The melt shop at LUKENS Steel Company has an IBM 1800 computer which provides assistance in the following areas: Cast scheduling, Power Demand Control, Operator process guidance, co-ordination of service functions, data monitoring and logging. The planning of charge blends is carried out within the computer system by utilising a library of L.P. solutions. The resource aggregates from these solutions for each production schedule are displayed to the raw material supplies controller. If there is infeasibility in terms of the resource inventory, the computer system iterates using alternative blends from the library to produce a feasible solution set. The solutions library is updated periodically by the O.R. department to account for any changes in element yields or alterations to the supply pattern. The L.P. model used by the LUKENS O.R. team differs significantly from those at other steelplants, because the objective function in this L.P. model relates to the "melting advantage" of each resource. The "melting advantage" is a Cost equivalent, representing the benefits and limitations arising from each resource during charging and melting. The benefits include considerations of expected yields of elements, density in terms of charging problems, credibility of type identity, etc. The limitations cover such aspects as risk of bound violations, high residual levels of tramp elements, problems of charging due to physical structure, etc. The O.R. team at Lukens claim that the use of a melting advantage objective function has provided them with better overall savings than could be expected from the use of a market price objective function.

ALLEGHENY LUDLUM STEEL SYSTEM, PITTSBURGH, Pa., U.S.A.

This company is a major stainless steel producer in North America. They tried the use of L.P. models for scrap blending at the WATERVLIET, N.Y., plant during 1965. The L.P. runs were carried out in an off-line weekly basis, using the head office computer at PITTSBURGH, Pa., under the direction of the O.R. department. The problems of data transmission and lack of interest by melt shop staff resulted in the system being terminated.

They have recently installed a computer system for the calculation of alloy additions at the BRACKENRIDGE melt shop. The production of stainless steels usually requires large amounts of Nickel and Chrome additions. They utilise a

DDP116 computer (8K words of core, 16 bit words) on an on-line basis for the evaluation of the least weight blend of additions, to meet a given objective of chemical composition. The furnace operator has access to the computer through remote terminals at each furnace control console. The melt shop expressed satisfaction with the performance of this system and confirm cost reductions from the use of the system.

United States Steel Systems, PITTSBURGH, Pa., U.S.A.

The system for charge blending developed by this corporation was installed at their South Works, CHICAGO, plant. The details of this system were presented in a paper by B. T. BERNACCHI and E. F. DUDLEY, JR., which is reviewed in the literature survey chapter of this thesis. In addition to this they have developed systems for burdening control in blast furnaces.

Conclusions

The earliest attempts at using L.P. models for furnace charge blending appear to have been made within steelplants in North America. In general they tend to favour on-line or time sharing systems which are independent of their in-house data processing computers. The systems they have implemented permit direct inter-action between the computer and melt shop staff. In contrast the systems developed in the U.K. rely on in-house data processing computers, operate in an off-line mode and use computer staff as the interface between the melt shop personnel and the computer.

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Mr. D. J. Smithson (Divisional Engineering Department)
"Fume Extraction and Containment"

Mr. R. Roebuck (Divisional Engineering Department)
"Arc Furnace Controls"

Mr. C. G. Cooksley (Divisional Engineering Department)
"Transformer Design and Interchangeability"

Dr. F. Fitzgerald (Divisional Research Department)
"Electrode Testing"

Mr. A. Hinchcliffe (Chemical Division)
"Electrode Coating"

Mr. G. Maw (Rotherham Works)
"Mechanical Aids for Furnace Lining Wrecking"

Mr. R. Crawshaw (Stocksbridge and Tinsley Park Works)
"Reclamation of Refractories"

SATURDAY, 11th MARCH

Mr. W. D. Hawke (Rotherham Works)
"The Utilisation of Pre-reduced Materials in Arc Furnace Charges"

Mr. J. Senior (Stocksbridge Works)
"Scrap Preheating and Drying of Turnings"

Mr. U. Menon (Rotherham Works)
"Computer Control of Arc Furnace Operations"

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BRITISH STEEL CORPORATION
SPECIAL STEELS DIVISION
ROTHERHAM WORKS

Operations Research Department

Productivity Services

21st February 1972

THE 4TH SPECIAL STEELS DIVISION STEELMAKERS CONFERENCE

TOPIC: "COMPUTER CONTROL OF ARC FURNACE OPERATIONS"

SPEAKER: MR. U. MENON, O.R. DEPARTMENT, ROTHERHAM WORKS

CONFERENCE CHAIRMAN: MR. J. R. RIPPON, DIVISIONAL MANAGER - METALLURGY

SYNOPSIS

This paper is a summary of the application of computers, which assist steelmakers in various operations within arc furnace shops. The following areas of computer assistance are outlined, with indications of companies in U.K., U.S.A. and Canada that are users of such systems.

(a) Least Cost Mix Systems

(b) Operator Guidance and Shop Co-ordination

(c) Power Control

(d) Cast Scheduling based on Physical Properties

INTRODUCTION

Computers can be of assistance in the planning or control of various activities within a melting shop, because they possess certain attributes which give them an advantage over manual systems performing certain types of work. The attributes implied in the last statement are:-

(i) Speed of performing calculations and processing information.

(ii) Large memory capacity permitting rapid storage and retrieval of information.

(iii) Ability to read information from a number of stations and equally to display information at various locations as required.

In this presentation we will consider the role of the computer within four major types of application for electric melting shops. These are:-

(i) The efficient blending of scrap charges and selection of alloys, at cheapest cost.

(ii) Operator guidance and co-ordination of melting shop activities.

(iii) Power control for maximum demand and efficient melt-down.

(iv) Cast scheduling based on the operating objective of meeting "physical properties" and not chemical specification.

We will now consider in detail the structure of each of these systems to appraise the benefits from the use of such systems, acknowledge the limitations, and briefly survey the experience of companies in the U.K., U.S.A. and Canada.

SYSTEM I

Least Cost Mix Systems for Alloy and Stainless Steel Furnace Charges

In building up the charge for a given steel quality, it is the usual practice to select a blend consisting of various proportions of particular scrap types, which is expected to provide a "melt-out" chemical analysis within a reasonable margin of the aim point for all the control elements. It is well known that there are usually several alternative blends which will provide a particular "desired melt-out analysis". In such situations it would be too time consuming to manually calculate the cost of each blend and then optimise cost by selecting the cheapest blend. The problem becomes more complex if we wish to optimise the overall cost of allocating blends to a group of casts scheduled in a given time period against prevailing stock levels of classified scrap. In such situations if we allocate scrap charges on the basis of "first come - first served", then undoubtedly the first cast considered gets the maximum choice, whilst the last cast gets the minimum choice of raw materials. It would be more sensible to consider the needs of all casts collectively against a given level of stocks, which will enable us to strive towards an overall optimum, within a given planning horizon.

Various mathematical procedures have been developed to assist in the calculation of cheapest furnace charges, which should provide the desired melt-out analysis in each case. These calculations, though lengthy, can be carried out within a matter of minutes on a computer. Computer systems for this task are referred to as "Least Cost Mix" systems. Because the schedules and stock levels in a melt shop are subject to frequent changes, it is advisable to maintain rapid access facilities to the computer through a teletype terminal in the melting shop office. We would input to the computer codes indicating steel qualities, aim points, weights, stock levels of scrap and alloys, special restrictions, if any, etc. This information is then transmitted from the terminal to the computer centre via normal telephone lines. The computer recalls from memory details of density, yields and residual limits, on relevant scrap and alloys, and carries out the least cost blend calculations. The solutions are transmitted to the melting shop terminal and printed out in the form of "charge build-up directives document", which is adequately lucid for use as a shop floor document.

Least Cost Mix systems should no longer be treated as being impractical, because an increasing list of companies have proved that it can be worked in practice, with substantial returns in terms of lower raw material costs and providing a better information base for the control of materials in melting shops.

We are aware that the following companies are using computer based Least Cost Mix systems in their melting shops. They are, in the main, producers of alloy and stainless steels.

North America

(i) Atlas Steels Company, Welland, Ontario, Canada.

(ii) Carpenter Steel, Reading, Pa., U.S.A.

(iii) Crucible Steel, Syracuse, N.Y., U.S.A.

(iv) Timken Steel, Canton, Ohio, U.S.A.

(v) Allegheny Ludlum Steel, Pittsburgh, Pa., U.S.A.

(vi) U.S.S. Corp., South Works, Chicago, U.S.A.

United Kingdom

Private Sector

(i) Dunford-Hadfields, Sheffield.

(ii) Samuel Osborn, Sheffield.

(iii) Sheepbridge Engineering Ltd., Chesterfield.

B.S.C.

Developments in progress at:-

(i) Cybor House for Panteg, Brymbo and Bilston.

(ii) River Don Works.

(iii) Stocksbridge and Tinsley Park Works.

In addition to providing least cost blends for furnace charges, Least Cost Mix systems give useful guides to cost reduction by identifying the "expensive limits" on particular steel qualities, as well as assisting in scrap buying by pointing out the relative importance of various grades of scrap from the point of its intrinsic worth to the melting shop in monetary terms.

The additional capital investment for a Least Cost Mix system is usually very low, if it can be tagged on to an existing computer, or if a bureau is used, and operational costs are extremely reasonable. The average level of savings from Least Cost Mix systems in terms of lower mixture costs has been found to be of the order of 10% for alloy steels. The actual savings achieved in each plant is a function of the quality of scrap segregation discipline that is adhered to in a particular environment. An equally important factor for successful implementation is the level of co-operation and active involvement in the system by melting shop staff in the development and commissioning of Least Cost Mix systems in a melting shop.

The scope for the use of Least Cost Mix systems lies mainly in the production of alloy and stainless steels. At the present time there is little justification for the use of such systems in carbon steel production.

SYSTEM II

Operator Guidance and Plant Co-ordination

The objective of using computer systems for operator guidance is to provide advisory information to melting shop operatives, which will assist them in achieving improved performance. The computer is capable of providing this sort of service because it can rapidly obtain and process information which will be useful to the operators in making better decisions. The systems in use at present operate in "open-loop mode", i.e. the computer only gives advice, it does not take action at the furnace. The decision to execute a particular instruction is made by the melter, the role of the computer being purely advisory in this situation. The advice from the computer is usually based on management approved operating standards, which are derived from a scientific analysis of past performance by the best melters in the shop. The standards are reviewed periodically and modifications made if recent performance consistently produced better results than expected by operators adopting different practices. Let us now consider the method of operation of this type of system.

Operator Guidance

Commencing from the "furnace fettled and ready for charge" stage, the computer provides a continuous guide to the sequence of operations required to produce a given melt. At the appropriate time it will provide advice concerning: the sequence of basket charges, power settings for melt-down, measuring temperature, blowing oxygen, taking samples, making alloy additions, etc. A number of measuring instruments are directly linked to the computer. The operator is provided with an input panel for giving instructions or replying to the computer messages. Time is an important consideration in the melting process, and hence the computer keeps track of durations into each melt. Information presented to the melter is displayed either on electronic display panels or through teleprinters. The cast number, temperature, carbon level, and durations into each melting phase, with delays separately indicated, are displayed continuously, whilst more detailed messages are typed out on the teleprinter.

The Bath Temperature Display

Each time a temperature dip is taken the readings are displayed and updated continuously until the next dip, by estimating the heat gain and heat loss in the furnace.

Carbon Level Display

Carbon levels are initially ascertained from TECTIP samples or spectrographic analysis from the laboratory. Based on this reference value, the computer maintains a continuous estimate of carbon level.

Oxygen Blow

The teleprinter suggests the correct time for the oxygen blow and the amount to be blown, which is also displayed on the panel. As the blow proceeds the display gives a "count-down" of the amounts blown, which assists in the prevention of "over-blow".

Display of Durations

The time spent on a current cast, the time into refining and accumulated delays, are all shown in hours and minutes. These displays assist in motivating the pace of work by the melting team. A further incentive is a display of bonus payments achieved relative to standard performance during each cast.

General Details

The computer keeps a log of all relevant events in the production of each cast, and this data base forms the basis of report generation, system re-appraisal and strategic studies for the formulation of operating plans.

The early days of operator guidance at Lukens (who pioneered this type of system) showed a compliance level to computer instructions of 50%, which is now at 95%, giving confirmation to the belief that by a process of continuous learning a satisfactory system can be evolved.

Plant Co-ordination

The computer assists in the co-ordination of the shop by maintaining information links between various production and service functions. The Raw Materials Controller is given an indication of the demand for various grades of scrap and alloys in each time period by accumulating the optimum charges for casts planned. The shop foreman's office has duplicates of the furnace teleprinters, giving him the ability to monitor activities from a central location. The system provides information to the casting bay on the progress of casts, which helps them to assess current priorities for preparation of ingot moulds or the "CONCAST" machine. A display is provided to the production control staff, which enables them to monitor progress and schedule the work load for processing departments.

Companies Utilising Such Systems

(1) Lukens Steel of Coatesville, Pa., U.S.A., were pioneers in this field and the company with the greatest success. The use of computer systems in their Melting Shop has given them the following benefits:-

(a) Increased productivity of 12%. Of this 12% improvement, 9% was achieved before the computer was switched on and came from the standard operating practices which were evolved during the studies for the computerised operator guidance project.

(b) Improved quality control.

(c) Better personnel supervision.

(d) Accurate information on shop operations.

(2) Western Canada Steel of Vancouver, Canada, use a melting shop computer to a lesser level of sophistication than Lukens, and with simpler instrumentation. Their main use of the computer is for cast scheduling to meet physical properties, which will be treated as a topic separately (See System IV).

(3) Phoenix Steel of Delaware, U.S.A. and Atlantic Steel of Atlanta, Georgia, have also been involved with such developments, but with limited success due to other factors. Phoenix Steel had a complete replacement of the management team when the computer was being installed. The new management revised the original specifications for the computer system and the new requirements are still in the process of development. The Atlantic Steel installation operated successfully with a small IBM 1620 computer. To undertake wider duties, a larger Westinghouse computer was acquired. During the commissioning period the plant suffered a six months strike, and on resumption of work the emphasis was on full pace production, which resulted in ineffective "running-in" of the new computer system and consequent discontinuation of the system.

It would usually be difficult to justify the use of a computer for operator guidance alone, and it is reasonable to accept that the primary justification for the computer being used in the shop is to control power to comply with maximum demand tariffs.

SYSTEM III

Computer Based Power Control for Maximum Demand and Melt-Down

Maximum Demand Control

The need for this type of computer control is dictated purely by the severity of the power supply tariff in certain parts of the country, which may impose high cost penalties for violating the limits of usage within particular time intervals. The role of the computer is simply to monitor usages and ensure that power demand from the shop does not result in the permissible levels of power usage being exceeded. The computer attempts to foresee events and take preventive measures either by controlling the transformer tap settings, or in extreme cases by selecting a furnace for power-off. The computer is particularly suited for this type of work because it can read various instruments rapidly and implement decisions at a rate which cannot be equalled by manual systems.

Melt-Down Power Input Control

This system works under the control of the Maximum Demand System and attempts to achieve melt-down at an efficient rate. Systems in this category usually have on-line transformer tap changing facilities which enables the melting team to concentrate on other aspects of the melting process.

Users of Such Systems

The list of companies using computers for power control is, indeed, a long one, and it is not intended to list them here. Within our Division, the Rotherham Works Templeborough Melting Shop uses an ARGUS 108 computer for power control. This melting shop was among the first to have a computer for the control of power usage. The computer carries out both M.D. control and power input control with on-line tap changing facilities. The Argus also assists in the control and logging of scrap charging activities. This computer is also interfaced with the Quantovac KDN2 computer for rapid transfer of sample analysis. The Argus computer is based in the central control room and its performance is monitored by the shift controller. The controllers have a number of display aids which are essential to their role of co-ordinating the numerous activities in such a large melting shop. The central control system at Rotherham is regarded as being an effective alternative to co-ordinate the shop using a computer system.

SYSTEM IV

Cast Scheduling Based on the Objective of Meeting "Physical Properties"

It is conventional to melt steel and produce casts which fulfil chemical specifications. At some point we must all have stopped to wonder why we do this at all. This issue is relevant because the majority of steel users are primarily interested in physical properties. We are all aware that the same physical properties can be provided by a number of alternative chemical specifications.

You may well wonder what all this has to do with computer applications in melting shops. The answer is that one small steel company in Canada found it extremely worthwhile to subject itself to this sort of critical examination, which led to a minor revolution in the operating strategy for their melting shop. The company concerned is Western Canada Steel of Vancouver, B.C. They decided to adopt the physical property objective for melting in their shop, which has just one 40 ton arc furnace and a small "concast" machine. My visit to this company was motivated primarily by a curiosity to establish how such a tiny melting shop could justify the expense of an IBM 1800 computer with an assortment of peripherals, for the exclusive use of the melting shop. The main function of this computer is to consider the level of elements at "melt-out" and select a cast from the order book which can be produced at the cheapest cost in terms of alloy additions to achieve the target levels for each element which should yield the desired physical properties. The relationship between physical properties and chemical analysis was established from experimental studies, the results of which contributed to the development of the order selection program.

Having completed the order selection, the computer issues refining instructions and advice on alloy additions, tapping temperature, etc. If the ladle analysis indicates a significant drift from target values of chemical analysis for the selected order, the computer repeats the selection process and, if possible, allocates a new order for the cast and retains the original order in file for future allocation.

In addition to this primary function, the computer provides operator guidance on temperature, oxygen blow, power settings, etc.

When the tapped steel is fed to the "concast", the computer issues cutting and storage instructions. The inventory record for all steel output is held on the computer file for future reference by production control.

The spectrograph machine is directly linked to the computer for direct interpretation of readings and hence rapid initiation of the cast selection program.

The use of the computer in this role has provided Western Canada Steel a reduction in raw materials cost of 17%, increased production of 5% - further increases being limited by the "concast" turn-round time. A useful fringe benefit is the accurate and readily accessed data base for improved shop management.

The major disadvantage of this system is that it denies us the knowledge of what we are likely to produce during any particular time period, in terms of specific orders planned. During difficult market conditions the system cannot operate efficiently because of the overriding priorities of delivery dates.

An on-line computer system for cast re-allocation based on "melt-out" analysis and final specification is planned for installation in the Templeborough Melting Shop at Rotherham Works. It will be operated via a remote terminal to the data processing computer centre at the works. Other works in the Division should consider the scope for such systems and appraise the benefits within their own operating circumstances.

Alternatives to Computer Systems

As far as Systems I and IV are concerned, we can assume that except for simple cases we must rely on computers for all practical purposes. But for Systems II and III, we do accept that there are alternatives to the computer system based on human controllers aided by instrumentation.

CONCLUSIONS

We have considered four basic types of computer applications in arc furnace shops. I am convinced that, in terms of the scope for computer assistance in arc furnace shops, we have only begun to scratch the surface of this extremely rich area. Electronic digital computers have only been with us about two decades. In this short period they have revolutionised various industrial systems. On this basis, it is reasonable to assume that within the next two decades computers will play a greater role in the productive functions of our companies. In the area of computer applications for electric arc melting shops, we were in the forefront in the early sixties, by virtue of the developments at Templeborough. Since then, the major developments have been in North America. It would be very nice if the next outstanding achievement in this field is a British one, and preferably a B.S.C. contribution.

U. MENON

DIVISIONAL TRAVEL AWARDS
1971

A STUDY OF
COMPUTER APPLICATIONS IN
ELECTRIC STEELMAKING PLANTS IN U.S.A. AND CANADA

by

U. Menon
PROJECT LEADER - O.R.
RIVER DON AND ASSOCIATED WORKS

OCTOBER 1971

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BRITISH STEEL CORPORATION
SPECIALS STEELS DIVISION

PROJECT No. 215

EFFICIENT UTILISATION OF SCRAP
"SCRAP CONTROL IN THE HEAVY FORGE"

WORK STUDY/O.R. DEPARTMENT
RIVER DON AND ASSOCIATED WORKS

JANUARY 1971.

BRITISH STEEL CORPORATION
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CONTENTS

INTRODUCTION

This project aims to develop a satisfactory system of scrap control in the Heavy Forge. The existing system was evaluated, to establish its effectiveness and the need for changes in the existing methods. The evaluation of scrap control effectiveness was made by comparing the amounts of recoverable scrap arising from production in each quality, with the amounts that were actually received into stock. The criterion for assessing performance is as follows: If there are significant differences between recoverable scrap arising and scrap actually received into stock under particular qualities, then scrap control is ineffective.

The results from earlier attempts to produce least cost scrap mixes for the melting shop, point to unreliable scrap sorting and segregation as one of the factors which makes the recovery of Nickel and Molybdenum from scrap difficult, and this leads to the excessive use of expensive virgin alloys.

ACKNOWLEDGEMENTS

We wish to thank the Forge Burners and the Forge Office Staff for their help and co-operation at various stages of this project.

Reported by : U. MENON and P. HUNTER

Approved by : J D A Scarrott

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PRESENT SCRAP CONTROL SYSTEM

The discards arising from forgings are hand stamped with the scrap code. The stamping is carried out by two press operatives. The discards are periodically transferred to the Forge Burners Bay, where they are stocked until required by the melting shops. Oversize lumps are cut to furnace size prior to despatch.

EVALUATION OF PRESENT SYSTEM

The production and scrap records for a 16 week period from 29th March, 1970 to 25th July, 1970, were examined to determine the proportions of recoverable scrap arising and the scrap actually received in each quality. The method of determining the recoverable scrap arising is outlined in Appendix A. The results obtained from this study were as follows.

Results

The results obtained from the evaluation are detailed on page 3. The following is an extract from the results.

$$\left\{ \begin{array}{c} \text{Loss incurred in} \\ \underline{\text{Stock Values}} \end{array} \right\} = \left\{ \begin{array}{l} \text{Value of Recoverable} \\ \text{Scrap Arising} \end{array} \right\} - \left\{ \begin{array}{l} \text{Value of} \\ \text{Scrap Received} \end{array} \right\}$$

$$= £97806.6 - £87108.95$$

$$= \underline{£10697.65 \text{ in } 16 \text{ weeks}}$$

$\underline{\text{Loss / Week} = £668.6}$

Loss / Ton = £10697.65/6207 tons

= $\underline{£1.72}$

RESULTS OF EVALUATION

Heavy Forge Scrap

29th March to 25th July, 1970 (16 working weeks)

	Type of Scrap	User Price £/ton	Recoverable Scrap ARISING		Scrap RECEIVED	
			Tons	Value £	Tons	Value £
	Carbon	12.85	2528	32484.8	3495	44910.75
	1 Cr Mo	14.75	1513	22316.75	1105	16298.75
	3 Cr Mo	13.45	129	1735.05	70	941.5
	1 Ni Cr	17.9	12	214.8		
	2 Ni Cr	20.6	191	3934.6		
	3 Ni Cr	25.2	52	1310.4		
	L/NCM + CP	17.1	286	4890.6	207	3539.7
	1 NCM	18.4	96	1766.4		
	2 NCM	21.15	594	12563.1	705	14910.75
	3 NCM	25.7	573	14726.1	10	257.0
*	Miscellaneous	14.20 - 30.40			118	2274.5
*	Mixed	8.0	233	1864.0	497	3976.0
			6207 tons	£97806.6	6207 tons	£87108.95

* The quantity of mixed scrap under 'ARISING', and the quantity of miscellaneous scrap under 'RECEIVED', consists of various abnormal qualities. A breakdown of the qualities which constitute Mixed Scrap arising, and Miscellaneous Scrap received, are given in Appendix B.

OBSERVATIONS

The differences between the amounts of recoverable scrap arising and scrap received, suggest that correct scrap identity is not being maintained. The identity stamping on lump scrap is often difficult to locate and when located may be illegible or incomplete. An example of incomplete marking is 'NCMV', which without a numeric prefix is inadequate identity.

The stock value losses that have been shown are only a measure of the real losses to the Company. The real losses occur in the Melting Shop when the scrap is used and fails to provide the expected recovery of Nickel and Molybdenum. Thus the returns from better scrap control in the Forge will be lower mixture costs.

RECOMMENDATIONS

Scrap Identification: It is proposed that a better method of identification be adopted, which will ensure that the markings are clearly legible and easily located. In addition to the quality code, the cast number and where appropriate low residual markings should be displayed on the identification. All these requirements can be met by using a mild steel tag on which the codes are embossed in large letters by a FIMA embossing machine. The tag will be nailed on to the scrap lump by a HILTI power hammer which is actuated by a controlled internal explosion. This method of identification is being used at some B.S.C. works for ingots and billets.

The task of punching the tags and fixing the tags on scrap shall be assigned to a full time scrap control operative, accountable to and under the direction of the Works Scrap Controller. It will be necessary to have one scrap control operative per shift in the Forge. Considering the potential savings from the work of such operatives, the creation of this job is justified on cost/benefit grounds.

It is expected that the scrap control operatives will check the specifications of all material in progress in the Forge and assign quality codes on a rational basis as directed by the Works Scrap Controller. This procedure will ensure better recovery of low residual scrap and avoid the present need for sampling. The reliability of scrap identity, particularly that of low residual grades, can contribute towards lower mixture costs.

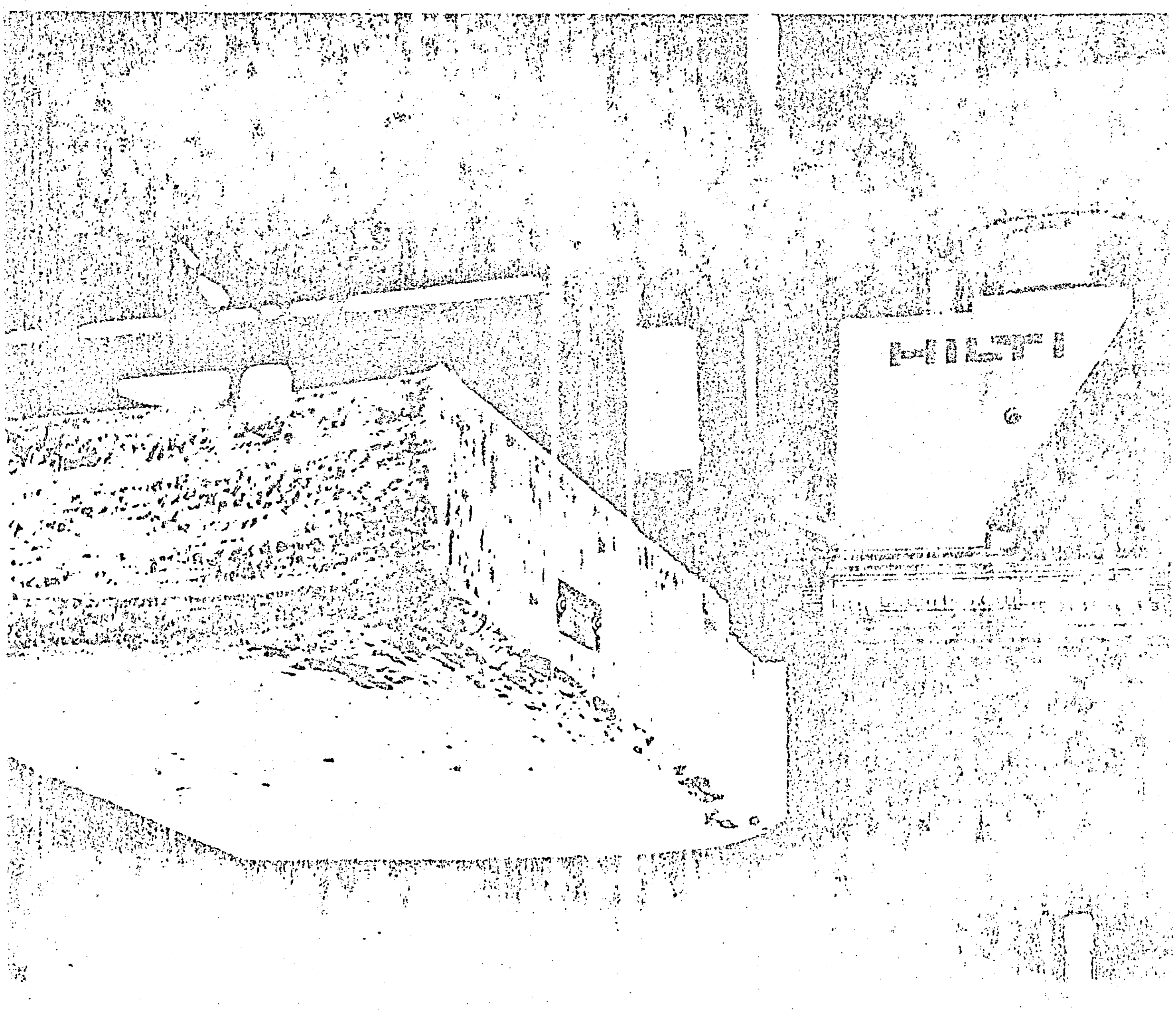
Scrap Storage: The storage areas allocated for stocking scrap are not sufficient to cope with the range of scrap that is being stocked. It is proposed that consideration be given to the allocation of more storage space for scrap in the Siemens and Cogging Mill bays. The dismantling of the 4-ton Davy Steam Hammer will assist the handling of scrap stored around it. If the North Welding Bay (under Machine Shop Control) could be released for scrap storage then it could be combined with the Hammer Bay to provide adequate scrap segregation.

Illustrations of Hilti Method at Other Works

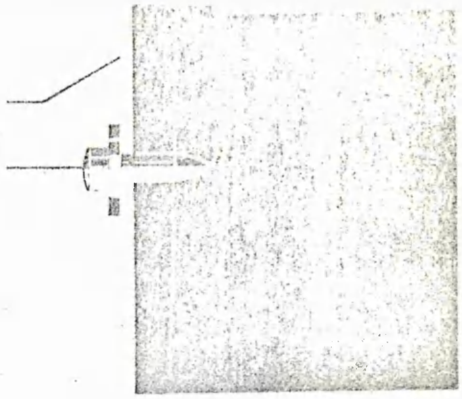
Page

Reliable ingot identification - modern, practical and economical with the Hilti Technique

Reliable identification of slabs, blooms and other hot or cold rolled products – economical, modern and safe with the Hilti Technique



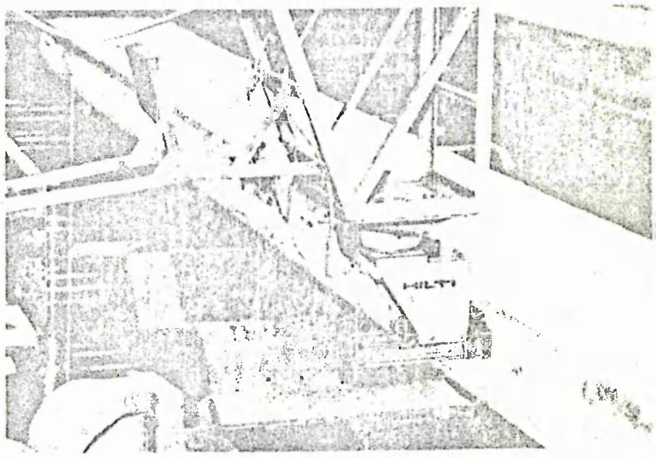
The metal tag, embossed with all necessary data, is direct fastened to the hot slab using the Hilti SX 315 equipment and Hilti pins.

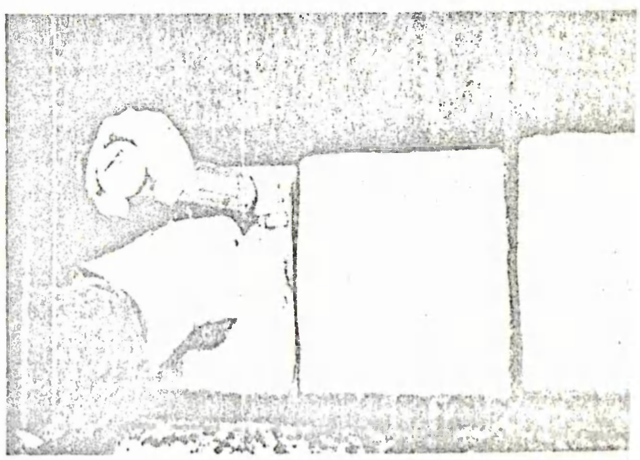


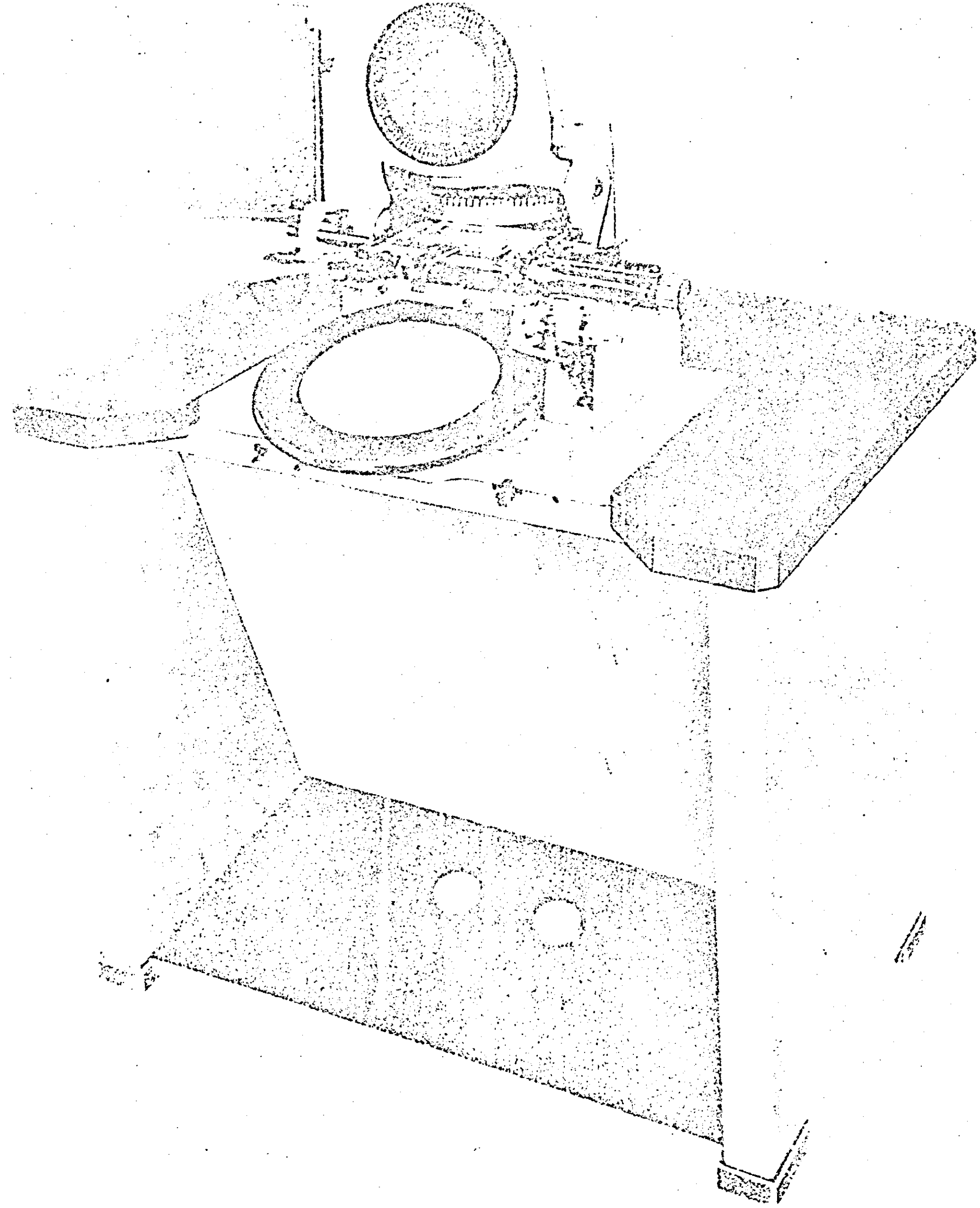
1. The Hilti SX 315 equipment is mounted on a suitable carriageway built on to the slab conveyor. The metal tag can be fastened either to the slab side or to the end face.

2. An identification tag after being fastened.

3. Identification of blooms on a concast run out table.







FIMA electrical embossing machine Model 8500

A noiseless and rapid embosser with attractive appearance, styled to fit into the modern office.

Standard Features:

Particular care has been given to equipping this machine with a highly dependable electromagnetic clutch combined with two convenient foot releases for the embossing operation. This makes the FIMA Model 8500 one of the most efficient wheel type embossing machines on the market.

90 pairs of embossing characters Elite or Pica, consisting of capital and small letters, normal and Block figures, punctuation marks and blanking-out dies - glarefree embossing dial - when operating the line spacing lever the carriage is returned to the starting point - plate holder - return key and spacer - copy holder - control gauge - tools and cover.

Optional Extras:

Attachment for changing to different plate model - attachment for the embossing of selection pips - tabulator - flare-free illumination for copy holder and embossing dial. Upon request model 8500 can also be supplied with embossing characters in Block, Double Block, Pica- or Elite-Block and Pica- or Elite-Double Block.

Available for all plate models.

EQUIPMENT REQUIRED FOR PROPOSED SCRAP IDENTIFICATION SYSTEM

EQUIPMENT REQUIRED FOR PROPOSED SCRAP IDENTIFICATION SYSTEM

Tag Preparation The cast number, quality code and in some cases residual levels, should be displayed on the tag. The printing of this information on the tag can be carried out either manually using hammer and dies, or by a powered tag embossing machine.

The powered embossing machine is preferred on the grounds that it prints larger and more legible letters than is possible manually, it is faster and less tiring to the operative.

Tag Application The tag (mild steel) will be held temporarily by the magnetic head of a HILTI hammer. A controlled internal explosion will hammer a nail into the discard, securing a permanent identity to the discard.

Costs

Tag Preparation

Manual		Powered	
$\frac{3}{8}$" Die Set with Holder	£40	Fima Electric Embossing M/C $\frac{1}{2}$" letters	£985
Marking Machine	£108.50		

Tag Application

HILTI Power Hammer	£42
Tags, Cartridges, & Pins 200 off per week	£8 per week

Other Applications for Embossing Machine

The FIMA embossing machine is fast in operation and will be under-utilised if used solely for heavy forge scrap control. It could be used for producing Ingot Mould Identity plates, Bin labels, Stores Shelf Labels, Machine Tool Labbls, etc.

We are informed by HILTI that the embossing machine and tag nailing method are used at other B.S.C. Works: Dorman Long, Consett, Ebbw-Vale, Steel Co. of Wales, Ravenscraig, etc.

Appendix A

Evaluation of Expected Scrap Arising

Let I_i = Weight of the i^{th} ingot

F_i = Weight of the i^{th} forging

S_r = Weight of Scrap Received

P = Proportion of Scrap recovered relative to total metal removed in processing.

t_o, t_n = start and finish times corresponding to 1^{st} and n^{th} forging

$$\left.\begin{array}{l}\text{Total Metal Removed}\\ \text{in producing n forgings}\end{array}\right\} = \sum_{i=1}^{n} (I_i - F_i)$$

$$P = \left\{ \sum_{t=to}^{tn} (S_r)_t \right\} \Big/ \left\{ \sum_{i=1}^{n} (I_i - F_i) \right\}$$

$$\left.\begin{array}{l}\text{Recoverable Scrap Arising}\\ \text{in each quality. Q}\end{array}\right\} = P \sum_{i=1}^{n} (I_i - F_i)_Q$$

This method of evaluation ensures that the totals of expected arisings and actual receipts of scrap are numerically equal.

Appendix B

Abnormal Qualities which Constitute Mixed Scrap Arising

Cost Code	Quality Group	Specification	Quantity Tons
29	Cr	Cr 1.0/1.75	7
37	Mn.Cr	Mn. .90/1.6 Cr. 1.0/1.75	1
56	Cr.Mo	Cr. 4.0/6.0 Mo. .40/.60	37
27	Cr	Cr .40/.75	33
35	Mn.Cr	Mn. 1.2/1.8 Cr. .40/.75	26
47	Ni.Mo	Ni 3.25/3.75 Mo .20/.30	40
91W	Cr.Mo.V	Ni. .2/.3 Cr. .25/.35 Mo. .17/.25	6
33	Mn.Mo	Mn. 1.2/1.8 Mo. .40/.60	38
25	Ni	Ni 3.25/3.75	45
		TOTAL	233

Abnormal Qualities which Constitute Miscellaneous Scrap Received

Quality	Quantity (Tons)	Value (£/ton)	Total Value (£)
C.Cr	29	14.20	411.8
$3\frac{1}{2}$ Ni	15	30.40	456
Mn Mo	7	14.55	101.9
C.Mo	17	14.55	247.3
No. 5 Die	50	21.15	1057.5
		Total	2274.5

Appendix III

Specimen Print-Out from "Melt-Out" Simulation Program

RESULTS OF SIMULATION MELTING

A(I,J)= RANDOM NORMAL SAMPLE OF ELEMENT(NI,CR,OR MO) FROM SCRAP OR TURN

CORRESPONDING MELT OUT SPEC , ETC. ON NEXT PAGE

A(I,J)	A(MEAN)	SIGMA	I	J
0.3382	0.2000	0.1500	1	1
0.1930	0.0000	0.0800	1	3
0.3179	0.2000	0.1500	1	9
0.1136	0.1000	0.0500	2	1
2.6092	3.0000	0.3000	2	3
0.0246	0.1000	0.0500	2	9
0.0361	0.0500	0.0800	3	1
0.5218	0.8000	0.2000	3	3
0.0539	0.0500	0.0800	3	9

A(I,J)	A(MEAN)	SIGMA	I	J
0.1956	0.2000	0.1500	1	1
0.0417	0.0000	0.0800	1	3
0.1434	0.2000	0.1500	1	9
0.1510	0.1000	0.0500	2	1
2.9491	3.0000	0.3000	2	3
0.0317	0.1000	0.0500	2	9
0.0628	0.0500	0.0800	3	1
0.9706	0.8000	0.2000	3	3
0.0397	0.0500	0.0800	3	9

TOTAL CHARGE = 36.88 TONS

CONSISTING OF FOLLOWING

SCRAP

CARBON	LOCROM	HICROM	1 NCM	2 NCM	3 NCM	MIXD
22.128	0.000	7.376	0.000	0.000	0.000	0.000

TURNINGS

A	B	D	E	F	G	H
7.376	0.000	0.000	0.000	0.000	0.000	0.000

VIRGIN

NICKEL	FECR	MO BQ
0.000	0.000	0.000

CAST SPEC

NI 0.00 / 0.30 CR 0.60 / 0.70 MO 0.15 / 0.20

AIM POINTS ARE NI = 0.16 CR = 0.68 MO = 0.20

SIMULATED CASTS MELTED OUT AS FOLLOWS/

CAST	NICKEL	ERROR	CHROME	ERROR	MOLY	ERROR
1	0.31	0.01	0.59	-0.01	0.14	-0.01
2	0.15	0.00	0.69	0.00	0.20	0.00
3	0.18	0.00	0.72	0.02	0.14	-0.01
4	0.24	0.00	0.70	0.00	0.18	0.00
5	0.19	0.00	0.70	0.00	0.31	0.11
6	0.13	0.00	0.54	-0.06	0.16	0.00
7	0.15	0.00	0.74	0.04	0.19	0.00
8	0.12	0.00	0.58	-0.02	0.25	0.05
9	0.18	0.00	0.63	0.00	0.16	0.00
10	0.15	0.00	0.70	0.00	0.20	0.00
11	0.09	0.00	0.82	0.12	0.18	0.00
12	0.10	0.00	0.70	0.00	0.20	0.00
13	0.09	0.00	0.62	0.00	0.20	0.00
14	0.20	0.00	0.56	-0.04	0.25	0.05
15	0.06	0.00	0.77	0.07	0.34	0.14

FORECAST MIXTURE COST = £ 417.187

AVERAGE EXTRA COST = £ 0.000 + 0.941 + 0.619

CORRECTED MIXTURE COST = £ 418.746

RESULTS OF SIMULATION MELTING

A(I,J)= RANDOM NORMAL SAMPLE OF ELEMENT(NI,CR,OR MO) FROM SCRAP OR TURN

CORRESPONDING MELT OUT SPEC , ETC. ON NEXT PAGE

A(I,J)	A(MEAN)	SIGMA	I	J
2,4737	2,7000	0,3000	1	6
1,7660	1,8000	0,2500	1	16
0,3262	0,7000	0,1500	2	6
0,6662	0,7000	0,1500	2	16
0,5742	0,5000	0,1200	3	6
0,4683	0,5000	0,1200	3	16

A(I,J)	A(MEAN)	SIGMA	I	J
3,0424	2,7000	0,3000	1	6
1,9887	1,8000	0,2500	1	16
0,8527	0,7000	0,1500	2	6
0,6792	0,7000	0,1500	2	16
0,4468	0,5000	0,1200	3	6
0,5302	0,5000	0,1200	3	16

TOTAL CHARGE = 12.66 TONS

CONSISTING OF FOLLOWING

SCRAP

CARBON	LOCROM	HICROM	1 NCM	2 NCM	3 NCM	MIXD
0.000	0.000	0.000	0,000	0,000	9,928	0,00

TURNINGS

A	B	D	E	F	G	H
0,000	0,000	0,000	0,000	0,000	0,000	0,00

VIRGIN

NICKEL	FECR	MO BQ	J
0.080	0.147	0.023	2,482

CAST SPEC

NI 3.10 / 3.30 CR 1.50 / 1.70 MO 0,60 / 0,70

AIM POINTS ARE NI = 3,10 CR = 1,50 MO = 0,60

SIMULATED CASTS MELTED OUT AS FOLLOWS/

CAST	NICKEL	ERROR	CHROME	ERROR	MOLY	ERROR
1	2,92	-0,18	1,20	-0,30	0,65	0,00
2	3,41	0,00	1,61	0,00	0,56	-0,04
3	3,12	0,00	1,30	-0,20	0,50	-0,10
4	3,08	-0,02	1,64	0,00	0,65	0,00
5	2,97	-0,13	1,59	0,00	0,52	-0,08
6	2,91	-0,19	1,38	-0,12	0,51	-0,09
7	2,96	-0,14	1,57	0,00	0,66	0,00
8	2,61	-0,49	1,43	-0,07	0,58	-0,02
9	3,22	0,00	1,65	0,00	0,61	0,00
10	2,90	-0,20	1,45	-0,05	0,64	0,00
11	2,73	-0,37	1,55	0,00	0,82	0,02
12	3,10	-0,00	1,60	0,00	0,76	0,00
13	3,23	0,00	1,41	-0,09	0,67	0,00
14	3,13	0,00	1,36	-0,14	0,70	0,00
15	3,04	-0,06	1,51	0,00	0,64	0,00

FORECAST MIXTURE COST = £ 347,242

AVERAGE EXTRA COST = £ 14,420 + 2,472 + 3,048

CORRECTED MIXTURE COST = £ 367,182

Appendix IV

Statement of Courses and Conferences Attended

1. Operational Research Lectures, Sheffield Polytechnic 1969-1970.

2. Operational Research Society Conference, Eastbourne, November, 1969.

3. Recovery of Secondary Metals from Scrap, Institution of Metallurgists, University of Leeds, January, 1971.

4. British Steel O.R. Conference, Harrogate, May, 1971.

5. 4th Special Steels Steelmakers Conference, Harrogate, March, 1972.