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ASPECTS OF MANAGEMENT CONTROL

IN THE FOUNDRY INDUSTRY

BY

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SYNOPSIS

Detailed scrutiny of castings manufacture via an extensive literature survey and discussion with a wide cross-section of people associated with foundries, revealed a real contraction of the industry in terms of gross turn-over. This appears to be associated with adverse supplier/customer relations plus poor business technique, and, therefore, offers potential for an investigation of aspects of management control within the industry.

Since foundries provide a service, it is advocated that the business be based on customer satisfaction, tempered by the necessity to remain economically viable, and since these are primarily achieved by reliable delivery of adequate quality, at the right price, it is suggested that tight production control, backed by financial competence and a good marketing capability, are the objectives at which to aim.

Work scheduling is considered the root of any improved system of control, and this is argued in the two case studies selected, these being chosen to represent the wide diversity of casting manufacture. Job sequencing, using a simulation model, is developed to cope with the complexity of scheduling job/batch production, whilst a mathematical optimization routine is offered to overcome the work centre load balancing difficulties associated with batch/long run production.

Limitations based on inaccuracy of process details with respect to simulation, and computation time with respect to mathematical optimization, are found. However, within the confines of the data, simulation modelling is shown to have a beneficial effect on output, stock control and delivery reliability, while restriction to a 'best' solution rather than the optimum, proves the potential of mathematical programming. Both are financially viable and have wide application to the foundry industry in general

Job scheduling, foundries, short and long run

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INTRODUCTION

The initial intention of this work was to isolate, after thorough investigation, a suitable research area associated with management control of foundries. To accomplish this, a detailed literature survey was undertaken, plus extensive discussions with a wide cross-section of informed foundry personnel. These included representatives from Boards of Directors and shop floor management of foundries, purchasers of castings, suppliers of foundry equipment and representatives of research and development organisations associated with the industry.

It quickly became obvious that castings manufacture is an ailing industry. Although the majority of industries have suffered badly from the alternating recessive and inflationary effects of recent years, few have the serious deep-seated problems of wholesale decline which is undoubtedly associated with castings manufacture. In brief, this decline is seen as customer disenchantment with the industry which has resulted in castings being substituted by alternative forms of semi-finished product. Also, there appears to be a reluctance on the part of people to become associated with foundries.

If it is accepted that Britain, being an industrially orientated nation, needs a healthy foundry sector, then it is obvious that the problem must be tackled with some urgency. Hence, a thesis aimed at examining the production of castings, with a view to shedding light on these problem areas, was felt to have relevance.

Although inherent factors such as inadequate service performance and inconsistent properties of castings are important, it was decided to concentrate on external aspects. Since the basic motivation of the industry is customer satisfaction together with successful business enterprise, efficient job scheduling and production control are seen as the roots to any fundamental improvement in the present situation.

Reliable delivery is a prime customer requirement, while business success is based on efficient utilization of resources plus the establishment of a sound financial system. Scheduling and control of production look after the former, and by providing necessary information, must be the source of a satisfactory financial structure. Furthermore, inconsistent quality will be reduced by better process control. To this end, a quality control system, often part of production control, is becoming a necessity.

The concept of establishing informed job selection and subsequent process control, as the basis on which other benefits to foundry management might be built, is adhered to throughout the thesis. The problem of foundry decline due to business ineptitude is firmly established in Part 1, as is a critical examination of factors promoting decline. Finally this theoretical part of the thesis considers improved scheduling and production control in foundries, together with other relevant factors.

No exercise of this type could be complete unless supported by suitable case studies. Part 2 looks at the problem via a detailed examination of two foundry operations, one representing jobbing/batch production, and the other batch/long run production. The scheduling and production control activities of both are shown to have important failings which have severe repercussions in other management sectors.

The manufacturing complexity of the jobbing situation is shown to promote fluctuating output, variable stock levels and delivery date unreliability, while inadequate ability to control job mix creates load balancing difficulties where flow production operates.

A simulation model of production activities is built to handle the multitude of interdependent decisions associated with job sequencing in the jobbing/batch environment and 0-1 integer programming is used to formulate job combinations to prevent work flow bottlenecks in the batch/long run situation. Both are sufficiently complex to require computer aid.

There are restrictions in the benefits which these initially bestow, but their potential for improved production control is proven. Application of these systems, together with the development of other management aspects is finally examined both for the companies involved in the case studies and the industry in general.

PART 1

PROBLEM FORMULATION

1. DEFINITION OF THE PROBLEM

Support for the belief that the castings industry faces a serious problem can be found in published statistics. Fig. 1.1, from a paper; by Williams[1], illustrates the number of foundries - iron and steel - reported as being in operation in successive years from 1964 to 1974. It is obvious that both iron and steel foundries have reduced in number over the period, and that iron foundries number less than half those in production a generation ago. Fig. 1.2, from the same paper, shows the reduction in numbers employed over the same period. It becomes quite clear that individual foundries are getting larger and that the foundries most prone to closure are the small units.

These statistics are not at first sight particularly disturbing since, as shown in Tables 1.1 and 1.2[2], the industry traditionally has comprised a large number of small units which are highly labour intensive. Thus, the reduction in the number of units (and people employed to operate them) could imply growth in productivity as a result of concentration of capacity into fewer centres. Unfortunately, this theory is disproved by Figs. 1.3 and 1.4, since they reveal a decline in total tonnage produced in UK foundries over the past ten years.

The reasons underlying this decline govern whether or not a reduction in the total number of castings requested by customers is implied, since this will indicate an overall contraction of the industry, particularly if the true total value received is also less.

Figs. 1.5 and 1.6, compiled by Lamont Smith[3], confirm contraction to be real. The graphs, which are corrected to remove trade cycle

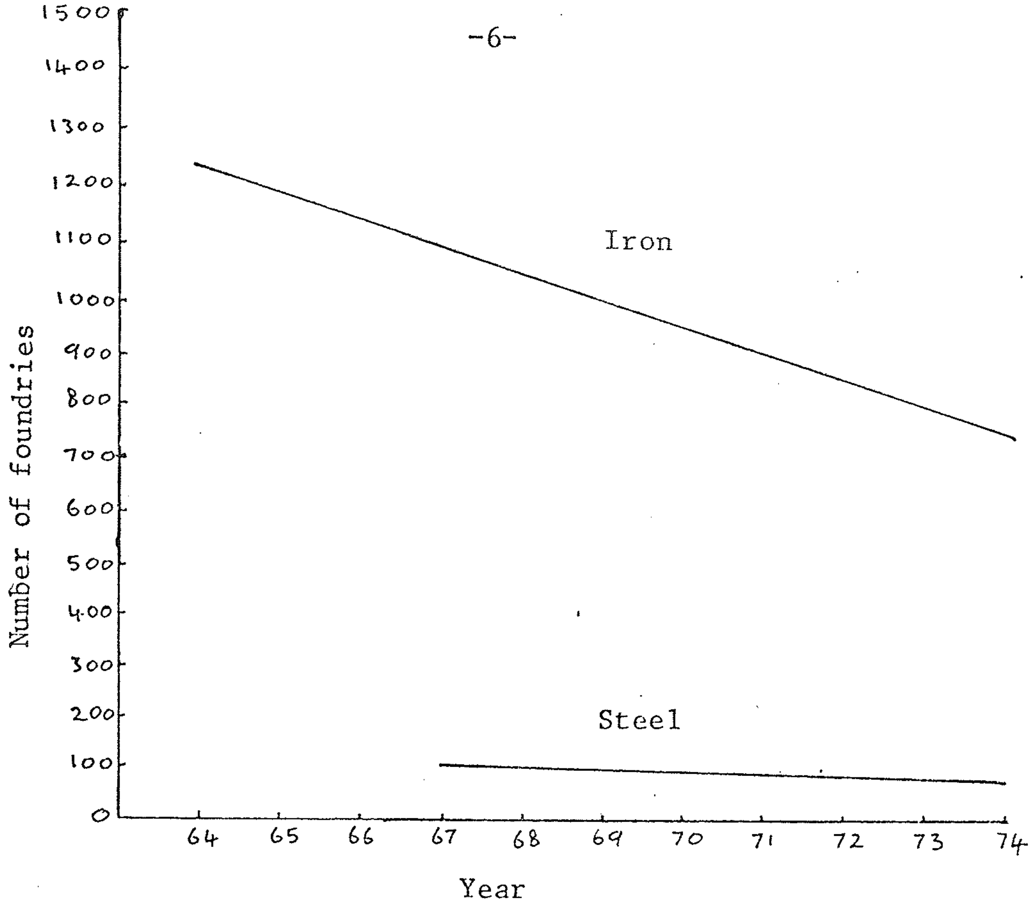


Fig. 1.1. Number of foundries in operation at the end of successive years - 1964 to 1974.

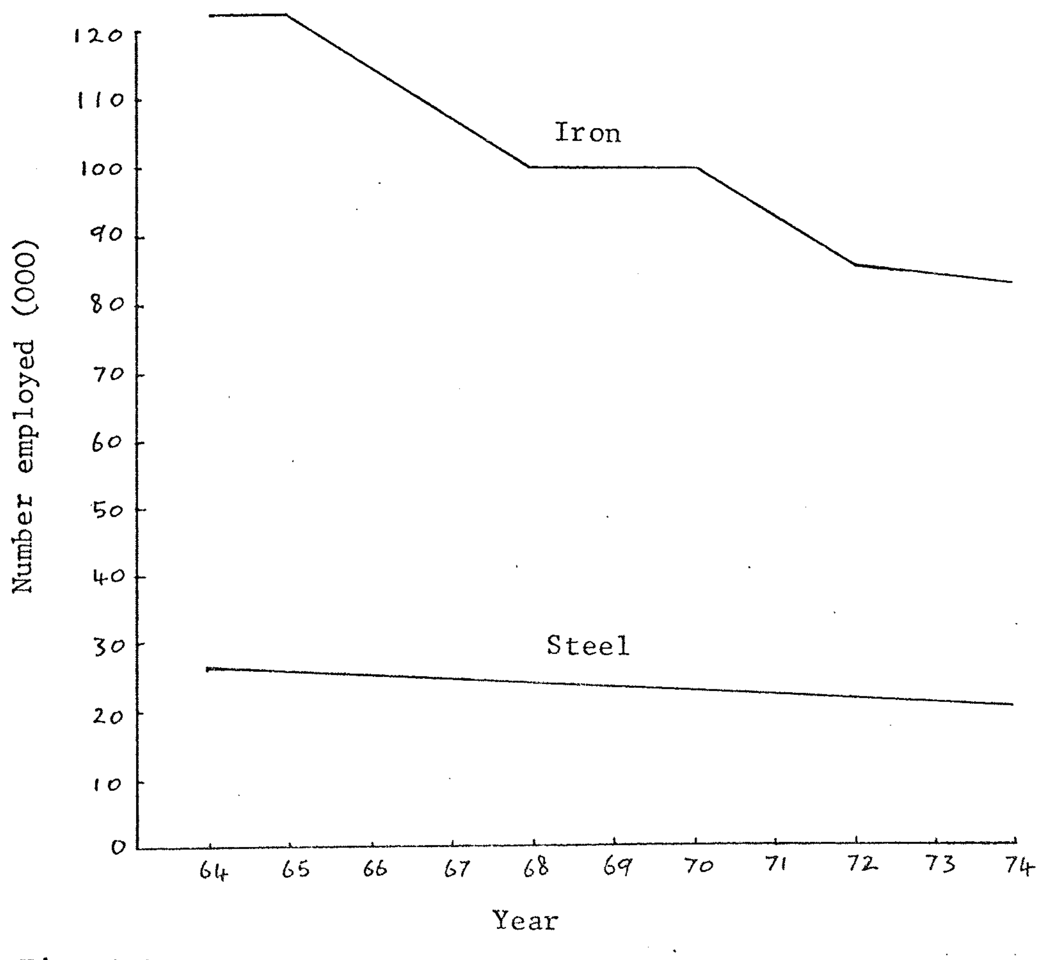


Fig. 1.2. Movement in numbers employed by foundries over ten years.

Table 1.1. Number of foundries and closure statistics.

Year	Iron foundries		Steel foundries	
	No. of foundries at year end	Net closure during year	No. of foundries at year end	Net closure during year
1962	1370		115	
1963	1306	64	110	5
1964	1243	63	104	6
1965	1176	67	95	9
1966	1111	65	87	8
1967	1037	74	85	2
1968	965	72	88	+3
1969	920	45	84	3
1970	887	33	79	5
1971	843	44	78	1
1972	806	37	78	-

Table 1.2. Number employed in foundries statistics.

	Iron foundries				Steel foundries			
	1963	1967	1971	1971 as % of 1963	1962	1967	1971	1971 as % of 1962
Total foundries	1306	1037	843	62	115	85	78	68
No. of employees								
1 - 50	822	615	497	57	30	20	18	60
51 - 200	351	307	248	69	43	27	21	49
201 - 500	96	88	73	74	31	26	25	81
501 - 1000	28	17	15	50	8	9	11	138
1000 and over	9	10	10	111	3	3	3	100

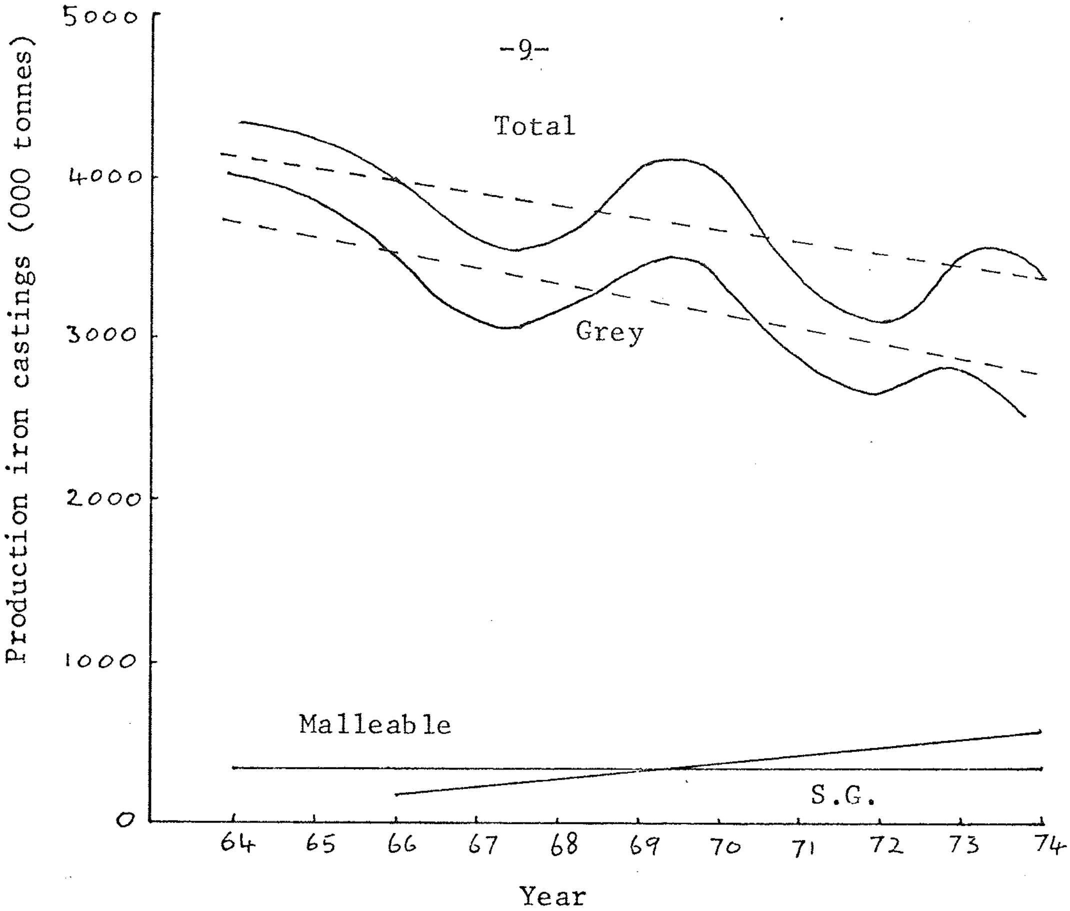


Fig. 1.3. Total tonnage of production of iron castings - 1964 to 1974.

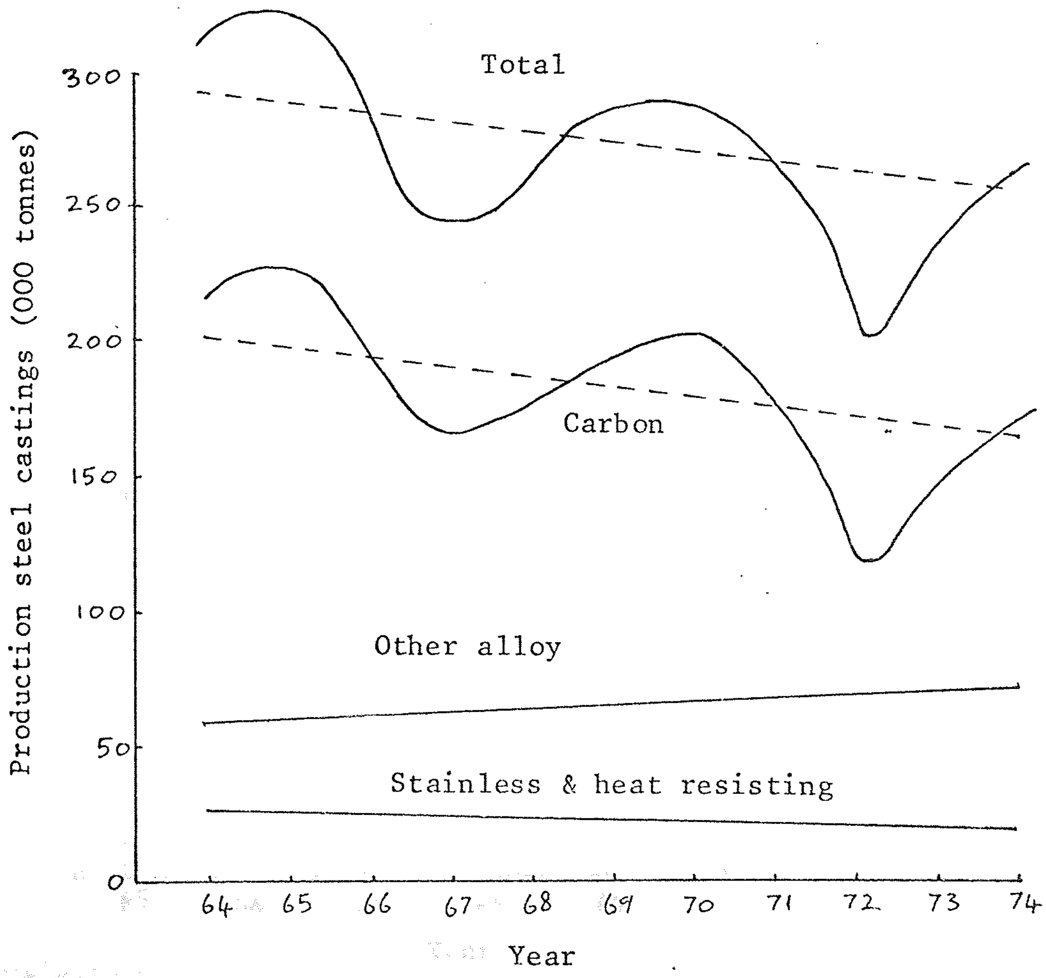
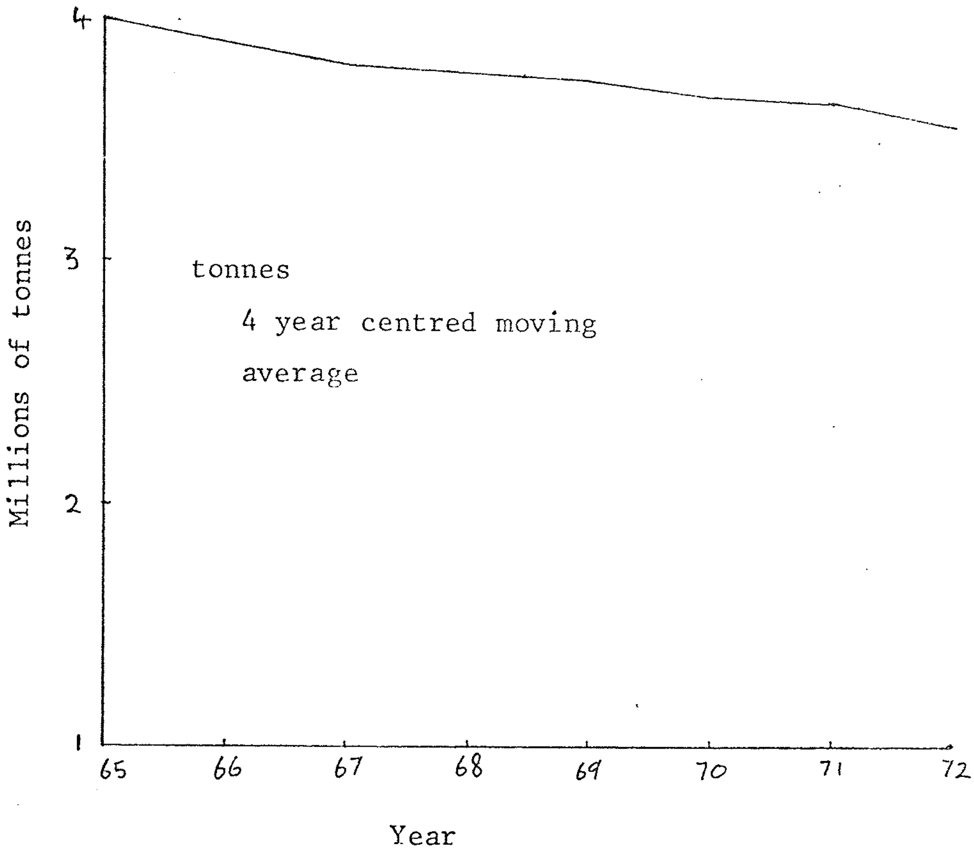


Fig. 1.4. Total tonnage of production of steel castings - 1964 to 1974.



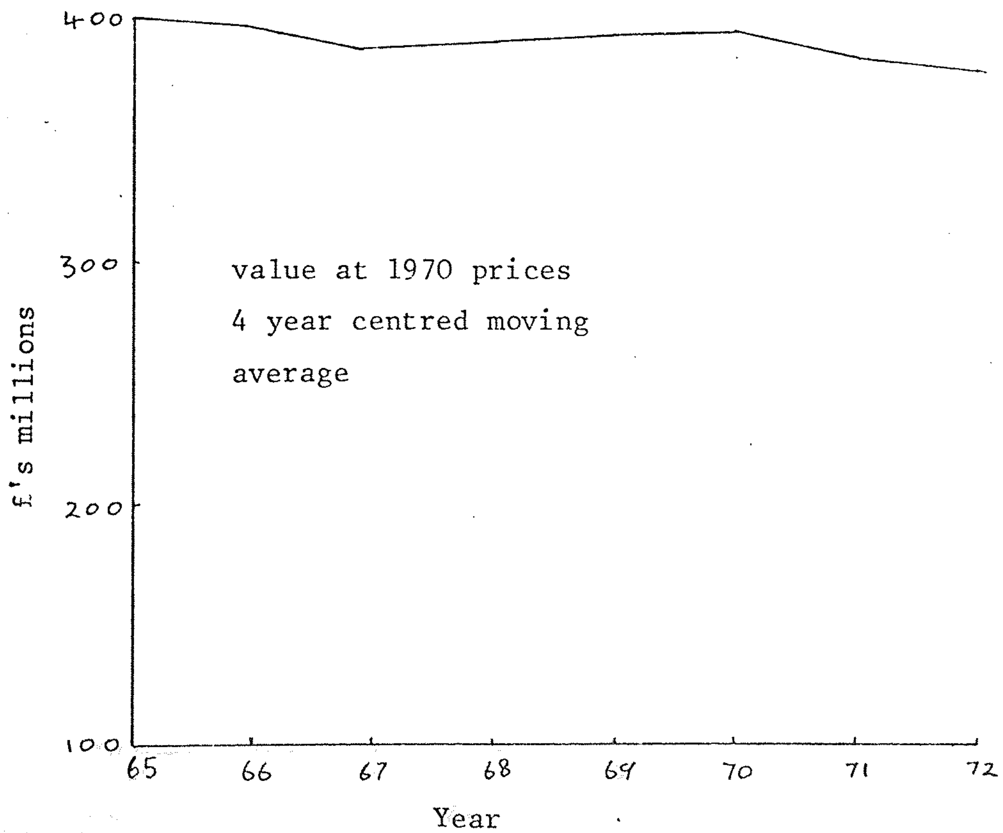
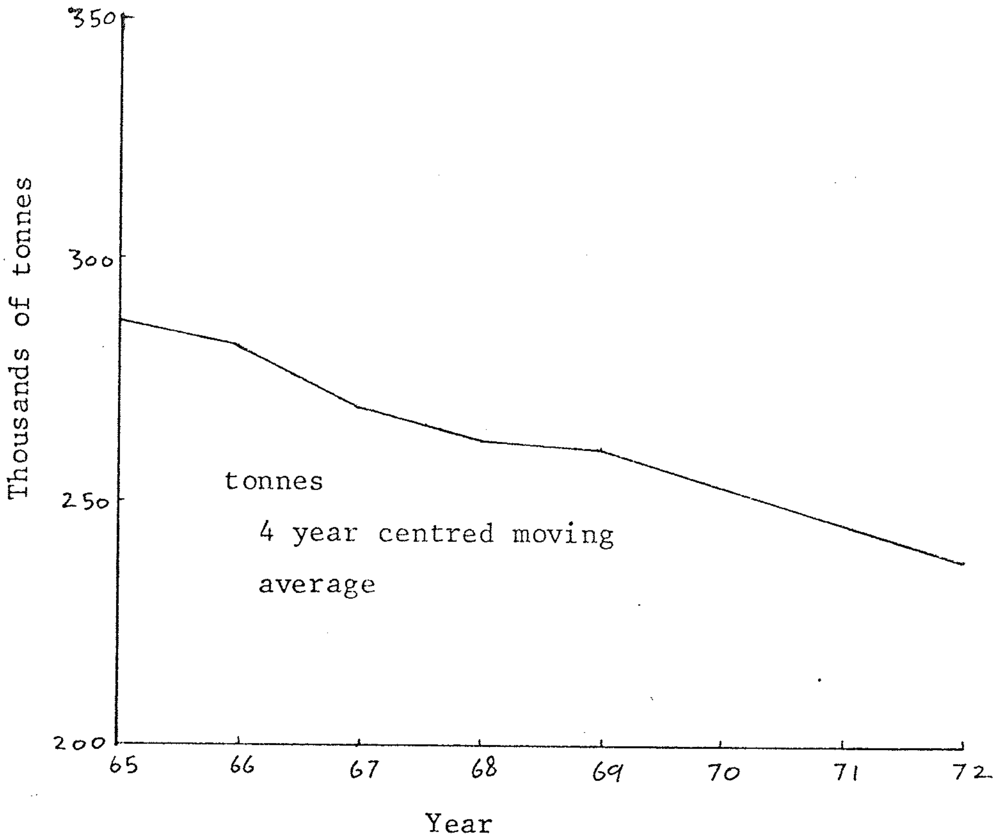


Fig. 1.5. Output of the iron castings industry - 1965 to 1972.



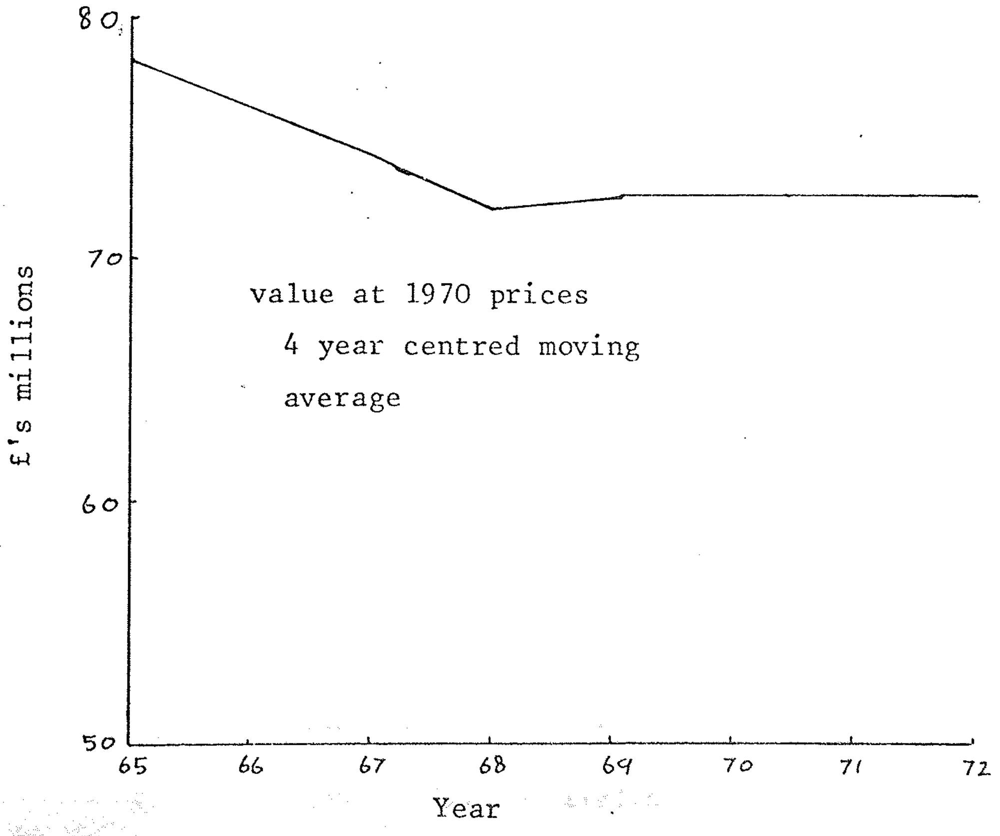


Fig. 1.6. Output of steel castings industry - 1965 to 1972.

effects, even though the foundry industry suffers greatly from these, show a fall of 17 per cent in the production of iron castings and 15 per cent in the production of steel castings, together with falls of 5 per cent and 3 per cent respectively in the value of sales. An interesting point is that the value of sales fell less significantly than tonnage, indicating that the average price of castings (in real terms) is steadily rising.

If the argument for decline in the foundry industry is to be completely accepted, a more detailed examination of the relevant information is needed. It is felt that this can be dealt with under:

(a) features showing evidence of decline

(b) features contributing to the decline.

1.1 Evidential Features

1.1.1 Demand for Castings

The motor vehicle industry is by far the most important consumer of castings, taking approximately 31.5 per cent of UK output in 1974. However, the recession of recent years has retarded this market considerably. The demand for castings from the building industry and engineering has likewise diminished, although some recovery in respect of the latter has recently become apparent - probably because alternative materials and structures have proved less satisfactory.

Other sectors such as ship building, railway, coalmining and ingot moulds have fallen to almost insignificant proportions. One bright spot, however, has been the steady growth of diecast aluminium, accounting to some extent for the decline in cast iron products.

Over the last few decades, there have been dramatic alterations in customer requirements. These might be summarised as follows:-

(i) long production runs of standard components cast to an exact tolerance have increased

(ii) use of more durable castings, e.g. the increasing trend toward the use of SG iron at the expense of flake graphite

(iii) high integrity castings with good quality assurance have been demanded.

1.1.2 Foundry Closures

The rate of foundry closure has been quite startling. The fact that in 1974 there were only 756 foundries in the UK as against 2000 in 1945 would appear to constitute an almost catastrophic decline. However, statistics show the section employing less than 50 people as being the area which has borne the brunt of the closures. The consequence is that the average size of units has increased. When this conclusion is allied to the fact that the total capacity for castings production has not reduced to anywhere near the same extent, it provides some reassurance.

The most disturbing feature of foundry closures is the capacity shortfall in the manufacture of certain castings. Notably, the general engineering casting, the production of which is the province of small jobbing foundries.

1.1.3 Return on Capital

It is perhaps the poor return on capital which is at the root of the problem, although it is, of course, the factors responsible for this which are of greatest importance. Low pre-tax profits are emphasised in the 1975 report of Greene and Company, members of the Stock Exchange[4]. Of the sample chosen for close financial scrutiny, which consisted of 50 ferrous foundries with turn-overs in excess of £1.1m, these stockbrokers found only twenty two companies able to report pre-tax profits in excess of £200 000, and the median profit margin on sales was as low as 6.3 per cent. Only eleven companies earned over 10 per cent on sales and only two companies earned over 15 per cent on sales. The median return on capital employed is 14.67 per cent, and only nineteen companies showed a return of 30 per cent or more, although four companies (specialist foundries) showed a return of 40 per cent or more.

In many cases plant and buildings will be well below replacement cost which means that the return on capital employed is even lower than the published figures suggest. It is accepted that in some cases (low capital investment, etc.) profit on turnover is a more relevant measure.

The performances quoted are abysmally low and would suggest that too many firms have allowed themselves to be dictated to by customers. Obviously, such a low net cash flow in relation to the current replacement cost of fixed assets would scarecly allow renewal of the industry's productive assets over fifteen years, which must be considered a minimum target.

1.1.4 Cyclic Demand and its Effects

Fig. 1.7 and Fig. 1.8[3] compare the annual change of Gross Domestic Product (GDP) with engineering production and iron and steel castings production. These show that GDP has a cyclical pattern; the engineering

------- gross domestic product

——— iron castings production

— — — — engineering production

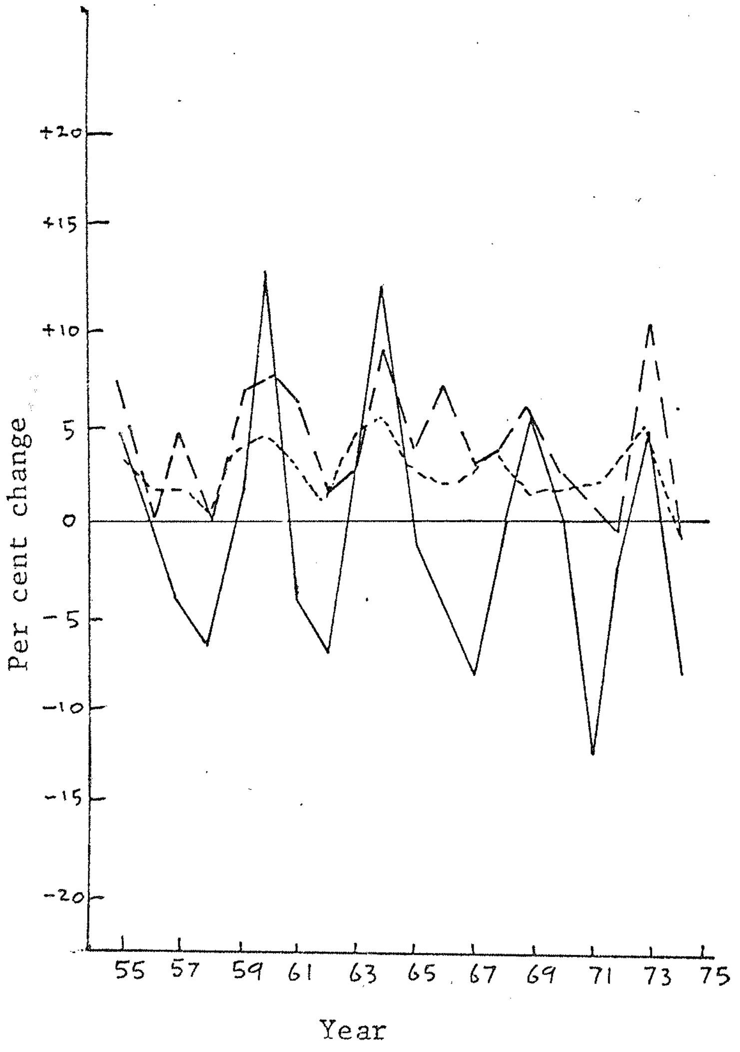


Fig. 1.7. Annual change of G.D.P.- engineering production and iron castings production.

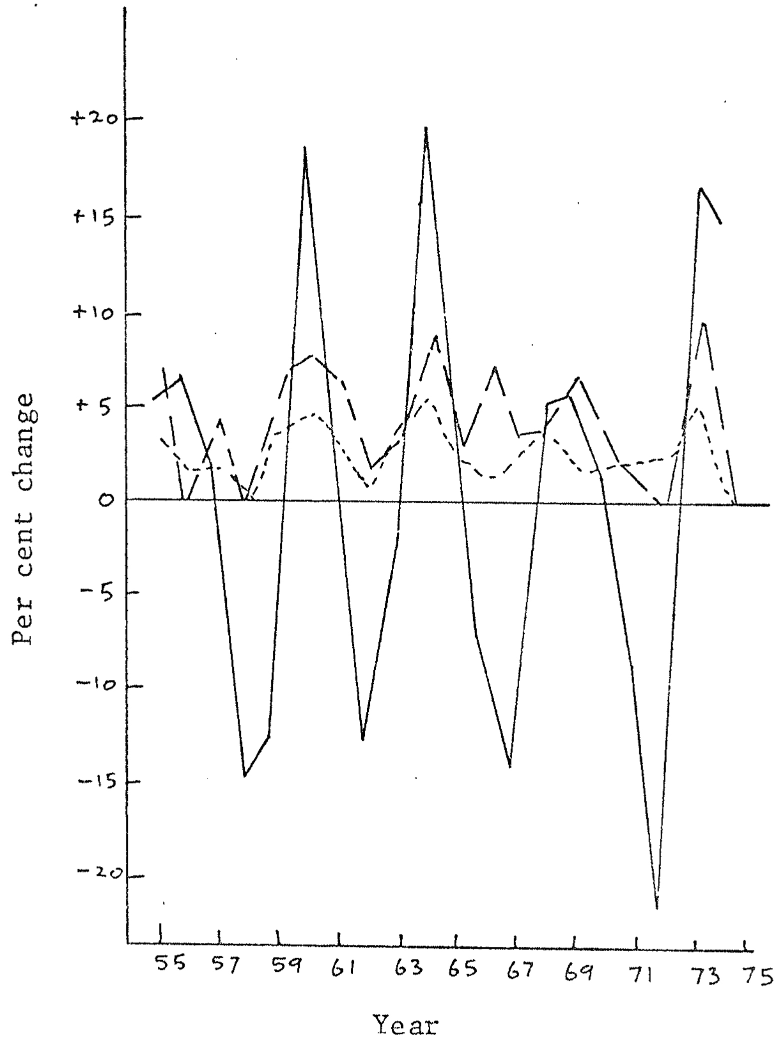


Fig. 1.8. Annual change of G.D.P. - engineering production and steel castings production.

industry (major foundry customer) follows a cycle in-phase but of much greater amplitude and casting production even larger in-phase amplitude.

The magnification of cycles through to a sector of industry can be described as a 'pipeline' problem. It exists where there is a long chain of sales and purchases between intermediate manufacturers before the final product is reached. As a result of events occurring in that pipeline, of stockbuilding (or de-stocking), capacity shortages (or excesses) and consequent over-ordering (or cancellation), there is gross amplification of demand during 'boom' and during 'bust'.

Evidence of this situation has been given to the author on numerous occasions. Many foundrymen relate tales of customer 'stop-go' policies which, incidentally, is worst among the biggest customers such as the motor vehicle industry.

1.1.5 Price Cutting

The price cutting problem has been a principal topic for comment in numerous Foundry Trade Journal leaders. Complaints from a multitude of sources have indicated that certain iron casting producers had salesmen going around offering to undercut at least 10 percent of their competitors quotations for the same job. As commented in one leader:- "This was presumably done to keep the firm's production wheels turning at whatever cost to themselves, to their competitors, or to the industry at large. What they fail to realise though we thought it had been brought home very clearly in late years is that they are not even doing a service, in the long term, to their customers who buy at prices which are not economically viable to the supply firm."

One informant explained that a small SG iron casting which they had been producing for years had just been lost to a competitor quoting 60 per cent of their price. This could not be more than breakeven price.

1.2 Contributory Features

1.2.1 Relationship with Customers

The supplier-customer relationship must obviously have dual fronts, each party having an appreciation of the other's requirements and both working toward the common goal of mutual satisfaction. This point was emphasised on numerous occasions at a conference entitled "Guide to Reliability of Deliveries and Supplier Delivery Assurance"[5]. Another general comment made was that in the main, suppliers of most commodities in this country are very poor in their ability to deliver goods of the right quality at the right time. In the past, foundries have often been severely criticised in this respect.

But according to these preceedings, in return for reliability, long term supply and value for money from the customer, the buyer should be prepared to give reliable forecasts of, say, tonnages and types of castings required in the next twelve months and for the following 3-4 years, if only in broad terms. To satisfactorily organise his production, the supplier has to be given comprehensive and accurate information regarding such things as the life expectancy of a casting. In other words, he requires to know accurate rather than optimistic volumes.

A large manufacturer of diesel engines endorsed these points when he described the setting up within his company of a Capacity Planning Department whose sole responsibility is to provide forecasts 3-5 years ahead with suppliers so that they would have some assurance on a long-term basis.

The exploitation of foundries by powerful non-responsible customers, who frequently make late changes to hard order commitments, and thereby markedly disrupt the schedules for castings production, is a common occurrence. But perhaps a more serious aspect of this exploitation is the reluctance by these same companies to pay outstanding debts promptly; a practice which has arisen largely because of recent inflation. In contrast, the small foundry has been forced into paying for raw materials before more are forthcoming.

It does, however, seem certain that if buyers could be guaranteed deliveries on time, with supplies to schedule, then they would be prepared to pay more for their castings. Reliability of supply is very important to a manufacturer and it is in his own interests to pay a bit more to ensure reliability. 'Stock-outs' can be as disasterous as a high inventory. The large diesel engine manufacturer mentioned earlier endorsed these points when he described how on several occasions production lines assembling engines comprising more than 6000 parts have been held up while waiting for cast cylinder blocks.

1.2.2 Financial Anomalies

Williams[6] considers the root cause of the declining situation to be due to lack of enterprise and shortsightedness on the part of foundries. He feels that, for many years, too many foundries have pursued an available pool of business which has led to marginal costing and to some foundries living off capital. This has led to a situation where a company worth

X thousands of pounds at a given date - for example, the mid 1950's - is still worth today not many more thousands of pounds than that original figure. It will have much the same equipment and buildings, very little provision having been made for their renewal. Such a foundry has been living off capital values, has almost certainly costed on a material-plus basis and certainly has constituted unfair competition to those foundries which have been seeking a reasonable return on their investment to enable them to replace and renew that investment as and when necessary.

But while lack of investment must take considerable blame for the poor state of the foundry industry, the root cause has been the inadequacy of a company pricing policy which has allowed profits to dwindle. This factor is developed later.

A point worthy of consideration here is that made by Baring[7] as a result of surveying a variety of manufacturing industries. He maintains that the most successful firm in terms of highest ratio of profits to assets and sales tend to be those with high distribution and marketing costs and low production overhead costs, material stocks and work in process.

1.2.3 Make-Up and Importance of Foundry Capacity

The foundry industry covers the broadest range of sophistication, process, metals, levels of expertise and types of production imaginable. There are presently no restrictions as to size, either in process, expertise, product mix or industry served.

However, in the evolution of the market, two big tendencies can be detected. On the one hand, there is a need for the manufacturer of castings in very long runs, and on the other, the need to respond to specific customer taste. In the long term, therefore, foundries will have to choose between two very different directions:-

(i) the 'made to measure' or jobbing foundry, which traditionally employs more craft than technology

(ii) the 'ready to wear' or mass production foundry.

One is left to ponder on how industry, restricted to these two divisions, is going to cope with the large volume of work at present catered for by the so-called 'batch producing' foundries.

It is opportune to discuss the role of tied foundries and group formation resulting from company mergers on the problems facing the castings industry. The comments relating to this are the result of the author's contact with the industry and may be summarised as follows:-

(1) Tied foundries are not profit motivated to the same extent as independents. Having a basic manufacturing nature, they are often disregarded both as profit making and capital investment centres.

(2) Being generally associated with company groups, within the mechanical engineering sector, they are expected to cater for a wide variety of interests; hence, they have rarely been allowed to build up specialist expertise.

(3) Tied foundry popularity could take a decided 'up turn' if future capacity proves inadequate.

(4) Group formation offers specialisation and financial stability to individual foundries.

(5) More customer respect is commanded from a group which controls a significant proportion of the available capacity.

While deliberating the shortcomings associated with castings manufacture, it is worthwhile establishing the importance of foundry capacity to the well being and prosperity of the nation in general. The industry has two decided advantages that assure its survival potential. The first is its position in manufacturing as a strategic basic industry. As long as the world economy grows, as it certainly will, foundries will play an important role. The second advantage is its diversity of customers. Just about all manufacturing, mining, agriculture and utilities are affected by the availability of cast products.

A general, if somewhat superficial, account of the factors associated within the manufacture of iron castings recently appeared in the Financial Times[8]. In this series of articles it was emphasized that in relation to the UK's GNP the foundry industry's output is comparatively small and yet its significance is enormous. Foundry products are essential to the well being of the country.

2. FACTORS INFLUENCING THE PROBLEM

The previous pages have attempted to isolate some of the problems and limitations associated with castings manufacture.

Before attempting to propose possible solutions to these problems, there remains a need to consider features arising from the changing pattern of modern industry and the more exacting demands that society places upon it. The changing pattern of industry invariably means mechanization and automation, which attempt to relieve men of undesirable tasks whilst at the same time increasing their rate of accomplishment. The increasing demands of society can be interpreted as increased resistance to the involvement with work injurious to health and safety, plus concern over the pollution of the environment.

2.1 Mechanization and Automation

The incentive for mechanization and automation can be generalised as the need to improve productivity, a somewhat ambiguous term implying more efficient use of total resources, i.e. manpower, money and materials.

Ellis[9] shows that national productivity increase in the UK has been lower since 1960 than most competitors. For example, during the period 1961-8, the average annual growth rate of GNP per capita was 9.9 per cent for Japan (highest), 3.4 per cent for USA and West Germany and 2.0 per cent for the UK.

The foundry industry has one of the lowest productivity records compared with other basic industries, and this is certainly one reason for its dismal image and low profit record. Figures quoted for the American economy[10] which mirror the position in the UK illustrate this point. Expressed as an average annual per cent growth in output per man hour, the manufacture of castings is found to be at the bottom of the industrial league.

Increasing scarcity and cost of suitable labour has further heightened the urgency to design, develop and install suitable mechanical systems. However, as with most new innovations, when incorrectly applied, mechanization may well eliminate semi-skilled personnel at excessively high capital cost and then prove to be an inferior replacement.

This point was emphasised by a company who, in 1967, commissioned automatic moulding plant costing £¼m to replace conventional jolt-squeeze machines for the manufacture of cast iron valve guides. A process resulted which, despite being initially budgetted to allow 10 per cent scrap (it was hoped this would quickly return to below the 5 per cent figure normal for the previous production set-up), was currently running at 20 per cent. This fact, together with a high incidence of plant breakdown, had reduced the foundry from a unit making a healthy annual profit of £20 000 to one making a loss (only the attached machine shop now makes the business viable). The underlying fault was diagnosed as an incorrect choice of plant, plus an inadequate maintenance programme. The solution advocated was complete replacement of the plant (large capital cost still outstanding) with a shell core assembly process.

2.1.1 Mechanization and Automation of Green Sand Moulding

Development initally concentrated solely on the moulding function. Here, the difficulty of uniform green sand compaction over large boxes at high speeds (soft rammed moulds give inferior surface finish and poor dimensional accuracy), was solved via vibration and higher squeeze pressures, optimized by the introduction of multiple compensating squeeze heads which allow transverse sand flow.

Usually, the fully automatic moulding machines are installed as a pair to make drag and cope moulds, though not infrequently, one machine will make both half moulds in alternate cycles. Because of the size of boxes made, and the need for accurate placement and location, there has been a major change from continuous movement into indexed movement.

There is constant competition between horizontally parted and vertically parted systems. However, whilst horizontally parted systems generally require bottom boards, collars and weights, necessitating handling and transfer, vertically parted systems are capable of producing entirely unsupported and unweighted moulds. Mould compaction, coring, closing, pouring and cooling are performed in a straight line on a continuous basis. Up to 700 moulds per hour can be produced and a vertically parted high pressure boxless moulding system offers a great many advantages over traditional tied flask methods: in particular, in the areas of capital cost, maintenance cost, operating efficiency, floor space area and labour requirement.

The problem of achieving the flexibility of mechanized moulding lines, employing several pairs of hand operated machines each with different box sizes if necessary, appears to be the biggest challenge to automatic moulding in general. However, according to both a member of the NEDC committee concerned with foundry production and a member of a foundry research organisation, automatic moulding equipment will not have achieved a major breakthrough until batches of sizes less than 50 castings can be contemplated for efficient manufacture. Indeed, it is felt that production of batch sizes containing fewer than 12 castings should not be outside the limits of realism for moulding on automatic plant This achievement would, of course, place automatic facilities within the reach of even jobbing foundries.

Designing an automatic moulding line for a limited range of products is relatively straightforward, but designing for a wide range, each of which may be required in different quantities, is a more difficult problem. Segmented patterns are one answer, but this immediately throws up the question of compatibility, one pattern with another, and the problem of maintaining a high yield.

An alternative to the single pattern system are manual pattern change tracks incorporated with an automatic pattern shuttle device. This allows the pattern plates to be changed within the moulding cycle and without loss of process time. Where the different pattern types have close similarity this technique is a proven success, exemplified by an automatic moulding unit concentrating on the production of automobile cylinder heads situated at C & B Smith Ltd., Wolverhampton. The system is often associated with the use of segmented patterns.

An improvement on this is the mounting of cope and drag plates side by side on a single pattern bolster, and utilising the shuttle pattern device for rapid pattern changing. With these systems, it is possible to inject a pair of patterns into the moulding cycle for, say. pattern trials of only two or three moulds.

However, none of the plant previously mentioned possess the necessary degree of flexibility to utilise a multiplicity of patterns in short production runs. For this purpose the pattern circulating system has been devised. In this system, six, or sometimes eight, separate pattern bolsters are indexed around a moulding system.

The pattern shuttle and pattern circulating systems appear the most promising approaches toward high order flexibility in automatic moulding plant. Certainly one company, who pride themselves on the wide variety of batch size within their capability, would agree with this point. They are moving (in a £3m venture) from a set-up involving numerous labour intensive centres to a production complex centred around a single automatic moulding machine. Their principal requirement from such equipment is obviously wide variety; pattern shuttle or pattern circulating techniques are felt to be the answer.

2.1.2 Mechanization and Automation of Other Aspects of Casting Manufacture

Developments have been slower in the moulding of large castings. The introduction of self-setting sands has meant a revolution in production method, but many hand operations remain. A major difficulty is associated with the very short setting time of the resins (involves both moulding and mixing).

Core-making took a big stride forward with the advent of new core binders which permitted the abolition of the drying stoves and also through the development of new types of core-making machines. However, most single core machines still have a single operator, but the blowing or shooting of the resin bonded sands into heated core boxes allows rapid production rates.

Impressive development is also taking place in the diecasting industry. Greater understanding of machine parameters, and factors affecting quality diecasting, is putting full automation of the process, probably controlled by a minicomputer, within early reach. Metal ladling, lubrication, die temperature control, injection and component handling are all becoming mechanized, although thixotropic casting involving the heating of a solid slug in the shot chamber prior to injection (present ferrous diecasting), is felt by Kay[11] to be the next major development.

In gravity diecasting, mechanized opening and closing of dies on tilting tables to avoid turbulence during casting, and complex movement of permanent cores, will continue to progress. The carousel principle is becoming increasingly attractive for long run work, while automatic pouring and extraction are now serious considerations. The latter will probably promote increased use of the low pressure process during future years.

Before completing this section, mention should be made of mechanized grinding. The need to convert grinding to an automatic operation is argued by Brouns[12], who considers that as the manufacture of cores and moulds becomes increasingly mechanized, and overall productivity rises, increase in grinding costs becomes very important.

Recent reports, such as that by Laurent[13], suggest that real headway is now being made toward automatic dressing. He describes a robot which is used for the removal of non-ferrous castings from a diecasting machine. This robot checks the castings at a sensing station, places them in a clipping press and finally retrieves the clipped-off sprue and returns it to the melting pot. Removal of the casting from the clipping press, due to the careful handling required, is performed manually.

Although still somewhat removed from complete automation, the above technique is a significant advancement on developments in the fettling of ferrous castings, which a member of the NEDC office for foundry development described as the greatest single barrier to progress in the metal castings field. However, he felt that attention to design and mould and core materials could markedly ease this restraint, under the guise "the best fettling is that which is not needed". He also gave a description of automatic fettling - which he had personally witnessed - at the end of an American production line confined solely to casting a specific type of engine cylinder block.

2.1.3 Other Associated Features

Mechanization and automation schemes will not reach their full fruition unless other associated features are also implemented. These can embrace many aspects, but primarily, they include good initial planning and the installation of suitable systems of control. These should be developed at the same time or even before the new plant is commissioned.

Obviously, mechanization in the foundry will require the adoption of new attitudes towards the manufacture of castings. This will almost certainly mean a new approach to systems development plus the incorporation of industrial engineering technqiues.

An increasingly important emphasis is being placed on maintenance efficiency as a means of achieving machine efficiency, and it is the author's opinion that this area is one of the first which should be given consideration when greater mechanization and automation is being planned.

Binmore[14] maintains that over 10 per cent of productive capacity in the country is lost due to equipment failure. A 25 per cent improvement in current maintenance performance could save the country over £300 million per annum. With the high capital cost of mechanized equipment, there is an outstanding urge to maximize productivity and overall profit. This in turn means minimizing 'down-time'. The introduction of preventive maintenance is, therefore, absolutely essential to ensure the long term success of automation.

2.2 Influence of Labour

2.2.1 General Details

There has been a steady decline in total numbers employed in all areas of castings manufacture, and particularly in iron and steel foundries. The statistics and their implications are studied in great detail in a publication by the Foundry Training Committee[15]. As inferred by a curve reproduced from this publication, Fig. 2.1, the fall has been most severe in iron foundries, which in 1972 employed

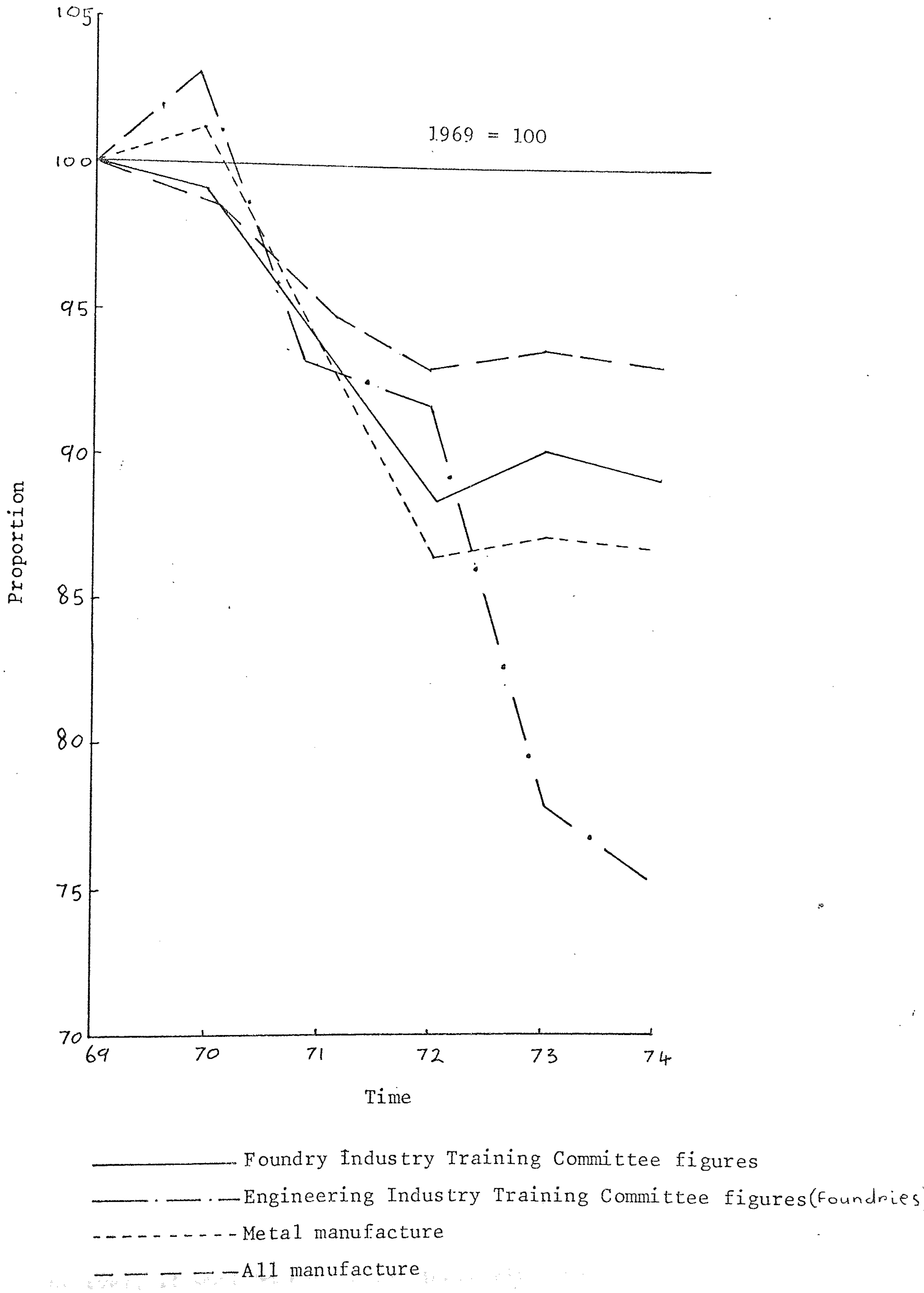


Fig. 2.1. Industry employment - 1969 to 1974.

nearly 30 per cent fewer people than in 1963.

Obvius ly, foundries need to compete in local labour markets which are often well developed and can offer many alternative employment opportunities. The unattractive nature of much foundry work, together with cyclicality of demand, has meant that in many cases, sufficient labour of the requisite quality has been unavailable. Almost all the foundries visited by the author had labour shortage difficulties, particularly the medium sized batch producing units using semi-mechanized production methods.

The implications are that the problem of attracting and maintaining labour is likely to grow in intensity in the long term unless working conditions are dramatically improved. Foundries seem adamant that labour shortages in the grinding and fettling areas will become chronically serious in the near future; as one equipment manufacturer remarked, "the offer of increasingly higher wages is not the long term answer".

2.2.2 The Effect of a Changing Foundry Scene

An influence which appears to offset labour recruitment is mechanization. The increased use of machines has perhaps not been resented more, elsewhere, than in foundries, since the foundryman has traditionally felt he is doing the work of a craftsman.

However, it must be made clear that, although the foundry industry must eventually become engulfed by the routine of automation, the craftsman's skills will not be completely lost. The one-off jobbing foundry catering for a wide spectrum of engineering needs will always be required. Although it will have to become a much cleaner and more comfortable place in which to work, nevertheless, it could still provide the satisfaction many young people seek. The skill going into the making of, for example, a 16 cylinder diesel engine block is akin to that of a sculptor, and the satisfaction of seeing a sound casting emerge from the sand is not easy to measure.

During the 50s and 60s, labour for unskilled foundry work, largely recruited from immigrant populations, was always a cheap and readily available commodity. Labour turnover was very high during these times; in fact, a recent NEDC report described the British foundry industry as traditionally a 'hire and fire' industry. Personnel were engaged at busy times and discharged at slack times. But the argument could be raised, of course, "how could it be otherwise when there are, through no fault of the metal casters, such wide fluctuations in demand through cyclical trading conditions?"

However, the recent Employment Protection Bill must change all of this since, in effect, it prevents firms from discharging personnel except under penalty amounting to payment of full wages for a long period.

Sir Monty Finniston, ex-chairman of BSC, considers that, henceforth, manpower should be regarded almost as a 'fixed asset'. If the metal casting industry takes this view, it will require a new approach to planning.

2.2.3 Managers and Technologists

It is perhaps the situation with respect to management and technical staff, as shown by Table 2.1, which is most depressing. At first sight, the very small numbers of scientists and technologists is surprising, particularly in view of the general trend toward more advanced processing technologies, improved product designs and stricter specifications. This is partly offset by the reliance of the industry on the staff of BCIRA and SCRATA, and the number of technically qualified managers and supervisors.

But half the managers and supervisors are over 47 years of age. About one-fifths are below 35, and this is roughly equal to the number over 55, most of whom are likely to retire in the next decade. The heavy concentration (54 per cent) in the 45-54 age group suggests that the industry will have an increasingly top heavy age structure.

Cook[16] considers lack of motivation to be at the root of this recruitment problem, since it reflects the lack of progress from which the industry is suffering. He considers progress not to be the result of impersonal activities such as research, marketing, management, etc., but rather the product of people who initiate, plan, implement, follow up and control. Progress is the net result of effectiveness of people, and to be effective, people need motivating. Such motivation is via the objectives of growth, profit, productivity or technical advancement; but not salary.

Table 2.1. Managerial and Technical employees.

		Iron foundries		Steel foundries	
		Numbers	%	Numbers	%
Managers & Supervisors	1969		7.4		8.0
	1970		7.7		8.1
	1971	6900	8.2	2118	8.6
Technologists &	1969		0.1		0.3
Scientists	1970		0.1		0.2
	1971	158	0.2	72	0.3
Administrative &	1969		1.5		1.7
Professional	1970		1.5		1.7
	1971	1341	1.6	409	1.7
Technicians	1969		1.9		3.8
	1970		2.0		3.6
	1971	1748	2.1	877	3.6
Totals	1969		10.9		13.8
	1970		11.3		13.6
	1971	10156	11.1	3746	14.2

2.3 Influence of External Factors

This section contains a number of miscellaneous considerations which all influence, to a greater or lesser extent, the problems which the foundry industry finds itself combating. These include: Government involvement and legislation and general market effects. In the former, tightening of safety and health measures is seen to be contrasted by an aid scheme devised to improve productivity, while in the latter, under-capacity in the jobbing sector is argued as having possible influence in the more enterprising batch and long run sectors, which, if anything, contain over-capacity.

2.3.1 Government Participation

Recent legislation aimed at improving the social acceptability of industry has had particular impact on foundries. Both the Clean Air Act, which restricts the pollution of the surrounding environment, and the Health and Safety at Work Act, which attacks danger from machinery, noise and fume are seen to pose the threat of massive financial burden (£340 million over the next few years is a popular choice). Smaller foundries are particularly worried, and it is felt that unless the Inspectorate turn a 'blind eye' toward certain practices, the shortfall of capacity in this sector might reach critical proportions.

This added monetary strain to an industry already low on capital spending is recognised by the Government - a fact endorsed by the following events:-

(1) In 1975 the Ryder Report[17] in its examination of the structure of British Leyland, was extremely critical of the foundry division.

It was felt that these units had fallen well behind modern standards due to lack of provision for capital expenditure, and further, that this limitation appeared equally applicable to the foundry industry in general.

(2) This report bought a response from the Government in the form of an announcement by the National Economic Development Council (NEDC) which declared its intention to establish a branch to look exclusively at foundries.

(3) As a result of NEDC recommendations the Government set up an aid scheme to encourage capital investment in foundries. Initially restricted to ferrous foundries, £40 million was made available to provide 25 per cent grants to approved projects. Closing at the end of 1976, some 200 applications had been sanctioned. Later, aid was extended to non-ferrous foundries when £20 million was made available on a similar basis.

Some authorities have reservations about certain effects stemming from the aid schemes. Farrant and Reynolds[18] observe, that for some years, the ferrous industry has maintained surplus capacity, a situation which is exacerbated by the new capacity being installed. This sentiment is echoed by Davis[19], who considers that it is not enough to treat each industry in isolation. Instead, more attention must be paid to the problem of matched supply resources within the country.

2.3.2 Market Effects

Government encouragement, via supplementary grants for modernisation schemes to increase productivity, has been shown, by and large, to have been received with enthusiasm by the industry. However, those foundries best suited to take advantage of such schemes are the larger units with a product range suited to mechanized production, i.e. batch and long run producers.

It has already been stated that a slow contraction of castings manufacture into fewer but larger units is taking place, and that it is the small jobbing foundries where closure rate is at a maximum. This could cause a supply scarcity of castings from this sector during the next business upturn, which, together with the over-capacity in the batch and long run sectors, could force large foundries into accepting these shortfall jobs.

A situation of this type must create production difficulties, since long run work will have to be mixed in with the short run variety. However, long run work lending itself to automation has induced machine intensive processing, for which the short run type is somewhat unsuitable and, therefore, difficult to accommodate.

3. REMEDIAL MEASURES TO AMELIORATE THE PROBLEM

For some appreciable period, the foundry industry has suffered decline, but during the past decade this has become critical. Two primary reasons are considered to be responsible for this decline, namely, limitations of an inherent character and management inadequacy.

The former includes deficiencies in cast metal properties, functional inconsistency and adverse basic manufacturing costs. The design engineer compares all of these with counterparts. These are alternative forms of semi-finished product such as plastics, fabrication, powder metallurgy and forging. Obviously, only limited room for improvement exists here and this will be relative to the advances in the rival fields. However, assuming that there will always be areas of application where only castings can be chosen, it is worthwhile contemplating the latter, i.e. management inadequacy.

Management inadequacy implies lack of competence in operating a foundry business, and the preceeding pages have examined in detail the manifestations of these deficiencies. It might be helpful to briefly list these again.

(1) Customers are somewhat dissatisfied with the service offered by castings manufacturers. This is largely the result of unreliable delivery, but also includes inconsistent quality.

(2) Inability of foundrymen to properly market their product, as against simply trying to sell them. This factor, together with customer dissatisfaction, is to some degree responsible for the encroachment currently being made by alternative processes into traditional area of castings' application.

(3) Reducing capacity in certain areas of foundry activity, notably one-off production for the engineering world which demands wide variety. This, of course, is the result of the massive closuresof small foundries.

(4) Lack of investment - largely a result of the considerable fragmentation of the industry into many small units plus a low return-on-capital. This is due to the low prices charged for castings, but has been aggravated by vicious price cutting at times of recession.

(5) A low pricing policy is largely the result of an inadequate financial structure, in particular, poor costing systems and return-on-captial allowances.

Most of these shortcomings are seen to be due to management inadequacy, which, in turn, is felt to be the result of a fragmented industry, owned by families with long traditions who jealously guarded the secrets of the trade and who were very resistent to any development on either the processing or management side. As a consequence, poor training policies failed to achieve an adequate supply of qualified people with management capability. This situation was worsened by the fact that, at the time, manufacturing industry was being completely transformed by the introduction of mechanization and automation.

The present day outcome is a declining industry, theoverall effect of which is a contraction in terms of tonnage, manpower and capital. Any remedies which are offered must therefore be fundamental to the whole management structure.

Since the production of castings is essentially a service industry whose prime objective is customer satisfaction, it is advocated that production planning and control should be the basis of any improved decision making systems. Acceptable quality apart, customer satisfaction implies on time delivery, hence, job scheduling is seen as the area warranting initial scrutiny.

Detailing the peculiarities of production control enables the weaknesses and limitations of this function to be isolated. Such exposure must then allow alternative construction which in turn should provide the basis for improved financial control and marketing prowess.

3.1 Production Planning and Control in Foundries

Most foundry customers have tight manufacturing schedules - production slack times are small and inventory (often on flow-line) is kept to a minimum. This position can only be maintained if casting supplies of satisfactory quality are on schedule. It would be worthwhile paying a premium of 5 to 10 per cent to ensure guaranteed delivery according to one customer.

But, important though it may be, the achievement of manufacturing reliability is not the only consideration. A business enterprise only remains an attractive proposition as long as the return justifies the endeavour expended. This, of course, implies cost control, which has relevance to production planning and control since cost minimization implies maximum resource utilization.

Production planning and control, therefore, must aim to optimize both customer satisfaction and resource utilization. However, as whose prime objective is customer satisfaction, it is advocated that production planning and control should be the basis of any improved decision making systems. Acceptable quality apart, customer satisfaction implies on time delivery, hence, job scheduling is seen as the area warranting initial scrutiny.

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Production planning and control, therefore, must aim to optimize both customer satisfaction and resource utilization. However, as explained by Trinder and Watts[20], these can become conflicting objectives. This view is confirmed by Benz[21], who considers that these objectives must be set by senior management. He summarises them as follows:-

(i) achievement of a suitably high proportion of on-time deliveries

(ii) optimum utilization of labour and production facilities

(iii) minimum levels of stock

(iv) economy of overall plant operation

Almost always, job choice to optimize on-time delivery is not the same as that to optimize resources. Indeed, from this standpoint, the job combination to suit efficient working in one production centre is rarely the same as that required to suit a neighbouring centre. Obviously, the scheduling exercise becomes something of a compromise.

Two added complications must also be considered when contemplating the scheduling exercise. Firstly, any proposed scheduling procedure must be tempered by other closely associated production control factors. Secondly, many customers have the habit of making last minute alterations to orders, which, whilst being condemned, must also, to some degree, be condoned by foundries.

3.1.1 Scheduling and the Influence of the Founding Process

The job combination and sequencing routine is largely dictated by method of production, which for castings, is quite distinct from production methods employed by other manufacturing industries. In addition, some foundries have machining or other final operation facilities, and these can have a marked influence on the order of job selection. Indeed, the author visited several foundries where scheduling was primarily geared to a metal removal department.

Foundry production divides naturally into three stages:-

(i) pre-casting

(ii) casting

(iii) post-casting

Because all work must pass through the casting stage, this is the focal point for both planning/scheduling and subsequent control activities, although in sand foundries, it is effectively the moulding stage which is in direct series with casting (Fig. 3.1). However, scheduling this stage determines the job mix for post-casting operation; a situation not always satisfactory.

Post-casting operations have a 'series' relationship, meaning flow-line type production. In contrast, the relationship between pre-casting operations is much more complex. Some operations such as core-laying and box-closure must, of necessity, be placed in series after mould-making and core-making, which themselves can be considered to have a parallel arrangement.

But core-making is often a much more prolonged operation, necessitating the build-up of adequate core stocks prior to the moulding operation (expensive).

Preparation of the molten metal is also a parallel activity to mould-making; however, it does not usually present problems of the same magnitude as core-making since normally the grade of metal is common to all jobs in a given mix. The emphasis here, is largely orientated toward ensuring that the metal is available at the time required, and in precisely the correct amounts.

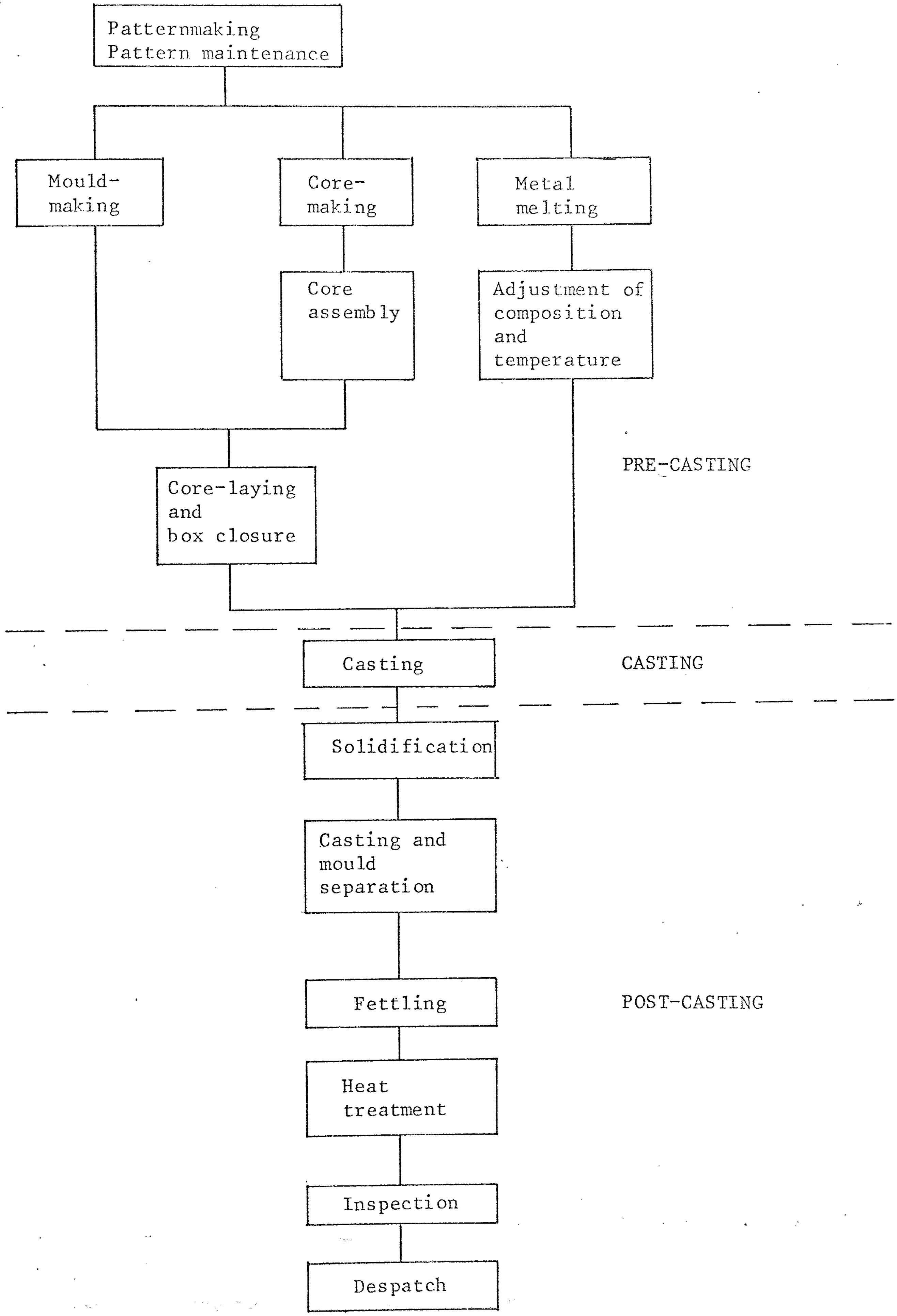


Fig. 3.1. Plan of foundry production.

Diecasting involves a somewhat modified situation. Whereas in automated sand casting the operations core-setting, mould-closure, casting and knock-out can all be carried out on a continuous basis, in diecasting they are all integral in each and every casting cycle. Hence, the focal point of scheduling is moved away from mould-making, since now all of the above sequence of activity must be summed when calculating production rate. But similarly to sand casting, if the core-making period for each individual mould considerably exceeds the casting time cycle, then this operation must play an important role in the selection of the job sequence.

3.1.2 Associated Control Features

Important as the job selection exercise is to the well being of foundry business, it cannot be considered in isolation, but must be treated as part of a fuller production control system. Since the processing of castings through a factory is dynamic, factors other than the planning of job sequence at the front end of production is necessary if the percentage of on-time deliveries is to be increased.

According to Binmore[22], the basic difficulty of progressing work through a foundry producing repetitive castings is that the castings produced as a batch in the foundry frequently do not stay in that batch during subsequent process operations. This is due either to a percentage of the batch requiring reworking, or to the processes in which castings are mixed. For this reason, a production control system cannot be based on progressing a batch of castings through a number of work centres. The batch is decreased at each centre by the number of castings sent back for reworking, and augmented by reworked castings joining the stream.

The conception of production control signifies an acceptance that production plans are likely to be upset during actual processing; hence, constant monitoring of plans and the subsequent modifications to cater for the variations that arise must be accepted. In other words, production control is the means whereby management co-ordinates all manufacturing activities.

But the situation is a dynamic one; i.e. sales levels and customer demands are continually changing. Also, the availability of production facilities is subject to constraint variations, due to plant breakdown, labour absenteeism, material shortages and the production of defective items. Hence, the objectives need to be constantly reviewed and re-stated.

3.2 Financial Control

Business success is inseperable from money aspects, therefore, it is important that a sound financial structure be established in a company. Costs are a very important aspect of price, although not the sole criteria.

Traditionally, many foundries have been managed by the MD's "feel or instinct". Often, once a selling price is established, even if it is based on a cost calculation, it is simply increased by a fixed percentage to cover any cost increases. During inflationary times, when material and overhead costs increase almost week by week, and wage increases are a frequent occurrence, decision making based solely on experience is at best difficult and at worst dangerous.

3.2.1 Cost Considerations

Cost assessment is initially based on manufacturing performance, utilizing information regarding production route and associated process times. The cost accountant then converts these into costs, and together with material costs and overheads, determines the cost of manufacture.

Fixed costs may be spread on the basis of tonnage or sales value, or per square metre of site area utilized in the particular process. In addition to the fixed overheads, there are semi-variable overheads, such as the costs of indirect labour, which must be spread over the production. An estimate of the volume of output of the particular enterprise plus a knowledge of processing periods is fundamental to the spreading of these costs.

According to Binmore[14] product mix variations make any cost estimation of this type at best, a good approximation. This is because of the effect of product mix on production rates of the various jobs and therefore overhead apportionment. Also, processing delays due to inadequate scheduling and production control add further to the inaccuracy of these approximations. Because of this situation, cost build-up cannot be relied upon as an absolute statement of fact, and tight control of production is essential if acceptable estimation of resultant variances is to be accomplished.

Overheads must include return-on-investment values, which Reynolds[23] considers should be weighed very carefully, particularly if the foundry is highly mechanized or automated. Such capital intensive situations should make allowance for both wear and tear and obsolescence. Appraisals using discounted cash flow techniques or the like are needed to indicate the rate-of-return necessary for that capital investment to be a viable proposition.

3.2.2 Pricing Policy

The objectives of having a good costing and budgeting system is not only to exercise financial control over the manufacturing process, but also to go some way toward establishing a realistic pricing system. Although costs should not be the sole criteria for determining price (the market largely determines this) unattractive jobs can be quickly identified if an efficient costing system exists. This, therefore, promotes the need for a pricing policy.

Price should not be arrived at on a production cost plus basis, but rather it should be market orientated. Those customers regarded as being of significant importance could, under some circumstances, expect the foundry to accept below normal profit margins. The author was told of several important customers of castings who will only place orders for attractive work on the understanding that less desirable jobs also be accepted. Obviously, a foundry needs to be accurately aware of true costs to be able to negotiate realistically on this basis.

Selling costs (representatives time, etc.) is often an underestimated factor, since these can vary from customer to customer. Apportioning the cost of a representative's time can prove quite difficult, yet in relation to the variables, number of orders placed and quantities ordered, it can prove an important exercise. Criticisms voiced on several occasions implied that some customers (not necessarily the best) were very demanding on representatives time, whereas others rarely required a visit. One foundry discovered that more than 2/3 of their customers represented less than 10 per cent of the turnover, and in addition, were expensive on representatives time.

3.3 Marketing Studies

The anticipation of future trends is brought about by using available knowledge to predict or forecast what is likely to happen in the years ahead. 'Crystal ball' gazing, as it is sometimes described, is always a somewhat difficult exercise which in the light of reality is often found to have been only of limited use. However, even limited prediction is a far superior situation to no prediction at all.

The methods employed to make such predictions are all based on the statistical analysis of past data of the variable being forecast. But nowadays it is usual to include, to a controlled degree, the statistical analysis of data or other variables which are shown to relate to the one of interest. However, it should be quickly added that regardless of the sophistication of procedure, the intuition of informed persons will always account for a large proportion of any conclusions arrived at in this respect.

Statistics which are of relevance to the sales trend for castings are those obtained from:-

(i) market opportunity analysis indicating which markets to serve and the competition to be faced

(ii) market strategy to accomplish objectives in the target market

Fugel[24] shows a detailed market analysis concerning the decision to set up a steel foundry. He considers the outlook of potential customers and outlines the manner in which decisions are taken regarding casting type specialisation and potential output in the face of existing competition.

According to Powell[25], input-output tables are becoming very popular for assessing market potential. These are presented in the form of a matrix of industries and enable the influence of output variation in a customer industry to be related to its supplier industries.

In considering the interrelationship between industries, changes affecting one can be interpreted in terms of others. For example, the effect of an increase in value added tax on the foundry sector supplying the automobile industry.

Although fairly comprehensive in the USA, tables of this type are only just starting to be compiled in this country.

4. MODERN ASPECTS OF THE PROBLEM REMEDIES

Development work in the field of scheduling and production control has been active for a number of years and with the ever-increasing availability of rapid computing facilities is multiplying. Although very little has been directly aimed at castings manufacture, it is pertinent to examine this development in the light of foundry requirements, particularly with respect to the application of computerized production control.

There is growing awareness that categorization of the similarities between the various characteristics of castings can be extremely useful in improving manufacturing process. Hence, group technology aspects are given brief consideration.

4.1 Scheduling Theory

During the last decade, considerable effort has been devoted to job scheduling in manufacturing processes, although it is true to say that theoretical studies have in the main been devoted to situations far more simple and straightforward than anything found in actual practice. Further, this work has largely concentrated on job shop scheduling (JSS) since it is the most commonplace industrial scheduling problem. However, both batch and flow production systems can also be considered using this approach. The book by Conway, Maxwell and Miller[26] gives an excellent account of this.

Problems differ in the number of jobs that are to be processed, the manner in which the jobs arrive at the shop and the order in which the different machine numbers appear in the operation of individual jobs. The nature of the job arrivals provides the distinction between static and dynamic problems. In a static problem, a certain number of jobs arrive simultaneously in a shop that is idle and immediately available for work. No further jobs will arrive, so attention can be focussed on scheduling this completely known and available set of jobs. In a dynamic problem, the shop is a continuous process. Jobs arrive intermittently at times that are predictable only in a statistical sense. Different methods are required to analyse questions of sequence in these two problems.

4.1.1 Scheduling a Static Order Book

The simplest situation concerns the sequencing of a job list for processing on a single machine and is by far the best understood. Although of little practical value, it is useful as a basis for studying more complex situations. The introduction of a series of machines identifies the well known n job, m machine situation, which even with moderately sized situations gives rise to a very large number of alternative schedules, i.e. $(n!)^m$. For example, 5 jobs to be scheduled on 5 machines gives 25 000 million possible schedules. Practical constraints, such as technological restriction, may reduce the number of possible solutions, but unfortunately even this reduced set of feasible schedules is often extremely large, even for complete enumeration by computer.

Added difficulty is experienced when set-up times are sequence dependent. Here the schedule becomes modified and the objective now aims to determine the schedule that will minimize the total time spent on set-ups. This is often referred to as the 'travelling salesman problem'. The term is derived from the analogous problem in the distribution field, in which a travelling salesman seeks to determine the optimal order in which to visit a number of towns, once only, and return to base in the shortest possible distance.

This type of job sequencing situation can also be represented by a tree whose branches, on moving from root to top, diverge like those of a real tree, allowing solution by the important analytical technique, branch and bound. Nodes in the tree constitute the jobs, and any branch connecting a group of nodes and running from the root of the tree upwards constitutes a unique schedule sequence, so that the complete tree designates all possible schedules.

Alternative to the branch and bound algorithm, this problem can also be solved by dynamic programming. Here, the solution is built up on working backward from destination to origin, by adding to the sequence at each stage of the decision making route, a town or job whose identity then determines which of a series of alternative routes will next be taken.

Natural ordering of machines, or a flow shop situation, has been considered extensively for a two machine situation. The celebrated 'Johnson solution' (intuitive procedure), although essentially restricted by complexity to two machines, has been shown to have some application in more ambitious circumstances. However, sequencing in large flow shops is extremely complex and recourse to successive solution build-up such as by the branch and bound technique, is often necessary.

Application of alternative types of mathematical programming have also been considered, in particular linear programming. Here, highly efficient programme codes are available which can deal with large problems involving many variables and constraints. Unfortunately, some of these constraints such as those involving either/or specifications, e.g. to use or not to use a particular machine, can be handled only by the introduction of integer variables. In fact, this implies 0-1 integer variables which, although seemingly to reduce the mathematics, precludes the use of efficient Simplex linear programming codes. Again, although the formulation of integer programming to accommodate job shop scheduling has been successful, so many variables and constraints need to be considered that the present integer programming codes available are overstreched even by very small job shop scheduling problem formulations.

The general n/m job shop schedule is, therefore, extremely difficult to manipulate. Most success has been attained to date by considering the job shop requirements as a type of graphical jigsaw puzzle, in which the blocks representing the set of operations are arranged in some order. Each job is given a set of blocks to represent each operation, and the length of the block is proportional to the processing time of that operation. These operation blocks are arranged in rows, according to their parent jobs and in numbered order such that time requirements for a machine or operations on a particular job do not overlap. This is the basis of the well-known Gantt chart and while the resulting schedule is possible, it is neither unique nor particularly good. However, the complex intellectual process by which a man manipulates a Gantt chart is almost impossible to reproduce by machine.

4.1.2 Scheduling a Dynamic Order Book

There are two situations, either or both of which may prevail in any factory:

(i) products are manufactured for stock, in which case it is possible to prepare the schedule and load at the beginning of the planning period, i.e. the 'marketing situation'.

(ii) products are manufactured only against customer orders, in which case it is necessary to schedule and load during the planning period, i.e. the 'selling situation'.

The former obviously identifies the condition previously discussed, i.e. simultaneous arrival of all jobs to be considered, whilst the latter identifies the more common condition, continous arrival of jobs.

Where job arrival is taking place on a continuous basis, scheduling cannot be treated in an entirely algebraic manner as previously, because arrivals are intermittent. Instead, probablistic studies are required since these arrival times are not known in advance. Such a process involves a queuing system with emphasis on the selection discipline, i.e. the rule by which one of the jobs waiting in a queue is selected whenever a machine becomes available for reassignment.

In general, the form of a distribution is known; hence, the generation of jobs and their attributes (flow times, etc.) are a sequence of independent random variables obtained from these distributions. Attention is centred on mean flow time as a measure of performance. Most of the queuing literature pertains to the special case in which the times between job arrivals are a sequence of independent observations from a fixed exponential distribution, usually of the Poisson type.

The incorporation of parallel machine working, produces the multiple-server queuing model, which is an extremely complex situation for which there are not extensive theoretical results. Tandem queues, or queues in series, can be visualised as corresponding to the flow shop situation.

Many attempts have been made to establish specific scheduling rules or procedures that can be shown to produce optimal solutions. One of the most popular of these rules is shortest processing time, which, it can be shown, minimizes mean or total waiting time and hence flow time (the total time jobs spend in the shop). Another common rule is to arrange the jobs in order of increasing due dates. This rule minimizes maximum lateness (positive lateness is described as tardiness).

Other more complex rules, which in general have look-ahead characteristics, take into account some aspects of the future progress of the job through the job shop. For example, maximum number of subsequent operations and maximum remaining total job processing time rules have shown promise. Also, minimum slack time rule in which job slack time is determined as the remaining time to due date minus the remaining total job processing time is popular. Here, the next job to be processed on a machine is chosen as the one with the smallest slack time.

4.1.3 Simulation Techniques

An alternative to the algebraic and probablistic methods, as a means of studying questions of sequencing, would simply be to try various procedures in a real shop and compare actual performances. The advent of the computer has made it possible to conduct such an experimental investigation by simulating the action of jobs, machines and scheduling procedures with a computer programme. Indicators, counters, lists and files, within computer storage, can effectively represent the state of a job shop process and a programme can be written to cause this state to change over time under the action of a particular scheduling procedure.

King[27] feels that this method of improved job scheduling holds most promise for the future, since it can be incorporated into an all-embracing production control system. More widespread application of computers, particularly the mini-type, will actively promote this.

4.2 Foundry Scheduling

A wide gap exists between scheduling theory and practice. This stems from the inability of the theory so far developed to cope adequately with the complexities of real world manufacturing process.

Nowhere is there greater diversity of manufacture than in the foundry industry. Here, both types of metal and size of casting promote wide disparity of production method. Diecasting contrasts with sand casting, as does the manufacture of castings weighing a few kilogrammes with those weighing several tonnes.

4.2.1 Individuality of the Scheduling Process

The fact that some foundries are jobbing units while others specialise in flow type production perhaps signifies more than any other the wide diversity of work scheduling procedure in this industry. Jobbing may be defined as one off or a very small quantity, usually special customer tailored and requiring a wide range of general purpose plant with minimal tooling, but with a very adaptable factory layout to suit skilled workmen. Flow, on the other hand, consists of any quantity where, because certain requirements have to be satisfied, finds it necessary to produce the product continuously over a period. Between these two extremes exists batch manufacture, which consists of the production of any quantity, all alike, and at the same time.

Few foundries, however, can be described solely as either jobbing, batch or flow. Jobbing foundries usually have a core of regular (made daily or weekly) work around which more intermittent orders have to be scheduled while few flow type foundries run jobs permanently. Further, customers with long run or extended batch requirements provide a monthly (or even longer) schedule with an indication of future needs, whereas others give solely an order for a single casting or batch with no indication of future needs.

In practice, the objectives of scheduling are achieved by the application of priority rules and constraints in the scheduling model.

4.2.2 A Summary of Actual Scheduling Procedure

The variety of scheduling procedures was forcably impressed upon the author when he visited a planned cross-section of the foundry industry. Although the space is not available to make an exhaustive study of the various systems witnessed, it is felt appropriate to list a few of the more important common features:-

(1) There is a definite tendency to optimize the use of plant and labour at the expense of delivery dates and customer satisfaction.

(2) Most foundries are of the batch production type having work loads of approximately 40 per cent regular orders and 60 per cent new or irregular orders.

(3) Such foundries almost always schedule around mould-making because this function is still largely labour intensive. Features such as absenteeism, scrap rate variation and production rate are often uncertain.

(4) Production is usually planned one month ahead and once per month as a weekly breakdown. Day-to-day details are normally decided upon once per week.

(5) Scheduling generally aims at keeping a moulder occupied with the same pattern for a full day; to this end, production of a job will be delayed until a batch size has become large enough to suit. A similar attitude is found regarding machine production, where pattern changes will only be tolerated at break times or the end of a shift.

(6) Most companies plan to full capacity, whenever possible, and because of vagueness regarding production rates during 'boom' times they often overload to 10 per cent as a safety precaution.

(7) Flow production, particularly of complex jobs, is often planned

around the core shop or dressing shop. For example, in manufacturing cylinder heads, core production constitutes the central feature. Here, day and night shifts build up core stocks (slower than mould production) prior to moulding and casting during the day. At other foundries the machine shop is initially planned before batch scheduling mould and core production to suit.

(8) Both batch and flow type foundries frequently experience major disruption to production plans as a result of last minute changes to schedule by important customers.

4.3 Computer Aided Production Scheduling and Control

With the increasing popularity of computers, job scheduling and subsequent monitoring of manufacture could rapidly become an integral part of a computerized production planning and control system. According to the literature, there are already a number of examples of computerized production control systems being employed in foundries.

4.3.1 Examples of Computerized Production Control in Foundries

(1) Deere[28], Holinshead[29], Seager[30] and Binmore[22] all broadly describe customer order processing and production control systems installed in their foundries. They describe customer schedules calling for periodic quantities of a recurrent job or one-off orders for a specific quantity. The computer couples this information with the figures from the production control system and the data available on the master file to give the following outputs:

(i) cast charts - computer compares customer schedules with the details of work in process and indicates the quantities required and the time when a particular job should be scheduled.

(ii) the computer compares requirements with capacity for each moulding facility and so determines the foundry schedule using priority rules.

(iii) process facility loading - taking the foundry schedule as input, the computer uses the lead time associated with each job in order to calculate and output the loading to be expected during the future period on all processing facilities (forecasts bottlenecks before they arise).

(iv) historical sales data record - future demand forecasting (attempt to forecast the prospects of the industries served).

Other output information includes:-

(a) exception reports detailing the jobs in arrears at the main processing stages

(b) scrap reports - weekly for each moulding facility

(c) basic production information and stock position - cumulative number of good castings from the foundry minus the number delivered gives the number of castings in progress for each job.

(2) Law and Green[31] describe a computerized production control system introduced to a blackheart malleable iron foundry. They explain how the system simulates the heuristic rules of moulding department personnel.

The model consists of fourteen sequentially linked programmes, which essentially receive orders and base subsequent delivery promises on a four week production cycle plus estimated order backlog. Current schedules are produced every week, each order being adjusted for the number in stock and anticipated yield. Job choice is based on management set priority rules which are formulated largely to promote a high rate of on time delivery.

(3) Dartmouth Autocast Foundries Ltd.[32] produced, a few years ago, a completely automatic computerized scheduling programme to control twentyseven moulding lines. The objective was to optimize the use of resources and allow the production control department to satisfy customer requirements.

The schedule produces for each line a list of job numbers and the times at which they will run. Techniques used in determining the schedule allow for observance of limitations on metal availability, moulding labour availability, duration of jobs and combination restrictions of box sizes. Also, the system will attempt to keep coring, grinding, chipping and viewing labour requirements as near as possible to preset levels. Sophisticated and somewhat complex formulae are employed for the calculation of priorities and hence job selection.

(4) Dudley Foundry Co. Ltd.[33] have built a production control system centred around a Datapoint 2200 model Ventek 'real time' mini-computer. Procedures performed on this unit include new order receipts, new order intake analysis, production made (cast-up), production performance (scrap), scrap analysis, customer rejects received, rejection analysis, forward load statements, pattern number, price updating, fettling shop stock (WIP), listings and consignment notes and invoice-issuing.

This foundry advocates the use of VD units rather than masses of paper-work as being the main advantage of the system.

4.3.2 Production Control Software Packages

Whenever the question of computer programmes for production planning and control is discussed, the question whether it is better to utlise standard packages or develop tailor-made programmes arises. The case for a tailor-made programme is that it will necessarily cater for the user's unique requirements. On the other hand the case against a tailor-made programme is essentially, that it will incur high development costs, involve lengthy development and require systems expertise which many companies do not possess.

With tailor-made programmes it is sometimes possible, by taking advantage of the special characteristics of a particular problem, to devise a model that will provide optimal solutions. This is possible for only simplified cases, hence tailor-made scheduling programmes are usually based on heuristic methods.

A variety of computer scheduling packages have been developed by computer manufacturers and others as generalised programmes for job shop scheduling. Thapar[34] carried out an assessment of pacakges for computer aided production control. He found that only the BCIRA/Hoskyns system catered specifically for the needs of castings manufacturers and that no existing software package could meet all the production control needs of the foundry. First time users of computers may be tempted to use packages because of the apparent ease of implementation, but they should be wary, since generally designed systems could prove distinctly inefficient when put to a specific use.

One foundry which has used the BCIRA/Hoskyns system has recently become disenchanted and finally abandoned it. Although the system gave good results and an abundance of information, it was found to be too rigid.

Thapar's findings are backed up by King in a survey of computer production control packages used by manufacturing industry in general. He found that 34 per cent of the companies surveyed used standard packages and almost all of these (90 per cent) had made modifications to meet their own specific requirements.

The scheduling programmes within the standard packages have similar structures which utilise network analysis for loading and heuristic methods for computing job sequence priorities. Typical in this respect are CLASS and CAPOSS (IBM) and PROMPT and NIMS (ICL). Long term forward scheduling to available capacity through the work centres is via job priority numbers.

Short term forward scheduling, which loads the individual machines with jobs in the order in which they are to be processed, is accomplished by a heuristic priority rule. This priority is based on the consideration of five factors:-

(i) the shortest processing time rule

(ii) a delay rule

(iii) whether the job has special priority

(iv) whether the job is in process at the moment

(v) whether there are successive operations to be performed on the same machine.

The jobs are sequenced on machines in priority number order, starting with the highest priority number.

4.4 Group Technology (GT) Considerations

GT is a somewhat imprecise term, but in the context of this thesis, it may be taken to mean a study which aims to benefit from the similarities of castings. It is an organisational principle which can act as an influence on all departments of a manufacturing enterprise.

4.4.1 Basic Features of GT

Eastern Europe gave birth to GT and while orginally being applied to rationalize the machine tool industry, it quickly extended to embrace all industries manufacturing semi-finished products, including foundries. The basic goal in respect of the foundry industry was an increase in productivity by greater standardisation of patternmaking and moulding practice, with the aim of efficient utilisation of production capacity and improved organisation of labour.

This was accomplished by identification of castings' similarity, using classification systems, allowing rationalization, via the segregation of closely related products, of the design and function of foundries on a national basis. Such benefits were recognised by the Western World some 10-15 years ago, although a contrasting industrial structure did not allow the same rationalization on a national scale. Hence, instead of a universal classification system embracing a complete industry, Western classification systems have tended to be developed on a company basis, although common systems such as those attributed to Brisch and Optiz have found general applications in some fields of component manufacture, notably the machining industry.

The Eastern Europeans were quick to conclude that in an industry such as the foundry industry where almost complete flexibility of shape exists, it is not geometric similarity which should constitute the main attribute of a classification system, but the formation of families of castings identified by process route similarities. This attitude is repeated by some British foundries who have incorporated GT ideas, their main motivation appearing to be definition of product mix and clarification of its effect upon business enterprise.

4.4.2 Production Flow Analysis (PFA)

Cell formation, with its Group Layout, is formulated by Product Flow Analysis, which according to Burbidge[35], is the technique for finding families of components and associated groups of machines for Group Layout. Here, process routes for various jobs are analysed to find the natural division into groups and families using the existing plant, tooling and processing methods. This contrasts with the more conventional Line Layout.

The author observed many situations during his contact with the foundry industry where PFA ideas could be usefully employed, particularly in the area of pressure diecasting, where machines are portable and limited machining of castings is normally carried out. Benefits would be derived if light alloy castings were concentrated into familie requiring similar sized casting machines and trimming presses. These could be grouped together, and manufacturing cells finally completed by the inclusion of appropriate drilling and metal cutting machines plus inspection and other quality control procedures.

4.4.3 Examples of GT Applications in Foundries

Current application of GT in UK foundries might be briefly summarised as follows:-

(1) Ley's Malleable Ltd., Derby, use a seven digit code which covers complexity, shape, size and material specification. The basic complexity/shape coding takes the form of pictorial matrices of castings, making it a simple matter to use a matrix of standards to compare new jobs with existing jobs. When a new job requires a quote, it is coded and compared by means of the code with existing similar jobs and a price determined using these records as a guide.

The system of identifying a casting by reference to its coded number rather than the customer's name, has been adopted by the production department. As a consequence, it is envisaged that the system will be of use for production scheduling in the near future. Toward this end, at present, Ley's are able to indicate the type of work flowing through the foundry, i.e. they are able for the first time to quantify their job mix. This example, by emphasizing shape as the control criterion, contrasts with the earlier views which advocate process route for castings' group identification.

(2) Calton & Co. of Leeds are an independent foundry producing sizeable batches of steel castings in a large, partially mechanized

foundry. They have been working on a cost estimating system based on classification. Its concept is to list the process routes in the plant and establish a cost rate for each. For simplicity, only three types of cost rate are proposed:-

(i) a rate per kg of liquid steel

(ii) a rate per shell, mould or box

(iii) a rate per kg of casting

Multiplying these rates (applicable for a casting's production route) by the actual quantities required, enables an estimate of batch cost to be arrived at. If the complexity of the casting is also taken into account, the estimate becomes more accurate.

(3) Anstie[36] proposed a classification system (later modified by Newman[37]) for the light engineering foundry, Johnson Radley Ltd. of Yorkshire. Designed initially to optimize the profitability of each department's operation, it was also seen to have application as a marketing tool, as a pricing tool and eventually as an aid to production scheduling. It was considered important to concentrate on the design features of castings rather than process variables, the factors taken into consideration being shape, complexity, size, material and patterns per board.

PART 2

PROBLEM CONSIDERATION

5. EXEMPLIFICATION OF THE PROBLEM

Problem exemplification necessitates close consideration of the foundry industry via detailed examination of selected items in the light of ideas formulated in the previous pages. This implies the use of case studies, carefully chosen, to represent as closely as possible the industry's diversification.

However, before considering the selection of suitable case studies, it is pertinent to review briefly the problem areas isolated and the measures suggested for their alleviation. In short, the foundry industry is seen to be experiencing wholesale decline. This decline is witnessed by reductions in the real gross turnover of the industry during recent years, together with a definite reluctance on the part of people to become associated with foundries.

These limitations are seen to be due to customer dissatisfaction, coupled with the inability of the industry to develop a sound financial base. The former, apart from the inherent inadequacies of castings, highlighted by competition from alternative forms of semi-finished shaped components, is due to variable quality and unreliable delivery. The latter is the result of poor costing and pricing procedures. Also, inadequate marketing adds to these weaknesses.

All constitute the basis of investigation, but they require, as a prerequisite, the existence of a sound production control base. Since delivery reliability is dependent on good manufacturing systems, and in particular efficient job selection procedures, scheduling is felt to be the fundamental base on which to build solutions to the problems confronting the foundry industry.

Some of the most difficult costing exercises involve the allocation of variable overheads associated with work in process and process times. This again places a heavy reliance on job scheduling and production control. Also, a vigorous and fully effective marketing campaign can only be totally successful if the company is completely aware of its manufacturing capability and cost make-up.

5.1 Case Study Selection

Since the foundry industry covers three broad production type areas, namely jobbing, batch and long run, and since castings manufacture is largely split between ferrous production in sand moulds and non-ferrous production in metal moulds, it was initially felt that a jobbing and a long run type situation be chosen from the ferrous area (largest) and a batch producer from the non-ferrous area. In addition, choice was also made with regard to geographical location to promote easy and frequent access. Unfortunately, in spite of initial encouragement, for reasons ranging from mistrust of academic pursuit, through peculiarities of group company structure, to lack of co-operation from middle management, none of the initial trio bore fruit.

A description is given of these early failures because they have considerable bearing on the final choice of case studies. Although attempt was made to adhere to the selection framework advocated, subsequent company tie-up was largely based on the establishment of enthusiastic co-operation for the work. Two companies finally became involved in the project and these may be briefly outlined as follows:

(i) Spunalloys is a small (less than 100 employees) jobbing/batch foundry concerned with the manufacture of simple shaped rings and tubes mainly in copper-base alloys. With its confinement to the centrifugal casting process, and its non-involvement with complex shaped components, the company might be considered to lie on the periphery of what is normally described as the foundry industry. However, it is representitive of a jobbing situation and therefore deemed suitable for this study.

(ii) Bridge Foundry is a medium (100-200 employees) sized batch/long run production foundry specialising in gravity diecasting aluminium alloys.

5.2 Description of the Companies

5.2.1 Spunalloys

The company is a recognised important producer (60 per cent of the British market) of spun copper-base alloys (extremely wide range). The castings made emphasize the marked jobbing character of the market supplied. Individual cast weights range from 100-2000 kg (limit of crane lifting capacity) with outside diameters varying from 100-1275 mm, internal bore down to 60 mm diameter and cast lengths up to 640 mm. Some idea of the size diversity can be formed from the list of die sizes currently in use, shown in Appendix 1.

Recently, in order to diversify still further, the company has started to centrifugally cast aluminium alloys, and is currently in the process of assessing the possibilities of entering the field of short run ferrous spun castings.

At present, foundry production is organised into four sections, with boundaries developed, in one case on metallurgical grounds, and for the other three on the basis of size capability or type of spinning machine used for production. General details of each production centre in the foundry can be summarised:

(1) Aluminium section. Consists of two horizontal spindle machines and two rotary type crucible furnaces and is largely self contained with its own labour force.

(2) Bushmaster section. Consists of a pair of Gibson Bushmaster horizontal spindle machines capable of making tube sizes up to 300 mm OD in standard 630 mm lengths. Forced water cooling and a casting ejection mechanism promote casting quality and production rate.

(3) Non-standard section. Consists of twenty seven horizontal spindles primarily used for the production of small quantity orders. Sizes range from 100-420 mm OD and a maximum length of 530 mm.

(4) Vertical section. Consists of four more horizontal spindle machines capable of making castings up to 1067 mm long and 430 mm OD and four vertical spindle casting tables able to accommodate up to 1250 mm OD.

No hard and fast rules regarding metal supply from any particular furnace to specific spinning machine are applied. Instead, size limitation and convenience generally dictate the pattern of supply. Molten metal is at present heated by a battery of three large capacity (one 750 kg and two 500 kg) mains frequency induction furnaces, a battery of two small capacity (both 180 kg) mains frequency induction furnaces, one gas fired crucible furnace of 680 kg capacity and one oil fired crucible furnace of 365 kg capacity. Additional oil and gas fired furnaces are available if required.

The machine shop for proof machining the rough castings consists of the following:

(1) Vertical boring section. Consists of two 915 mm table machines and one 220 mm table machine for processing castings within the size range 305-1020 mm OD and 380-1300 mm OD respecively.

(2) Heavy horizontal lathe section. Consists of four large horizontal machines used for castings 205-760 mm OD.

(3) Light horizontal lathe section. Consists of eight small horizontal machines used for castings up to 456 mm OD.

5.2.2 Bridge Foundry

The company is a member of the Clayton Dewandre Group of Companies and manufactures a wide alloy range of high quality aluminium gravity diecastings mainly for fluid pressure applications, e.g. cylinder heads, pump bodies, hydraulic braking systems, etc.

Castings are poured in the casting shop, after which they progress through the various sections of the dressing shop. Approximately 50 per cent are heat treated prior to despatch.

The casting shop consists of forty bale-out type gas fired furnaces or electrical cored induction furnaces. Sixty day casters and twenty night casters are deployed around these, gravity casting into dies ranging from fully hand operated for small batch quantities to limited machine operated (simple open and closure plus tilting tables, etc.) for larger quantities. Depending upon the rate of metal demand, some of these furnaces can be supplied with hot metal from six large oil fired base melter furnaces or from outside tanker deliveries There is complete flexibility regarding selection of alloy for melting in any particular small bale-out furnace, although change-over to an alternative alloy must be treated with care to avoid contamination.

Visual inspection is carried out on the castings before they move in to the dressing shop section to receive finishing operations. These consist of a combination of the following:

(1) Rotary saws (Sawyer section). Consists of five machines and four operatives who remove runner and riser systems from larger castings.

(2) Band saws (Ballinger section). Consists of seven machines and five operatives who remove runner and riser systems from small castings.

(3) Grinding. Consists of five machines and four operatives who remove saw marks and flash from larger castings.

(4) Linishing. Consists of four machines and four operatives who remove saw marks and flash from smaller castings. Some castings are both ground and linished.

(5) Male file. Consists of eight operatives who improve the surface finish of areas inaccessible to grinders and linishers on large castings.

(6) Female file. Consists of four operatives who improve the surface finish on small castings.

(7) Press. Consists of one operative who coins (serrated edge) a certain group of castings.

(8) Disc. Consists of two operatives who fine grind certain areas of a group of castings to a high finish.

(9) Ream. Consists of two operatives who drill and dress holes in a certain group of castings.

The size range of castings varies from 0.1-12 kg and there are 100-1200 dies in stock, but only 250-300 are 'live' (used several times a year). Up to 70 new dies (fresh orders) are received per year, the approximate die life ranges 100 000-150 000 castings and production rate ranges 250 (large complex jobs)-10 000 (small multi-impression jobs) per week. Only six jobs are run continuously (20 per cent total tonnage), although 60 per cent of production can be described as long run (dies kept in production for more than one week) and 40 per cent as batch. 40 per cent of capacity is confined to group company requirements, a further 40 per cent to six major customers and the remaining 20 per cent is shared between twenty five minor customers. Customer and die identity change very little (less than five new customers per year).

Bridge Foundry are adept at making certain types of castings and they tend to concentrate on this market area. As might be expected, because of favourable reputation, new business in this field automatically moves in their direction. Only in times of depression are they likely to seek work of a more varied nature.

5.3 Identification of Suitable Study Areas

Initial attempts at formulating a case study framework, at both companies, centred around detailed discussions with various strata of management. These ranged from interviews at directorate level, aimed at establishing company philosophy and policy, to talks with a wide range of middle management including production, sales and finance, with a view to identifying possible areas of investigation.

A weakness associated with the case studies is that neither caters for the mechanized and automated side of the foundy industry (ever increasing importance); both deal with essentially labour intensive situations.

5.3.1 Jobbing/Batch Foundry Characteristics

Normally, it is not possible to completely clean the interior of a crucible pot after melting, hence some contamination of the next metal charge, by the previous charge, is almost unavoidable. Therefore, melting programmes for companies such as Spunalloys, engaged in jobbing production of castings, are usually complex, calling for various quantities of many alloys to be melted in the course of any working day.

Consequently, permissible impurity levels have an important bearing on the structuring of the daily furnace work load. For example, alloys such as aluminium bronze, specifying very low contents of lead and tin, cannot be melted in a pot which has just melted tin bronze. Copper nickel alloys, calling for very low lead levels, should not be melted in curcible pots which have been used for the production of lead containing alloys.

The selection of a suitable die for making the individual castings consists of simply choosing, from those currently available, a die with the same dimensions as those of the casting. In many instances, an exact match cannot be achieved. Under these circumstances, the die with oversize dimensions closest to those of the casting is used.

Occasionally, it may be possible to make the casting from more than one favourable die. Selection is then on the basis of molten metal economy, the die consuming the lesser amount of metal being chosen.

Castings below 300 mm OD can frequently be made in either Bushmaster machines or in simple non-standard section die machines. It is usual to choose the former only if the number of castings ordered will require at least two 'pots' from the Bushmaster machine.

Orders received daily show either the required proof machined annulus dimensions, or contain a drawing (particularly when the casting has tapers and flanges, etc.). Number off and an indication of desired delivery date are also generally included. The variability of dimensions is almost continuous and this, together with a copper base alloy specification range of up to thirty different types, identifies the strong jobbing nature of the company. However, variations in the number off parameter of 1-700 indicate some association with batch production. Many orders are classed as 'urgent', presumably because of machine breakdown, e.g. bearing 'burn-out'.

Order acceptance is indicated by the despatch of a note of acknowledgement to the customer containing a proposed delivery date. This delivery date is worked out by the Sales Manager, who takes account of the forward load plus customer indications. Details of the forward load, which is considered in terms of the four casting shop sections, is ascertained simply by comparing the cumulative total of orders accepted with an average weekly tonnage figure (moving average compiled over the previous six months).

After including proof machining tolerances, rough casting dimensions and weight can be obtained by identification of the die (or ring cluster in the case of the vertical section) most suited for its production. These details are transferred to a Work's Card, supplied to the Production Office where it is grouped with others according to the week in which it is to be cast. A summary of loading by production centre is then displayed on the office wall.

The next two week's work is made available to the foundry every Monday morning, where, because of the complexity of constraints involved, it is left to the supervisory and operative personnel to decide the casting sequence. Attempts are made to cast at least two weeks ahead of proposed delivery, to allow adequate machining time and any heat treatment (outside contractor), although consideration needs to be given to die availability and furnace contamination.

The Work's Card follows the rough casting into the machine shop , where job selection is again left largely to the discretion of operators and supervisory staff, and finally on to despatch. Production control personnel endeavour, within the confines of order pattern, to concentrate cards in terms of alloy specification and die size, and it is noticeable that with forward loads of approximately sixteen weeks compared to forward loads of less than five weeks much can be accomplished in this respect.

Control over the work in process, identified as the rough castings awaiting machining, is exercised via monthly stock-taking. A balance is attempted between capital tied up and the flexibility of choice associated with large numbers, since a contamination problem also exists in the machine shop. Here, turnings (up to 2/3 of the rough casting is machined away) subsequently to be re-melted, need to be separated on an alloy basis. This can necessitate production delays because machines need to be 'swept down'. Frequently, work in process increases beyond an acceptable level, whereupon machine shop overtime is initiated, and/or work is contracted out.

Two final points are worthy of note because they strongly influence the production control activity. The first is the tendency to choose favourable jobs identified with easy die set-up and/or alloy convenience at the expense of less favourable jobs, even though these might be overdue. It is easy to disguise this move within other production control constraints. The second point is that Spunalloys are endeavouring to compile a restricted standard list of die sizes upon which all estimates can be easily calculated. At present, they compromise between excessive die numbers, which increase capital and storage costs and complex the scheduling routine and excessive metal removal. The ultimate objective is persuasion of customers to buy 'off the shelf' rather than ask for 'tailor made' sizes.

5.3.2 Batch/Long Run Founding Characteristics

Up to 80 per cent of orders placed with Bridge Foundry have a schedule base. They show, for weekly or monthly periods, the customer's forward requirements for various casting types. This is encouraged, since it allows a clearer indication of forward load.

The average schedule, received monthly, shows up to three months' 'hard' orders and a subsequent three months' 'tentative' quantities. In general, customer forecasts are poor, and not only are tentative requirements changed often, but all too frequently 'hard' orders and even current requirements are drastically altered. As the MD pointed out, overnight a particular job schedule situation can move from a position of surplus to one of arrears simply by the receipt of an early morning telephone call. The motor vehicle industry are notorious in this respect.

With a view to obtaining manufacturing stability and to avoid furnace contamination, effort is made to produce from a die in weekly units. This is evident in a number of ways. For example, the company is prepared to make up to three months' requirements as a single batch and then hold as stock. However, if the customer insists on a mid-week die change, then he is made to suffer a die-setting charge (cost of inspection, maintenance and warming up of the die).

Being labour intensive, capacity at Bridge Foundry can suffer drastically through absenteeism. This is particularly acute in the dressing shop, where teams of not more than eight operatives are processing work from up to eighty casters. Fortunately, through recent legislative policy promoting labour force stability this problem has lessened considerably.

Transfer of labour between dressing shop sections provides flexibility of work load capacity, but in spite of this, balancing production between the various sections is still a difficulty frequently experienced. Product mix can upset this balance to such an extent that work in process can build up astronomically in a few days.

Perhaps more alarming, the recording system is slow to notice this. Due to the peculiarities of payment (flat rate plus a ceiling piece work rate), in an effort to ensure consistent wages, fettlers often book more castings than the number actually processed, and vice-versa. Although standard times are used to matchcapacities, these are not very successful and often, when job mix changes are made in the foundry, severe non-balance is created in the dressing shop.

5.3.3 Comparison of Financial Characteristics

The contrast between the financial frameworks associated with jobbing type production and that of long run type production, as illustrated by thetwo case study companies is extensive. Although partly due to more efficient management (larger company) it is felt that the much superior financial framework at Bridge Foundry stems primarily from the simpler manufacturing system existing there. Because of the relatively straight-forward work-flow pattern compared to that at Spunalloys, accurate cost apportionment is made more easy.

Standard Costing is practised at Bridge Foundry, with casting and dressing shop prices for jobs being negotiated separately with operatives representatives. Budgetary Control standards are established at six monthly intervals, when metal price fluctuations (major variance) are written off, favourable or otherwise. The direct cost make-up of each job is considered separately by adding the material costs, which include a metal price and allowance for loss and scrap to the direct labour costs.

In comparison, no system of cost control, such as Standard Costing or budgeting of financial activities, is in existence at Spunalloys. Instead, a Nominal Ledger is operated which records the transactions of the business, indicating incomings and outgoings. Price determination is the financial focal point, and this exercise is carried out for every individual inquiry by simply building up the job costs at each of the three work centres, namely furnaces, casting machines and metal cutting machines.

Direct costs, such as operatives time and materials, are each multiplied by a factor. Based on information derived from the Nominal Ledger, this factor embraces operatives wages, power consumption, machine maintenance, a depreciation allowance and a so-called efficiency fraction. This latter parameter depends on the size of the order book, causing a cost increase when activity is low and lead time is short (few orders). In this situation both furnace contamination and die selection complexities are at a maximum, promoting reduced output.

The total direct cost figure is finally multiplied by an 'administration' factor to account for indirect labour costs, other overheads and inflation. After adding a suitable profit margin, the calculated price is arrived at, but this in turn is often manipulated according primarily to market trends and the likelihood of the inquiry being subsequently confirmed as an order.

Overhead apportionment at Bridge Foundry is carried out in a more precise manner, but even here, difficulties are recognised. At present, they are recovered from the various jobs by distribution on the basis of direct labour costs. However, product mix has such outstanding influence that if the ratio metal costs/labour costs are either high or low for a particular job combination, or if only poor load balancing of the various dressing shop sections is achieved, Budgetary Control targets can be missed by wide margins.

6. RESOLUTION OF THE PROBLEM

The jobbing/batch producer finds scheduling so complex that forward planning is restricted to the formulation of general guidelines such as the approximate week of manufacture. This necessitates detailed job sequencing having to be performed by the operatives as an on-going activity. In contrast, product mix selection to optimize load balancing of production centres constitutes the principal scheduling difficulty associated with batch/long run production.

6.1 Isolation of Specific System Deficiencies

Scheduling deficiencies ought to be manifest by shortcomings such as unreliable delivery, variable output and a less than tightly controlled stock policy. All of these areas are investigated and the performance of the two firms in respect of them analysed.

6.1.1 Delivery Reliability

Both companies have a spread of major and minor customers. However, whereas Spunalloys receive specific orders for which delivery dates have to be determined, Bridge Foundry supplies most of their castings according to customer request schedules. As a result, the former are required to sequence the various orders to allow maximum production efficiency, but within the confines of delivery date promises, whereas the latter have to sustain sudden 'last minute' adjustments to customer requirements whilst again endeavouring to maintain manufacturing continuity.

To establish the full nature of these effects, an investigation was instigated at both companies into order-delivery relationships. At Spunalloys, a comparison between promised delivery date and actual delivery date was made, while at Bridge Foundry, monthly variation in customer schedules plus the influence of such variation on corresponding deliveries was considered. Both investigations were carried out over extended periods (twelve months or more), and both concentrated on selected customers representing large, medium and small ranges.

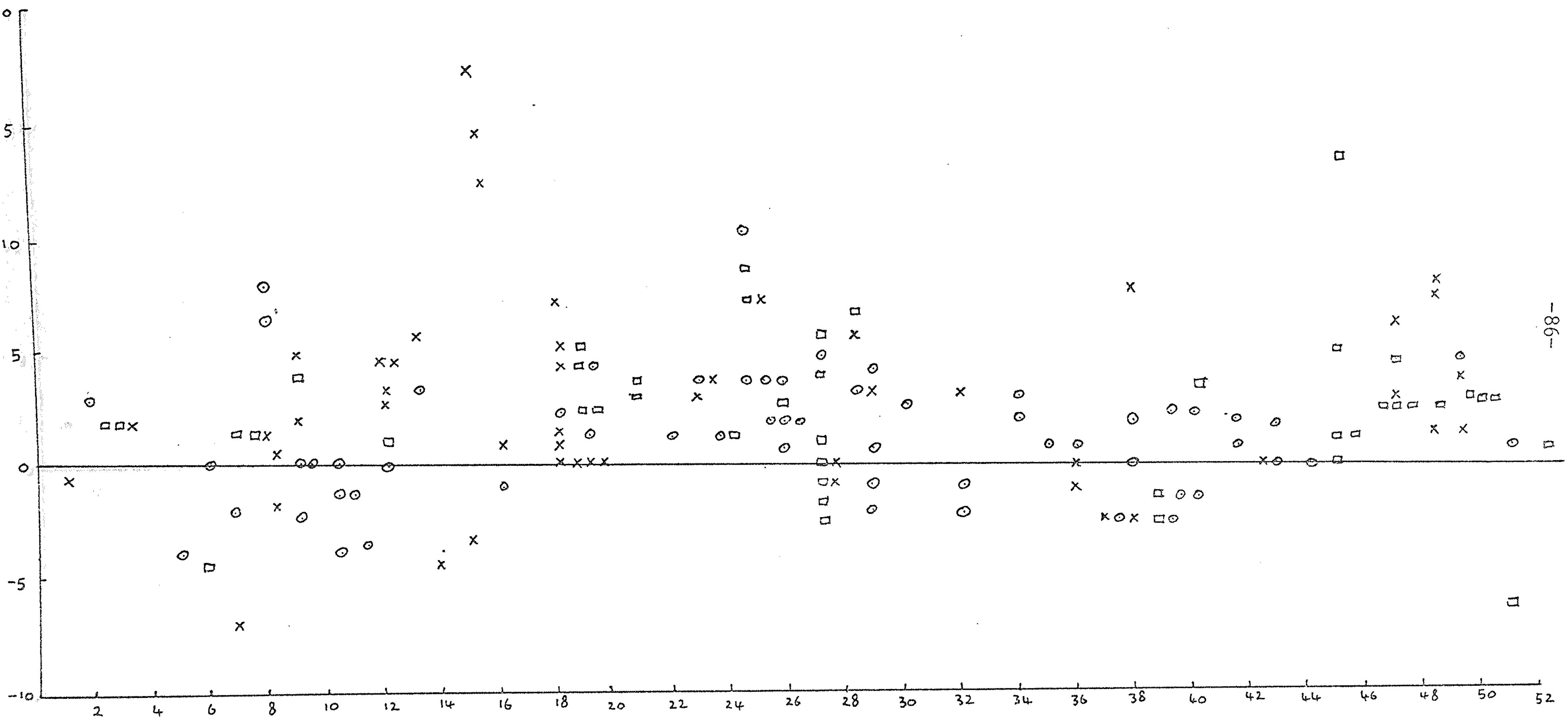
Only the results of the surveys and their implications are given here, fuller details being available in Appendix II, Section 1. It might be mentioned that some of these details are incomplete due to information being mislaid by the companies.

No useful relationships could be established from an analysis of the Spunalloys survey. It was found that less than 15 per cent of deliveries were actually made on time (during the week estimated), 55 per cent were delivered late and 30 per cent were delivered early. Further, no distinction was apparent between important and lesser important customers, or periods of the year when estimation was carried out. However, as is shown in the plot of accuracy of delivery date estimation vs time period when the order was received (Graphs 6.1 and 6.2), there appears to be blocks of time when lateness tended to predominate and regions where scatter was high.

It was felt that accuracy of delivery prediction might decline as lead time increased and output approached its maximum, i.e. periods of 'boom'. But although during the months considered lead time varied from 3-20 weeks with a similar wide spread of output figures

Graph 6.1. Accuracy of delivery date prediction at Spunalloys during 1975.

Key.
- ⊙ Large customer (many orders)
- □ Medium customer.
- x Small customer (few orders).



Week number when delivery was made.

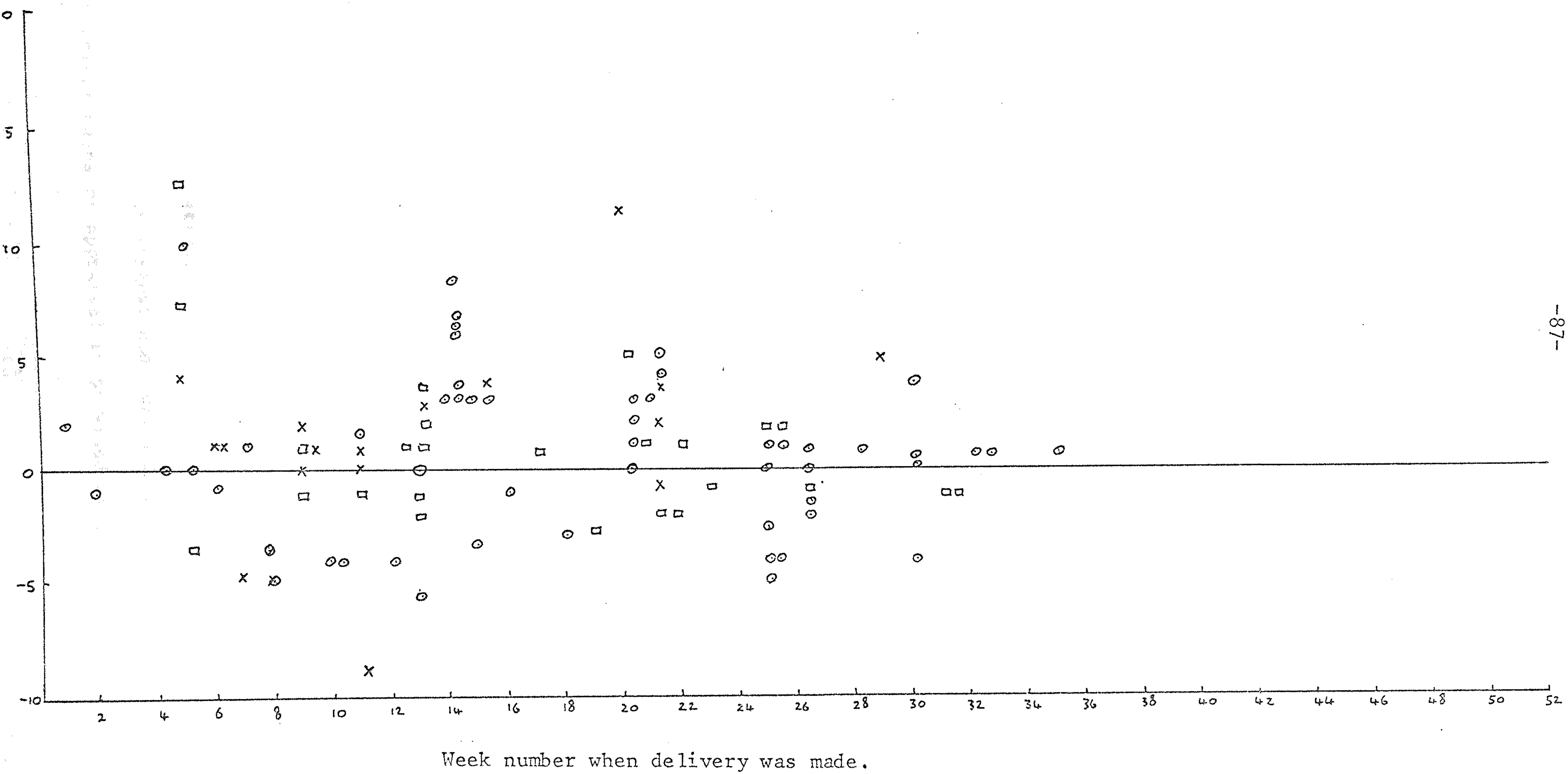
Graph 6.2. Accuracy of delivery date prediction at Spunalloys during 1976.

Key.

⊙ Large customer (many orders).

□ Medium customer.

× Small customer (few orders).



(discussed in the next section), no trend showed up.

To determine whether or not poor scheduling of the foundry or machine shop was responsible for this dismal record a limited investigation of progress pattern was carried out. Again full results are shown in Appendix II, Section 1, and only the summation of variability in the form of statistically calculated means and standard deviations are compiled in Table 6.1*.

Waiting time scatter, at both the buffer stock (rough castings awaiting machining) stage and despatch, obviously aggravates the delivery problem. Although some delay at despatch can be excused away on the grounds that loads destined for various areas of the country need to exceed some minimum value before transportation becomes economically viable, this would not seem to account for the considerable magnitudes actually encountered. Buffer stock also shows unaccountably high scatter, indicating small regard for delivery date promises.

Reasons for this situation appear to be associated with control systems weakness. Certainly the high incidence of early deliveries, which, according to the company are not normally paid for until the agreed delivery date, seem to be largely due to operatives selecting 'desired' jobs at the expense of 'less desired' ones. No information regarding customer opinion of the situation was available.

*There is no statistical significance attached to this presentation, in fact, the figures suggest non-normal data distribution. But a convenient means of appraisal is provided by such forms of expression.

Table 6.1. Details of the waiting time of castings manufactured during September and October 1976.

Casting Section	Statistics	Buffer stock (rough castings awaiting machining) waiting time - days	Waiting time in despatch - days
Heavy	Mean	9.72	5.86
	Standard deviation	11.45	6.90
Bushmaster	Mean	12.51	6.10
	Standard deviation	13.40	8.73
Non-standard	Mean	7.81	5.62
	Standard deviation	7.00	6.15

In contrast to Spunalloys, Bridge Foundry appears to suffer from a customer inability to accurately forecast future requirements. They spend much of their time trying to accommodate late modifications to request schedules. Again, only the trends revealed by the investigation are given here.

The large amount of data generated during the prescribed twelve months period, even for such a small sample, makes simple pictorial representation difficult. But realising that some attempt in this direction should be made, four jobs were chosen as representative of large, medium and small customers. Graphs 6.3, 6.4, 6.5 and 6.6 were prepared and show graphs superimposed on histograms. Scrutiny of these charts and the details shown in Appendix II, Section 1, give rise to the following views:-

(1) Forward planning by the customer of future castings' requirements rarely show the expected gradual trend in prospective production due to market movements in a dynamic economy. Instead, requirements frequently show wild fluctuations, perhaps indicating the use of short-term crisis measures to counter inadequate long term planning.

(2) It logically follows that little of the information shown on customer schedules can be confidently used by the foundry to plan production. Even the 'firm' orders have a high frequency of alteration.

(3) Delivery trends follow the arrears plot, but show a lag of one month. Also, the peaks of the delivery curve generally exceed those of arrears by a magnitude approximating to the delivery requirements for that month. This is perhaps not unexpected,

Graphs 6.3., 6.4., 6.5., and 6.6.
Histograms of requirement forcast variations on customer schedules and plots of arrears and delivery levels for consecutive months.

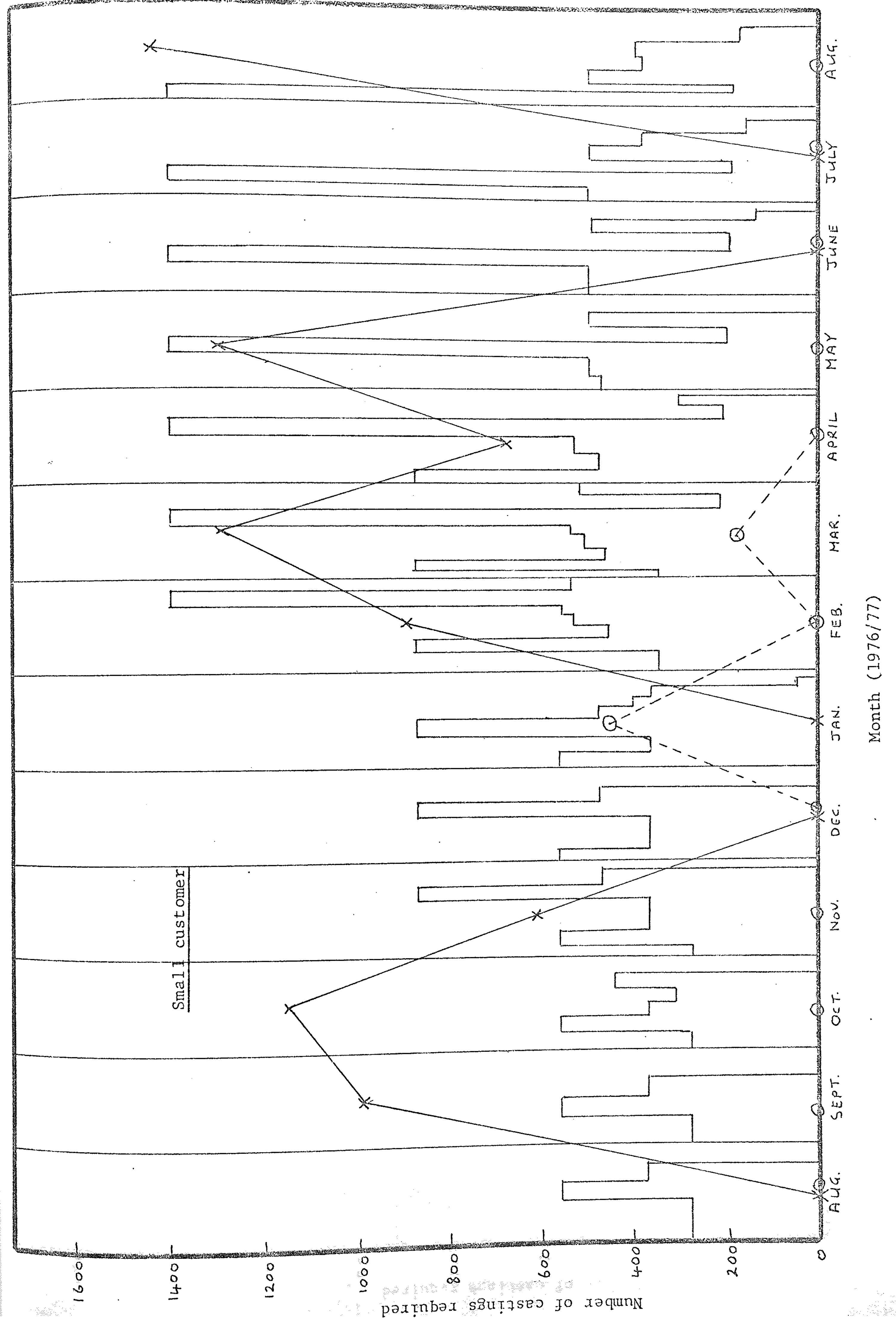
Key

The columns representing the various months show levels of customer predictions for that month. These prediction levels are given at monthly intervals and range from a forecast nine months previous to the month in question (indicated at the extreme left edge of each column), to a current requirement (indicated at the right edge). The appropriate figures for these charts are detailed in the first four tables of that part of Appendix II Section 1 concerned with the Bridge Foundry order schedules.

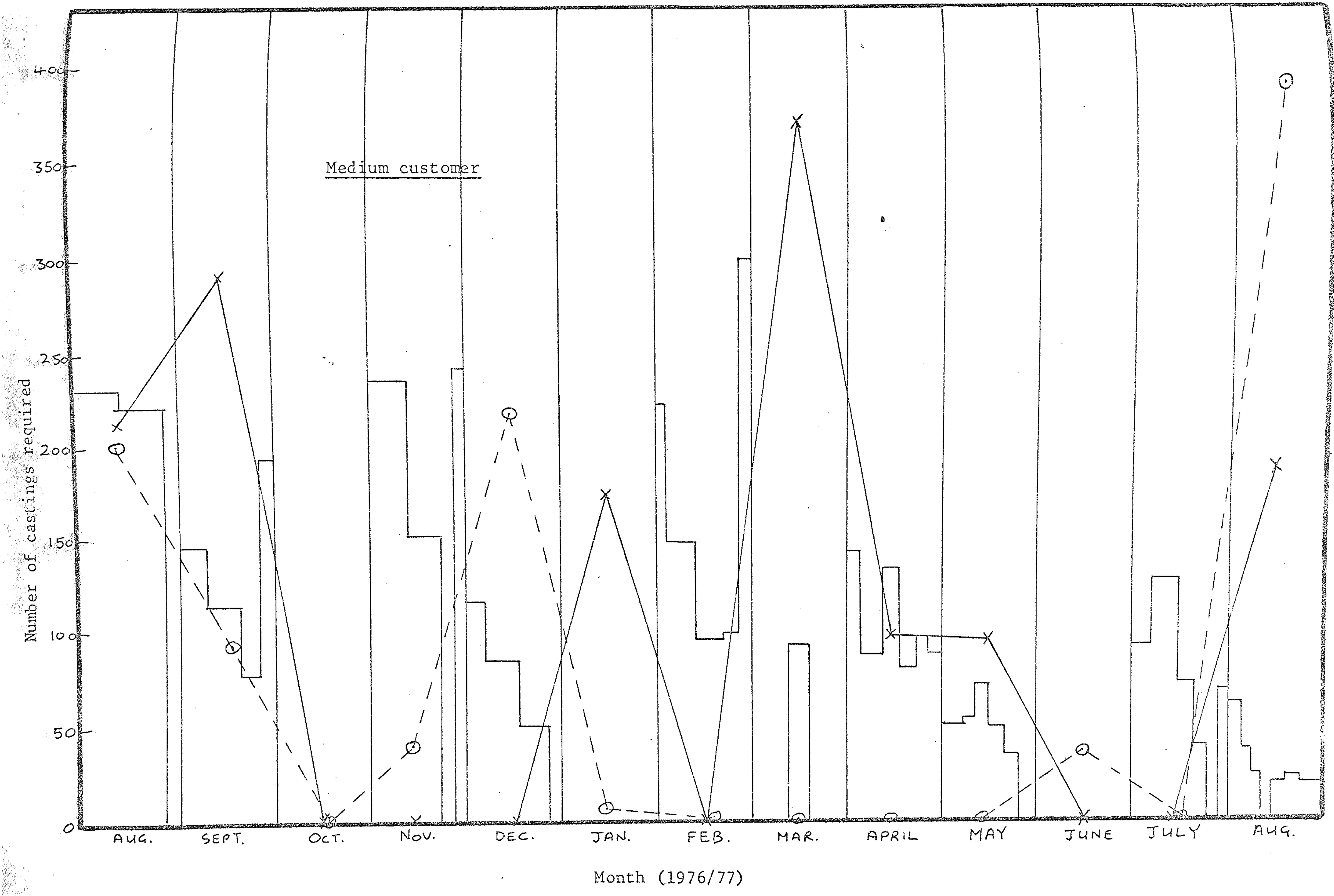
The superimposed plots indicate the following:-

— — — — —arrears figures shown on each monthly schedule received from the customer

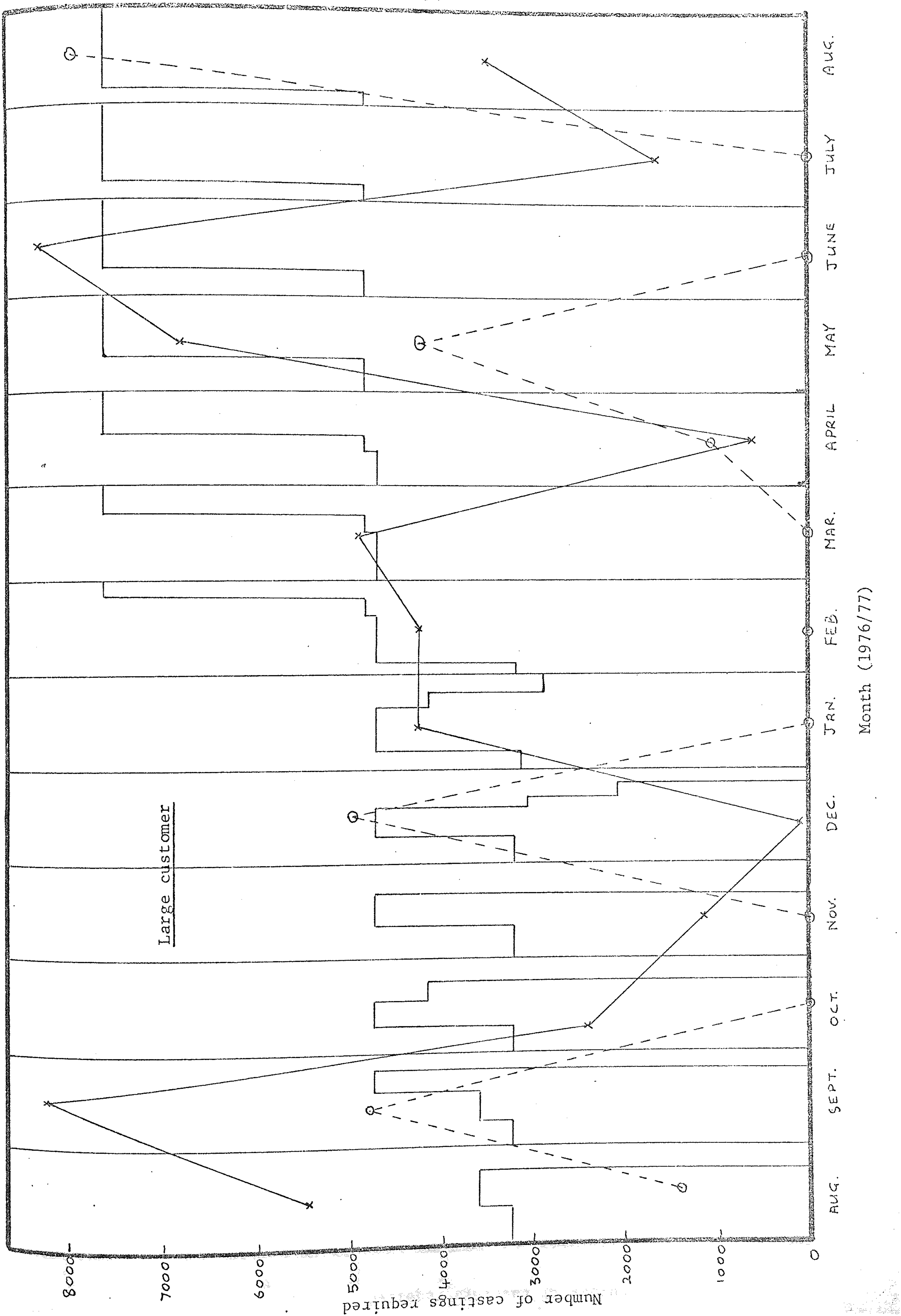
__________deliveries made during the current month.

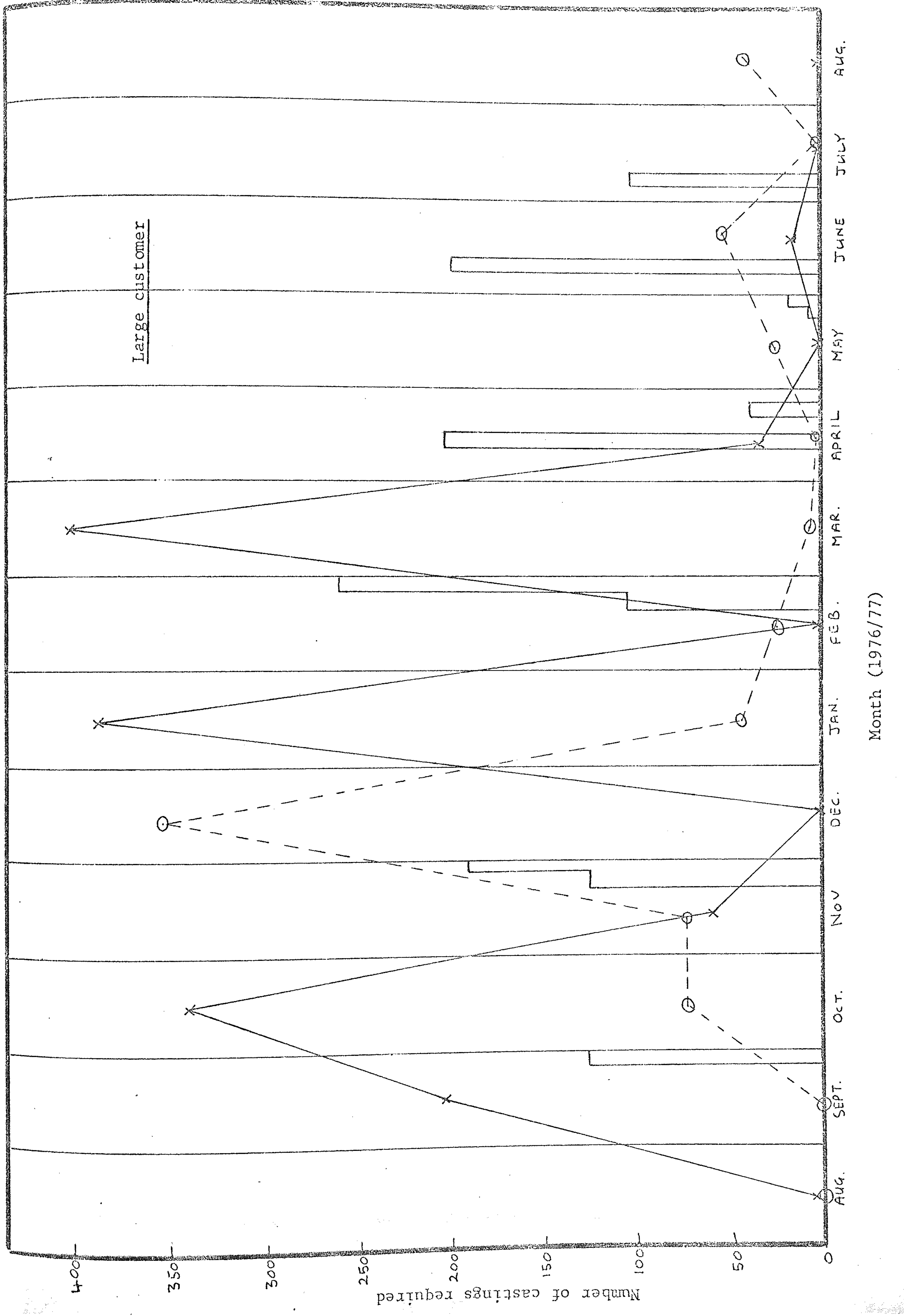


Small customer
Number of castings required
0
200
400
600
800
1000
1200
1400
1600
Month (1976/77)
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APRIL
MAY
JUNE
JULY
AUG.



Medium customer
Number of castings required
0
50
100
150
200
250
300
350
400
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APRIL
MAY
JUNE
JULY
AUG.
Month (1976/77)


Large customer
Number of castings required
0
1000
2000
3000
4000
5000
6000
7000
8000
Month (1976/77)
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APRIL
MAY
JUNE
JULY
AUG.


Large customer
AUG.
SEPT.
OCT.
NOV
DEC.
JAN.
FEB.
MAR.
APRIL
MAY
JUNE
JULY
AUG.
Month (1976/77)
0
50
100
150
200
250
300
350
400
Number of castings required

since the foundry will endeavour to satisfy customer wishes.

These points were endorsed by the production control personnel at Bridge Foundry and the comment was made that much of the planning for the following week's production is via telephone conversations with customers a few days before the foundry schedule is drawn up.

6.1.2 Output Variability

Apart from the influence of market trends (governs the onset of short time working), product mix (determines light/heavy castings ratio), absenteeism or plant breakdown, output tonnage can be considered as a reflection of scheduling and production control competence.

At Spunalloys, tonnage will be reduced if a high incidence of 'wash' heats are necessary to overcome contamination, or if on numerous occasions, furnaces cannot be emptied immediately the metal is ready because of a lack of die availability. A similar situation can apply in the machine shop if substantial time is wasted having to clean down machines; again to avoid contamination.

Bridge Foundry, on the other hand, will show reduced tonnage if a production bottleneck is created at one or other of the dressing shop sections. Queues of castings form as a result of load imbalance. This will be promoted by an incorrect product mix which fails to maintain an even spread of work throughout the dressing shop.

It was therefore considered pertinent to analyse and compare the output figures for the two companies during the previous two years. The figures in total are shown in Appendix II, Section 2 and only the implications stemming from them are detailed here. Table 6.2 shows output variabilities as statistically compiled mean values and standard deviations.*

Production variability is much higher at Spunalloys than at Bridge Foundry, particularly when the effects of short time working at Bridge Foundry are taken into account; no short time working took place at Spunalloys during this period. Although part of the Spunalloys scatter (standard deviation values), together with the lower mean value for 1976 can be offset against the disruption to smooth working caused by the installation and changeover to predominantly electric melting facilities during this period, appreciable variability still remains. This is supplemented by the 1975 totals, where production was not hindered by the work of contractors and by the figures quoted for the machine shop.

Obviously, production control limitations are the basic cause, a point further endorsed when an attempt is made to construct a relationship between tonnage output and numbers of castings output. It is logical to assert that during periods of high demand emphasis would

*No advantage is forthcoming from significance testing these compiled statistics. Contrast between successive time periods would provide little further information and it is quite obvious that the Bridge Foundry and Spunalloys figures have been drawn from different populations.

Table 6.2. Output statistics.

Output from Spunalloys.

	Foundry		Machine shop	
	Mean	Standard deviation	Mean	Standard deviation
1975				
Tonnes	34.9	5.6	32.2	4.9
No. of castings	342	95		
1976				
Tonnes	25.6	8.9	27.7	5.5
No. of castings	222	51		

Note.

Machine shop figures have been increased by three times to make comparable with foundry figures (2/3 of metal removed during machining).

Output from Bridge Foundry.

Year	Period	Mean - tonnes	Standard deviation - tonnes
1975	1	61.04	4.27
	2	43.50	1.12
	3	54.85	2.45
	4	41.26	1.83
1976	1	38.22	2.46
	2	52.55	2.96
	3	50.74	2.75
	4	59.74	4.15

Note.

Short time working operated during periods 2 and 4, 1975, and during period 1, 1976.

move toward the production of heavy castings (order selection) where profit margin is highest giving output limitations in the form of metal melting capacity. Alternatively when demand is low, the trend should move back toward the production of mainly small castings (all orders accepted) and, therefore, die/spinning machine limitations on capacity.

Hence, a relationship of the form shown in Fig. 6.1A would be expected, rather than that of Fig. 6.1B, which is more reflective of the actual results (Graph 6.7 and Graph 6.8). The company was unable to offer a satisfactory explanation for these trends, except to note that furnace and heavy section capacities impose constraint on the proportion of large castings made.

Bridge Foundry figures reveal extremely even working in comparison with Spunalloys, and, therefore, cannot be used to highlight work mix limitations. But it can be inferred that having less variety in product range, batch/long run producers can more readily achieve manufacturing consistency than can jobbing/batch producers.

6.1.3 Stock Control

Spunalloys exercise stock control through monthly stock taking when ingot and swarf stocks, together with rough castings' stock, is estimated by eye.

Published stock figures for a twelve month period are shown in Appendix II, Section 3. Graph 6.9, based on these figures, shows the high degree of variability associated with ingot stocks, which, if

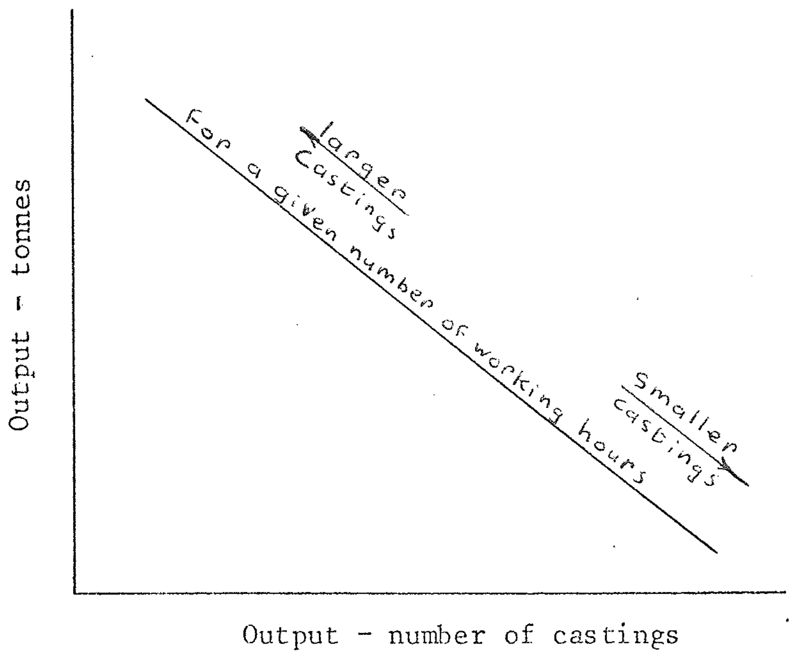


Fig. 6.1A. Theoretical relationship between output in terms of tonnage and output in terms of number of castings made from the foundry at Spunalloys.

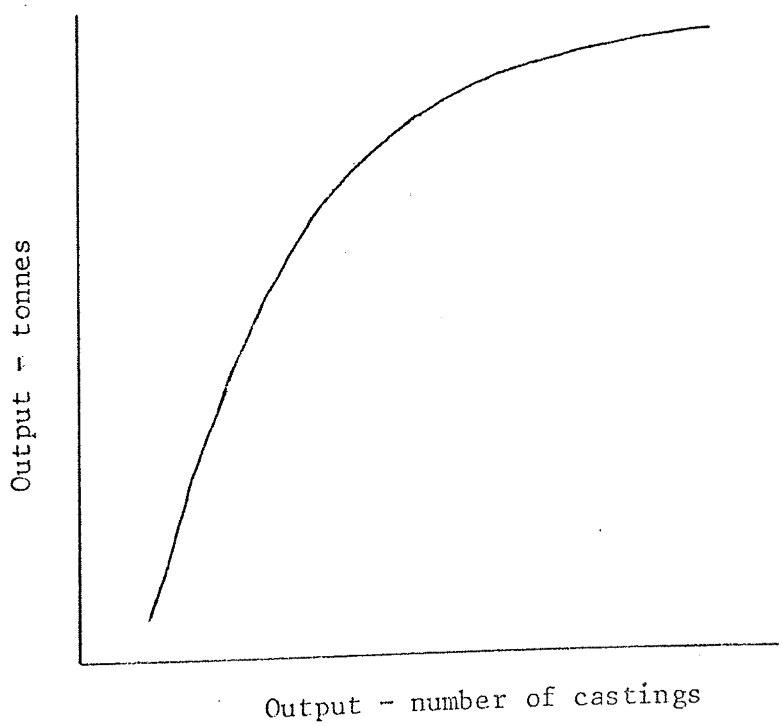
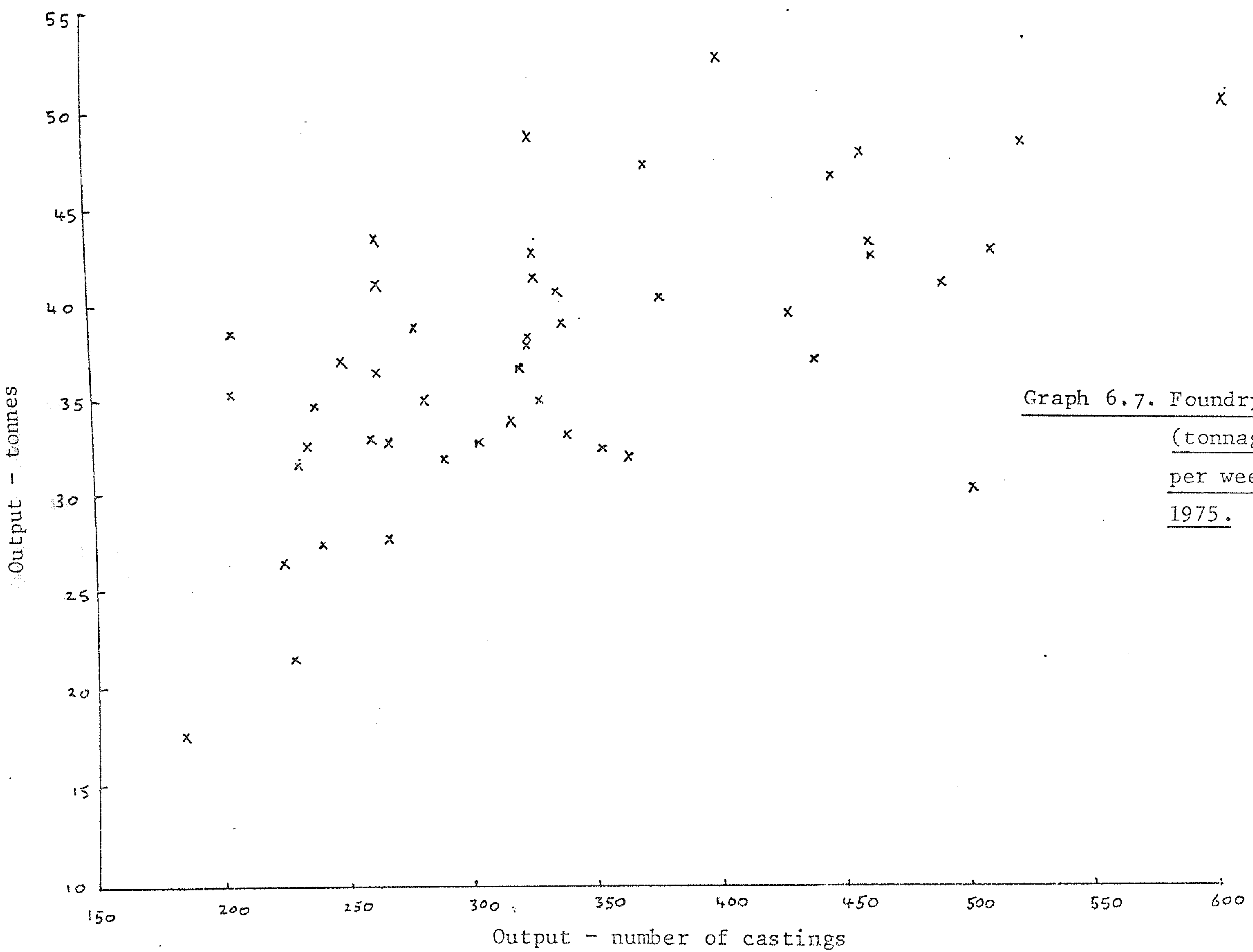
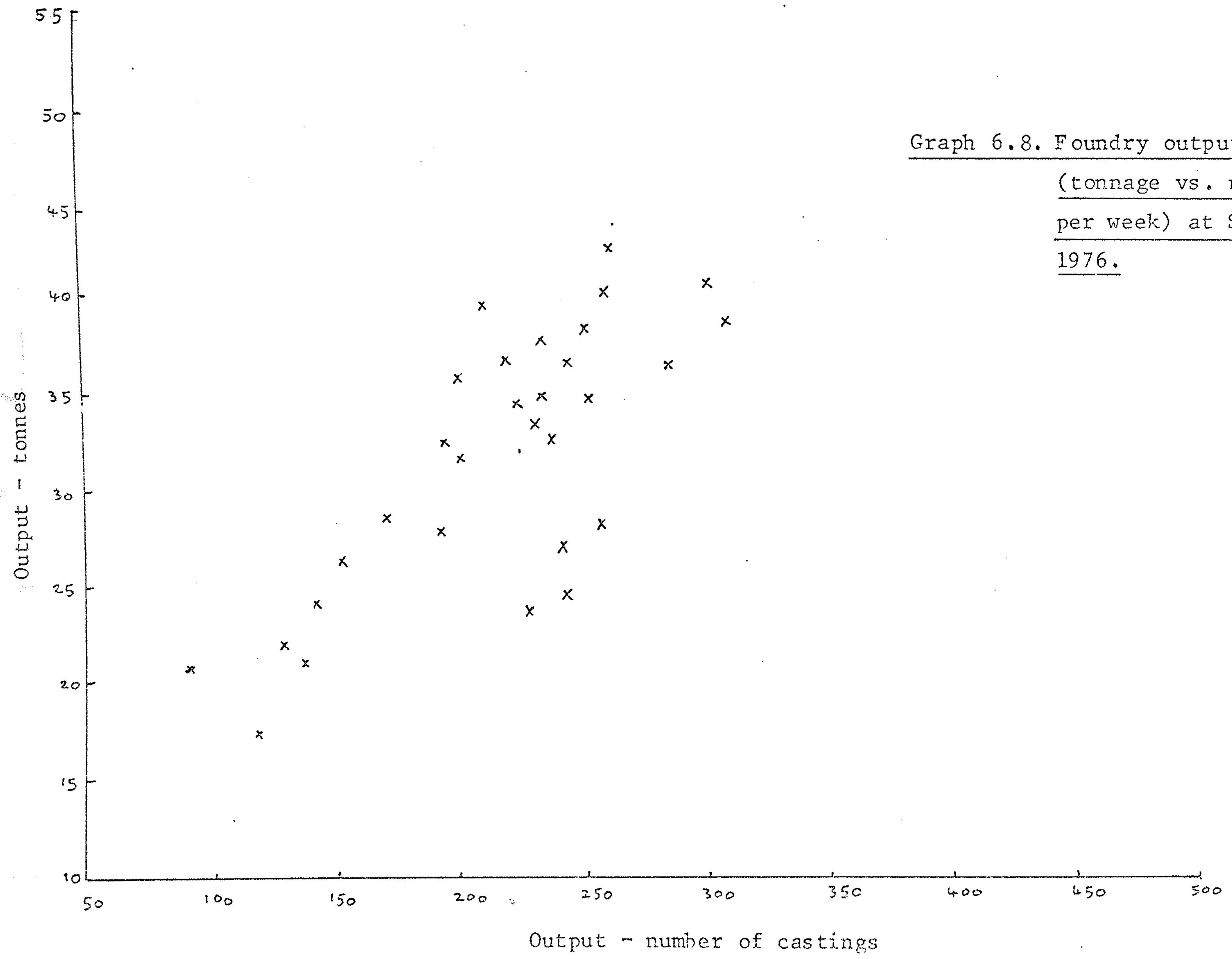


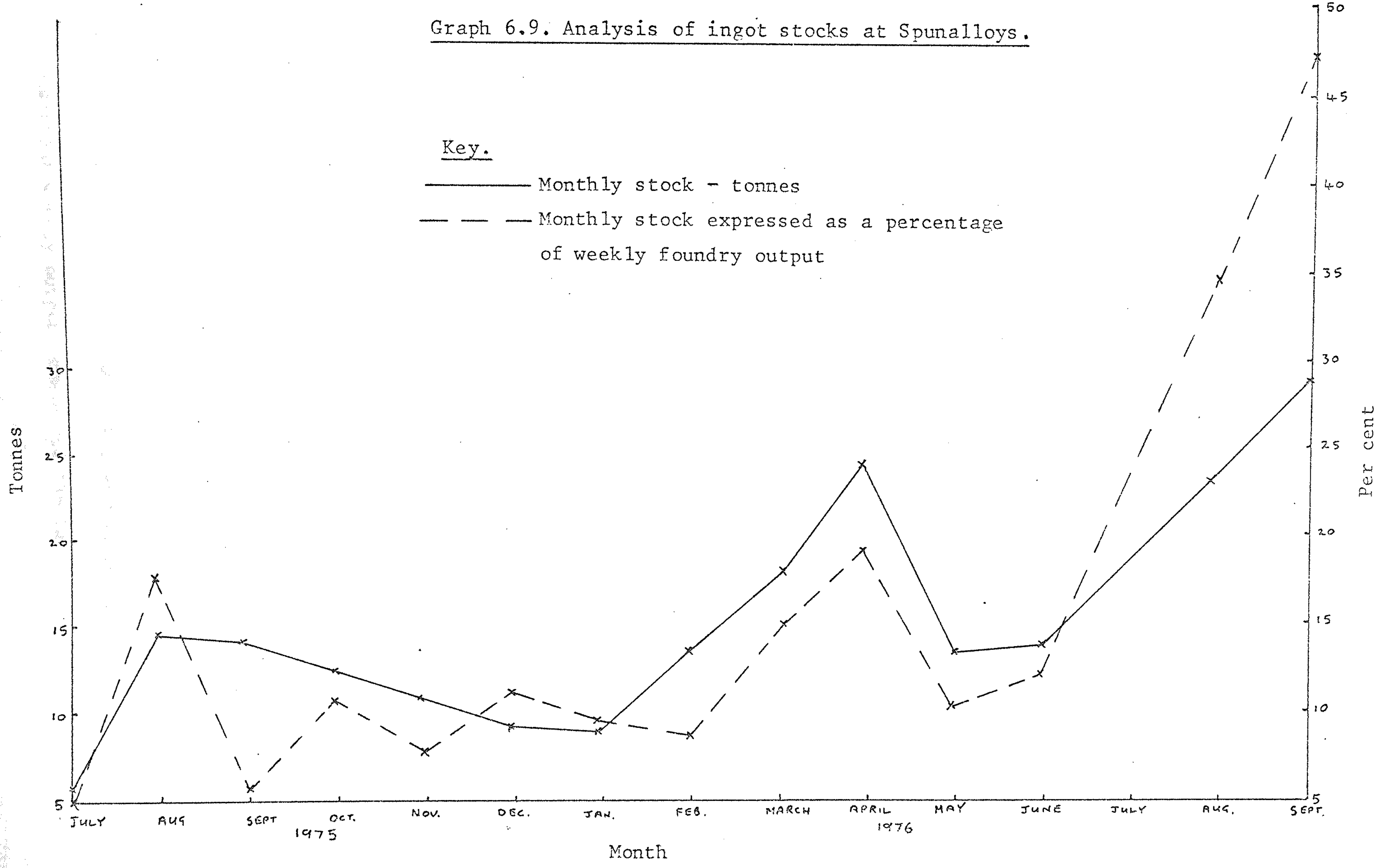
Fig. 6.1B. Real relationship between output in terms of tonnage and output in terms of number of castings made from the foundry at Spunalloys.



Graph 6.7. Foundry output relationship (tonnage vs. number of castings per week) at Spunalloys during 1975.



Graph 6.8. Foundry output relationship (tonnage vs. number of castings per week) at Spunalloys during 1976.



Graph 6.9. Analysis of ingot stocks at Spunalloys.

anything, is greater when expressed as a percentage of output.

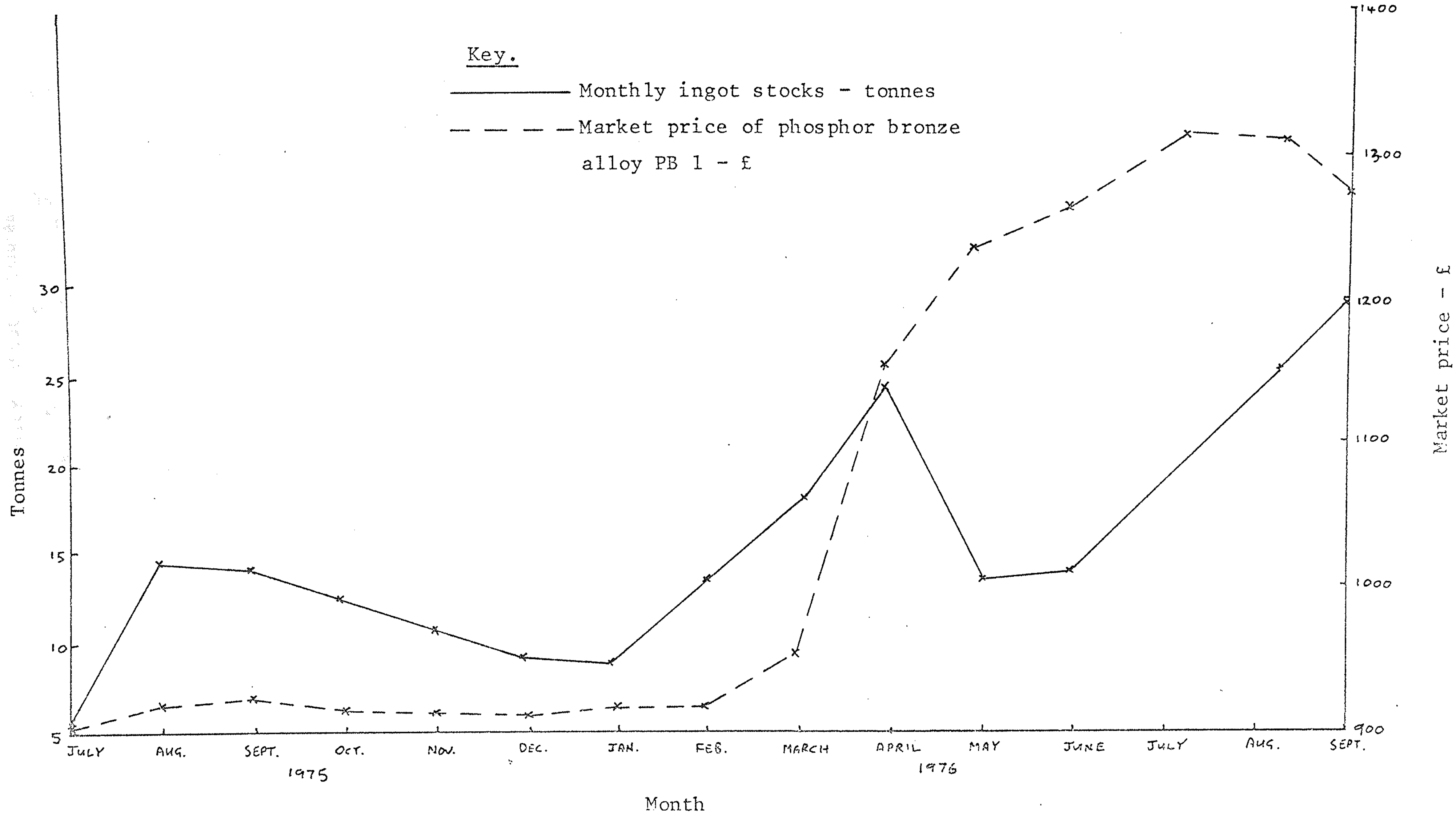
Stock control should obviously aim to minimize stocks co-incident with the prevention of a 'stock-out' position, particularly in view of the high price of copper base alloys. However, it is financially prudent to stock up during periods when notoriously oscillating copper prices are low, and to allow these to dwindle as prices increase. Price variations during 1975, for tin bronze, the most popular of the Spunalloys metals, are quoted in Appendix II, Section 3, and a plot of this relationship is superimposed on the ingot stocks tonnage plot for the same material over the same time span in Graph 6.10.

A favourable relationship is revealed, which is endorsed by comments from the company who admit that a stocking policy of the type described is actively pursued.

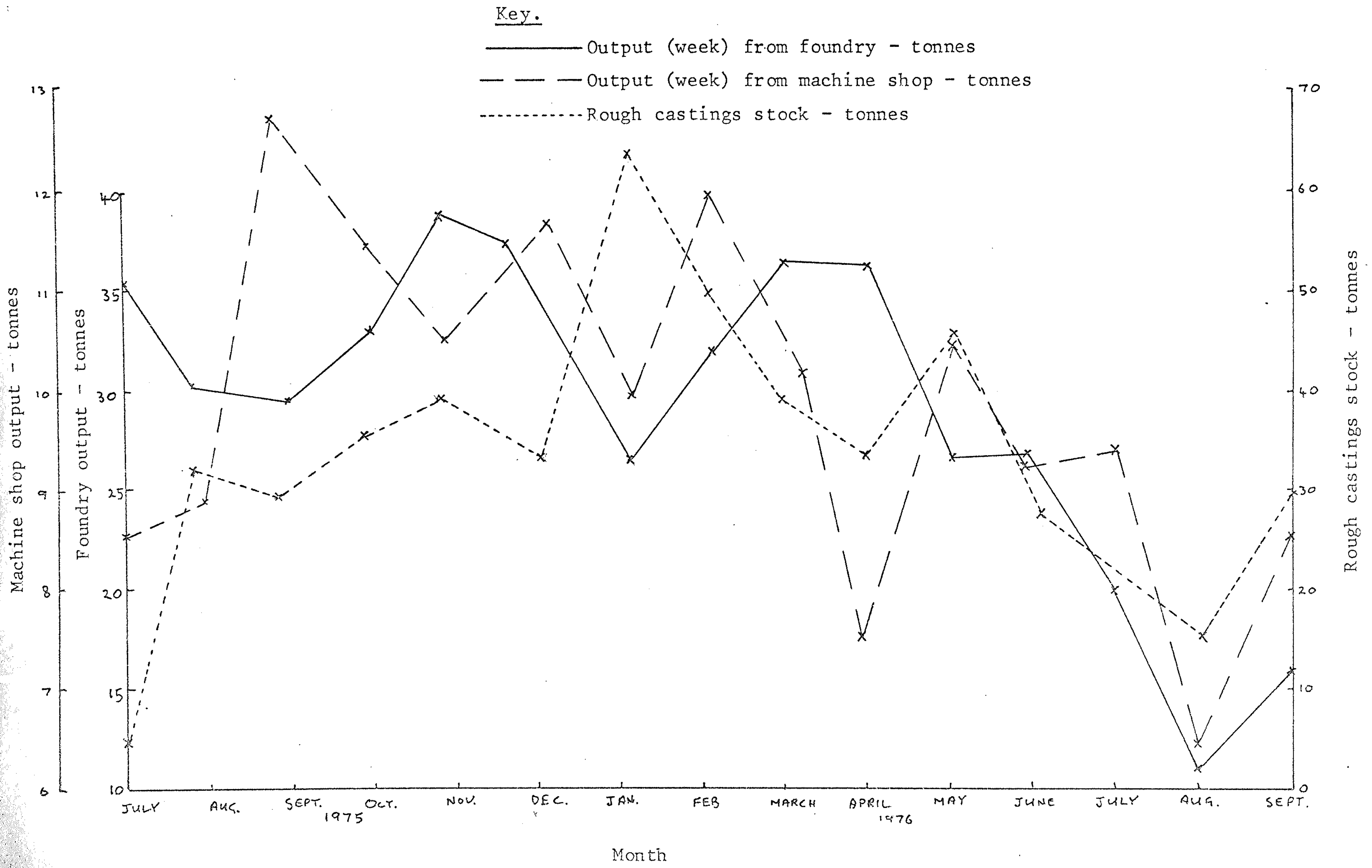
Graph 6.11 endeavours to establish a relationship between the level of production and the level of rough castings awaiting machining. Although weekly tonnage levels from both foundry and machine shop indicate vaguely similar fluctuation , this work in process shows a minimum level when machine shop output is high. The company confirmed that due to capacity limitations, there is a natural tendency for rough casting stocks to gradually build up at a rate dependent upon degree of foundry activity and work mix and that from time to time the machine shop is put on an overtime basis to reduced these stocks; also this is supplemented by the use of outside contractors.

Stock information offered by Bridge Foundry was scant, but consistent weekly output levels and the fact that 25 per cent

Graph 6.10. Analysis of metal purchasing policy at Spunalloys.



Graph 6.11. Analysis of rough castings stock at Spunalloys.



of liquid metal used is purchased outside and shipped daily to the factory by tanker, allows ingot stocks to be minimized. Although a policy of stocking up when prices are low is followed, the prices of aluminium alloys do not fluctuate to the same extent as copper alloy prices and in any event, metal costs do not play such a significant role in total cost make-up as they do with Spunalloys' products.

Bridge Foundry agreed that this is not a problem area, and, therefore, does not warrant deep analysis. Similar feelings were also expressed with regard to the stocking of finished castings. Again, this latter is of such rare occurrence that it can be discounted from futher investigation.

With respect to work in process, or more precisely, queue length variation at the various dressing shop work centres, it is impossible to accurately determine the level of castings awaiting dressing operations without physically counting the stillages containing these castings. This is due to the peculiarities of the recording and payment systems. Operatives paid a ceiling rate for a day's production often process more than the maximum number of castings allowed on some days and compensate with lower figures on subsequent days.

6.2 Analysis and Choice of Superior Control Techniques

At Spunalloys, due to the large variety of work handled, complexity makes production planning virtually impossible. This is reflected in the inaccuracy of delivery date prediction, inconsistent weekly output figures and largely uncontrolled stocks (particularly rough castings awaiting machining). Further, this lack of production control makes financial control or more precisely, accurate cost allocation, poor.

In contrast, Bridge Foundry find difficulty balancing work centre loadings in a flow type production set-up. Their position is aggravated by job mix uncertainties, primarily due to frequent late changes by customers to submitted schedules. Poor co-ordination of the various dressing shop sections, which results in job queues in front of some at the expense of insufficient work for others, is worsened by the lack of precise knowledge of work in process figures. This situation is also somewhat responsible for costing inabilities.

Obviously, these factors must influence the development of alternative control systems since they constitute the areas of weakness which require most urgent attention.

6.2.1 Requirements of Alternative Systems

Spunalloys need a job choice capability, which while maintaining a high level of customer satisfaction, optimizes production efficiency. Bridge Foundry also need improved means of assembling the job mix, but with the aim of achieving closer load balancing of work centres. Again customer satisfaction must take high priority.

In constructing suitable systems to achieve these objectives, it should be borne in mind that later, other control parameters will need to be built on. Spunalloys, for example, require a more efficient stocking policy. Such a policy should provide closer identity of true cost make-up and subsequently allow the introduction of Standard Costing and Budgetary Control. At Bridge Foundry, a means of accurately assessing and recording levels of work in process is needed. This should be helpful in improving the apportionment of overheads to the job mix.

6.2.2 Selection of Alternative Systems

Production processing at Spunalloys can be identified with the 'n job, m machine' job shop scheduling situation, in which there are parallel machines (any unit upon which an operation is performed) in the series built process. Although an n by m matrix of processing times (high to preclude selection where use of a machine is not permitted) can be constructed, when dynamic constraints such as furnace contamination and die availability are added, the problem becomes enormous. This situation, which will always exist as long as Spunalloys make to customer order rather than for 'shelf', not only precludes the use of an optimization technique but even makes the manipulation of a Gantt chart a formidable proposition. Hence, simulation modelling remains as a suitable means of improving this job sequencing exercise.

In contrast, Bridge Foundry, with its more narrow range of product and its area of concern largely confined to the load balancing of production centres, suggests a more rigorous approach, with the formulation of an optimal solution as the ultimate goal. The natural ordering of operations in the dressing shop identifies flow type processing with individual jobs visiting various, but not all, dressing shop sections.

The scheduling procedure involves choosing a job combination which will optimize loading of the dressing shop sections. Such a description could be identified as a 'knapsack' problem, for which the 'branch and bound' algorithm is a popular solution procedure. However, being multi-constrained, the problem is more suited to mathematical programming, although decisions of the either/or type (selection or rejection of a job) precludes the use of linear programming and the highly efficient Simplex solution code. Instead, the scheduling procedure must be treated as a 0-1 integer programming problem.

6.3 Programme Construction

Both the simulation model for Spunalloys and the mathematical model for Bridge Foundry will be sufficiently rigorous to require the aid of computing facilities. This will necessitate the construction of suitable programmes, in respect of which the two models are in complete contrast. The simulation model describes events and the times associated with these events during some prescribed period, and the mathematical model chooses a limited number of candidates from some extended range. Hence, simulation requires the identification of decision areas, plus the factors associated with these decisions, whereas mathematical modelling requires the construction of an objective function together with its controlling constraints.

The obvious architecture of the Spunalloys programme must be the processing of the order book through the foundry and machine shop, with observation of job selection, output achieved and stock variation. This should allow comparison between the results from the model and those achieved in practice. In contrast, the Bridge Foundry programme must choose a job combination which optimizes dressing shop facilities.

Again, by running weekly schedules, results from the programmes can be compared with the choice of jobs actually made.

Because of the wide contrast between the two models, programme construction will inevitably necessitate separate consideration. However, prior to this, process detail pertinent to programme construction, ought to be identified.

It is incidental to note that for reasons discussed in Part 1, it is felt that none of the available production control packages would be of any great value to either the Spunalloys or Bridge Foundry investigations. Decision making is sufficiently individualistic to necessitate the use of tailor-made programmes, although it is recognised that certain aspects of commercial packages might be of value at some later date.

6.3.1 Spunalloys Production Details

Job sequencing should aim at optimization of customer satisfaction and efficient use of facilities. With this in mind, therefore, jobs are chosen in order of priority, bearing in mind production constraints such as die availability and furnace suitability (size and contamination). In respect of the latter, endeavour is made to process jobs such that natural follow-on in the various furnaces can be maintained with a minimum of cleaning out between heats. Likewise, choice of jobs for themachine shop from the rough castings' stock, is based on priority ruling within the confines of size limits allowed by the various machines. Molten metal requirement and the metal to be removed by machining are calculated after the selection of a suitable die. This choice depends on proof machining requirements and order size (number off). Determination of molten metal must also include metal loss factors, which vary from alloy to alloy.

Melting and solidification times depend upon such factors as type of alloy, weight of metal, type of furnace and casting machine (Bushmaster castings are water cooled). Similarly, metal cutting times depend upon alloy type, amount to be removed and machine identity.

No allowance is made in the programme for absenteeism or plant breakdown. But while the former can become a major factor due to the labour intensive nature of the work, the latter should be small indeed if the very limited maintenance of furnace linings, spinning machines and cutting lathes is regularly carried out. The company confirmed these observations.

6.3.2 The Simulation Model

The programmes are written in the high level language EXTENDED FORTRAN, primarily because appreciable programme length was anticipated, and because it is the language with which the author is most familiar. However, it is recognised that other language formats such as BASIC and SIMON are possible alternatives, which in some instances are more suited than straight FORTRAN to simulation work. Full programme statements are given in Appendix III, Section 1.

To facilitate testing of the simulation model an order generation routine has been included. Using random numbers (Monte Carlo routine), this programme is employed to feed the decision making programmes. The overall macro outline is shown in the flow chart, Fig. 6.2. This comprises a main programme which supervises the operation of the model and is responsible for the assessment and presentation of results. Several sub-programmes, which look after calculation and the various decision making routines, are subservient to it.

The sub-programmes carry out the following tasks:-

(1) Order generation - using random numbers the various requisite parameters are assigned to the individual orders. These parameters include proof machined casting particulars such as outside diameter, inside diameter, length, alloy identification and number off required.

(2) Calculation of production parameters - rough casting dimensions and die choice are determined for every order generated from which the number of rough castings required together with molten metal per casting can then be assessed.

(3) Furnace scheduling - this is the first of the decision making sub-routines which schedules orders to furnaces and casting machines and determines melting and solidification times. Raw materials such as virgin ingot, scrap castings and swarf are allocated for charge make-up in proportions which are alloy dependent and the respective stocks are appropriately depleted. If ingot stock is reduced below some minimum value, re-order is initiated; corresponding delivery is assumed to be one week away. All of these activities comply with actual practice. Finally, random numbers are again used to determine whether or not the resultant casting is scrap.

(4) Machine shop scheduling - another decision making sub-routine

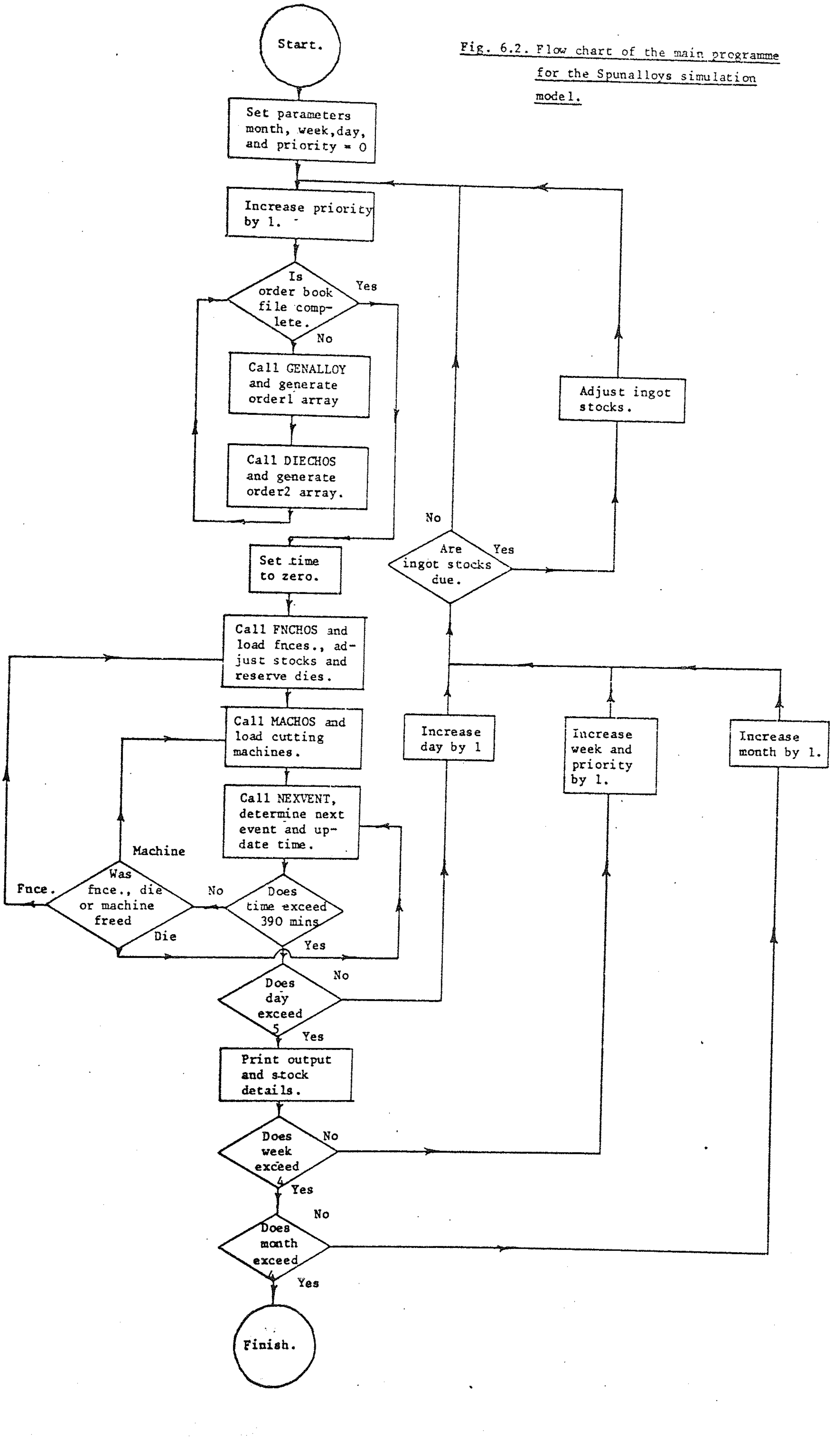


Fig. 6.2. Flow chart of the main programme for the Spunalloys simulation model.

which allocates rough castings from the work in process stock to cutting machines. Processing times are calculated in accordance with alloy, dimensions and cutting machine chosen.

(5) Determination of next event - this sub-routine is a time based procedure which up-dates by looking for the next occurrence. It decides when a furnace shall be tapped and poured, a solidified casting removed from its die and a proof machined casting sent to despatch.

The main programme initially generates the order book to a length governed by the desired lead time and calculates appropriate production parameters. This is achieved by alternately calling the first two sub-routines. Because 'impossible' orders are generated (up to 20 per cent), e.g. by inside diameters being unrealistic in comparison to outside diameters and rough casting weights exceeding crane lifting capacity, the process is repeated.

Next, the foundry is scheduled using the third sub-routine, hence when rough castings are available, the machine shop is allocated work according to the fourth sub-routine. Scheduling via updating by the fifth sub-routine as production units become available is continued in this manner until 6.5 hours have been simulated. At this point, scheduling ceases, and the remaining work time for that day, in accordance with practice, is used to complete unfinished operations in both foundry and machine shop, and to effect a clean-up.

A day is now complete, and this signals the return of the order generation and production details programmes to replace any completed orders. By adding new orders in this way, on a daily basis, it is hoped that actual practice will again be simulated. The stock array parameter is also scanned to determine whether or not any stock deliveries are due.

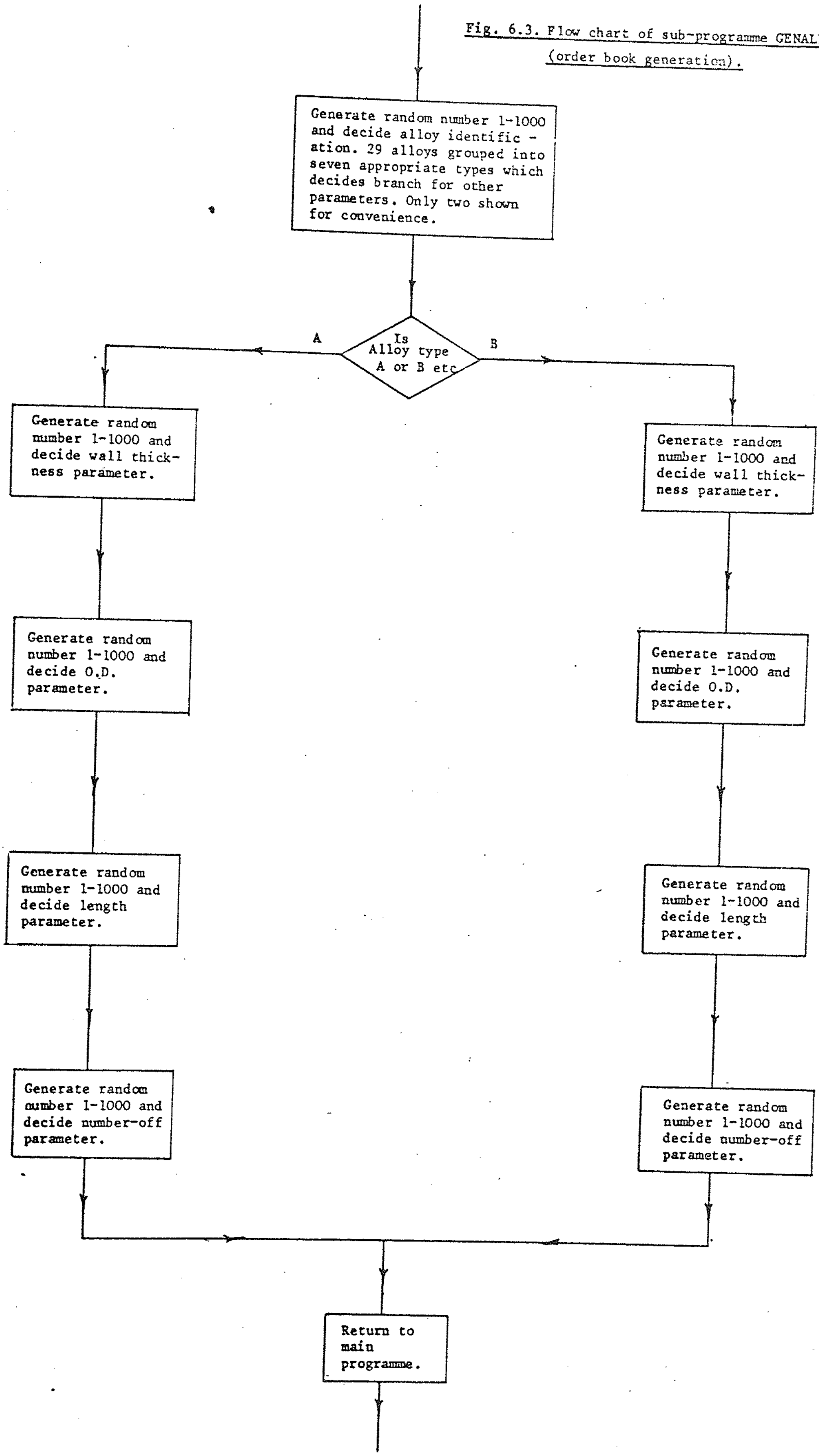
On the completion of one week, or five production days, statistics of the weekly production are printed, together with all stock details. After simulating one month, details of work in process is indicated in accordance with actual practice.

6.3.3 Sub-Routine Details

Order generation is the first sub-routine based on the Monte-Carlo technique, the full details of which are given in Appendix III, Section 2. The flow chart for this routine, shown in Fig. 6.3, indicates that initial choice of alloy dictates the choice of casting dimensions and number off. The most popular metal cast at Spunalloys is leaded tin bronze, and this can be sub-divided into numerous alloys which differ according to minor element variation. Details of these alloy specifications plus the specification for all other of the twenty-nine copper-base alloys available at Spunalloys is given in Appendix III Section 3.

Although these minor element differences have significance in the melting programme and therefore need to be considered to avoid furnace contamination, they show very little influence on the proportional variation of dimensions. Hence, in the interests of reduced computation they are combined for the purposes of determining the remaining order parameters. This reduces the level of indentification at these stages to seven different materials. Because the processing of aluminium is

Fig. 6.3. Flow chart of sub-programme GENALLOY (order book generation).



confined to an independent section of the factory, and because the production of ferrous castings is still in a pilot stage, these alternative alloys are not included in the simulation.

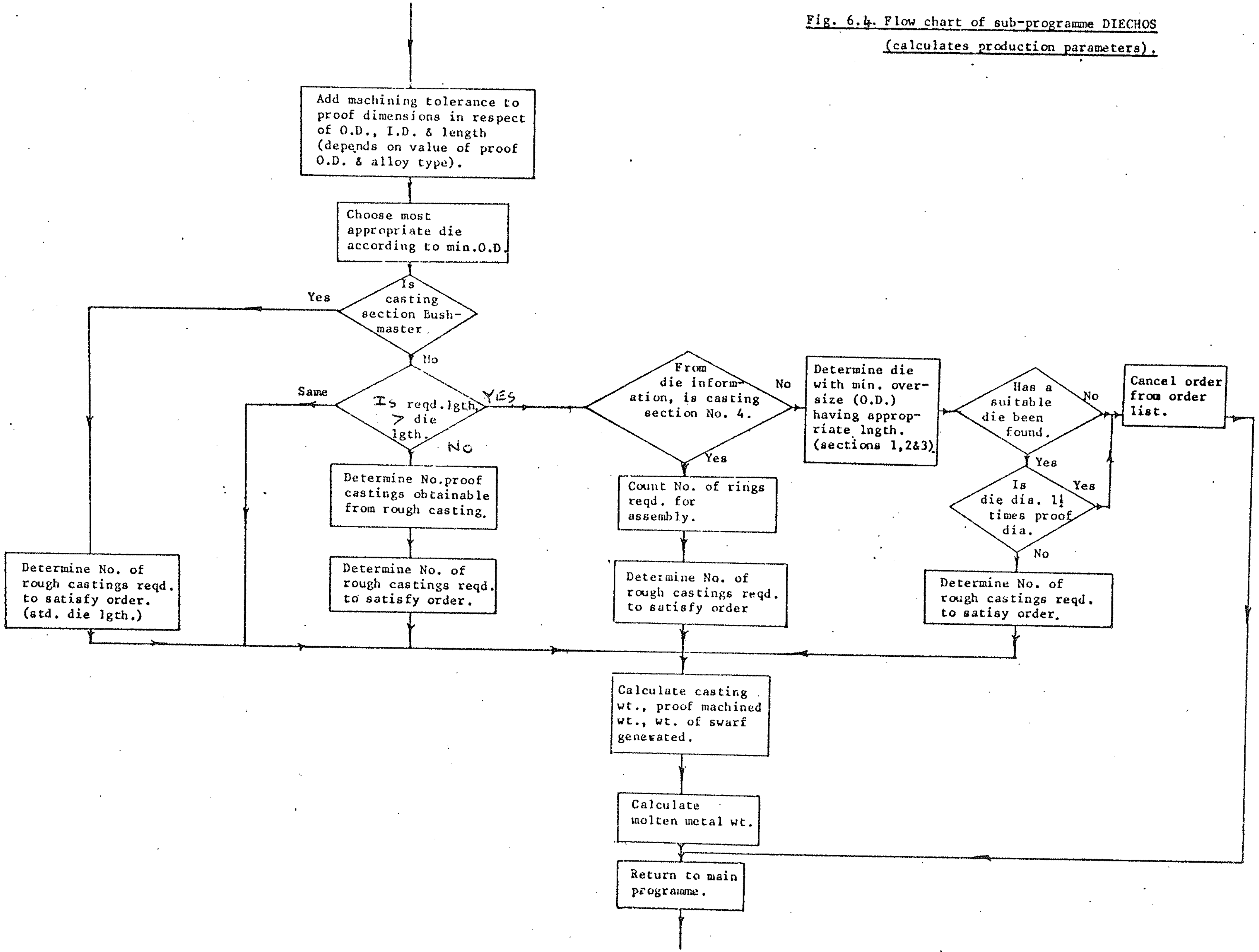
The cumulative frequency charts necessary to operate the Monte Carlo technique were produced from an analysis of the final three months of the current order book. Full details of this analysis are shown in Appendix III, Section 4.

The second sub-routine, in simply calculating some necessary production parameters for each and every order generated, is completely straightforward and needs no further comment except to show the appropriate flow chart in Fig. 6.4.

Foundry scheduling is the heart of the model and as shown in Fig. 6.5A and 6.5B, this sub-programme attempts to sequence jobs in order of priority while at the same time minimizing the furnace contamination problem. This is achieved by searching the order array for jobs in the sequence defining contamination, as shown in Appendix III, Section 3.

A subtle balance is attempted between job priority and avoidance of contamination delays by specifying a crucial level of priority. If an order exceeds this level it is scheduled even if contamination delays have first to be dealt with, otherwise such disruptions to production are avoided. Furnace scheduling also recognises the additional constraints imposed by die availability and furnace capacity.

Fig. 6.4. Flow chart of sub-programme DIECHOS (calculates production parameters).



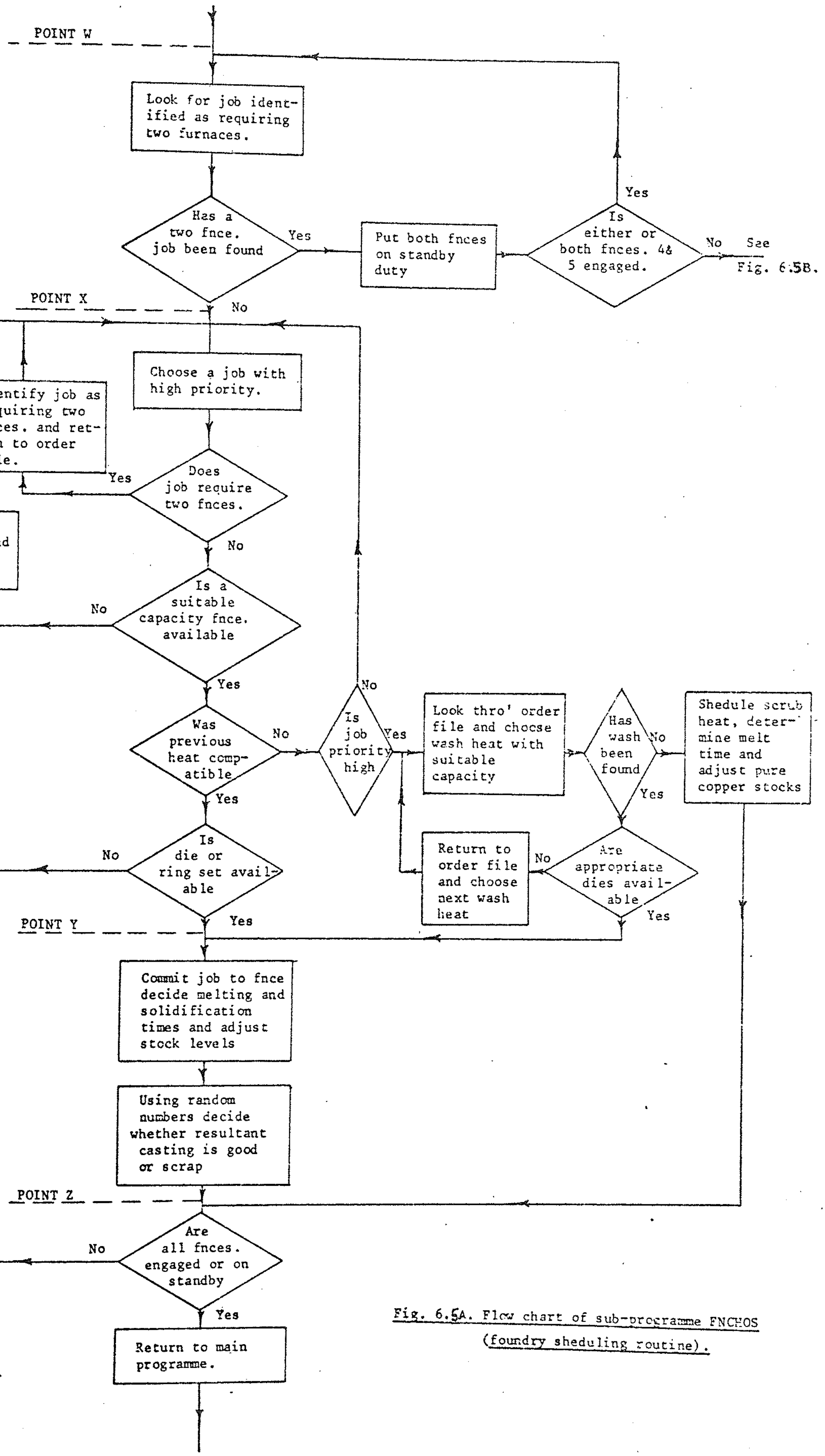
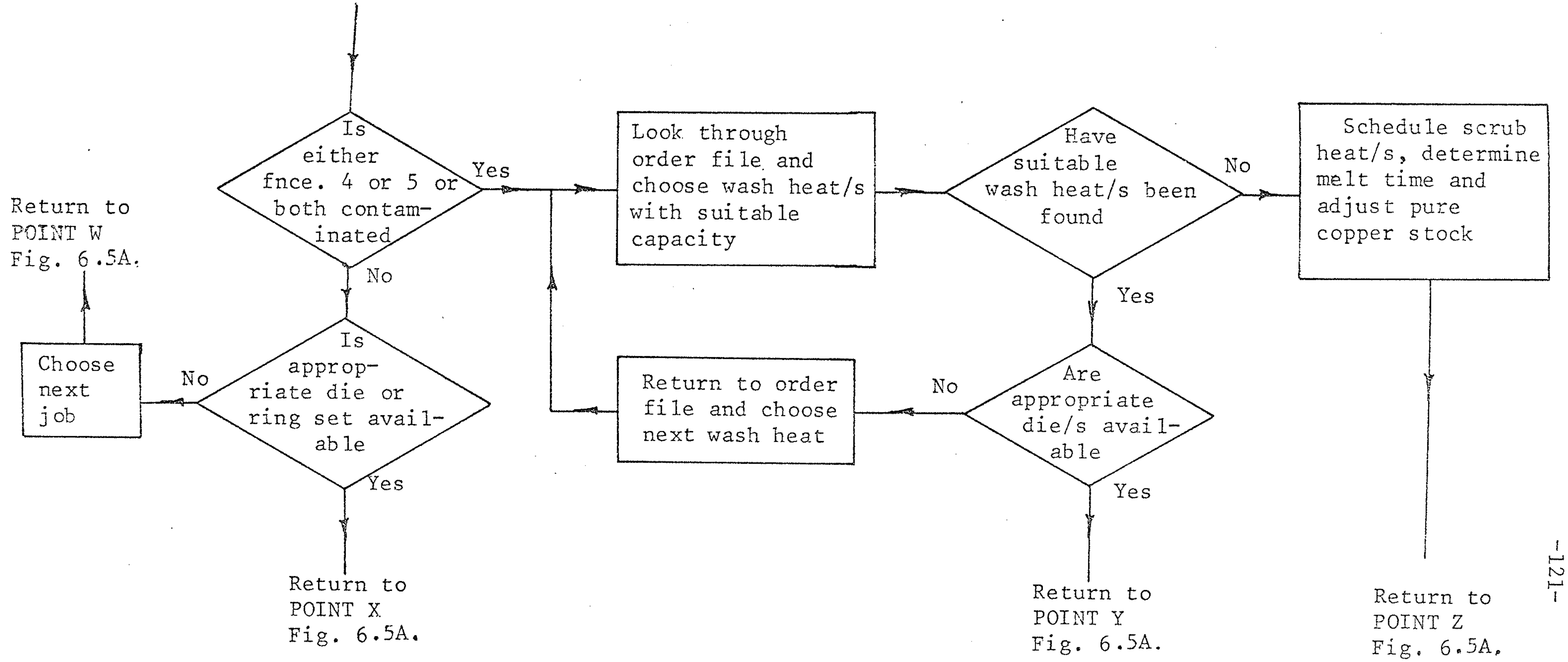


Fig. 6.5A. Flow chart of sub-programme FNCHOS (foundry sheduling routine).



Note.
Provision has had to be made in the programme instructions at all stages of this section to treat furnaces 4 and 5 either seperately or together depending upon the situation at hand.

Fig. 6.5B. Flow chart of sub-programme FNCHOS (schedules heavy jobs requiring two furnaces).

Where contamination is unavoidable, two courses of action may be pursued. These are as follows:-

(1) the nickel rich copper alloy, which can follow all other alloys and can also be followed by all other alloys without creating contamination, can be used to 'wash out' the furnace. This is the most favoured remedy, since although low priority jobs often get chosen, commercially saleable castings are being made.

(2) Where a suitable 'wash' heat cannot be located in the order book, a 'scrub' heat is scheduled. This simply involves melting a small quantity of pure copper in the appropriate furnace, which then becomes the equivalent of a scrap casting for use in the charge make-up of a high nickel copper alloy.

This procedure again follows practice although it is felt that the use of 'scrub' heats might be totally avoided if a 'shelf' stock of high nickel copper alloys could be carried by the company.

Certain castings exceed 750 kg in weight, which means that two furnaces are needed to supply the requisite molten metal. This is provided for in the programme by designating one of the 500 kg capacity furnaces to work with the 750 kg unit. When an order requiring two furnaces is located, then whichever of the two designated furnaces becomes available first, it is forced to wait until the other is freed.

Scheduling the machine shop through the fourth sub-programme is carried out in a similar manner to foundry scheduling. Job sequence is formulated according to order priority and within the confines of size acceptance by the various machines. Smaller machines are considered first in an effort to minimize the use of large machines for processing small castings. The appropriate flow chart is shown in Fig. 6.6.

The fifth sub-programme employs a digital minute clock simulation routine and searches all activities to determine the 'next event'. These include melting, pouring, solidification and metal cutting. The flow chart shown in Fig. 6.7 indicates how the time clock is operated.

It is incidental to note that in all instances the flow charts are unable to do full justice to the programming intricacies without making them unweildly to the extent that the key logic becomes difficult to follow.

6.3.4 Bridge Foundry Production Details

The production schedule for the following week is compiled on the Thursday of the preceeding week and the process itself can be split into two divisions. Approximately half of the requisite jobs cannot be involved in any choice. They are jobs having sufficient urgency and priority to warrant compulsory selection. About 60 jobs are therefore needed to complete the schedule, and this choice is usually made from roughly 70 jobs.

Of the selected jobs, approximately twenty per cent are changed mid-week, which means substitute jobs require nomination. Urgent jobs which are requested after the schedule has been drawn up also often utilise this facility.

The only flexibility available to reduce load imbalance of the

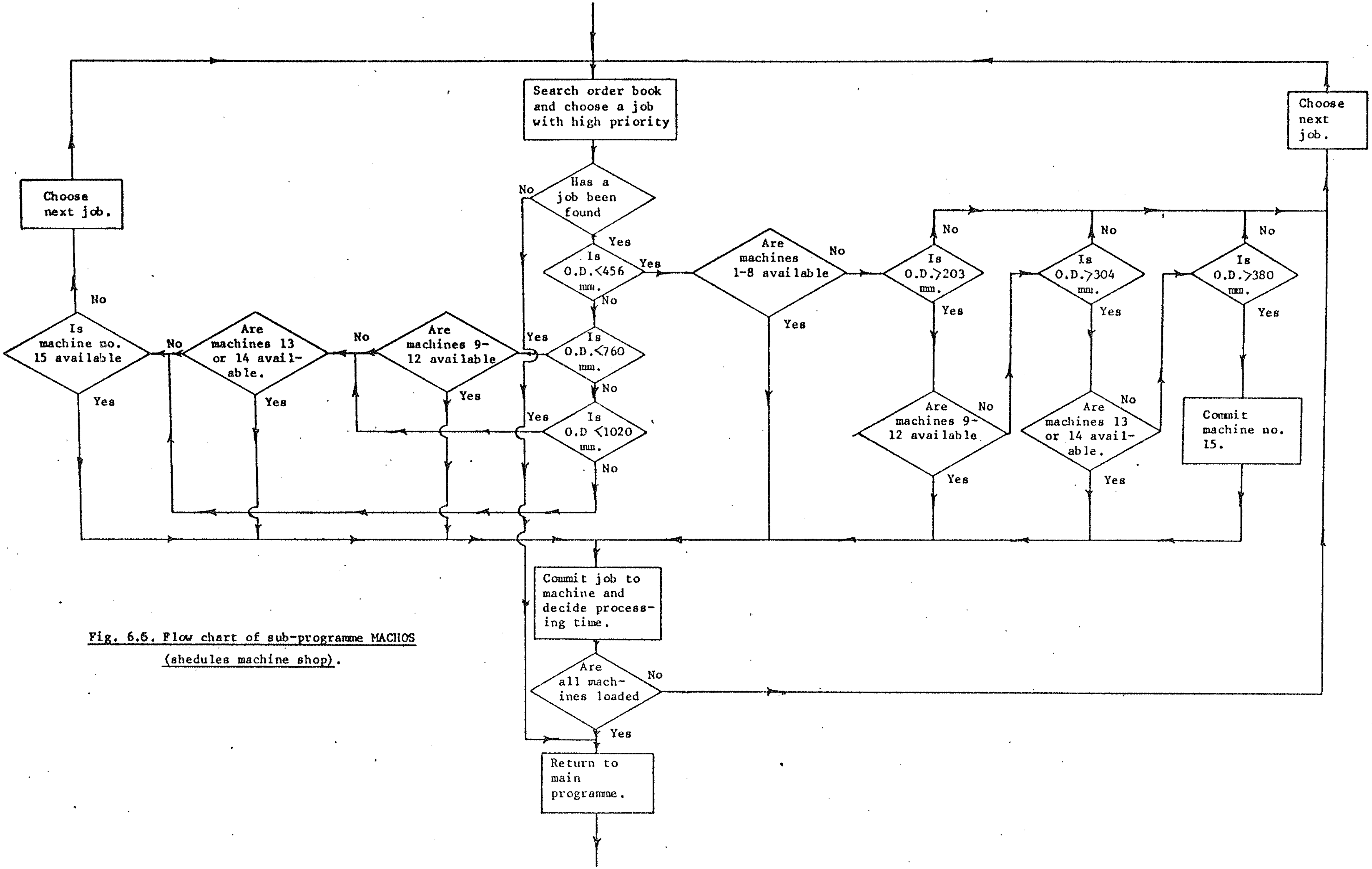
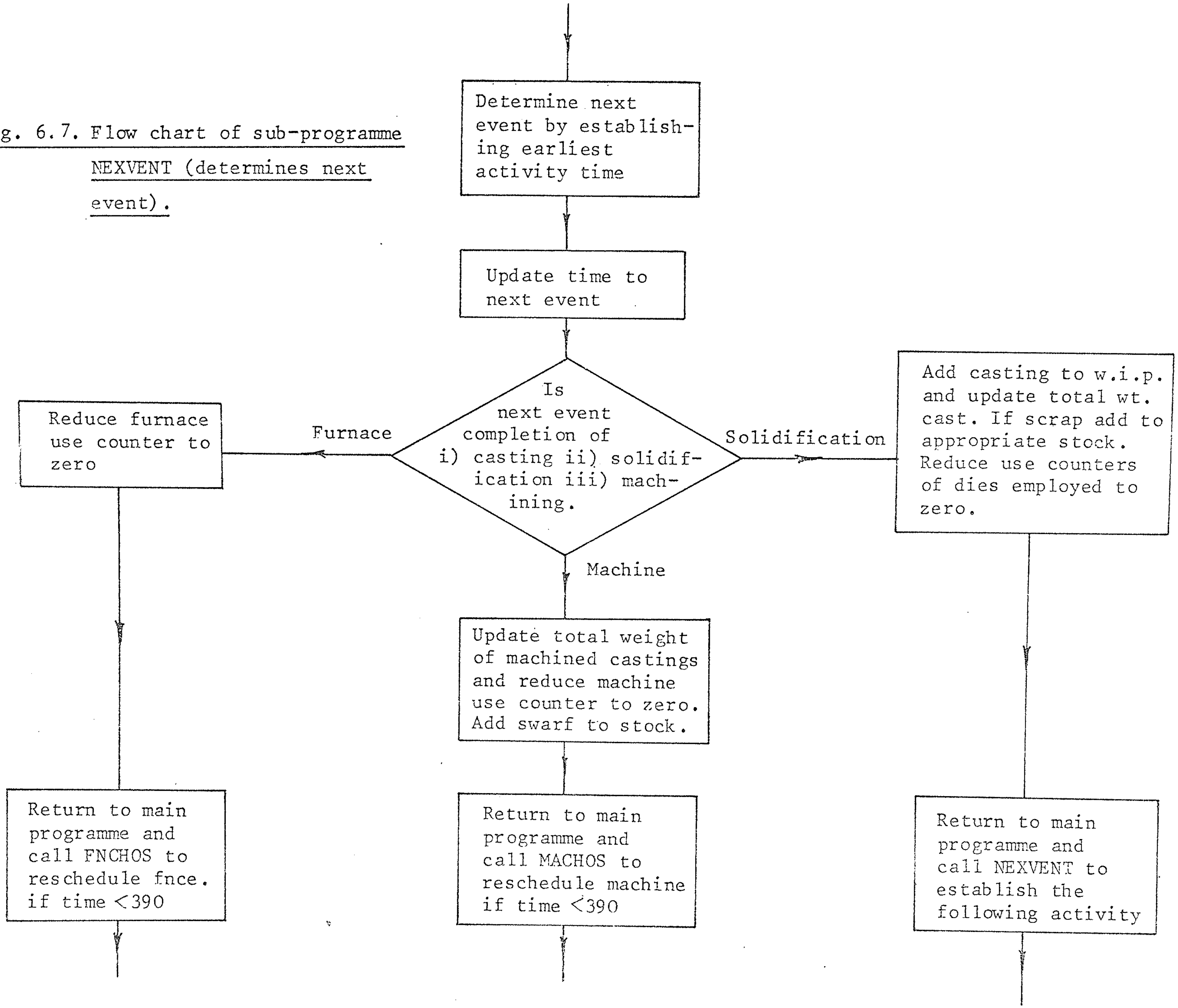


Fig. 6.6. Flow chart of sub-programme MACHOS (shedules machine shop).

Fig. 6.7. Flow chart of sub-programme NEXVENT (determines next event).



dressing shop sections is transfer of labour (restricted due to space limitations) and a ten per cent increase in capacity by the instigation of overtime working.

6.3.5 The Mathematical Optimization Routine

0-1 integer programming is classically written in the form: minimize cx subject to $b + Ax \geqslant 0$, $x_j = 0$ or 1, where c is an n-vector, b and 0 are m-vectors, A is an m by n matrix, and x is a binary n-vector to be chosen. This can be expanded to be shown in the following array form:-

minimize the objective function

$$A[0,1] \times x[1] + \ldots\ldots\ldots\ldots + A[0,n] \times x[n]$$

subject to the following constraints:

$$A[i,1] \times x[1] + \ldots\ldots\ldots\ldots + A[i,n] \times x[n] + A[i,0] \geqslant 0 \quad (i = 1,2,\ldots\ldots,m)$$

and $x[j] = 0$ or $1 (j = 1,2,\ldots\ldots\ldots,n)$

The algorithm employed to find the optimal solution is exhaustively explained by McMillan[38], and has its computational potentialities reviewed by Geoffrion[39]. Formulation attributed to Balas with useful extensions proposed by Glover, in essence, consists of a gradually improving bound on the optimal value of the objective function as better and better feasible solutions are found. During explicit enumeration of solutions to improve the objective function bound, it is found that many possible solutions can be enumerated implicitly and by careful backtracking to ensure against the redundancy of enumerating any of the solutions (implicit or explicit) more than once, an optimum solution can be arrived at after examining only a proportion of the available solutions. A fuller account of these techniques, together with their adaptation to computer is given in Appendix IV, Section 1.

A computer programme written by Byrne and Proll[40] in the high level language ALGOL 60, and employing the above algorithm, was used as the basis for this case study. The flow chart from this publication is reproduced in Fig. 6.8 and the routine operates in the following way:

Step 1a considers whether or not there is a constraint violation by setting all but the variables under review to zero. If constraint violation is found, then the programme moves to 1b, where those variables not yet considered are scrutinized to determine which variables if raised to one might ease the violation. Eventually, as more variables are raised, a feasible solution is arrived at. These procedures move the programme through steps 1c and 2 back to 1a. If this feasible solution is superior to any previous solution (incumbent) then step 1d is carried out and the new solution unseats the incumbent. Since the objective function is of the minimizing type and since its bound is initially set at a very high value (infinity), a solution will always be generated if at least one exists. Backtracking is then initiated via step 3. This replaces the right most element (latest one generated) by its complement (zero) and moves back to 1a for enumeration.

When enumeration is completed other elements not fully enumerated (yet to be underlined) are replaced by their complements, moving one at a time from the right. On completion this set of solutions is said to be fathomed. During these enumerations all other elements to the right

Key to Fig. 6.8.

S = the partial solution vector currently under consideration.

X^S = the solution vector when S is completed by setting all other variables = 0.

$\tilde{Z}$ = the least value of the objective function so far; i.e., the incumbent best feasible solution, which the algorithm tries to improve upon.

$\hat{X}$ = the solution associated with $\tilde{Z}$.

Y^S = the vector of values of the constraint functions, evaluated at S completed by setting all other variables = 0.

T^S = 'free variables' - variables (not specified in S) which by being elevated to 1 might eliminate infeasibility in one or more constraints.

j = the subscript of the variables currently specified in S.

i = the constraint number.

c = the vector of coefficients in the objective function.

a_{ij} = coefficient of variable j in the i th constraint.

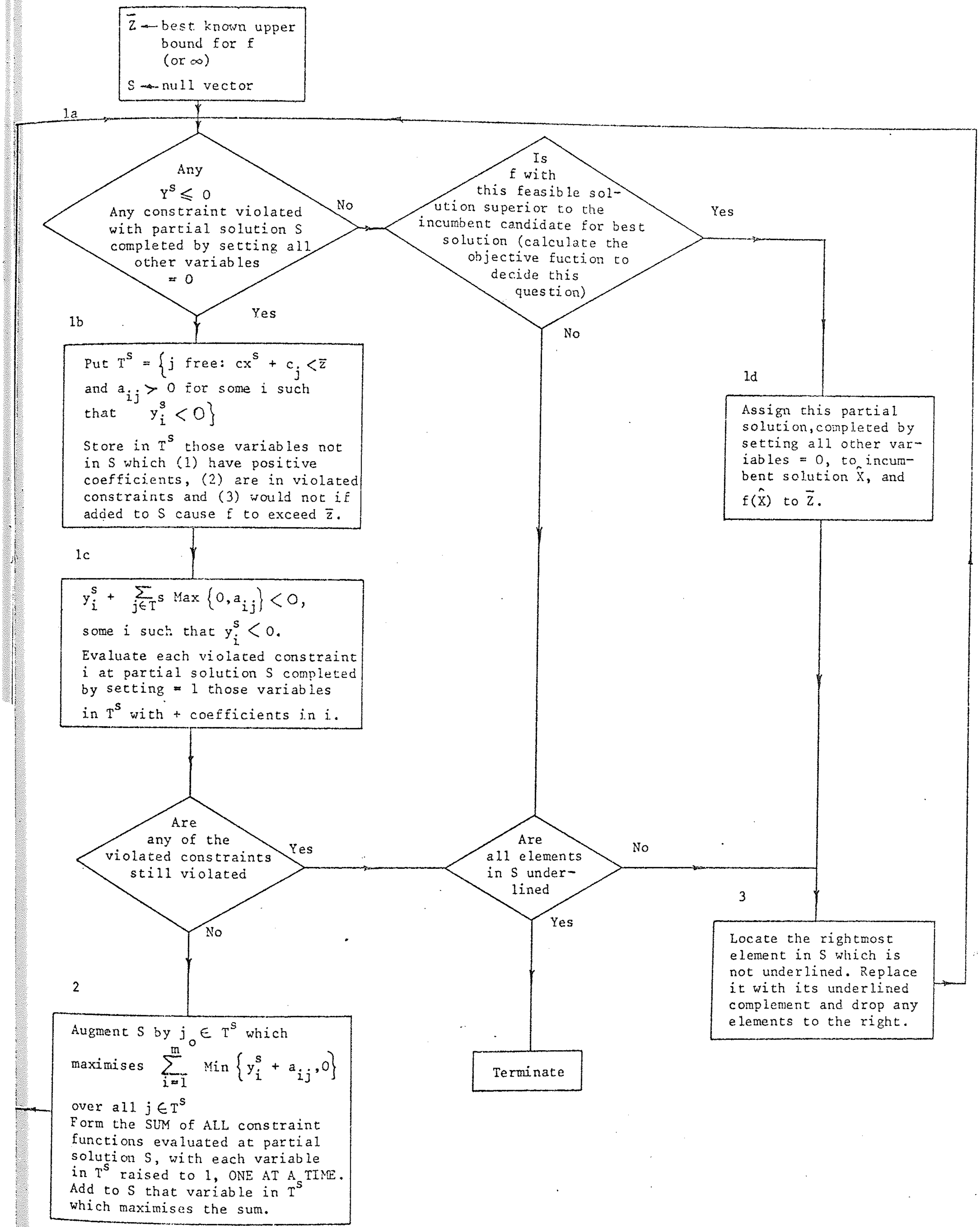


Fig. 6.8. Flow chart of the Balas algorithm for solving 0-1 integer programming problems.

are discarded. Consequently, not all solutions are explicitly enumerated, but rather, implicitly enumerated by considering groups of solutions together. When all elements are underlined, the best solution found is accepted as the optimal solution.

6.3.6. Adaptation of the Mathematical Optimization Routine to Bridge Foundry

Modifications to the programme were necessary in order to make it suitable for the Bridge Foundry schedule. These involved building a 'front end' to the programme to provide for data acceptance and a 'back end' to reveal the results required. These and all other programme statements are shown in Appendix IV, Section 2.

Before the Bridge Foundry data could be utilised by the 0-1 integer programme, its description had to be modified. Specifically, this meant compiling the dressing shop requirements of all the jobs likely to be scheduled.

Level of production of a particular job is governed by the rate paid for that job to the diecaster. This rate determines the number of castings made per day since each operative is held to a ceiling earnings. When two or more jobs are cast simultaneously, the standard rate for each job is reduced by 12½ per cent.

Fortunately, the majority of operators cast two dies simultaneously and few anomalies such as the necessary pairing of jobs of widely differing production rate arise. Hence, on consultation with the management, it was agreed that initially, factors such as these should be ignored.

When handling two jobs, a diecaster's daily ceiling earnings with respect to production bonus (part of his total earnings is a flat rate payment) is £6. This is essentially divided evenly between the two jobs; therefore, to earn the maximum (they almost always do), diecasters must produce the maximum number of castings permitted on both jobs. These numbers can obviously be calculated by dividing the price per casting, reduced by 12½ per cent, into £3.

Dressing shop operatives, in contrast to the casters, are paid according to measured time in minutes. They are allowed a specific time in minutes per casting which in turn dictates production rate in the various dressing shop sections, because again the operatives are tied to ceiling earnings. Bridge Foundry show this relationship as a Standard Time which is defined as the time allowed for the processing of 100 castings.

Obviously, a relationship between production rates in the foundry and dressing shop is necessary if a balance between the two in terms of job combination is to be achieved. It was decided that, in order to make this information suitable for use by the programme, the time requirement in minutes for a day's production from the foundry in terms of every dressing shop section on a job by job basis was needed. This is calculated from:

$$\text{requirement in minutes} = \frac{\text{mins. per 100 castings}}{100} \times \frac{300}{(\text{pence per casting})\times 0.875}$$

Totals of these requirements for a given job combination and for all the dressing shop sections will indicate the daily load to be carried by each of these sections as a total time required. If these total times are compared with the time avaialable for each section, degrees of underloading or overloading can be established. Times available are obtained from multiplying the number of operatives by 800 minutes (standard daily time is 480 minutes, but operatives are allowed to work at 1.66 times the daily rate, and 480 x 1.66 = 800).

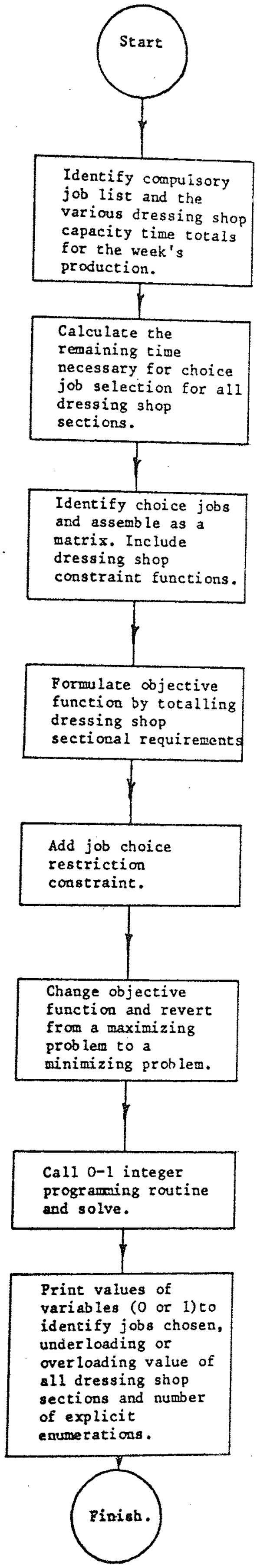
The results compiled in the form of the data bank used by the programme are shown in Appendix IV, Section 3.

6.3.7 Features of the Bridge Foundry Programme

The programme is operated to schedule job combinations at Bridge Foundry as shown in Fig. 6.9. The compulsory jobs are intially identified and their total time requirements for each dressing shop section is calculated. These figures are next subtracted from the total times available, giving the times remaining to which the non-compulsory job combination totals must be balanced. The resultant values, plus the various dressing shop requirements for the non-compulsory job choice, are then adjusted into a matrix suitable for solution by the programme. Finally, an additional constraint is added which controls the number of jobs chosen.

Before completing this description a discussion regarding the formulation of objective function and constraint functions to suit the Bridge Foundry problem need to be given. Obviously, the ideal solution would be the choice of an exact number of jobs to suit casters

Fig. 6.9. Flow chart of the Bridge Foundry sheduling programme.



Note.

Because the matrix has been converted from a maximising to a minimising formulation jobs indicated as 0 are in fact the jobs chosen to be included in the shedule. This is the result of the reversing nature of the process.

which underloads or overloads individual sections of the dressing shop to an absolute minimum. Unfortunately, the algorithm is unable to operate in this ideal way, due to objective function and constraint limitations.

It is pertinent to note at this juncture that maximizing constitutes the complement of minimizing and 'less than or equal to' is the complement of 'greater than or equal to'. These facts make available various formulations of objective function and constraint construction for solution of the Bridge Foundry schedule.

If the objective function is considered as the addition of all dressing shop requirements by the various jobs involved in the choice then the objective function/constraint construction alternatives shown in Table 6.3 become available. It should be borne in mind, that under these circumstances, minimizing the objective function promotes the choice of those jobs with the least total dressing shop requirements, while maximization has the reverse effect.

Considering the formulations of Table 6.3, the following comments can be made:-

(i) the formulations must counterbalance each other - this fact makes 1 and 8 unrealistic since 8 will promote the choice of ALL of the jobs and 1 will promote the choice of NONE of the jobs.

(ii) 2 and 7 are realistic, but respectively, underloading and overloading might be excessive.

(iii) all other alternatives appear capable of avoiding excesses (positive or negative) and only deeper investigation of their relative merits will decide order of suitability - depends

Table 6.3. Choice of matrix formulation for the Bridge Foundry schedule.

Combination number	Form of objective function	Type of dressing shop section constraint	Control of job choice constraint
1	minimizing	underload	less than or equal to
2	minimizing	underload	greater than or equal to
3	minimizing	overload	less than or equal to
4	minimizing	overload	greater than or equal to
5	maximizing	underload	less than or equal to
6	maximizing	underload	greater than or equal to
7	maximizing	overload	less than or equal to
8	maximizing	overload	greater than or equal to

somewhat on the types of job (dressing shop requirements) offered for choice.

As a somewhat arbitrary choice in the primary interest of developing the system, option 5 was chosen. Intuitively, because overloading of dressing shop sections prompted the investigation, underloading is felt to be more appropriate, and because under this circumstance extra jobs can always be added later, 'less than or equal to' is also chosen.

It is fully recognised that alternative, perhaps more complex and sophisticated combinations of objective function, constraints and job choice might be formulated. Effects such as greater objective function emphasis on dressing shop sections most sensitive to the scheduling routine plus the restriction to tighter limits of numbers of jobs chosen are felt to be worthy of future investigation.

7. APPLICATION TO THE PROBLEM

Before detailed examination of possible benefits can be made, it should be ascertained that the respective programmes are accurately describing the true situations. Therefore, after successful compilation of the programmes, testing to ensure their reliability was carried out.

As a consequence of the resultant weaknesses and limitations, a detailed investigation of possible avenues for theirimprovement was undertaken.

7.1 Testing and Execution of the Programmes

Both programmes were initially built to be run on the ICL 1904S machine at Aston. With respect to successful construction and acquisition of results the programmes proved to be complete contrasts in the difficulties and shortcomings which they posed.

Whereas the simulation model presented a formidable programming exercise, execution times were found to be the main worry associated with the mathematical programme. The simulation routine contains almost two thousand statements but execution time is largely dependent upon the working period simulated. Compared to this the mathematical algorithm with only two hundred statements is a relatively short programme, however, execution times escalate alarmingly as problem size is increased.

7.1.1 Ensuring Correct Simulation

The systems necessary to choose near optimum job sequences must be highly complex because they need to embrace the majority of constraint factors. This implies large and intricate programmes, which unless constructed as simple modular forms, complicate the alleviation of even trivial computation and logic errors.

Incorporation into the programmes of all the factors influencing the scheduling exercise was found to be the major obstacle to successful completion of the model. For example, it had to be proved conclusively that dies were not being used to produce two castings at the same time, that furnace contamination was always fully dealt with and that large castings requiring two furnaces were always made in a satisfactory manner with respect to process times. In this latter instance, difficulty was experienced detaining one furnace while the other was being subjected to a 'wash' heat to avoid contamination.

After successful operation of the routine with simulations of up to three months, a multitude of 'write' statements were inserted at numerous strategic points throughout the programme requesting various items of evidential information. It is impossible to show the full extent of such an investigation, since the amount of data needed is colossal, and only the use of magnetic tape files plus a Visual Display Unit enabled such a procedure to be carried out at all. For example, a month's simulation generated seventy thousand lines of information. However, a few hundred lines of print illustrating this technique are shown in Appendix V, Section 1.

Details of job choice were scrutinized to ensure the observation of priorities, as was furnace selection and the constraints imposed by alloy type, weight and die availability. Stock adjustments, both for charge make-up and work in process were also looked at. A similar investigation was instigated with respect to the machine shop and the selection of 'next event' also received attention.

For completeness, illustration of a section of the order book is given in Appendix V, Section 2. Array Order 1 shows information supplied by the customer, while Array Order 2 indicates information necessary for manufacture of the casting.

7.1.2 Solutions from the Mathematical Model

The computation time required for optimization increases appreciably with problem size. A selection of trials (shown in Table 7.1) is culminated with the running of a real schedule matrix for which programme termination was not forthcoming even after an execution time of 6½ hours.

It can be seen that with very small problems detection of the optimal solution is very rapid, but increasing the size of the matrix escalates the time enormously. Obviously, the time required to search a matrix for an optimal solution will depend upon the number of constraints and the number of possible combinations available for explicit/implicit enumeration. The number of possible combinations of variables and solutions from which to choose are given by 2^n, where n is the number of variables involved. If the number of variables (jobs available for choice) is compared to the subsequent programme termination time, a log

Table 7.1. Details of various problems and their solutions used to verify the suitability of the 0-1 integer programming routine.

Problem size (7 variables were detailed as compulsory in every case)	Number of possible combinations	I.C.L. 1904S computer			C.D.C. 7600 computer		
		Solution details	Execution time - secs	Count number (iterations)	Solution details	Execution time - secs.	Count number (iterations)
choose 7 variables from 10	2.52×10^{2}	optimal	11.2	87	optimal	1.8	89
choose 14 variables from 21	3.1×10^{6}	optimal	45.4	2162	optimal	4.7	2141
choose 21 variables from 28	2.1×10^{7}	optimal	109.1	5669	optimal	11.4	5742
choose 28 variables from 35	2.7×10^{8}	optimal	148.8	7748	optimal	14.9	7536
choose 35 variables from 42	3.4×10^{10}	optimal	1481.1	46999	optimal	130.5	60333
choose 42 variables from 49	4.4×10^{12}	optimal	6482.3	191491	optimal	577.5	219357
choose 49 variables from 56	5.6×10^{15}	no soln.	10000.0	-	no soln.	1279.0	526341
choose 58 variables from 68 (real schedule - 63 compulsory variables)	1.8×10^{18}	no soln.	20000.0	-	no soln.	5120.0	3141882

relationship results (Graph 7.1).

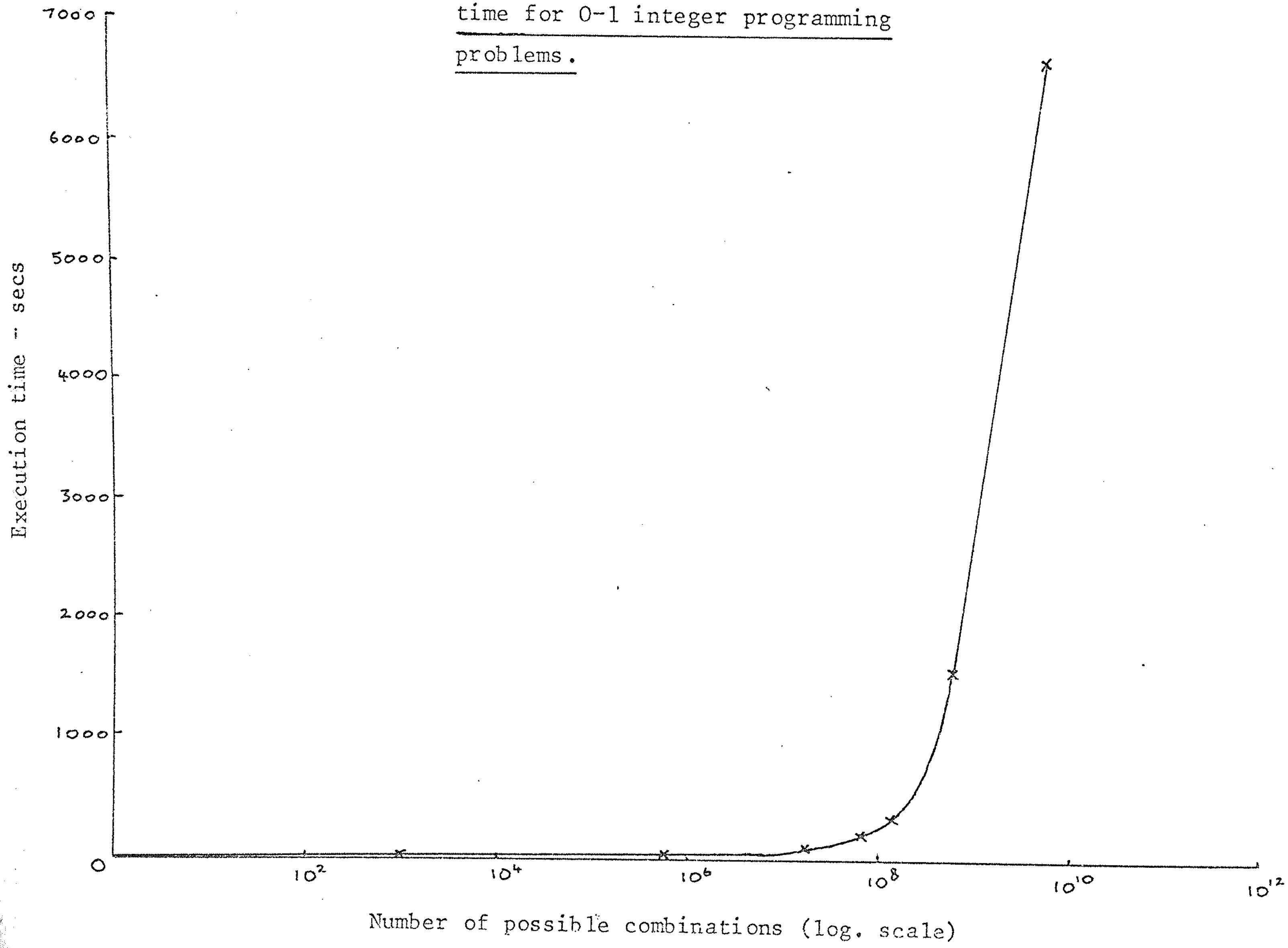
It seems logical to conclude that a certain fraction of possible solutions will always have to be explicitly enumerated in order to arrive at an optimal solution. As larger problems are considered (Table 7.1), even a small fraction of solutions can amount to sizeable proportions.

The programme was initially designed to operate on an ICL 1904S machine but it was transferred to the CDC 7600 machine at Manchester University because of improved computational powers and speed of data manipulation. This meant modification of the programme statements to suit the Algol language used by the latter.

A ten-fold improvement in speed of iteration (explicit enumeration) was obtained as shown in Table 7.1. Even this machine however, 'timed out' after 1280 seconds (the maximum computation time normally allowed on the 7600), without realising an optimal solution for a problem the size of the Bridge Foundry schedule. As indicated in Table 7.1, a special run of 5120 seconds also proved fruitless in isolating an optimal solution in spite of the fact that over a million iterations were performed.

7.2 Suitability of the Programmes and Possible Modifications

The suitability of the two routines can only be judged by their capability to improve weekly scheduling. Consequently, after commissioning the simulation model (decision making satisfactory), its benefits were ascertained. Limitations were spotted, however, Graph 7.1. Relationship between number of possible combinations and execution time for 0-1 integer programming problems.



and suitable modifications were incorporated.

It has already been stressed that the 0-1 integer programme has severe shortcomings associated with the time required to solve large programmes. Obviously, before practical application could seriously be considered this anomaly had to be overcome.

7.2.1 Appraisal of the Simulation Model

Order book lead time can vary widely depending upon the economic climate, being as low as two weeks after some downturns and as high as sixteen weeks after some upturns. This should be recognised during operation of the model. Consequently, numerous runs were made using various lead times.

'Start-up' constitutes a model deficiency since it presents a situation never experienced by the company. While in practice the order book contents at any given time will vary in priority, at the commencement of a model run, an initial batch of orders are generated (the size of which depends on the lead time chosen) all with identical priority.

This initial bias in order information is a handicap commonly associated with simulation modelling since 'start-up' from the idle state is a popular procedure particularly when stochastic processes are employed. In the present study, the 'start-up' is by order generation using random numbers according to a probability pattern. Gordon[41] discusses 'start-up' difficulty at some length and suggests two possible remedies. The first of these involves running the programme to some predetermined time, then stopping the run and restarting with the system now in this preset state. The second involves the elimination of an initial section of the run. Both are essentially variations on the same theme.

The second alternative was chosen for this study since the use of stochastic variables is somewhat incidental, being applied solely to test the applicability of the model to the Spunalloys scheduling problem.

Establishment of a suitable cut-off point enabling discard of results containing initial bias can, according to Gordon, only be satisfactorily accomplished by suitable statistical analysis. He advocates observation of standard deviation variation with sample size, starting from the idle state. Since in the absence of initial bias, standard deviation is inversely proportional to $n^{\frac{1}{2}}$ (n = sample size), careful examination of a log plot of such a relationship should indicate the onset of this condition and, therefore, a suitable cut-off point.

But scrutiny of a nine week lead time (500 initial orders) order book, after nine weeks simulated production, as detailed in Appendix V, Section 3, revealed no order with priority exceeding 8. Conclusions to be drawn from this fact is that at such a stage in the simulation, all orders initially generated have been dealt with and the order book has now settled down to a steady state. These thoughts were endorsed by examination of the order book after a full three month's production when it was found that no priority exceeded 8 (furnace schedule).

In view of this fact, plus the distribution of weekly output figures from the model, as shown in Table 7.2, it was decided not to pursue Gordon's ideas with respect to 'start-up' bias, but rather to accept that with all lead times less than or equal to nine weeks, steady state has been reached after eight weeks' simulation. Such an acceptance allows simplified statistical analysis of these results. This decision receives further backing from Graphs 7.2 and 7.3, where it would appear that if 8 weeks' simulation is made the cut-off point, output variations during subsequent weeks are somewhat less than during the preceeding weeks.

The effect of lead time on production figures is shown in Table 7.2. When the order book size is reduced to a two week lead time, scheduling becomes so difficult that simulation is stopped after only a very limited period. This occurs when no suitable order in respect of capacity and die availability for a waiting furnace can be found in the order book. It loosely describes the situation when a furnace is shut down through lack of orders.

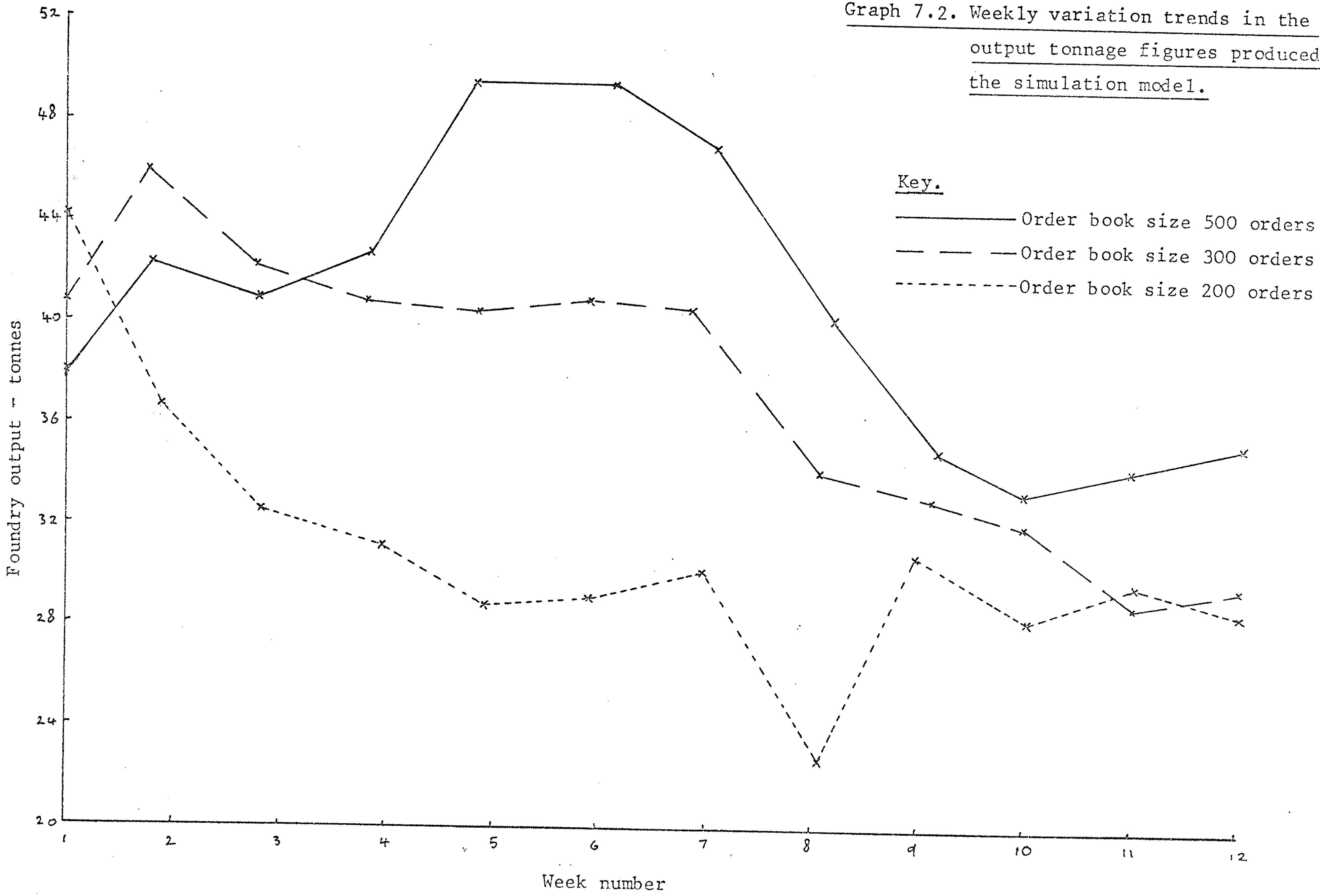
Table 7.2 and Graphs 7.2 and 7.3 further illustrates the increasing difficulty associated with scheduling as the order book size is reduced in that lower output figures are found. This would, of course, occur as a result of the contamination problem becoming more severe, which, in effect, will mean increased use of the non-productive 'scrub' heat.

Results obtained from the statistical analysis of output figures shown in Table 7.2 are compiled in Table 7.3. The aim of this analysis is to determine whether or not observed trends can be statistically proven via the establishment of confidence limits on the comparisons.

Table 7.2. Foundry output figures from the model compared to actual output figures at Spunalloys over the analysis period.

Month number	Identity	Simulation model foundry output figures										Actual output figures achieved by Spunalloys over the simulated period	
		Order book size 500 (9 week lead)		Order book size 300 (5 week lead)		Order book size 200 (3 week lead)		Order book size 100 (2 week lead)		Order book size 50 (1 week lead)			
	Data group identity	A	B	C	D	E	F					G	H
	Week number	Tonnes	No. off	Tonnes	No. off	Tonnes	No. off	Tonnes	No. off	Tonnes	No. off	Tonnes	No. off
1	1	38.1	192	40.8	171	44.1	195	37.4	171	32.7	155	35.28	252
	2	42.6	193	46.0	185	36.8	174	33.7	166	programme stopped running		30.41	242
	3	40.9	178	42.1	202	32.6	165	29.2	144			29.02	262
	4	43.4	189	41.0	176	31.2	156					26.57	249
2	5	49.4	203	40.5	183	28.5	147	Programme stopped running				23.87	152
	6	49.4	199	41.0	197	28.8	147					29.38	207
	7	46.5	195	40.1	175	31.2	159					26.27	201
	8	40.1	183	34.1	157	22.4	141					19.78	140
3	9	34.5	160	33.3	169	30.8	158					32.45	205
	10	32.9	152	31.8	145	28.1	136					24.85	237
	11	33.7	153	28.6	149	29.4	147					26.31	179
	12	34.8	172	29.4	148	28.3	142					20.82	130

Graph 7.2. Weekly variation trends in the foundry output tonnage figures produced by the simulation model.



Graph 7.3. Weekly variation trends in the foundry output number off figures produced by the simulation model.

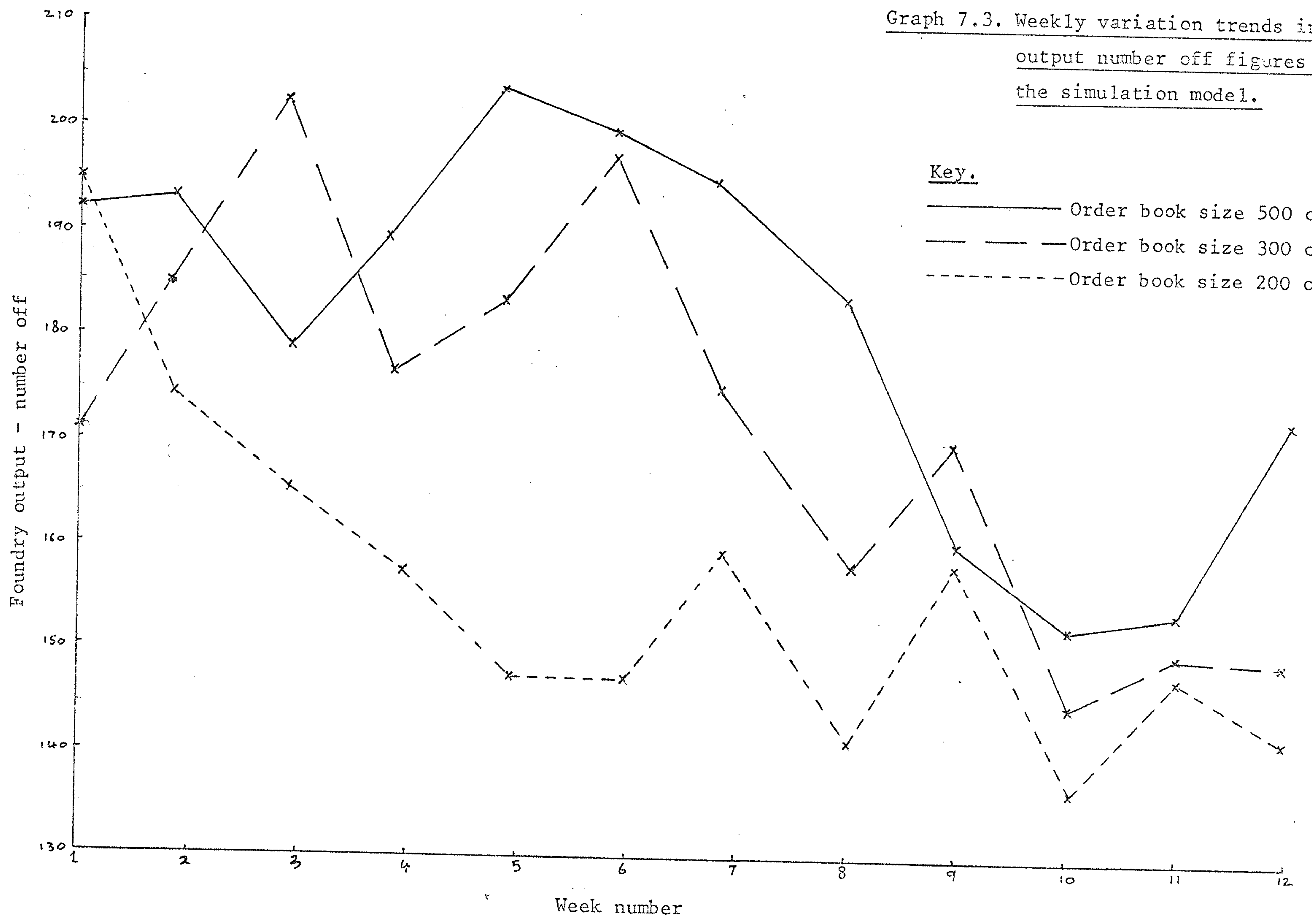


Table 7.3. Statistical analysis of both actual output figures from Spunalloys and those produced by the simulation model.

Data group	Mean	Standard deviation	Data group comparison		
			Groups compared	Null Hypothesis verdict	
				F test	t test
1A	41.25	2.35	1A & 2A	A	A
1B	188	6.9	1B & 2B	A	A
2A	46.35	4.40	2A & 3A	R	–
2B	195	8.7	2B & 3B	A	R
3A	33.97	0.86	3A & 3C	A	R
3B	159	9.3	3B & 3D	A	A
1C	42.48	2.41	1C & 2C	A	A
1D	183	13.6	1D & 2D	A	A
2C	38.90	3.25	2C & 3C	A	R
2D	178	16.7	2D & 3D	A	A
3C	30.77	2.16	3C & 3E	A	A
3D	153	11.0	3D & 3F	A	A
1E	36.17	5.90	1E & 2E	A	A
1F	172	15.8	1F & 2F	A	A
2E	27.70	3.76	2E & 3E	A	A
2F	149	7.6	2F & 3F	A	A
3E	29.15	1.24	3A & 3E	A	R
3F	146	9.3	3B & 3F	A	R
G	27.55	4.65	3A & G	A	R
H	205	46.0		(98% C.L.)	

Note.

Data group identity follows from Table 7.2. - month number and column. 3C indicates weeks 9,10,11 and 12 (month 3) of column C. The Null Hypothesis advocates no significant difference (95 per cent confidence limits) between data groups. The F test assesses variance similarity and the t test mean similarity between data groups. A = accept Null Hypothesis, R = reject Null Hypothesis. When output levels from different order book sizes are being compared (3A & 3C, 3C & 3E and 3A & 3E), the Null Hypothesis is rejected if $x_1 > x_2$ hence, the t test is single sided.

Underlying theory to the analysis is shown in Appendix VI.

Such proof is accomplished via the consideration of a Null Hypothesis which advocates that the various group data comparisons represent populations with the same mean, although to claim this postulation it must first be established that variances are the same. Hence, each of the comparisons shown in Table 7.3 is first subjected to an F test to verify variance similarity and then to a t test to consider mean dissimilarity. Both must exceed at least the 95 per cent confidence limits before being accepted.

A limitation immediately apparent is the small number of values (four) comprising most data groups. This occurs because the model runs were terminated after three months simulation. Unfortunately, this position had to be condoned since further simulation exceeds the maximum time limit for a normal run on the Aston computer.

As seen by Table 7.3, the results are somewhat mixed. Although significant differences cannot be established between figures (tonnage and number off) for the first and second month, or second and third months, it is intuitively felt that such differences exist and that these would be verified if it were possible to increase sample size. These thoughts are endorsed by the significant differences between first and third month figures.

Actual output figures are also included in Table 7.2. Although their relationship with results from the model is not explained until a later section (8.1.1), they are included here because they enable verification to be made of the authenticity of the model and also allow an anomaly to be discussed.

Obviously, with respect to the objectives of this study, it is confirmation that the simulation programmes accurately reflect production procedures at Spunalloys which is paramount. Closeness of magnitude between the groups of figures in 3A and G, plus acceptance of the F test (similar variance of population even at 98.0 per cent confidence limits), promotes such a conclusion. But in addition, the 95.0 per cent certainty that the tonnage output from the model (using an identical lead time of nine weeks) is greater than the figures actually obtained, advocates the superiority of the model.

The difference in number off values between actual and model figures is distinct. However, it was perceived that unlike the model, the company's number off figures represent finished castings in rough cast form. Since rough castings often contain two or even more finished castings, it is not surprising that the company figures are much higher than those of the model.

An important feature, indicated by Table 7.4, is the continually increasing tonnage of rough castings awaiting machining as simulation progresses. The reason for this is of course imbalance in capacity between foundry and machine shop.

It has been pointed out already that the company makes use of overtime working and outside assistance to control work in process, and this feature is not accounted for in the model. But as shown by the simple calculation in Table 7.4, rate of increase in work in process exceeds the 15 per cent of machine shop capacity available in the form

Table 7.4. Comparisons of the monthly variations in rough castings stock with the corresponding monthly machine shop output.

Month number	Rough castings stock at the end of the month - tonnes		Monthly output from the machine shop - tonnes		Increase in rough castings stock over the previous month expressed as weight of finished castings by dividing true weight by 3 (assumed 2/3 metal machined away) - tonnes		Monthly increase in rough castings stock expressed as a percentage of the output from the machine shop for that month - per cent	
	Model	Actual	Model	Actual	Model	Actual	Model	Actual
0	0	31.2	-	-	-	-	-	-
1	42.9	43.7	26.25	35.19	14.30	4.22	54.5	12.0
2	113.0	28.9	22.73	33.06	23.33	-4.93	102.0	-14.9
3	136.1	14.8	20.25	38.84	7.70	-4.70	38.0	-12.1

of overtime and the use of outside contractors. Since foundry capacity in the simulation model approximates that associated with practice, the anomaly suggests divergence between theoretical and real machine shop capacities. This is borne out by comparison between the model figures and equivalent recorded machine shop tonnages as shown in Table 7.5.

The close attention previously given to the working mechanisms of the various sub-routines rules out incorrect scheduling technique, and since the size range of machines is sufficient to avoid machine hold-ups due to lack of suitably dimensioned castings, the weakness must lie with the production data employed by the model.

The source of processing times incorporated in the scheduling sub-routines has not been previously mentioned. Detailed observation of the foundry processes by Shipley[42], whose work showed the financial benefits to the company of installing three large (750 kg and two 500 kg) capacity electric furnaces resulted in accurate operation times being compiled. Formulation of these times using multiple regression techniques in some instances is reproduced from Shipley's work in Appendix V. Section 4.

Unfortunately, Shipley was not concerned with the machine shop; therefore the necessary production data for this area of manufacture had to be obtained from company personnel. Some of this information was unclassified, much less the result of formal observation; hence, it's accuracy was immediately suspect.

The control of raw materials stocks by the model was also inferior to that achieved in practice. This was manifest by differences in monthly stock level figures. However, attempts to reduce ingot tonnages

Table 7.5. Machine shop output figures produced by the model compared to actual figures from Spunalloys over the period simulated.

Week number	Machine shop output according to the model - tonnes	Machine shop output actually achieved over the period simulated - tonnes
1	3.42	8.34
2	6.85	8.60
3	7.16	10.57
4	8.82	7.68
5	6.99	7.12
6	4.59	7.83
7	5.00	9.10
8	6.15	9.01
9	5.03	10.45
10	5.68	9.44
11	5.41	9.22
12	4.13	9.73

stocked by the model, via smaller re-order quantities and reduced initial amounts, caused the monthly stock figures in the model to often go negative indicating a 'stock out' position.

Again, an anomaly was apparent. Re-order of ingot stocks is initiated in the model when minimum levels are reached. Since delivery as reported by the company is one week after invoice reception by the supplier, minimum re-order levels cannot be less than one week's requirement if 'stock-out' is to be avoided. Close scrutiny of company figures showed this to be a nonsense and, on pointing out the fact, it was revealed that 'urgent' delivery can be made three days after invoice reception. It is the author's opinion that this constitutes a regular feature of the stock replenishment pattern.

Stock figures recorded during part of a model run when initial values and re-order quantities were based on order generation pattern are shown in Appendix V, Section 5. Also shown are weekly output figures and a monthly rough castings stock tonnage.

7.2.2 Appraisal of the Mathematical Routine

At the rates currently charged for commercial computation (£1 per second execution time on the CDC 7600) implementation of the routine by Bridge Foundry is financially unsound because of the time periods involved in identifying an optimum solution for a realistically sized programme. Further, from discussion with computer personnel, it would appear that the shortcomings are of a fundamental nature.

They advised a transfer from ALGOL language to that of FORTRAN.

Being associated with a more powerful compiler (machine dependent), manipulation is more efficient via this latter alternative. Table 7.6 compares the enumeration efficiencies of the two languages while Appendix VII shows the statement details of the Fortran version. Iteration is approximately one and a half times more rapid using Fortran on the ICL 1904S machine and seven times more rapid on the CDC 7600 machine.

Reduction in the number of possible combinations by confining the number of jobs for choice to more narrow limits, must reduce enumeration. However, such a benefit will be offset by the introduction of an additional constraint. This is confirmed by Table 7.7, where the effect is shown to be only marginal.

An alternative method of reducing possible combinations is to confine to a smaller number the job range from which choice is to be made by including more jobs in the compulsory sector. Table 7.8 using details from a real schedule verifies this, an optimal solution being found within the time limit allowed when the job list was restricted to 48 from which 38 jobs are required.

Consultation with Bridge Foundry revealed that some of the dressing shop committments might be combined since overloading of some sections at the expense of others can be offset by the limited transfer of labour. This provides a ready means of reducing the number of constraints handled by the programme; hence, the following mergers were made:-

(i) band saws and rotary saws

(ii) grind and linish

Table 7.6. Comparison of Algol and Fortran language efficiencies in the manipulation of the 0-1 integer programme.

Language	I.C.L. 1904S computer				C.D.C. 7600 computer			
	Solution details	Execution time - secs	Count no. (iterations)	Iterations per sec.	Solution details	Execution time - secs.	Count no. (iterations)	Iterations per sec.
Algol	Optimal	1481.1	46999	32.0	Optimal	130.5	60333	462.0
Fortran	Optimal	1327.0	60159	46.4	Optimal	15.5	54279	3400.0

Note.

The problem used by the programmes consisted of 7 compulsory choice jobs and 42 possible choice jobs from which 35 were required for selection.

Table 7.7. Effect on the solution time of the 0-1 integer programme if the number of possible combinations is reduced by restricting the job choice.

Job choice constraint	Solution details	Execution time - secs.	Count no. (iterations)	Iterations per sec.	Number of combinations
Choose N jobs	Optimal	1481.1	46999	32.0	3.4×10^{10}
Choose N jobs and N - 5 jobs	Optimal	1533.2	46915	30.6	3.2×10^{9}

Note.

The problem used by the programmes consisted of 7 compulsory choice jobs and 42 possible choice jobs from which 35 were required for selection. The language used was Algol and the programmes were run on the I.C.L. 1904S machine.

Table 7.8. Effect of data size on the iteration rate of the 0-1 integer programme.

Number of jobs made compulsory	Number of jobs available for choice	Number of constraints	Solution details	Execution time - secs.	Count no. (iterations)	Iterations per sec.
63	68	4	No solution	1279	436088	342
73	58	4	No solution	1279	567985	444
83	48	4	Optimal	1268	736753	578
93	38	4	Optimal	394	27338	695

Note.

The problems used by the programme were derived from an actual Bridge Foundry scheduling situation. The language used was Algol and the programmes were run on the I.C.L. 1904S machine.

(iii) male file

(iv) female file, disc, press and ream

Improved speed of iteration occurs as shown in Table 7.9, although an optimal solution to a real schedule is still unattainable. These alternatives for shortening solution time can, of course, be combined as indicated in Table 7.8.

The algorithm initially constructs the combinations (possible solutions) as a network of the type shown in Appendix IV, Section 1. It then proceeds to work through this network by establishing feasible solutions from explicit and implicit enumeration until the optimal solution is arrived at. Hence, if a programme is stopped after some prescribed time, it is probable that a 'good' solution (not necessarily optimal) will already be identified. This line of thought was pursued in two ways. Firstly, statements were added to the programme causing details of the fixed and free variables associated with the partial solution vector to be written to a file. These results are overwritten when a more feasible solution is located. When 'time up' occurs this 'best' solution is indicated.

Unfortunately, as shown by the results (real schedule) in Table 7.10, transferring information to a file in this way severely reduces the rate of iteration. Because of this, the second alternative was considered. Knowing the number of iterations performed on earlier programmes at 'time up', a statement was included in the programme which causes the relevant results to be printed after a specific count value is reached. Again, as revealed by Table 7.11 (real schedule), a 'best solution' is obtained, but on this occasion, rate of iteration

Table 7.9. Effect of constraint reduction on the iteration rate of the 0-1 integer programme.

Number of jobs made a compulsory choice	Description of the possible job choice	Number of constraints	Solution details	Execution time - secs.	Count no. (iterations)	Iterations per sec.
7	choose 28 from 35	9	Optimal	148.8	7748	52.0
7	choose 35 from 42	9	Optimal	1481.1	46999	32.0
7	choose 42 from 49	9	Optimal	6482.3	191491	29.5
7	choose 28 from 35	5	Optimal	138.1	8650	62.4
7	choose 35 from 42	5	Optimal	1264.0	56735	45.6
7	choose 42 from 49	5	Optimal	4861.3	204361	41.8

Note.

The language used was Algol and the programmes were run on the I.C.L. 1904S machine.

Table 7.10. Effect on the 0-1 integer programme of using a transfer file to provide a 'Best' Solution at 'Time-up'.

Problem details	Solution details	Execution time - secs.	Count no. (iterations)	Iterations per sec.
83 jobs made a compulsory choice 48 possible jobs available for selection. 4 constraints. Look for Optimal Solution.	Optimal	1268	736753	578.0
83 jobs made a compulsory choice 48 possible jobs available for selection. 4 constraints. Print out 'Best' Solution on 'Time-up'.	Best	1279	38147	29.7

Note.

The problem used by the programmes was derived from an actual Bridge Foundry scheduling situation. The language used was Algol and the programmes were run on the C.D.C. 7600 machine.

Table 7.11. Effect of number of iterations on the value of the 'Best' Solution and number of combinations considered.

Count no. (iterations)	Execution time - secs.	Value of slack variables				Value of Objective Function (minimizing)	Number of jobs chosen	Number of chosen jobs yet to be underlined	Approximate number of combinations considered
		Sawyer + Ballenger	Grind + Linish	File	Fefile + Disc + Press + Ream				
51	1.1	10.38	572.06	66.90	475.90	5417.93	46	20	$10^{14.5}$
101	1.2	5.38	531.26	80.90	400.12	5310.33	46	19	$10^{14.8}$
501	1.8	0.58	477.11	66.90	399.12	5236.38	46	18	$10^{15.0}$
1001	2.6	6.45	432.78	80.90	323.32	5136.12	46	18	$10^{15.0}$
5001	8.8	1.65	402.63	66.90	308.32	5072.17	46	17	$10^{15.4}$
10001	16.7	13.40	343.46	80.90	261.92	4992.30	46	17	$10^{15.4}$
25001	40.5	13.40	343.46	80.90	261.92	4992.30	46	16	$10^{15.6}$
50001	80.2	13.40	343.46	80.90	261.92	4992.30	46	16	$10^{15.6}$
100001	160.1	8.50	285.25	80.90	171.12	4838.44	45	16	$10^{15.6}$
300001	482.6	8.50	285.25	80.90	171.12	4838.44	45	15	$10^{16.0}$
500001	805.8	3.45	255.10	80.90	80.32	4712.44	44	15	$10^{16.0}$
750001	1211.8	3.45	255.10	80.90	80.32	4712.44	44	15	$10^{16.0}$

Note.

The problem used by the programme was derived from an actual Bridge Foundry scheduling situation. It consisted of 63 compulsory choice jobs and 68 possible choice jobs. The language used was Algol and the programme was run on the C.D.C. 7600 machine. Approximate total number of possible combinations is 3.2×10^{20}.

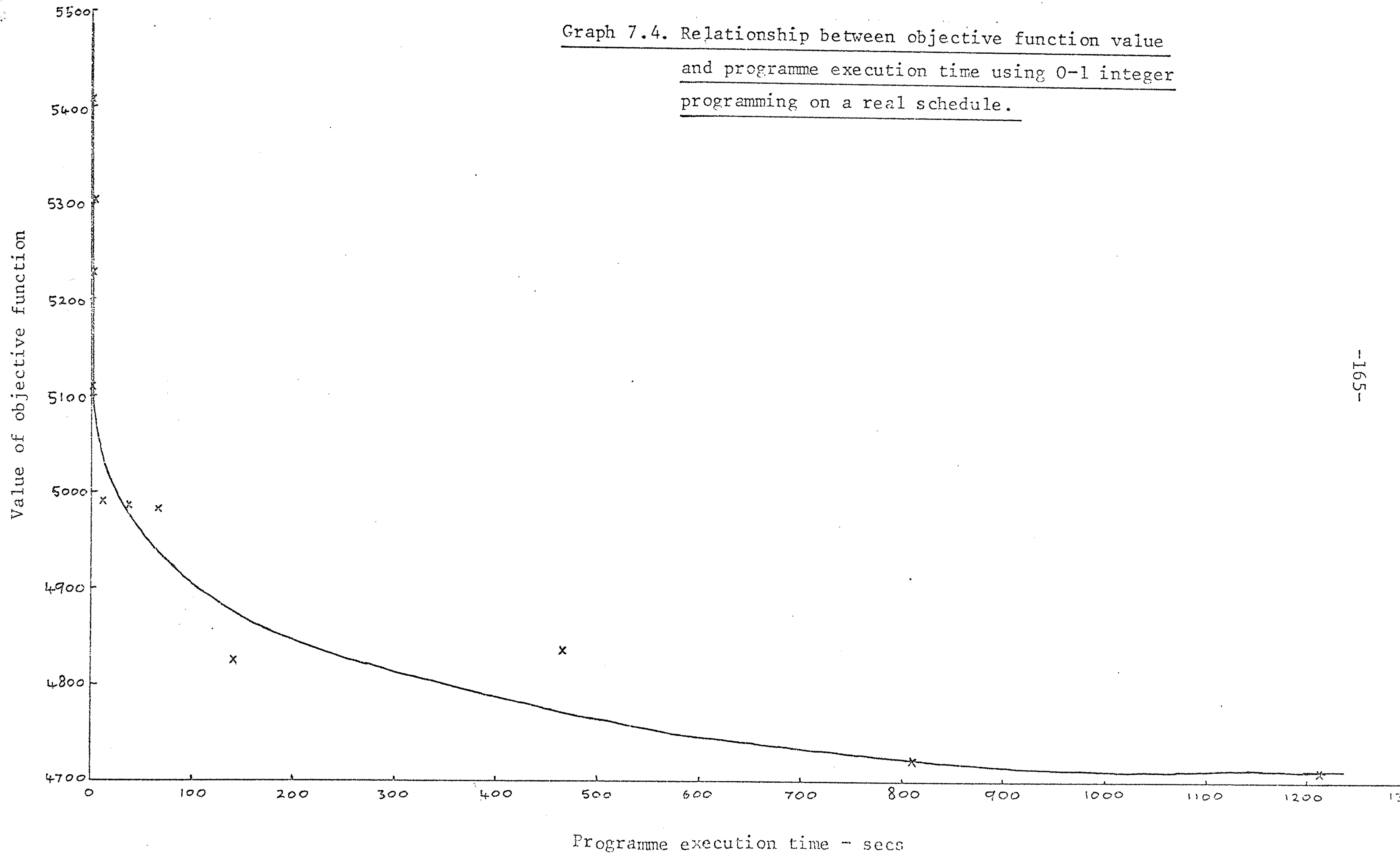
is unaffected.

Details of the elements identified in the partial solution vector enable an estimation to be made of the extent of explicit and implicit enumeration at termination. By noting the point to which 'underline' (negative complement of chosen variables) has proceeded, as indicated by the first negative element encountered in the variables specified in the current solution counting from the left, the number of combinations considered up to that time can be calculated. Table 7.11, in showing details of this, reveals that while initial enumeration is rapid, further progress becomes increasingly retarded. Slow decrease shown in constraint values together with the complementary increase in objective function is added endorsement. These trends suggest that only marginalimprovement to the solution would be possible on further operation of the programme. This conclusion is supported by comment in Geoffrion's paper from which the algorithm is derived.

Development of these thoughts stimulates a belief that a suitable cost effective cut-off point for the programme might be forthcoming. Since objective function variables are the sum of appropriate job variables for the dressing shop sections, improvement of objective function (maximization) with increasing iteration will be proportional to reduction in slack variables. Further, number of iterations is proportional to execution time; hence, a plot of objective function value against execution time should enable a suitable termination point to be determined.

From Graph 7.4, which of course is based upon a real schedule, it is apparent that objective function improvement slows after 10 seconds

Graph 7.4. Relationship between objective function value and programme execution time using 0-1 integer programming on a real schedule.



and becomes even more retarded after 200-300 seconds.

7.3 0-1 Integer Programming Experiences

Because of the controversy surrounding the use of 0-1 integer programming in the Bridge Foundry case study, it was decided to conduct a literature search for further information on the limitations inherent in it.

7.3.1 Inherent Programme Modifications

One of the earliest attacks on programme deficienciesis that attributed to Geoffrion[43], who developed an algorithm to accelerate the convergence process by the construction of a 'strong' surrogate constraint. This is formed by adding to a constraint generated from the objective function, a new constraint that is some multiple of the sum of all the original constraints. This so-called imbedding approach increases the effectiveness of implicit enumeration, but the development of these additive values can involve appreciable computation, which will slow down the rate of iteration. White[44] endorses this point in a more recent paper which compares various approaches to additive value function formulation. It would appear that the balance struck between improved implicit enumeration and rate of iteration depends upon the problem at hand. Byrne and Proll[45] suggest that Geoffrion type algorithms may quickly find the optimal solution, but the subsequent verification that this solution is optimal may take a considerable time.

Additional work has been done to further strengthen surrogate constraint formulation. Rodman[46] describes the generation of numerous surrogate constraints. These are built into a Simplex tableau and then, via choice of pivot row and column, the composite constraint showing most benefit is indicated. This in turn identifies the variable showing most promise if raised to one in the sub-set.

In contrast to acclerating the isolation of the optimum solution by more informed forward movement through the solution network (increasing the number of variables assigned the value one), many workers have tried to elevate the efficiency of implicit enumeration by improving backtracking techniques. Fiala[47], for example, constructed a supplement constraint, which by manipulation of the objective function, enables the element giving strongest improvement to be chosen as the complement in the backtrack procedure. Alternatively, Ellwein[48], after criticising the narrow view associated with all Balas based single node implicit enumeration schemes, suggests that multi node considerations of the type used by Land and Doig in their branch and bound algorithm (mentioned previously) could have useful application in 0-1 integer programming although computer storage requirements would increase markedly.

Ellwein finally advocates an approach, which, using a branch and bound routine, gives extra flexibility to backtracking by appraising the possibilities associated with all non-underlined variables. They are arranged in order of benefit to the objective function and considered in this preferential manner. This is in contrast to normal practice which simply assigns complementary values to the last variable included in the sub-set. However, he concedes that more experience with actual problems is necessary before this technique can be fully assessed.

Concentration on backtracking to improve implicit enumeration is also advocated by Christofides[49], who avoids the increased storage associated with the previous method by using an intuitive ruling heuristic to choose the order in which non-underlined variables are given their complement value of zero. He suggests that branching should be in accordance with choosing the reduced set which will produce the smallest lower bound on the resulting node. The reasoning behind this is that the escalation of the bounds is then as fast as possible and this may again hopefully tend to reduce the size of the tree that is searched. But again, little practical evidence is offered to verify the theorising.

As explained by Fiala and Mahendrarajah[50], many algorithms for solving 0-1 integer programming problems have been proposed in thelast decade, and although most have been analysed, compared and subjected to computer tests by different authors, all are still at an experimental level requiring additional examination and analysis. Three alternative algorithmsare compared in this paper and it is of some significance that when applied to a variety of different sized problems, in general, the basic algorithm used in the present thesis gave the most encouraging results. The other two algorithms examined include the one by Fiala, mentioned earlier, which employs improved backtracking procedure and a routine attributed to Lawler and Bell which includes surrogate constraint formulation of the type developed by Geoffrion. Fig. 7.1 is reproduced from this paper.

With respect to inherent programme modifications for improving operating efficiency, Zironts[51] makes a pertinent point when he states that any implicit enumeration scheme, regardless of how

Fig. 7.1. Comparison of the operating efficiencies of various 0-1 integer programming algorithms.

Problem number	Algorithm 341						Algorithm 449 (Fiala)						Lawler and Bell					
	FFS		FOS		Completion		FFS		FOS		Completion		FFS		FOS		Completion	
	I	T	I	T	I	T	I	T	I	T	I	T	I	T	I	T	I	T
1	5	.00	5	.00	43	.00	18	.00	18	.00	28	.14	185	.43	298	.63	370	.85
2	4	.00	4	.00	11	.00	7	.00	7	.00	9	.00	59	.13	206	.45	233	.54
3*	3.3	.00	3.3	.00	30	.00	7.7	.00	55.1	0.36	59.3	.41	5.1	.00	17	.05	610	2.27
4	11	.00	11	.00	673	3.15	9	.30	9	.30	953	19.30	91	.20	474	1.45	1926	5.71
5	6	.00	6	.00	153	.00	17	.00	17	.00	103	.00	44	.20	44	.20	265	1.10
6	8	.00	177	.00	561	4.43	21	.00	21	.00	459	21.61	60	.44	60	.44	1565	12.29
7	10	.00	10	.00	2497	14.43	16	.66	16	.66	2865	64.20	46	.24	46	.24	7655	75.89
8	702	3.38	702	3.38	1189	7.16	30	.94	30	.94	52	2.08	—	—	—	—	—	>1200
9	17	.00	17	.00	1651	8.41	128	4.18	128	4.18	1089	47.8	—	—	—	—	—	>720
10	7	.00	809	5.68	5651	42.60	93	13.44	93	13.44	8010	710.04	—	—	—	—	—	>1200

* Average of 9 problems.

Key.

Problem	Constraints	Variables
1	6	12
2	7	10
3	11	10
4	15	15
5	20	10
6	65	15
7	50	15
8	19	25
9	5	40
10	11	44

I is the number of iterations and T is the programme execution time in secs. Both I and T are given for the first feasible solution found (FFS), the first optimal solution (FOS) and the completion of the algorithm.

effective it is, still must examine some fraction of all possible solutions. For large problems, even the number of solutions corresponding to a tiny fraction of the total may still be enormous.

7.3.2 Other Ideas on Programme Improvement

Christofides[49], on the question of protracted times associated with large programmes, backs up the present author's thoughts on utlilising the benefits from the generation of a 'best' solution, which could, in fact, be very close to optimal. He describes how the tree search methods have the advantage of producing a good feasible solution early in the search before an optimal solution is verified. Thus, if computation is interrupted before the conclusion of the search, a solution, which is often the unproven optimal solution, is available.

Nauss[52] promotes the idea of initial movement toward an optimal solution via a pre-assessment of variable potential prior to 0-1 integer programming. This is carried out by first treating the situation as a 'knapsack' problem and loading the variables (assigned a value of 1) in descending order of smallest constraint satisfying cost. Using a 'bang for buck' ratio concept, variables are ordered on the basis $c_1/w_1 \geqslant c_2/w_2 \geqslant c_n/w_n$, where c indicates the influence of the variable on the objective function and w indicates the influence of the variable on the constraints. This allows a 'knapsack' dominance test to be used. The 'knapsack' is loaded until a constraint is violated, whereupon the tree-search programme is set into operation from this node. Although not fully suited to the present application, since the objective function's only significance is that it forces the minimum slack time into the constraints, this technique emphasises the usefulness of giving the programme a 'good' start.

Few practical applications of 0-1 integer programming for solving scheduling problems could be found in the literature. In fact, the only one of any significance to this thesis was that described by Patterson[53]. He used the algorithm to solve an assembly line balancing problem, and in doing so, extolled the virtues of pre-programme adjustment of variables. The procedure consisted of choosing groups of jobs to be processed at various work stations along a continuous production line, such that the total throughput time was minimized.

8. BENEFITS TO THE PROBLEM

This section is devoted to a critical analysis of the two models. Included is an assessment of both implementation difficulties and likely benefits to the two companies followed by a consideration of possible adaptation by the foundry industry in general.

8.1 Improvements Accruing from the Adaptation of such Systems to the Two Companies

8.1.1 Implementation by Spunalloys

Although not presently included in the programme since they would serve no useful purpose, write statements could be inserted so that details of job sequencing during the simulation might be reported. This would enable the completion time of an order to be ascertained and hence the determination of an accurate delivery date.

A facility not previously mentioned is that if so desired, early delivery can be accomplished. Designation of a high priority number can 'force' the choice of an order during a particular processing period. In other words, degrees of urgency associated with various orders could be recognised and acted upon.

More constistent output will show many benefits including greater workforce satisfaction through more stable earnings (wages partly controlled by output level) and improved predictability of profits. Less non-productive time must also promote accurate costing.

Stock control improvements have not been achieved by the programme, but as explained earlier, this is almost certainly the fault of inaccurate data.

Proof of improvement can only be fully accepted if the programme is run using actual data and a comparison with real results made. But a number of factors deter the author from doing this. On the strength of the experience gained during data gathering for the Monte Carlo based order generation routine, the exercise of converting the current order book would be a formidable one. In addition, depending upon the length of the trial, several months would need to elapse before decisive conclusions could be drawn. Also, because of inaccurate machine shop times, only the foundry schedule could be used to provide the comparison. Finally, the production pattern could very well be modified from that which existed when the programme was first envisaged, i.e. die range could have changed as could the identity of the furnaces currently employed.

However, a point which is perhaps more pertinent than any of the previous in deciding against such a course of action is that ostensibly the exercise has already been carried out. Order generation is based upon information taken from the order book existing at the time of programme construction. Since the order array so produced has been shown to accurately reflect the pattern of the order book from which it was derived, a programme run is effectively a simulation of production during that period, i.e. 1st July 1976 to 28th September 1976 inclusive.

The output figures for this period are shown in Table 7.2 and a favourable comparison is made with results obtained from the model in section 7.2.1. But a factor which is lacking is a comparison of predicted and actual delivery dates, i.e. programme results compared to those obtained by the company.

It is recognised that prompt customer notification of delivery date could constitute difficulty because a true fix would not be forthcoming until the job was eventually scheduled by the model. However, the ability to firmly detail short term production schedules should allow the manual prediction of longer term production. Since present delivery date estimation procedure has been shown to be exceedingly inaccurate a model aided alternative must have a high chance of providing improvement.

The model shows higher and more stable output during the period under consideration. Hence, had the programme been used during this period, the 25 per cent profit margin added to the cost of manufacture of each casting would be realised for the extra tonnage made. Unfortunately, production costs were unavailable to this research; therefore a true financial balance cannot be established. However, if the manufacturing cost of a casting is restricted to 1/2 the market value of its metal content (advised by the company) and in turn, the metal is considered to be phosphor bronze (PB1 the most popular alloy), then a simple and certainly conservative appraisal becomes possible.

The analysis information derived for the statistically significant difference between data groups 3A and G (details in Tables 7.2 and 7.3) enables both a pessimistic and optimistic figure (at a suitable confidence level of say 95 per cent) for the difference between true and theoretical output tonnages to be established. Table 8.1 shows the calculation involved.

The minimum difference is 3.87 and the maximum 8.97 tonnes per week. A convenient average for the market price of PE during 1977 (when the programme was run) is £1200 per tonne. Applying the pessimistic figure, extra profit available per week using the model is £195, while the optimistic figure is £450 (2/3 rough casting removed).

The cost of realising this extra capital must be dependent upon the computer time required for simulation (if the cost of programme construction is ignored). Execution time for the programme was found to depend upon the period of time simulated and the order book lead time. The latter stems from increased order book scanning as lead time becomes greater. However, at the time of the survey the lead time was 9 weeks, therefore, this figure was chosen for the comparison.

Implementation by the company would involve simply a substitution of the first sub-programme (order generation) with a routine allowing direct feed of customer order details. From information derived during the early stages of programme development, order generation time during a 3 month simulation run is 426 seconds (192 + 192 x 11/9). Since full simulation occupied an execution time of 3356 seconds, simulation of one week would require 245 seconds ([3356 - 426] x 1/12). This gives a cost, at present University of Aston rates, (2.2p per second - comparable to bureau rates) of £5.38.

Thus, under the worst circumstances, a weekly profit improvement of £190 is immediately accomplished, with the prospects of up to £445

Table 8.1. Estimation of maximum and minimum values of output tonnage improvement by the model over figures actually achieved by Spunalloys - obtained by a comparison of means of the two sets of data at a 95 per cent confidence level.

Data group identity	Estimate of mean $\overline{x}$	Number of values in group n	Estimate of standard deviation s	Variance of data s^2	Degrees of freedom ϕ (n - 1)	Standard error of difference of means S.E. $(\overline{x}_1 - \overline{x}_2) = \sqrt{\frac{s_1^2}{(n_1-1)} + \frac{s_2^2}{(n_2-1)}}$	t value from tables at P = 0.05 level according to degrees of freedom $(\phi_1 + \phi_2)$	Comparison of means according to $(\overline{x}_1 - \overline{x}_2) \pm$ S.E. x t	Minimum value of difference between means	Maximum value of difference between means
3A	33.97	4	0.86	0.729	3	1.5	1.76	(33.97 - 27.55) ± 1.5 x 1.8	3.87	8.97
G	27.55	12	4.65	21.6	11					

Note.

The t test is single sided since the hypothesis being tested is $\overline{x}_2 \leqslant \overline{x}_1$ and the Null Hypothesis is rejected if $\overline{x}_1 > \overline{x}_2$.

becoming available. When expressed as a percentage of present output tonnage, these extra output tonnages realise the values 14 and 32.5 which should of course be added to the unestimatible savings associated with greater customer and operative satisfaction. In addition, production control personnel would be released from the present major pre-occupation of progress chasing, allowing more customer liaison which might promote movement toward manufacture for 'shelf' rather than to customer order.

This line of thought assumes weekly programme runs confined to providing the schedule for the following week. In practice this might not prove wholly satisfactory. For example, forward planning and the need for continuity might require information on likely job sequence up to say four weeks ahead. However, such are the magnitudes of difference between costs and savings that complete flexibility exists regarding length of simulated time per weekly (or even daily) programme run.

Detailed information on virgin ingot requirements could be made available. This would enable a re-ordering routine to be planned which could take into account minimization of stock holding together with a purchasing policy based on metal price fluctuation. Also, precise control of rough castings stock, via recourse to overtime and outside capacity, could be maintained (suitable programmes incorporated).

When once firmly established, various cost control parameters could be built on, opening the way for eventual Standard Costing and Budgetary Control, so necessary at Spunalloys if the company is to progress.

8.1.2 Implementation by Bridge Foundry

The 0-1 integer programming routine has been shown to be well suited for scheduling production at Bridge Foundry. Unfortunately, computation time for optimal solution determination increases rapidly with problem size. This severely restricts the effectiveness of the technique.

Results have shown the following developments to be of benefit:-

(i) problem size reduction by restriction to fewer constraints

(ii) acceptance of a 'good' solution rather than the optimal solution

(iii) use of Fortran language rather than Algol

Although algorithm modifications aimed at improving enumeration efficiency are worthy of further investigation, it is felt that their effect will be only marginal. Instead, it is contended that pre-programming assistance prior to matrix tableau assembly will give greatest benefit.

If the jobs included for selection by the programme are restricted to those jobs with a high probability of acceptance, then the 'good' solution subsequently generated will be improved. This facility could put even the optimal solution within grasp.

During development of the model the rotary saw production centre appeared to constitute the critical constraint. But because of the restricted range of actual schedules dealt with (two), it is felt that under alternative circumstances the principal constraints might be shifted to some other production centres. Obviously, only experience through extensive use of the model will reveal this.

However, if the dressing shop requirements of jobs could be identified quickly, then compulsory job nomination through control of the remaining slack capacities of the various production centres could be used for the informed reduction of the 'choice' job list. In other words, isolation of the critical constraints for a particular run would allow those jobs in the 'choice' job list making heavy demands on the critical constraint to be identified and hence, discarded. Likewise, those making light demands would be transferred to the compulsory job group. Eventually, the array size would be pruned to a realistic level.

Classification constitutes a suitable means of quick identification of dressing shop requirements for the various jobs, a series of digits being employed to make such identification. It is proposed that numbers from 0-9 be used to signify narrow ranges of requirement for the various production centres (four or nine depending upon experience). In this manner, identification coding of all the jobs could be carried out and if so desired, could be extended to include information regarding alloy type, quality control demands and heat treatment details.

Simple appraisal of the various digit columns for the 'compulsory' job series would allow rapid approximation of work centre committments. This could then be followed by segregation of the 'choice' job list, giving programme matrix reduction down to a realistic level. In this manner, the mathematical routine would be used to maximum advantage.

Introduction of a classification system would make available many alternative Group Technology benefits. These include design retrieval, cost estimation and subsequent price determination, and most ambitious of all, cellular structurisation of the manufacturing base. This latter proposal would ease scheduling difficulties considerably. By using Product Flow Analysis techniques, jobs could be partitioned into groups having manufacturing similarities, allowing production facilities to be set up specifically catering for each group or number of similar groups.

In this respect, larger castings, which normally require Sawyer/grinding dressing shop treatment, as distinct from smaller castings which utilise Ballinger/linishing facilities, could be confined to a production centre catering specifically for this range of casting and vice-versa. The initial diecasting function could even be included here, since heavy jobs are usually associated with semi-mechanization such as pneumatically operated die opening and closing procedures and tilting tables. However, some flexibility regarding the various proportions of heavy and light jobs in the job mix might be lost.

The financial attributes of incorporating a 0-1 integer programming algorithm into the scheduling routine at Bridge Foundry must be formulated by weighing costs against savings. It is convenient to note at this juncture, that during the time interval between investigation and processing of the initial two production runs, the company finalised a fresh production and wage agreement with the operatives. In doing this, they made the data bank for the programme obsolete. This, unfortunately, precluded further realistic application of the programme without considerable modification to the data.

These two examples of the weekly schedule are shown in Table 8.2, where comparisons are drawn between the hand constructed versions and those arrived at by the programme. For reasons argued previously, the dressing shop constraints have been reduced to 4 (instead of 9) and unlimited job choice allowed. A simple, but not necessarily complete, financial appraisal can be made if both slack time and over capacity time for the various dressing shop sections is costed at operatives rate plus an allowance for indirect costs. It is appreciated that overtime working will command a higher rate, but this will be countered by the financial benefits associated with a higher turn over (improved profit margin and lower proportions of indirect costs and overheads).

Dressing shop rate (all sections), as advised by the company, is approximately £2 per minute; hence, totalling slack time and over capacity time for both the hand and computed schedules gives results for the two examples as shown in Table 8.3.

Savings made by the computer programme over the hand schedule are compared with the cost of computer run time. As seen, the breakeven or maximum execution time which can be allowed, taking computer time on the CDC 7600 to cost £1 per second, is 800 seconds approximately. Obviously, pre-programme manipulation of the job matrix using classification techniques, plus the use of Fortran as opposed to Algol, will considerably improve on this.

If the schedule were requesting choice from 68 jobs, which appears to be the average, then according to Table 7.11 and Graph 7.4, approximately 160 seconds would appear to be the best compromise

Table 8.2. Comparison of hand constructed schedules with equivalent ones compiled using the 0-1 integer programme.

Calculation number	Description of parameters under consideration		Sawyer + Ballenger sections	Grind + Linish sections	Male file section	Female file + Disc + Press + Ream sections
	Total minutes per day of production time available (applies to both schedules)		4470.0	5600.0	5200.0	4660.0
			SCHEDULE NO. 1 (considered in Tables 7.8., 7.10 and 7.11.) 63 compulsory choice jobs, 68 possible choice jobs from which 58 were required for selection			
	Total minutes per day of production time actually scheduled		4638.65	5841.84	4933.50	4465.73
1	Difference between minutes per day available and those actually scheduled		-268.65	-241.84	266.5	194.27
	Programme execution time - secs.	Number of jobs chosen	Difference between minutes per day available and those scheduled by the programme			
2	8.8	46	1.65	402.63	66.90	308.32
3	160.1	45	8.50	285.25	80.90	171.12
4	805.8	44	3.45	255.10	80.90	80.32
			SCHEDULE NO. 2 66 compulsory choice jobs, 70 possible choice jobs from which 56 were required for selection			
	Total minutes per day of production time actually scheduled		4463.14	4723.11	4914.30	4197.03
5	Difference between minutes per day available and those actually scheduled		6.86	266.89	85.7	262.97
	Programme execution time - secs.	Number of jobs chosen	Difference between minutes per day available and those scheduled by the programme			
6	163.2	61	10.21	56.48	94.72	283.63

Table 8.3. Comparison of costs associated with hand constructed schedules with the equivalent ones compiled using the 0-1 integer programme.

Calculation number (from Table 8.2.)	Total slack time + overtime per day for all dressing shop sections - mins	Associated cost of total slack time + overtime per day for all dressing shop sections assuming £2 per min.	Cost of running the programme assuming £1 per sec. execution time
	SCHEDULE NO. 1		
1	871.26	£1742.52	
2	789.5	£1579.00	£8.8
3	645.77	£1291.54	£160.1
4	419.77	£839.54	£805.8
	SCHEDULE NO. 2		
5	622.42	£1244.84	
6	445.04	£890.08	£163.2

between programme execution time and solution improvement. To further aid performance at the 160 seconds time limit such that a 'good' solution is based on enumeration of at least 1/10 the possible combinations (a fraction advised by the literature as being a figure to aim for), would require the number of jobs offered for choice to be reduced to approximately 55 ($2^{55} = 10^{16.6}$). Formulation of an optimal solution would require reduction of the job choice to at the most 52 ($2^{52} = 10^{15.6}$).

This observation agrees favourably with programme trial results (see Table 7.1), although modification of matrix size obviously alters rate of enumeration. Incorporating the above ideas will, therefore, marginally alter the optimum cut-off point and the figures shown.

More precise knowledge of job requirements for the various production centres will allow realistic allocation of both direct and indirect costs. This will be endorsed by improved regularity of working with respect to slack time and over capacity time. Classification will be of additional aid here, since similar castings will have similar cost make-up, allowing anomalies to be quickly spotted. Information on the profit margins capable of being realised by various types of casting would indicate 'desirable' and 'undesirable' jobs within a group of similar castings. Since these would be realising margins much less or much greater than the average, advantageous investigation of them could be carried out.

8.2 Association with the Foundry Industry at Large

The foundry industry embraces very wide and diverse manufacturing techniques with only the casting of molten metal registering as the common production activity. Unfortunately, the case studies chosen are not very representative of foundries in general, since neither includes the use of sand moulds, nor is involved in the casting of ferrous metals.

However, in so far as these case studies accurately describe the production conditions associated with jobbing, batch and long run type manufacture, it should not be too difficult to extend many of the ideas formulated to other types of foundry. The experience gained by the author in his contacts with a wide cross-section of the industry during the early periods of this work is of considerable help here.

Any situation in which there is competition for resources together with job sequence constraints, and where there is variety of job identity (strongly jobbing), then ideas of the type formulated in the simulation model ought to be applicable. In the Spunalloys study, competition existed for dies, furnaces and cutting machines, but this could easily be transferred to a grey iron situation where demand is being made for core-making facilities, moulding sites (perhaps pit moulds which are non-transportable) and surface dressing facilities.

However, because of the tremendous individuality associated with jobbing foundries, for a simulation programme to be as effective as the one built for Spunalloys, it would have to be tailor-made to suit the situation being controlled.

Few foundries can be described solely as jobbing, batch or long run, most are hybrids of two or even all three of these. Nevertheless, in contrast to the individuality of control systems for essentially jobbing foundries, batch/long run producers of castings, all experience load balancing difficulties of one form or another. Logically, this is to be expected, since flow type processing is a strong characteristic of them all.

Certainly, other gravity and pressure diecasters have similar identity of manufacture to that of Bridge Foundry since by definition, they are restricted to work for which there is extensive repetition. Likewise, sand casters of ferrous alloys, who fall within this category, have the same basic production flow systems, although here such activities as core-making, core-laying and rate of molten metal consumption are important features of control.

Traditionally, as with Bridge Foundry, it has always been mould-making or casting which has held the primary role in the job scheduling exercise, all other functions being subservient to it. However, in view of the shortcomings exposed in this thesis, it would seem beneficial if individual foundries determined their schedule sensitive areas and built job selection systems around these. But whatever the circumstance, in all situations where various constraints need to be complied with in choosing job combinations, optimization routines such as the mathematical programming algorithm will have application.

Foundries contemplating the introduction of these ideas will probably incorporate Group Technology by way of classification as a pre-programming aid to scheduling. Such identification of job similarity will promote manufacture of castings by group.

Closer identification of costs associated with similar castings will be made possible, and by smoothing the fluctuations in work in process figures by improved scheduling and cellular production, more accurate cost assessment of the otherwise difficult associated indirect cost parameter will be forthcoming.

RECOMMENDATIONS FOR FUTURE WORK

Being of such a basic nature, this thesis has generated a multitude of ideas for further work and development. Immediately obvious is the need to completely establish and implement the job scheduling systems built for Spunalloys and Bridge Foundry. With respect to the former, this will initially entail work study to obtain accurate process detail for the machine shop and to establish a firmer stocking policy (virgin ingot re-ordering practice). The latter, on the other hand, requires complete up-dating of the data bank to accommodate recent revision of operatives rates of pay, plus the creation of a suitable classification system to aid rapid identification of the dressing shop sectional requirements for the various jobs.

Integration of the systems into the management functions of the two companies should facilitate further pursuits. At Bridge Foundry these include:-

(i) a comparison of alternative formulations of objective function and constraints

(ii) more precise information regarding size of matrix offered for choice to the 0-1 integer programme and its effect on the development of 'best' and optimal solutions

(iii) determination of any useful advantage to be gained (rapid isolation of an optimal solution) by including in the programme the various surrogate constraints described in the literature

At Spunalloys such pursuits include:-

(i) the influence of order book description (size and make-up) on level of production

(ii) the above should allow investigation of the policy change, manufacture for 'shelf' rather than to customer order - a routine simulating market variations could be included (use of forecasting techniques)

(iii) formulation of a stocking policy geared to copper base alloy price fluctuations.

With respect to more long term areas of study, an important aspect for future work is a tie-up between production control and financial control. Production control and financial control do, of course, constitute parallel development pursuits, which, while having separate natures, at the same time, have appreciable interdependence.

At Spunalloys this means the formulation of Standard Costing and Budgetary Control systems and at Bridge Foundry a more precise apportionment of overheads to the various jobs included in the weekly schedule. Planning policy deliberations could also be included here. This is of particular interest to Spunalloys, who must frequently ponder the purchase of more semi-automatic Bushmaster casting machines. Finally, creation of a classification system and corresponding incorporation of Group Technology ideas must surely invite investigation of eventual turn over to cell type manufacture at Bridge Foundry.

Work such as this and the ideas promoted by it must have wider applications in castings' manufacture. Hence, investigation of possible adaptation of both case studies to other foundries provides endless scope for future work.

DISCUSSION

Detailed examination of management aspects of the foundry industry, together with the isolation and subsequent development of suitable case studies, has proved a worthwhile exercise, if only in its identification of the urgent need in this field of manufacture for work on control systems. Although motivation must always be based on continued financial well-being, customer and workforce satisfaction are the ideals at which initially to aim. As a service industry, foundries must be able to rapidly re-orientate manufacture to comply with customer wishes, but at the same time this should create minimum dislocation to business fluency and employee participation. Deficiencies in these ideals are advocated as the central cause of the decline problem currently being suffered by the industry, and for which no permanent solution will ever be forthcoming until such ideas and policies are accepted.

But these are contrasting ideals, which will never achieve a satisfactory balance until a full knowledge of working parameters and their associated monetary effects become established. This invariably means precise production and cost control, which, in view of the servicing nature of these businesses, is primarily rooted in job scheduling. It is incidental to note that these difficulties are becoming ever magnified by increasing mechanization and automation.

Hence, the establishment of a more informed job selection procedure constitutes the platform on which more relevant production planning and control and financial policies can be fixed. This improved command of the manufacturing base will allow decision making at all levels to be of greater significance. In fact, it is advocated that the introduction of other skilled management control systems cannot achieve full fruition until the job selection routine is a satisfactory one.

However, before developing this theme further, manufacturing description should be mentioned because of its important role in the study of job scheduling. Separation into job, batch and long run is needed for detailed examination of scheduling systems, although most companies are hybrids of these.

Job selection systems must be built to satisfy individual needs; nevertheless, while those foundries primarily engaged in jobbing find job sequencing the main area of concern, those involved in batch, and to a lesser extent, long run production, see job mix as the crux of their scheduling activity. Both constitute formidable tasks, with optimum scheduling of the jobbing foundry being generally beyond the scope of present facilities.

These points are demonstrated in the two case studies. At Spunalloys, due to imprecise job sequencing, delivery date prediction is wildly inaccurate, little control can be exercised over stock levels and output fluctuations are considerable. In addition, cost control is almost non-existent. Bridge Foundry, on the other hand, in acknowledging deficiencies associated with the formulation of product mix, see this as the cause of unbalanced work flow through the various dressing shop sections. This results in work load variations at these production centres which in turn promotes fluctuations in the size of work in process. Both contribute significantly to the uncertainties associated with overhead cost apportionment.

Neither of the two models built to overcome these deficiencies is completely successful. However, both are shown to have financial benefit - a fact which does not include the unestimatable value of improved customer and employee satisfaction which also results.

While the simulation model suffers the handicap that certain process detail is inaccurate, plus the restriction of using the Monte Carol technique for order book generation rather than processing the real order book, higher and less variable output tonnages are achieved and improved stock control is shown to be possible. Also the opportunity to introduce Standard Costing and Budgetary Control becomes available together with the contemplation of changeover to manufacture for 'shelf' rather than to customer order. Both are seen as long term objectives by Spunalloys.

In contrast, the 0-1 integer programming algorithm is unable to isolate an optimum solution in reasonable time when handling the full Bridge Foundry scheduling problem. However, restriction to a 'best' solution rather than an optimal one should enable a satisfactory job mix to be chosen. Introduction of a classification system will not only allow more effective use to be made of the mathematical programme through informed reduction of the jobs available for choice, but by providing the base for other Group Technology applications should enable thought to be given to an eventual changeover to cell manufacture and the associated improvement in both production and cost control.

Both case studies underwrite the tremendous potential for business viability associated with improved scheduling. However, of even greater merit is the fact that in spite of the individuality associated with various foundries there is sufficient common ground to enable the application of such systems (with modification) to be widespread amongst the industry.

CONCLUSIONS

(1) Evidence relating to output and true values of sales indicate the foundry industry to be in a state of serious decline.

(2) Although partial responsibility for this decline can be offset against the substitution of metal castings by alternative materials and manufacturing techniques, a significant proportion of the blame must be levelled at a lack of control of essential business parameters.

(3) Financial viability must rank as the most important objective of any foundry company; nevertheless, being a service industry, customer satisfaction must command important concern as must employee contentment.

(4) To ensure complete progress, development of foundry management systems must proceed along the parallel fronts production control and financial control. But while both have a separate identity there is a large degree of interdependence between them.

(5) Efficient job scheduling is advocated as a prime factor in establishing high customer satisfaction and being a basic activity serves as a foundation upon which all other control (production and cost) systems can be built.

(6) Since this thesis can only cover a narrow sector of the development areas indicated, efficient job scheduling is the theme concentrated upon in the two case studies.

(7) In the case study chosen to represent jobbing/batch type production (Spunalloys), job sequencing inability gives rise to erratic delivery date, poor stock control and output fluctuation, all of which promote a lack of financial control.

(8) In the case study chosen to represent batch/long run type production (Bridge Foundry), failure to choose the correct job mix gives rise to fluctuations of work in process due to queue length variations in front of the various dressing shop sections. These, in turn, lead to difficulties in the accurate apportionment of overheads.

(9) Due to the complexity of production at Spunalloys, the control system developed is a simulation model which has not been totally proven due to a lack of accurate process data for the machine shop. Nevertheless, foundry output figures from the model are encouraging, showing financial benefit when compared to figures obtained in practice.

(10) The system built to cater for Bridge Foundry uses a 0-1 integer programming algorithm. Although designed to generate an optimum solution for the product mix problem, the size of job choice in a normal schedule is too large for the programme to handle in a reasonable amount of computer time. Acceptance of a 'best' solution rather than an optimal one shows the programme to be financially feasible. However, the construction of a classification system could be instrumental in initially moving the problem toward an optimal solution prior to use of the programme.

(11) Successful implementation of the simulation model should allow the introduction of Standard Costing and Budgetary Control at Spunalloys, and enable manufacture for 'shelf' rather than to customer order to be studied.

(12) Successful implementation of the 0-1 integer programme in steadying the work in process figure, should allow more accurate overhead cost apportionment and give opportunity for full computerization of the costing system. The introduction of a classification system, by giving a lead in to Group Technology, should provide various benefits, the most important of which is the promotion of cell manufacture, seen as an outstanding asset to Bridge Foundry.

(13) Application of these techniques with modifications for individual foundries is wide in both the ferrous and non-ferrous sectors, and should help to stem the rate of decline in the industry.

REFERENCES

1. Williams, H. E: 'The Suppliers Predicament'
The British Foundryman, August 1975, Vol. 68, part 8, p 216-220

2. NEDO: 'Iron and Steel Castings Industrial review to 1977'
published by National Economic Office

3. Lamont-Smith, S. G: 'Medium term prospects for ferrous industries'
The British Foundryman, November 1975, Vol. 68, part 11,
p 281-285

4. Anon: 'Investment in foundries, 1975', published by Green and Co.,
members of the Stock Exchange

5. Anon: 'Supplier/Customer conference', Foundry Trade Journal,
August 15th 1974, p 215-232

6. Williams H. E: Private communication

7. Baring, P and Haywood-Shott, D: 'Financial controls in foundry
marketing management', The British Foundryman, June 1976,
Vol. 69, part 6, p 135-140

8. Anon: 'Ironfoundry review', Financial Times, February 28th 1975

9. Ellis, K. R: 'Productivity in the foundry industry',
The British Foundryman, August 1974, p 205-213

10. Schaum, J. H: 'Lagging Productivity', Modern Castings,
September 1975

11. Kay, A: 'Diecasting - 75 years of development'
Foundry Trade Journal, August 18th 1977, p 389-408

12. Brouns, W: 'A new approach to an iron foundry finishing problem'
Foundry Trade Journal, February 5th 1976, p 139-167

13. Laurent, B. P: 'Robot operation improves quality standards'
Diecasting Machines & Materials, January/February 1976

14. Binmore, A. C: 'Industrial engineering'
The British Foundryman, July 1977, Vol. 70, part 7, p 183-190

15. Anon: 'Statistical review 1973-1974', published by the Foundry Industry Training Committee

16. Cooke, A. J: 'Management attitudes and techniques in the future', The British Foundryman, November 1971, p 411-418

17. Anon: Leader article, Foundry Trade Journal, March 4th 1976

18. Farrant, D. L. and Reynolds, J: 'Future strategy for the UK ferrous foundry industry', The British Foundryman, August 1977, Vol. 70, part 8, p 227-234

19. Davis, F. H: Presidential Address, The British Foundryman, June 1976, Vol. 69, part 6, p 133-134

20. Trinder, C. V. and Watts, G. A: 'Production Control in the non-ferrous castings industry', Institute of British Foundrymen Conference Paper, 1973

21. Benz, H: 'Production control and scheduling in a foundry by means of Electronic Data Processing', Foundry Trade Journal, April 11th 1974, p 395-400

22. Binmore, A. C: 'An inroduction to the use of computers as an aid to foundry management', The British Foundryman, June 1969, p 224-229

23. Reynolds, J. A: 'The prospects for cast metals', The British Foundryman, September 1973, Vol. 66, part 9 p 245-257

24. Fugel, T. F: 'A marketing approach to foundry planning' Modern Castings, January 1977, Vol. 67, No. 1, p 48-52

25. Powell, R: 'Director's guide to management techniques' published by Gower Press Ltd., 1974

26. Conway, W., Maxwell, W. and Miller, L: 'Theory of scheduling' published by Addison-Westly Co., 1967

27. King, J. R: 'The theory-practice gap in job-shop scheduling' The Production Engineer, March 1976, p 137-141

28. Anon: 'Deere Waterloo's computer recording system', Foundry M & T, September 1975

29. Hollinshead, H. W: 'Foundry control by computer', S.C.R.A.T.A. Annual Conference 1972, Paper 12:1

30. Anon: 'Thomas Seeger Ltd. - a decade of progress', Foundry Trade Journal, June 13th 1974

31. Law, T. D. and Green, R. J: 'The use of computers for foundry scheduling and production control', The British Foundryman, May 1970, p 138-153

32. Dartmouth-Autocast Foundries Ltd., a private communication

33. Jones, G. L: 'Computer aided production control for jobbing and short series foundries', Foundry Trade Journal, March 3rd 1977, Vol. 142, No. 3106, p 439-442

34. Thapar, A. K: 'An assessment of packages for computer aided production control in ferrous foundries', M.Sc. thesis, University of Aston, September 1974

35. Burbridge, J. L: 'Production Flow Analysis', The Production Engineer, May 1971, p 139-152

36. Ainstie, J. N: 'Design of a castings classification system' M.Sc. thesis, University of Aston, September 1974

37. Newman, T. D: 'Aspects of developing foundry classification schemes particularly for cost-estimating', M.Phil. thesis, University of Aston, September 1975

38. McMillan, C: 'Mathematical Programming', published by John Wiley & Sons, Inc., 1970

39. Geoffrion, A. M: 'Integer Programming by implicit enumeration and Balas' method', S.I.A.M. Review, Vol. 9, No. 2, April 1967

40. Byrne, J. L. and Proll, L. G: 'Remarks on algorithm 341(H) solution of linear programs in 0-1 variables by implicit enumeration', Communications - A.C.M., 1968, Vol. 782, 11th November, p 782

41. Gordon, G: 'System Simulation', published by Prentice-Hall, 1969

42. Shipley, F: 'Use of simulation modelling methods,to predict the utilisation of reorganised melting plant in a non ferrous industry', M.Sc. thesis, University of Aston, October 1976

43. Geoffrion, A. M: 'An improved enumeration approach for Integer programming', The Rand Corporation, June 1968, RM-5644-PR

44. White, D. J: 'An imbedding approach to additive value zero-one problems', Management Science (USA), September 1973, Vol. 20, No. 1, p 85-100

45. Byrne, J. L and Proll, L. G: 'Initialising Geoffrion's implicit enumeration algorithm for the zero-one linear programming problem', Computer Journal, November 1969, 12, 4, p 381-384

46. Roodman, G. M: 'Postoptimatality analysis in zero-one programming by implicit enumeration', Naval Research Logistics (USA), September 1972, Vol. 19, No. 3, p 435-437

47. Fiala, F: 'Algorithm 449 Solution of linear programming problems in 0-1 variables', Communications A.C.M., July 1973, 16, 7, p 445-447

48. Ellwein, L. B: 'A flexible enumeration scheme for zero-one programming', Operational Research (USA), January 1974, Vol. 22, No. 1, p 144-150

49. Christofides, N: 'Zero-one programming using non-binary tree-search', Computer Journal (G.B.), November 1971, Vol. 14, No. 4, p 418-421

50. Fiala, F. and Mahendrarajah, A: 'A comparison of three algorithms for linear (0,1) Programs', A.C.M. Trans. Math. Software (USA), December 1976, Vol. 2, No. 4, p 331-334

51. Zionts, S: 'Generalized implicit enumeration using bounds on variables for solving programs with zero-one variables', Naval Research Logistics (USA), March 1972, Vol. 19, No. 1, p 165-181

52. Nauss, R. N: 'An efficient algorithm for the 0-1 knapsack problem', Management Science, September 1976, Vol. 23, No. 1, p 27-31

53. Patterson, J. H: 'Assembly line, zero-one programming, with Fibonacci search', Operational Research (USA), January 1976, Vol. 23, No. 1, p 166-172

CONTACTS

Below is shown a list of individuals and associated organisations with whom theauthor made personal contact and in many instances visited.

1. Mr. K. Walton, Financial Director and Mr. F. Pye, Production Controller, Chamberlin & Hill Foundry Ltd., Walsall

2. Mr. J. Lees, General Manager, Metro-Foundry Ltd., Brierley Hill

3. Mr. J. McMorry, Technical Director, Amblecote Foundry Ltd., Stourbridge

4. Mr. J. R. Smith, Managing Director, Mr. R. Smellie, Commerical Director and Mr. J. Rickhoss, Production Controller, C & D Smith (Foundry) Ltd., Wednesfield, Wolverhampton

5. Mr. M. S. Owen, Director, Hoskyns Computer Systems Ltd., Broad Street, Birmingham

6. Mr. D. Martin, Production Controller, Bean Industries (Foundry) Ltd., Tipton, Staffs.

7. Mr. S. Leyland, Foundry Manager, Cradley Foundry and Engineering Co., Cradley Heath

8. Mr. B. Mail, Production Controller, Cradley Castings Ltd., Cradley Heath

9. Mr. T. Watts, British Non Ferrous Association, Wantage

10. Mr. R. Leighton, Production Controller, Clancey Ltd. (Foundry), Halesowen

11. Mr. C. N. Grigsby, Manager UK, British Ronceray, (manufacturers of foundry equipment), Tamworth

12. Mr. A. Fuller, British Cast Iron Research Organisation, Redditch

13. Mr. N. Jones, Commercial Director, Fordath Engineering Co., (manufacturers of foundry equipment), West Bromwich

14. Mr. W. A. Train, Chief Designer, Maverex Ltd., (designers and builders of foundries), Cradley Heath

15. Mr. L. Chaiter, Purchasing Manager, Production Purchasing, (castings' buyer), British Leyland, Longbridge, Birmingham

16. Mr. M. Shippel, Manager, Disa (UK), (manufacturers of foundry plant), Walsall

17. Mr. D. Osborne, Purchaser Foundry Products, Perkins Engines Ltd. (castings' buyer), Peterborough

18. Mr. R. Langford, Foundry Manager, Conegrie Foundry Ltd., Tipton

19. Mr. P. Perry, Training Officer, Birmid-Qualcast Ltd., West Bromwich

20. Mr. F. Spencer, General Manager, Duport Foundries Ltd., Tipton

21. Mr. S. Lamont-Smith, Former Chairman of the Foundry Committee, N.E.D.O. Office, London

22. Mr. A. Staves, Sales Director, British Industrial Sands (foundry supplier), Kings Lynn

23. Mr. G. Mellor, Production Controller, Perry Barr Metals (light alloy diecasters), Perry Barr, Birmingham

24. Mr. T. White, Production Controller, Fry's Diecasting, Stourbridge (light alloy diecasters)

25. Mr. N. Button, Technical Director and Mr. R. Butler, Production Controller, Qualcast Foundry Ltd., Wolverhampton

26. Mr. L. Staffings, Managing Director, Dartmouth Autocast and Midland Motor Cylinder, Smethwick

27. Mr. B. Wilson, Commercial Director and Mr. A. Griffiths, Production Controller, John Harper Foundry Ltd., Walsall

28. Mr. D. Silcock, Managing Director and Mr. S. Mason, Works Director, F. H. Lloyd, Darlaston

29. Mr. G. Smith, Engineer (briefed to implement Ryder report in respect of the foundry division), British Leyland Ltd.

30. Mr. S. Moore, Cannon Industry (Foundry) Ltd., Deepfields, Bilston

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APPENDIX I

Die sizes available at Spunalloys.

Die sizes available for heavy horizontal section.

Size range. mm.	330 - 380		381 - 431		432 - 482		483 - 532		533 - 584		585 - 635	
Dimensions. mm.	O.D.	Length	O.D.	Length	O.D.	Length	O.D.	Length	O.D.	Length	O.D.	Length
	305	507	387	318	454	279	483	445	533	76	597	229
	349	432	394	521	445	445	495	216	546	102	622	445
	349	1054	419	495	451	432	492	432	572	216		
					470	222	508	213	572	406		
					457	229	527	216				
							521	495				

Die sizes available for heavy vertical section.

Ring system	35" Table		45" Table		50" Table		65" Table	
Diameter range mm.	406 -- 737		711 -- 940		914 -- 1194		1164 -- 1474	
	O.D.	Length	O.D.	Length	O.D.	Length	O.D.	Length
	482	80	761	79	958	51	1270	165
	482	80	761	79	958	114	1358	76
	507	165	825	89	964	51	1358	83
	533	76	825	140	964	89	1396	121
	554	76	876	82	1009	140	1466	133
	559	146	876	120	1054	137		
	596	83	876	171	1054	165		
	596	102	902	76	1161	165		
	647	57	902	140	1196	140		
	647	140	939	165	1207	76		
	647	143			1240	38		
	673	127			1240	51		
	673	130						
	685	86						
	723	86						
	723	133						
	723	136						
	723	140						
	723	70						
	736	76						

Die sizes available for Bushmaster section.

Size range mm.	Individual die diameters available in size range mm.				
93 - 101	93	98			
102 - 126	103	108	114	118	125
127 - 152	130	135	140	145	149
153 - 177	155	160	172		
178 - 203	181	191	201		
204 - 228	213	222			
229 - 254	233				
255 - 279	254	263	273		
280 - 304	283	293	303		
305 - 330	313				

All steel dies for the Bushmaster section are available with a standard length of 648 mm.

Die sizes available for non standard section.

Graphite dies for the non standard section are available for a spread of diameters matching those used on the Bushmaster section but with standard 8 and 16 inch (203 and 406 mm.) die lengths. In addition a miscellaneous array of steel dies are available to the section.

Diameter range mm.	279 -- 304		305 -- 330		331 -- 355		356 -- 380		381 -- 405		406 -- 432	
Dimension	O.D.	Length	O.D.	Length	O.D.	Length	O.D.	Length	O.D.	Length	O.D.	Length
	279	83	305	203	337	216	356	127	381	114	419	121
	279	165	318	216	330	318	362	268	387	216	419	216
	286	210	311	248	349	398	368	248	400	216		
	299	203	324	210								
	299	267	305	533								

APPENDIX II

Production control proficiency at Spunalloys and Bridge Foundry.

Section 1: Customer orders and delivery analysis.

Section 2: Weekly output statistics.

Section 3: Monthly ingot and work in process stock statistics.

Section 1: APPENDIX II.

Customer order and delivery analysis.

Note. In the customer schedules shown for a selection of jobs cast at Bridge Foundry the quantities indicated represent numbers of castings. The periods ahead when forecasts are made are in monthly intervals and represent the likely requirements for a particular month as estimated by the customer those many months previous. Description of the forecast tentative or firm is also indicated.

NOTE-no delivery date is offered if the order is requested as urgent(U) or very urgent(VU).

Date order received-week no. (year)	Delivery date offered-week no. (year)	Actual delivery date-week no. (year)	Difference between actual & predicted delivery-weeks.
Large	sized customer		
45(74)	32(75)	34	2
45(74)	33(75)	38	5
2(75)	6(75)	9	3
6	14	12	-2
6	12	12	0
6	12	12	0
7(75)	22(76)	20(76)	-2
9	16	16	0
11	19	16	-3
13	19	23	4
16	22	21	-1
19	25	30	5
20	27	30	3
22	28	30	2
24	28	30	2
26	35	36	1
27	32	38	6
28	34	38	4
29	U	34	5
32	39	38	1
34(75)	39	43	4
34	39	42	3
36	41	42	1
38	45	43	-2
42	46	48	2
40	49	51	2
41(75)	10(76)	9(76)	-1
1(76)	7	9	2
6	10	9	-1
15	17	20	3
19	U	26	7
21	24	28	4
25	28	26	-2
26	27	28	1
29	VU	30	1
21	VU	26	5

Promised delivery date and actual delivery date comparisons at Spunalloys.

Date order received-week no. (year)	Delivery date offered-week no. (year)	Actual delivery date-week no. (year)	Difference between actual & predicted delivery-weeks
Medium sized customer			
21(75)	U	25	4
24	U	26	2
26	U	30	4
27	U	34	7
39	44	42	-2
47(75)	51	2(76)	3
47	51	2	3
47	51	4	5
48	13	16	3
50	3	6	3
5	8	15	7
13	15	17	2
13	15	16	1
13	15	19	4
13	15	16	1
17	21	22	1
22	24	25	1
26	29	28	-1
Small sized customer			
20(75)	VU	20(75)	0
20	VU	20	0
20	VU	31	11
27	27	27	0
38	43	41	-2
25	27	27	0
Small sized customer			
25(75)	U	34	9
40	48	5(76)	9
20(76)	26	37	11

Promised delivery date and actual delivery date comparisons at Spunalloys.

Description of customer size according to no. of orders placed.	No. of orders delivered early.	No. of orders delivered late.	No. of orders delivered on time.	Orders registered URGENT(no. of orders delivered in the weeks following)						
				1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	6 weeks
Large	6	12	4	0	2	4	2	1	1	0
Large	9	20	3	1	0	0	0	2	0	1
Large	14	11	4	0	1	0	2	1	0	0
Medium	4	5	3	0	0	3	0	0	0	0
Medium	9	11	2	0	0	2	0	0	0	0
Medium	2	12	0	0	1	0	2	0	0	1
7 customer statistics amalgamated	17	28	9	0	2	3	6	7	1	6

Summary of order book and delivery performance at Spunalloys.

Section A-Heavy horizontal & vertical sections.

Date cast	Date machined	Date delivered	No. of days as rough casting stock.	No. of days in despatch.
21.10.76	27.10.76	29.10.76	6	2
27.10.76	1.11.76	9.11.76	5	8
27.10.76	1.11.76	9.11.76	5	8
16.10.76	27.10.76	5 .11.76	11	9
18.10.76	1.11.76	4.11.76	14	3
22.10.76	22.11.76	22.11.76	30	0
14.10.76	15.11.76	16.11.76	31	1
16.10.76	19.10.76	20.10.76	3	1
22.10.76	27.10.76	28.10.76	5	1
13.10.76	22.10.76	22.10.76	9	0
13.10.76	18.10.76	21.10.76	5	3
13.10.76	22.10.76	22.10.76	8	0
19.10.76	29.11.76	-	40	-
13.10.76	14.10.76	22.10.76	1	8
28.10.76	22.11.76	-	24	-
16.10.76	21.10.76	22.10.76	5	1
14.10.76	28.10.76	-	14	-
16.10.76	18.10.76	20.10.76	2	2
16.10.76	18.10.76	20.10.76	2	2
14.10.76	18.10.76	21.10.76	4	3
18.10.76	21.10.76	22.10.76	3	1
19.10.76	22.10.76	22.10.76	3	0
12.10.76	19.10.76	22.10.76	7	3
18.10.76	25.10.76	29.10.76	7	4

Analysis of progress of manufacture at Spunalloys according to casting section.

Section B-Bushmaster section.

Date cast	Date machined	Date delivered	No. of days as rough casting stock.	No. of days in despatch.
9.6.76	12.7.76	21.7.76	33	9
13.7.76	11.10.76	22.11.76	90	12
21.6.76	9.7.76	16.7.76	18	7
15.7.76	23.7.76	9.8.76	8	17
10.6.76	7.7.76	10.8.76	27	34
1 .7.76	2.7.76	2.7.76	1	0
1.7.76	9.7.76	9.7.76	8	0
1.7.76	15.7.76	15.7.76	14	0
1.7.76	17.7.76	17.7.76	16	0
27.8.76	10.9.76	13.9.76	14	3
30.9.76	4.10.76	4.10.76	4	0
14.7.76	16.7.76	23.7.76	2	7
18.8.76	7.10.76	7.10.76	50	0
24.8.76	31.8.76	3.9.76	7	3
7.10.76	22.10.76	25.10.76	15	3
10.8.76	12.8.76	17.8.76	2	5
13.9.76	15.9.76	17.9.76	2	2
13.9.76	16.9.76	17.9.76	3	1
10.8.76	13.8.76	17.8.76	3	4
17.8.76	18.8.76	19.8.76	1	1
20.10.76	1.11.76	3.11.76	11	2
22.10.76	14.11.76	17.11.76	22	3
7.10.76	12.11.76	-	35	-
10.9.76	15.9.76	-	5	-
29.9.76	29.9.76	29.9.76	0	0

Analysis of progress of manufacture according to casting section at Spunalloys.

Section C-Non standard section.

Date cast	Date machined	Date delivered	No. of days as rough casting stock.	No. of days in despatch.
5.10.76	12.10.76	14.10.76	7	2
5.10,76	11.10.76	14.10.76	6	3
13.10.76	14.10.76	20.10.76	1	6
13.10.76	18.10.76	21.10.76	5	3
7.10.76	18.10.76	-	11	-
6.10.76	7.10.76	20.10.76	1	13
7.10.76	18.10,76	-	11	-
6.10.76	18.10.76	20.10.76	12.	2
13.10.76	15.10.76	18.10.76	2	3
13.10.76	14.10.76	14.10.76	1	1
13.10.76	18.10.76	-	5	-
13.10.76	14.10.76	14.10.76	1	0
13.10.76	14.10.76	14.10.76	1	0
13.10.76	14.10.76	14.10.76	1	0
7.10.76	11.10.76	20.10.76	4	9
6.10.76	19.10.76	21.10.76	13	2
12.10.76	18.10.76	22.10.76	6	4
12.10.76	19.10.76	22.10.76	7	3
14.10.76	21.10.76	22.10.76	7	1
7.10.76	12.10.76	21.10.76	5	9
13.10.76	22.10.76	22.10.76	9	0
7.10.76	15.10.76	18.10.76	8	3
13.10.76	21.10.76	-	8	-
8.10.76	14.10.76	21.10.76	6	7
8.10.76	13.10.76	21.10.76	5	8

Analysis of progress of manufacture according to casting section at Spunalloys.

Large customer.

Month for which projected forecast is made.		Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Monthly periods ahead when forecasts are made plus arrears and delivery particulars.														
Tentative	9	0	0	0	0	0	0	0	0	0	4961	0	0	0
	8	3325	3352	0	0	3811	0	0	0	4961	4985	4947	4845	5161
	7	3352	3352	0	3811	3811	0	3855	4961	4985	4947	4845	5161	8000
	6	3352	3352	3811	3811	3811	3855	4961	4985	4947	4845	5161	8000	8000
	5	3352	3811	3811	3811	3855	4961	4985	4947	4845	5161	8000	8000	8000
Firm	4	3811	3811	3811	3855	4961	4985	4947	4845	5161	8000	8000	8000	8000
	3	3811	3811	3855	4961	4985	4947	4845	5161	8000	8000	8000	8000	8000
	2	3811	3855	4946	4985	3283	4845	5161	8000	8000	8000	8000	8000	8000
	1	3855	4954	4305	0	2113	4478	8000	8000	8000	8000	8000	8000	8000
	0	0	0	0	0	0	3014	0	1480	8000	8000	8000	0	8000
Arrears		1399	5270	0	0	5325	0	0	0	1350	4564	0	0	8098
Deliveries		5342	8130	2221	1126	53	4362	4348	5029	645	6857	8238	1862	3241

Customer schedule details and subsequent delivery details for a selection of jobs cast at Bridge Foundry.

Large customer

Month for which projected forecast is made.		Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Monthly periods ahead when forecasts are made plus arrears and delivery particulars.														
Tentative	9	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	105
	7	0	0	0	0	0	0	0	0	0	0	0	210	0
	6	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0	0	0	105	0	0	0
Firm	4	0	0	0	0	0	0	0	0	210	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	105	0	0	0	0	0	0
	1	0	129	0	130	0	0	253	0	48	0	5	0	0
	0	0	128	0	193	0	0	0	0	7	0	17	0	0
Arrears		0	0	73	73	367	57	0	11	0	0	72	0	62
Deliveries		0	212	338	55	0	388	0	411	48	0	15	0	0

Customer schedule details and subsequent delivery details for a selection of jobs cast at Bridge Foundry.

Medium customer.

Month for which projected forecast is made.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Monthly periods ahead when forecasts are made plus arrears and delivery particulars.													
Tentative 9	0	0	0	234	117	0	230	0	0	0	0	50	0
8	280	143	0	234	117	0	230	0	160	78	0	106	73
7	286	143	0	234	117	0	230	0	156	50	0	146	42
6	286	143	0	234	115	0	160	0	100	53	0	84	42
5	286	117	0	234	115	0	156	0	106	73	0	84	32
Firm 4	234	117	0	230	80	0	100	0	146	42	0	64	0
3	234	117	0	160	78	0	106	0	84	42	0	0	27
2	234	115	0	156	50	0	164	0	84	32	0	1	32
1	230	80	0	9	50	0	317	106	106	0	0	74	32
0	0	184	0	245	0	0	317	0	90	0	48	0	25
Arrears	207	109	0	47	224	10	0	0	0	0	0	0	418
Deliveries	223	291	0	0	0	181	0	381	110	109	0	0	200

Customer schedule details and subsequent delivery details for a selection of jobs cast at Bridge Foundry.

Small customer.

Month for which projected forecast is made.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Monthly periods ahead when forecasts are made plus arrears and delivery particulars.													
Tentative 9	265	265	265	265	527	527	377	377	377	915	475	534	545
8	265	265	265	265	527	527	377	377	915	475	534	545	1359
7	265	265	265	527	527	527	377	915	475	534	545	1359	221
6	265	265	527	527	527	377	915	475	534	545	1359	221	221
5	265	527	527	527	377	915	475	534	545	1359	221	221	522
Firm 4	527	527	527	377	915	475	534	545	1359	221	221	522	404
3	527	527	377	915	475	465	545	1359	221	221	522	404	415
2	527	370	306	454	0	513	1359	221	221	522	148	160	205
1	366	0	429	0	0	44	538	221	328	0	0	0	0
0	0	0	0	0	0	0	538	542	0	0	0	0	0
Arrears	0	0	0	0	0	539	0	189	0	0	0	0	0
Deliveries	0	1005	1187	617	0	0	865	1291	661	1307	0	0	1386

Customer schedule details and subsequent delivery details for a selection of jobs cast at Bridge Foundry.

Medium customer.

Month for which projected forecast is made.		Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Monthly periods ahead when forecasts are made plus arrears and delivery particulars.														
Tentative	9	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	614	562	0	0	548	0	0	0	706	794	0	1050	354
	7	1124	562	0	1096	548	0	1168	0	1588	0	0	708	368
	6	1124	562	0	1096	548	0	706	0	0	525	0	736	368
	5	1124	548	0	1096	584	0	1588	0	1050	354	0	736	263
Firm	4	1096	548	0	1168	353	0	0	0	708	368	0	526	0
	3	1096	548	0	706	794	0	1092	0	736	368	0	0	544
	2	1096	584	0	1781	0	0	278	0	736	263	0	736	176
	1	1168	253	0	987	271	0	514	0	499	265	0	0	0
	0	0	353	0	0	0	0	0	0	815	0	0	0	0
Arrears		1803	2155	748	0	0	0	0	0	0	0	0	0	0
Deliveries		0	190	791	837	1114	0	396	175	764	2060	0	0	182

Customer schedule details and subsequent delivery details for a selection of jobs cast at Bridge Foundry.

Small customer.

Month for which projected forecast is made.		Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.
Monthly periods ahead when forecasts are made plus arrears and delivery particulars.														
Tentative	9	35	35	0	0	0	23	23	23	36	45	47	36	31
	8	35	0	0	0	23	23	23	36	45	47	36	31	13
	7	0	0	0	23	23	23	36	45	47	36	31	0	3
	6	0	0	23	23	23	36	45	47	36	31	0	0	3
	5	0	23	23	23	36	45	47	36	31	0	0	0	25
Firm	4	23	23	23	36	45	47	36	31	0	0	0	0	0
	3	23	23	36	45	47	36	31	0	0	0	0	68	0
	2	23	36	45	47	144	40	0	0	0	0	68	0	0
	1	336	347	45	47	132	0	0	0	0	68	0	0	0
	0	0	347	0	38	0	0	0	0	51	0	0	0	0
Arrears		64	37	326	0	0	0	0	0	0	0	0	0	0
Deliveries		0	0	0	0	44	102	0	0	0	140	0	0	0

Customer schedule details and subsequent delivery details for a selection of jobs cast at Bridge Foundry.

Section 2: APPENDIX II.

Weekly output statistics.

Output figures from Spunalloys during 1975

Week no.	Weight of metal cast per week-tonnes.	Weight of castings machined per week tonnes.	Number of finished castings cast per week.
1	28.93	11.30	504
2	42.67	10.91	621
3	43.98	11.23	464
4	39.99	11.42	431
5	38.44	11.38	524
6	45.06	11.31	527
7	47.14	11.19	410
8	43.85	11.44	320
9	42.51	11.79	374
10	43.42	13.31	444
11	39.52	12.47	453
12	36.65	10.92	378
13	29.6	10.79	294
14	19.02	6.61	235
15	36.37	12.64	428
16	36.6	10.72	322
17	30.19	11.92	309
18	33.76	13.51	330
19	37.96	11.74	496
20	38.39	11.41	327
21	25.13	8.82	268
22	15.29	5.37	183
23	34.0	8.45	439
24	31.3	8.52	245
25	31.86	6.64	219
26	30.34	10.89	348
27	30.2	9.4	359
28	31.19	10.75	325
29	34.84	9.12	346
30	35.6	8.56	234
31	36.17	10.46	343
34	30.37	8.87	277
35	24.86	8.32	243
36	32.98	9.47	255
37	35.68	9.63	287
38	29.53	12.6	240
40	30.5	9.5	265
41	33.77	9.57	318
42	33.45	11.4	318
43	29.49	10.75	226
44	24.03	10.44	276
45	30.37	11.1	272
46	38.37	10.5	322
47	32.5	11.8	315
48	32.6	11.65	270
49	39.28	9.46	272
50	36.73	11.5	273
51	28.55	7.2	238

Output figures from Spunalloys during 1976

Week no.	Weight of metal cast per week-tonnes.	Weight of castings machined per week-tonnes.	Number of finished castings cast per week.
1	15.84	5.7	124
2	33.12	7.1	252
3	32.5	8.4	287
4	25.76	9.75	250
5	36.35	10.95	304
6	39.18	11.95	261
7	34.14	11.01	246
8	31.78	11.92	238
9	22.35	11.92	146
10	22.35	10.13	258
11	31.19	11.11	227
12	35.36	10.17	311
13	29.98	8.77	200
14	35.13	9.13	238
15	34.16	13.18	227
16	35.78	12.16	211
17	19.35	7.49	98
18	35.28	8.34	252
19	30.41	8.6	242
20	29.02	10.57	262
21	26.57	7.68	349
22	23.87	7.12	152
24	29.38	7.83	207
25	26.27	9.1	201
26	19.78	9.01	140
27	32.45	10.45	205
28	24.85	9.44	237
29	26.31	9.22	179
30	20.82	9.73	130
33	8.17	6.81	143
34	10.29	6.49	167
35	12.73	6.49	220
36	13.80	8.76	257
37	13.71	9.35	223
38	15.79	8.78	252
40	12.27	7.34	239
41	15.48	8.17	276
42	15.97	11.02	332
43	24.29	11.99	385
44	23.70	12.90	416
45	20.02	11.34	418
46	20.29	12.03	375
47	21.11	13.89	420
48	17.90	11.65	345
49	15.25	10.48	327

Output figures from Bridge Foundry during 1975

Period	Week number	Weight of metal cast-tonnes.
1	1	43.91
	2	64.29
	3	61.3
	4	63.12
	5	62.81
	6	58.97
	7	63.13
	8	62.54
	9	67.18
	10	64.19
	11	67.25
	12	60.02
	13	55.88
	14	42.49
	15	55.77
	16	53.83
	17	55.35
2	18	42.93
	19	43.99
	20	42.22
	21	42.93
	23	41.94
	24	41.59
	25	44.28
	26	44.56
3	27	56.69
	28	57.64
	29	55.87
	30	52.14
	33	55.51
	34	55.35
	35	55.37
	36	50.22
4	37	44.46
	38	43.69
	40	41.77
	41	38.14
	42	40.31
	43	41.04
	44	40.38
	45	41.57
	46	40.24
	47	41.06
	48	43.71
	49	42.32
	50	40.19
	51	38.81

Output from Bridge Foundry during 1976

Period	Week number	Weight of metal cast-tonnes.
1	1	25.04
	2	33.22
	3	37.50
	4	38.16
	5	40.66
	6	38.40
	7	40.05
	8	39.57
2	9	49.28
	10	50.38
	11	52.09
	12	50.67
	13	56.8
	14	54.27
	15	52.79
	16	43.68
	17	49.62
	19	57.10
	20	41.08
	21	44.03
	22	38.83
	23	36.30
	25	37.03
	26	37.40
	27	50.10
	28	45.07
	29	47.87
	30	52.78
	31	48.05
	32	52.40
	33	52.40
	34	54.70
3	35	63.5
	36	65.3
	37	56.5
	40	53.26
	41	59.56
	42	58.33
	43	61.75

Section 3: APPENDIX II.

Monthly ingot and work in process stock statistics.

Alloy no.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1	0	0	999	681	0	715	509	579	720	688	437	0	0	1280	0
2	0	0	0	0	0	0	0	0	0	465	1407	3816	0	571	0
3	0	0	0	0	1312	2160	1308	1036	408	418	416	426	0	0	0
4	0	0	0	0	0	0	0	0	0	310	0	1252	0	292	0
7	187	7777	2282	2501	486	150	55	1320	3108	7978	0	0	0	0	1919
8	1699	1633	669	669	205	0	0	0	0	649	0	0	0	0	0
9	0	0	0	722	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	602	0	0	0	0	5770	4007
11	0	0	0	0	0	0	0	0	0	0	307	0	0	0	0
13	409	7	0	423	2929	1253	614	0	1253	1729	1025	579	0	3094	2948
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	2122	0	0	0	1003
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	327
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1028
22	0	670	6995	5521	3640	796	0	4397	3755	3116	3706	3706	0	4758	6279
23	1600	3353	1923	2002	1019	1906	5212	2758	8456	7998	2568	1890	0	7737	6950
24	388	306	259	337	337	337	309	0	0	0	610	610	0	618	618
25	0	0	0	0	0	804	564	0	319	454	283	748	0	810	3023
28	0	0	0	0	549	394	209	0	0	424	415	415	0	0	193
29	1434	1129	824	753	745	759	571	580	580	579	571	570	0	570	570
5	0	0	78	78	78	78	78	478	508	507	0	0	0	0	0
6	0	0	0	0	0	0	0	3000	0	1294	0	0	0	0	0

Ingot stocks - Kg reported by Spunalloys at monthly stocktaking July 1975 to September 1976.

Month.	Weight of ingot stock-kg.	Weight of rough castings stock awaiting machining -kg.
July	5711	4275
Aug.	14875	31335
Sept.	14029	29510
Oct.	13687	36471
Nov.	11300	39118
Dec.	9352	31454
Jan.	9429	62490
Feb.	14148	48965
March	19709	39240
April	26609	31206
May	13867	43674
June	14314	28874
July	-	-
Aug.	25500	14835
Sept.	28863	29499

Total copper base alloy stocks reported by Spunalloys at monthly stocktaking July 1975 to September 1976.

Month	Price per tonne £				
	Cu cathode	Brass	Gunmetal LG 2	Phos. bronze PB 1	Leaded Phos. bronze LPB 1
July	574	488	597	908	715
Aug.	583	495	602	920	718
Sept	563	498	602	925	724
Oct	562	496	596	916	715
Nov.	566	496	596	915	713
Dec.	551	490	594	909	708
Jan.	586	510	606	921	720
Feb.	585	504	608	923	720
March	609	523	628	950	740
April	816	689	810	1184	922
May	828	708	840	1230	942
June	844	703	830	1250	951
July	919	724	851	1309	976
Aug.	877	702	825	1297	950
Sept.	823	680	800	1283	928

Market price variation of copper base alloy ingot July 1975 to September 1976.

APPENDIX III.

The simulation model for Spunalloys.

Section 1: The simulation model for Spunalloys computer programme statements and key to control parameter identity.

Section 2: The Monte Carlo technique as used by the simulation model.

Section 3: Details of the copper base alloys cast at Spunalloys.

Section 4: Order book analysis base used by the simulation model to generate the order file via the Monte Carlo technique.

Section 1: APPENDIX III.

The simulation model for Spunalloys computer programme statements and key to control parameter identity.

Key to the identity of control parameters used in the Spunalloys simulation model programme.

Array ORDER1(N):- N = 1 - x (x orders in the current order book)

ORDER1(N),1	= Furnace requirements for order (0 if only one furnace required - ordinary, 1 if two furnaces required - sets FNCINF(N),4 to 1 giving furnace 4 or 5 standby status).
ORDER1(N),2	= Priority number (1,2,3,4,.....,etc.)
ORDER1(N),3	= Alloy type (1 - 29).
ORDER1(N),4	= Wall thickness of proof machined casting - mm.
ORDER1(N),5	= Outside diameter of proof machined casting - mm.
ORDER1(N),6	= Length of proof machined casting - mm.
ORDER1(N),7	= Number off of proof machined castings to satisfy order.
ORDER1(N),8	= Order status (0 if available for manufacture, 1 if order completed or dimensions or weight render production unrealistic).
ORDER1(N),9	= Weight of proof machined casting - kg.

Array ORDER2(N):- N = 1 - x (x orders in the current order book)

ORDER2(N),1	= Spinning machine section on which order will be cast (1 identifies Bushmaster, 2 identifies non standard, 3 identifies horizontal, 4 identifies vertical).
ORDER2(N),2	= Outside diameter of rough casting - mm.
ORDER2(N);3	= Inside diameter of rough casting - mm.
ORDER2(N),4	= Length of rough casting - mm.
ORDER2(N),5	= Number off of rough castings to satisfy order (two or more proof machined castings can be

produced from one mould) - mm.

ORDER2(N),6 = Number of consecutive rings in the die assembly (applies solely to the vertical casting section, i.e., ORDER2(N),1 = 4).

ORDER2(N),7 = Weight of molten metal required to make rough casting (includes metal losses) - kg.

ORDER2(N),8 = Weight of rough casting - kg.

ORDER2(N),9 = Die number (1 - 119)

ORDER2(N),10 = Number of rough castings awaiting machining (1,2,3,....,etc.) associated with the order.

ORDER2(N),11 = Weight of swarf and cut-offs produced during machining per rough casting - kg.

<u>Array FNCINF(N)</u>:- N = 1 - 7 (seven furnaces)

FNCINF(N),1 = Furnace capacity - kg.

FNCINF(N),2 = Furnace availability (0 if furnace free, 1 if furnace engaged).

FNCINF(N),3 = Identity of previous alloy (0 if scrub heat was previous, 3 if wash heat was previous, otherwise 1 - 29).

FNCINF(N),4 = Identifies whether or not furnaces 4 and 5 are required to combine to make a heavy casting (0 if not required for combination purposes, 1 if required for combination purposes; always zero for furnaces other than 4 and 5).

FNCINF(N),5 = Identifies whether or not a scrub heat is being employed (0 if not, 1 if scrub heat is being melted).

Array DIESIZ(N):-   N = 1 - 119 (119 dies)

DIESIZ(N),1	= Outside diameter of rough casting if made in die (N) - mm.
DIESIZ(N),2	= Length of rough casting if made in die (N) - mm.
DIESIZ(N),3	= Spinning machine section in which die is used (1 identifies Bushmaster, 2 identifies non standard, 3 identifies horizontal, 4 identifies vertical).

Array STOCK(N):-   N = 1 - 29 (29 alloys)

STOCK(N),1	= Weight of virgin ingot stock currently available - kg.
STOCK(N),2	= Weight of scrap castings stock currently available - kg.
STOCK(N),3	= Weight of swarf from machining currently available - kg.
STOCK(N),4	= Identifies whether or not further ingot stocks are currently on order and the weight to be delivered (0 if no order has been placed, number indicates kg to be received).
STOCK(N),5	= Identifies day of the week on which delivery of ingot stock on order is expected (1 signifies Mon., 2 signifies Tues., etc.).

Array MACHINF(N):-   N = 1 - 15 (15 cutting machines)

MACHINF(N)	= Cutting machine availability (0 if cutting machine free, 1 if cutting machine engaged).

Array ICOUNT(N):- N = 1 - 119 (119 dies)

ICOUNT(N) = Die availability (0 if die free, 1 if die engaged).

Array VACHTIM(N):- N = 1 - 141 (141 Activities - furnaces, dies, cutting machines)

VACHTIM(N) = Current time plus time of operation (identifies Event times).

Array TEMSCRAP(N):- N = 1 - 29 (29 alloys)

TEMSCRAP(N) = Weight of any scrap castings of alloy (N) which are added to STOCK(N),2 at the end of the day - kg.

Array TEMSTOR(N):- N = 1 - x (x orders in current order book)

TEMSTOR(N) = Identifies die number associated with the order (ORDER2(N),9) if a casting is currently being made.

Other parameters

AMOLWT = Weight of metal charge committed to the furnace currently under consideration - kg.

TIMELT = Time required to melt metal in the furnace currently under consideration - mins.

TIMDIE = Time to pour and subsequently solidify the casting currently under consideration - mins.

TIMACH = Time to clean and set-up cutting machine currently under consideration - mins.

SKNMACH = Time to machine outside and bore of casting currently under consideration - mins.

PARTIM = Time to part if rough casting currently under consideration contains more than one proof

	machined casting - mins.
TIM	= Current time of the day - mins.
WTCAST	= Cumulative weight total of rough castings made during the current week - kg.
NOCAST	= Cumulative number total of rough castings made during the current week.
WTMACH	= Cumulative weight total of proof machined castings processed on the cutting machines during the current week - kg.
WKINPG	= Cumulative weight total of rough castings awaiting maching during the current month (work in process) - kg.

MOP

```
#LISTING OF :EPP7050.SPUN301(2/)    PRODUCED ON 20MAR78 AT 12.33.19

#G8.62M AT ASTON    IN ':EPP7050.MOPJER' ON 20MAR78 AT 12.37.38 USING  U14

DOCUMENT    SPUN301

      TRACE 1
      MASTER MAIN
C     MAIN PROGRAMME
      DIMENSION ORDER1(300,9),ORDER2(300,11),STOCK(29,6),ENGINE(7,5),
     1ICOUNT(119),VACHTIM(141),TEMSCRAP(29),TEMSTOR(300),MACHINE(15),
     1DIESIZ(119,3)
      EQUIVALENCE(X,Y,Z)
      INTEGER MONTH,WEEK,DAY
       DATA DIESIZ/93,96,103,108,114,116,125,130,135,140,145,149,155,
     1160,172,181,191,201,213,222,233,254,263,273,283,293,303,313,279,
     1279,286,295,299,305,305,311,318,324,330,337,349,356,362,368,381,
     1387,400,419,419,305,349,349,367,394,419,445,451,454,457,470,
     1483,492,495,508,521,527,533,540,572,572,597,622,482,482,507,
     1533,554,
     1559,590,596,647,647,647,673,673,685,723,723,723,723,723,736,
     1761,701,825,875,876,876,876,902,902,939,958,958,964,964,1009,
     11054,1054,1161,1196,1207,1240,1240,1270,1358,1358,1396,1466,
     123*648,83,165,210,293,267,203,553,248,216,210,318,216,398,127,
     1268,248,116,216,216,171,210,507,432,1054,318,521,495,445,432,279,
     1229,222,445,432,216,213,495,210,70,102,216,406,229,445,
     180,80,165,76,76,146,83,102,57,140,143,127,130,86,86,113,136,140,
     170,76,79,79,89,140,82,120,171,70,140,165,51,114,51,89,140,137,
     1165,105,140,70,38,51,165,70,85,121,133,
     128*1,21*2,25*3,47*4/
      DATA ICOUNT/119*0/
      DATA TEMSTOR/300*0.0/
      DATA TEMSCRAP/29*0.0/
      DATA VACHTIM/141*0.0/
      DATA MACHINE/15*0/
      DATA STOCK/500,250,4000,4000,500,500,7000,4000,
     11500,1500,0,0,5000,0,0,0,0,4000,0,0,1500,600,5000,
     11000,5000,500,500,1500,500,
     129*0,29*0,29*0,29*0,29*0/
      DATA ENGINE/2*160,2*500,750,365,680,28*0.0/
      DO 6029 N=1,300
 6029 ORDER1(N,8)=1.0
      PRIOR=1
      MONTH=1
 6001 WEEK=1
C     CLEAR ALL ALLOCATIONS IN ENGAGED,NOT ENGAGED REGISTERS
 6055 WTCAST=0
      NOCAST=0
      WTMACH=0
      DAY=1
 6000 DO 6050 JOBNO=1,300
      IF((ORDER1(JOBNO,8).EQ.0.0).OR.(ORDER2(JOBNO,10).GT.0.0))
     1GO TO 6050
```

```
      CALL GENALLOY(JOBNO,ORDER1)
      CALL CASTDIN(ORDER1,ORDER2,DIESIZ,JOBNO)
      ORDER1(JOBNO,2)=1.0                                    xxx
      ORDER1(JOBNO,1)=0.0
      ORDER2(JOBNO,10)=0.0
 6050 CONTINUE
       DO 615 JOBNO=1,300
      IF((ORDER1(JOBNO,3).EQ.0.0).OR.(ORDER2(JOBNO,10).GT.0.0))
     1GO TO 615
      CALL GENALLOY(JOBNO,ORDER1)
      CALL CASTDIN(ORDER1,ORDER2,DIESIZ,JOBNO)
      ORDER1(JOBNO,2)=1.0
      ORDER1(JOBNO,1)=0.0
      ORDER2(JOBNO,10)=0.0
  615 CONTINUE
      TIM=0
 6060 CALL FNCPOS(ORDER1,ORDER2,STOCK,FNCINF,ICOUNT,VACHTIM,TEMSCRAP,
     1TEMSTOR,PRIOR,TIM,DAY)
 6070 CALL MACPOS(ORDER1,ORDER2,VACHTIM,MACHINF,STOCK,
     1PRIOR,WTMACH,TIM)
 6080 CALL NEXVENT(ORDER1,ORDER2,STOCK,FNCINF,ICOUNT,VACHTIM,TEMSCRAP,
     1TEMSTOR,MACHINF,TIM,WTCAST,NOCAST,NRK)
      TIMES=0
 6085 IF(TIM.GT.300) GO TO 6090
      IF(NRK.GT.7)GO TO 6094
      GO TO 6060
 6094 IF(NRK.GT.126)GO TO 6070
      GO TO 6060
 6090 DO 6100 LCJ=1,7
      FNCINF(LCJ,2)=0.0
      IF(FNCINF(LCJ,3).LT.1.0)GO TO 6100
      JAX=INT(FNCINF(LCJ,3))
      STOCK(JAX,2)=STOCK(JAX,2)+TEMSCRAP(JAX)
      TEMSCRAP(JAX)=0.0
 6100 CONTINUE
       DO 6101 LDJ=1,300
      IF(TEMSTOR(LDJ).EQ.0.0)GO TO 6101
      ORDER2(LDJ,10)=ORDER2(LDJ,10)+1
      TEMSTOR(LDJ)=0.0
      WTCAST=WTCAST+ORDER2(LDJ,6)
      NOCAST=NOCAST+1
 6101 CONTINUE
      DO 6103 LFJ=1,119
      ICOUNT(LFJ)=0
 6103 CONTINUE
      DO 6104 LGJ=1,15
 6104 MACHINF(LGJ)=0
      DO 6105 LJJ=1,141
 6105 VACHTIM(LJJ)=0.0
       DO 6102 M=1,29
       STOCK(M,2)=STOCK(M,2)+TEMSCRAP(M)
      TEMSCRAP(M)=0.0
 6102 CONTINUE
      DAY=DAY+1
C     LOOK TO SEE IF INGOT DELIVERY IS DUE
      DO 6120 NCT =1,29
      IF(STOCK(NCT,4).EQ.0.0)GO TO 6120
      IF(INT(STOCK(NCT,5))-(DAY-1))6120,6130,6120
 6130 STOCK(NCT,1) =STOCK(NCT,1)+STOCK(NCT,4)*1000
      STOCK(NCT,4)=0.0
      STOCK(NCT,5)=0.0
 6120 CONTINUE
 6131 IF(DAY.GT.5)GO TO 6133
      GO TO 6060
 6133 WEEK=WEEK+1
```

```
 801 FORMAT(1H ,5HMONTH,I5,5X,4HWEEK,I5)
     WRITE(2,6135)WTCAST,NOCAST,WTMACH
6135 FORMAT(2X,10HCASTWEIGHT,2X,7HNO CAST,2X,15HMACHINED WEIGHT//F11.2,
    1I7,F16.2)
     WRITE(2,6136)((STOCK(JCX,JCY),JCY=1,3),JCX=1,29)
6136 FORMAT(2X,8HINGOT WT,2X,8HSCRAP WT,2X,8HSWARF WT//3F10.2)
     IF(WEEK.GT.4)GO TO 6141
     PRIOR=PRIOR+1
     DO 6150 JDJ=1,300
     IF(ORDER1(JDJ,8).LT.1.0)
    *ORDER1(JDJ,2)=ORDER1(JDJ,2)+1
6150 CONTINUE
     GO TO 6055
6141 MONTH= MONTH+1
C    DETERMINE WT OF ROUGH CASTINGS AWAITING MACHINING
     WKINPG =0
     DO 6200 KDJ=1,300
     IF(ORDER2(KDJ,10).GE.1.0)
    *WKINPG=WKINPG+ORDER2(KDJ,8)*ORDER2(KDJ,10)
6200 CONTINUE
     WRITE(2,6203)WKINPG
6203 FORMAT(2X,20HWEIGHT OF WORK IN PROGRESS//F14.2)
     IF(MONTH.GE.4)GO TO 9998
     PRIOR=PRIOR+1
     DO 6250 LDJ =1,300
     IF(ORDER1(LDJ,8).NE.1.0)GO TO 6250
     ORDER1(LDJ,2)=ORDER1(LDJ,2)+1.0
6250 CONTINUE
     GO TO  6001
9998 DO 834 N=1,300
      WRITE(2,833)ORDER1(N,1),ORDER1(N,2),ORDER1(N,3),ORDER1(N,7),
    1ORDER1(N,8),ORDER2(N,1),ORDER2(N,5),ORDER2(N,7),ORDER2(N,10)
 833 FORMAT(1H ,7HSTANDBY,2X,8HPRIORITY,2X,5HALLOY,2X,6HNO OFF,
    12X,9HAVAILABLE,2X,7HSECTION,2X,6HNO OFF,2X,
    19HWT MOLTEN,2X,10HROUGH CAST//9F9.2)
 834 CONTINUE
     STOP
     END
     SUBROUTINE GENALLOY(JOBNO,ORDER1)
     DIMENSION ORDER1(300,9)
     INTEGER X,Y,Z
     ORDER1(JOBNO,2)=1
C       CALL G05BBF
     X=G05ABF(0.0,1000.0)
     IF  (X-2)20,20,30
  30 IF  (X-87)40,40,50
  50 IF(X-681)60,60,70
  70 IF(X-790)80,80,90
  90 IF  (X-896)100,100,110
 110 IF(X-921)120,120,130
  20 ORDER1(JOBNO,3)=1
     GO TO 1000
  40 ORDER1(JOBNO,3)=2
     GO TO 1010
C       CALL G05BBF
  60 Y=G05ABF(0.0,1000.0)
     IF  (Y-487)150,150,160
 160 IF(Y-753) 170,170,180
C       CALL G05BBF
 150 Z=G05ABF(0.0,1000.0)
     IF(Z-480)200,200,210
 210 IF(Z-772)220,220,230
 230 IF(Z-880)240,240,250
 250 IF(Z-973)260,260,270
 270 ORDER1(JOBNO,3)=11
     GO TO 1085
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      GO TO 1085
  240 ORDER1(JOBNO,3)=9
      GO TO 1085
  220 ORDER1(JOBNO,3)=8
      GO TO 1085
  200 ORDER1(JOBNO,3)=7
      GO TO 1085
C        CALL G05BBF
  170 Z=G05ABF(0.0,1000.0)
      IF(Z-95)300,300,310
  310 IF(Z-773)320,320,330
  330 IF(Z-928)340,340,350
  350 IF(Z-988)360,360,370
  370 ORDER1(JOBNO,3)=16
      GO TO 1085
  360 ORDER1(JOBNO,3)=15
      GO TO 1085
  340 ORDER1(JOBNO,3)=14
      GO TO 1085
  320 ORDER1(JOBNO,3)=13
      GO TO 1085
  300 ORDER1(JOBNO,3)=12
      GO TO 1085
C        CALL G05BBF
  180 Z=G05ABF(0.0,1000.0)
      IF(Z-26)400,400,410
  410 IF(Z-540)420,420,430
  430 IF(Z-553)440,440,450
  450 IF(Z-668)460,460,470
  470 IF(Z-912)480,480,490
  490 ORDER1(JOBNO,3)=22
      GO TO 1085
  480 ORDER1(JOBNO,3)=21
      GO TO 1085
  460 ORDER1(JOBNO,3)=20
      GO TO 1085
  440 ORDER1(JOBNO,3)=19
      GO TO 1085
  420 ORDER1(JOBNO,3)=18
      GO TO 1085
  400 ORDER1(JOBNO,3)=17
      GO TO 1085
C        CALL G05BBF
   80 Y=G05ABF(0.0,1000.0)
      IF(Y-983)500,500,510
  500 ORDER1(JOBNO,3)=23
      GO TO 1200
  510 ORDER1(JOBNO,3)=24
      GO TO 1200
C        CALL G05BBF
  100 Y=G05ABF(0.0,1000.0)
      IF(Y-962)600,600,610
  610 IF(Y-962)620,620,630
  600 ORDER1(JOBNO,3)=25
      GO TO 1285
  620 ORDER1(JOBNO,3)=26
      GO TO 1285
  630 ORDER1(JOBNO,3)=27
      GO TO 1285
C        CALL G05BBF
  120 Y=G05ABF(0.0,1000.0)
      IF(Y-924)700,700,710
  700 ORDER1(JOBNO,3)=28
      GO TO 1380
  710 ORDER1(JOBNO,3)=29
      GO TO 1380
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  130 Y=G05ABF(0,0,1000,0)
      IF(Y-293)800,800,810
  810 IF(Y-951)820,820,830
  830 IF(Y-975)840,840,850
  850 ORDER1(JOBNO,3)=6
      GO TO 1420
  840 ORDER1(JOBNO,3)=5
      GO TO 1420
  820 ORDER1(JOBNO,3)=4
      GO TO 1420
  800 ORDER1(JOBNO,3)=3
      GO TO 1420
C        CALL G05BBF
 1000 X=G05ABF(0,0,1000,0)
      IF(X-500)1001,1001,1002
 1001 ORDER1 (JOBNO,4)=13
      GO TO 1005
 1002 ORDER1 (JOBNO,4)=110
C        CALL G05BBF
 1005 X=G05ABF(0,0,1000,0)
      IF(X-500)1003,1003,1004
 1003 ORDER1 (JOBNO,5)=88
      GO TO 1006
 1004 ORDER1(JOBNO,5)=325
 1006 ORDER1(JOBNO,6)=63
      ORDER1(JOBNO,7)=3
      GO TO 9999
C        CALL G05BBF
 1010 X=G05ABF(0,0,1000,0)
      IF(X-22)1011,1011,1012
 1011 ORDER1(JOBNO,4)=8
      GO TO 1025
 1012 IF(X-155)1013,1013,1014
 1013 ORDER1(JOBNO,4)=25
      GO TO 1025
 1014 IF(X-377)1015,1015,1016
 1015 ORDER1(JOBNO,4)=35
      GO TO 1025
 1016 IF(X-647)1017,1017,1018
 1017 ORDER1(JOBNO,4)=45
      GO TO 1025
 1018 IF(X-880)1019,1019,1020
 1019 ORDER1(JOBNO,4)=55
      GO TO 1025
 1020 IF(X-947)1021,1021,1022
 1021 ORDER 1(JOBNO,4)=65
      GO TO 1025
 1022 IF(X-971)1023,1023,1024
 1023 ORDER1(JOBNO,4)=75
      GO TO 1025
 1024 ORDER1(JOBNO,4)=95
C        CALL G05BBF
 1025 X=G05ABF(0,0,1000,0)
      IF(X-163)1028,1028,1029
 1028 ORDER1(JOBNO,5) =150
      GO TO 1042
 1029 IF(X-395)1030,1030,1031
 1030 ORDER1(JOBNO,5)=200
      GO TO 1042
 1031 IF(X-558)1032,1032,1033
 1032 ORDER1(JOBNO,5)=250
      GO TO 1042
 1033 IF(X-605)1034,1034,1035
 1034 ORDER1(JOBNO,5)=300
      GO TO 1042
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 1035 IF(X-721)1036,1036,1037
 1036 ORDER1(JOBNO,5)=350
      GO TO 1042
 1037 IF(X-684)1038,1038,1039
 1038 ORDER1(JOBNO,5)=400
      GO TO 1042
 1039 IF(X-907)1040,1040,1041
 1040 ORDER1(JOBNO,5)=500
      GO TO 1042
 1041 ORDER1(JOBNO,5)=620
C        CALL G05BBF
 1042 X=G05ABF(0,0,1000,0)
      IF(X-140) 1043,1043,1044
 1043 ORDER1(JOBNO,6)=17
      GO TO 1061
 1044  IF(X-210)1045,1045,1046
 1045 ORDER1(JOBNO,6)=23
      GO TO 1061
 1046 IF(X-373)1047,1047,1048
 1047 ORDER1(JOBNO,6)=27
      GO TO 1061
 1048 IF(X-559)1049,1049,1050
 1049 ORDER1(JOBNO,6)=33
      GO TO 1061
 1050 IF(X-675)1051,1051,1052
 1051 ORDER1(JOBNO,6)=45
      GO TO 1061
 1052 IF(X-768)1053,1053,1054
 1053 ORDER1(JOBNO,6)=78
      GO TO 1061
 1054 IF(X-838)1055,1055,1056
 1055 ORDER1(JOBNO,6)=125
      GO TO 1061
 1056 IF(X-861)1057,1057,1058
 1057 ORDER1(JOBNO,6)=173
      GO TO 1061
 1058 IF(X-977)1059,1059,1060
 1059 ORDER1(JOBNO,6)=204
      GO TO 1061
 1060 ORDER1(JOBNO,6)=295
C        CALL G05BBF
 1061 X=G05ABF(0,0,1000,0)
      IF(X-174)1062,1062,1063
 1062 ORDER1(JOBNO,7)=1
      GO TO 9999
 1063 IF(X-239)1064,1064,1065
 1064 ORDER1(JOBNO,7)=2
      GO TO 9999
 1065 IF(X-521)1066,1066,1067
 1066 ORDER1(JOBNO,7)=3
      GO TO 9999
 1067 IF(X-565)1068,1068,1069
 1068 ORDER1(JOBNO,7)=4
      GO TO 9999
 1069 IF(X-587)1070,1070,1071
 1070 ORDER1(JOBNO,7)=5
      GO TO 9999
 1071 IF(X-717)1072,1072,1073
 1072 ORDER1(JOBNO,7)=6
      GO TO 9999
 1073 IF(X-782)1074,1074,1075
 1074 ORDER1(JOBNO,7)=9
      GO TO 9999
 1075 IF(X-847)1076,1076,1077
 1076 ORDER1(JOBNO,7)=14
      GO TO 9999
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 1077 IF(X-934)1078,1078,1079
 1078 ORDER1(JOBNO,7)=25
      GO TO 9999
 1079 IF(X-956)1080,1080,1081
 1080 ORDER1(JOBNO,7)=53
      GO TO 9999
 1081 ORDER1(JOBNO,7)=95
      GO TO 9999
C        CALL G05BBF
 1085 X=G05ABF(0,0,1000,0)
      IF(X-56)1086,1086,1087
 1086 ORDER1(JOBNO,4)=3
      GO TO 1106
 1087 IF(X-508)1088,1088,1089
 1088 ORDER1(JOBNO,4)=14
      GO TO 1106
 1089 IF(X-662)1090,1090,1091
 1090 ORDER1(JOBNO,4)=25
      GO TO 1106
 1091 IF(X-755)1092,1092,1093
 1092 ORDER1(JOBNO,4)=35
      GO TO 1106
 1093 IF(X-860)1094,1094,1095
 1094 ORDER1(JOBNO,4)=45
      GO TO 1106
 1095 IF(X-918)1096,1096,1097
 1096 ORDER1(JOBNO,4)=55
      GO TO 1106
 1097 IF(X-946)1098,1098,1099
 1098 ORDER1(JOBNO,4)=65
      GO TO 1106
 1099 IF(X-979)1100,1100,1101
 1100 ORDER1(JOBNO,4)=85
      GO TO 1106
 1101 IF(X-993)1102,1102,1103
 1102 ORDER1(JOBNO,4)=120
      GO TO 1106
 1103 IF(X-998)1104,1104,1105
 1104 ORDER1(JOBNO,4)=195
      GO TO 1106
 1105 ORDER1(JOB,4)=300
C        CALL G05BBF
 1106 X=G05ABF(0,0,1000,0)
      IF(X-69)1525,1525,1526
 1525 ORDER1(JOBNO,5)=40
      GO TO 1130
 1526 IF(X-151)1107,1107,1108
 1107 ORDER1(JOBNO,5)=103
      GO TO 1130
 1108 IF(X-291)1109,1109,1110
 1109 ORDER1(JOBNO,5)=150
      GO TO 1130
 1110 IF(X-495)1111,1111,1112
 1111 ORDER1(JOBNO,5)=200
      GO TO 1130
 1112 IF(X-594)1113,1113,1114
 1113 ORDER1(JOBNO,5)=250
      GO TO 1130
 1114 IF(X-676)1115,1115,1116
 1115 ORDER1(JOBNO,5)=300
      GO TO 1130
 1116 IF(X-726)1117,1117,1118
 1117 ORDER1(JOBNO,5)=350
      GO TO 1130
 1118 IF(X-802)1119,1119,1120
 1119 ORDER1(JOBNO,5)=412
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 1120 IF(X-692)1121,1121,1122
 1121 ORDER1(JOBNO,5)=525
      GO TO 1130
 1122 IF(X-918)1123,1123,1124
 1123 ORDER1(JOBNO,5)=623
      GO TO 1130
 1124 IF(X-968)1125,1125,1126
 1125 ORDER1(JOBNO,5)=728
      GO TO 1130
 1126 IF(X-992)1127,1127,1128
 1127 ORDER1(JOBNO,5)=838
      GO TO 1130
 1128 IF(X-996)1527,1527,1528
 1527 ORDER1(JOBNO,5)=1150
      GO TO 1130
 1528 ORDER1(JOBNO,5)=1225
C        CALL G05BBF
 1130 X=G05ABF(0.0,1000.0)
      IF(X-64)1131,1131,1132
 1131 ORDER1(JOBNO,6)=20
      GO TO 1160
 1132 IF(X-176)1133,1133,1134
 1133 ORDER1(JOBNO,6)=40
      GO TO 1160
 1134 IF(X-222)1135,1135,1136
 1135 ORDER1(JOBNO,6)=60
      GO TO 1160
 1136 IF(X-334)1137,1137,1138
 1137 ORDER1(JOBNO,6)=80
      GO TO 1160
 1138 IF(X-367)1139,1139,1140
 1139 ORDER1(JOBNO,6)=100
      GO TO 1160
 1140 IF(X-433)1141,1141,1142
 1141 ORDER1(JOBNO,6)=120
      GO TO 1160
 1142 IF(X-497)1143,1143,1144
 1143 ORDER1(JOBNO,6)=140
      GO TO 1160
 1144 IF(X-530)1145,1145,1146
 1145 ORDER1(JOBNO,6)=160
      GO TO 1160
 1146 IF(X-592)1147,1147,1148
 1147 ORDER1(JOBNO,6)=180
      GO TO 1160
 1148 IF(X-687)1149,1149,1150
 1149 ORDER1(JOBNO,6)=208
      GO TO 1160
 1150 IF(X-755)1151,1151,1152
 1151 ORDER1(JOBNO,6)=250
      GO TO 1160
 1152 IF(X-841)1153,1153,1154
 1153 ORDER1(JOBNO,6)=313
      GO TO 1160
 1154 IF(X-916)1155,1155,1156
 1155 ORDER1(JOBNO,6)=448
      GO TO 1160
 1156 IF(X-973)1540,1540,1541
 1540 ORDER1(JOBNO,6)=600
      GO TO 1160
 1541 ORDER1(JOBNO,6)=750
C        CALL G05BBF
 1160 X=G05ABF(0.0,1000.0)
      IF(X-420)1161,1161,1162
 1161 ORDER1(JOBNO,7)=1
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 1162 IF(X-624)1163,1163,1164
 1163 ORDER1(JOBNO,7)=2
      GO TO 9999
 1164 IF(X-708)1165,1165,1166
 1165 ORDER1(JOBNO,7)=3
      GO TO 9999
 1166 IF(X-763)1167,1167,1168
 1167 ORDER1(JOBNO,7)=4
      GO TO 9999
 1168 IF(X-777)1169,1169,1170
 1169 ORDER1(JOBNO,7)=5
      GO TO 9999
 1170 IF(X-836)1171,1171,1172
 1171 ORDER1(JOBNO,7)=7
      GO TO 9999
 1172 IF(X-881)1173,1173,1174
 1173 ORDER1(JOBNO,7)=9
      GO TO 9999
 1174 IF(X-906)1175,1175,1176
 1175 ORDER1(JOBNO,7)=11
      GO TO 9999
 1176 IF(X-948)1177,1177,1178
 1177 ORDER1(JOBNO,7)=17
      GO TO 9999
 1178 IF(X-962)1179,1179,1180
 1179 ORDER1(JOBNO,7)=28
      GO TO 9999
 1180 IF(X-966)1181,1181,1182
 1181 ORDER1(JOBNO,7)=48
      GO TO 9999
 1182 IF(X-996)1183,1183,1184
 1183 ORDER1(JOBNO,7)=120
      GO TO 9999
 1184 ORDER1(JOBNO,7)=190
      GO TO 9999
C        CALL G05BBF
 1200 X=G05ABF(0,0,1000,0)
      IF(X-216)1201,1201,1202
 1201 ORDER1(JOBNO,4)=21
      GO TO 1210
 1202 IF(X-649)1203,1203,1204
 1203 ORDER1(JOBNO,4)=35
      GO TO 1210
 1204 IF(X-960)1205,1205,1206
 1205 ORDER1(JOBNO,4)=45
      GO TO 1210
 1206 IF(X-987)1207,1207,1208
 1207 ORDER1(JOBNO,4)=65
      GO TO 1210
 1208 ORDER1(JOBNO,4)=135
C        CALL G05BBF
 1210 X=G05ABF(0,0,1000,0)
      IF(X-36)1530,1530,1531
 1530 ORDER1(JOBNO,5)=63
      GO TO 1240
 1531 IF(X-60)1211,1211,1212
 1211 ORDER1(JOBNO,5)=150
      GO TO 1240
 1212 IF(X-84)1213,1213,1214
 1213 ORDER1(JOBNO,5)=200
      GO TO 1240
 1214 IF(X-179)1215,1215,1216
 1215 ORDER1(JOBNO,5)=250
      GO TO 1240
 1216 IF(X-239)1217,1217,1218
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 1217 ORDER1(JOBNO,5)=300
      GO TO 1240
 1218 IF(X-359)1219,1219,1220
 1219 ORDER1(JOBNO,5)=350
      GO TO 1240
 1220 IF(X-431)1221,1221,1222
 1221 ORDER1(JOBNO,5)=400
      GO TO 1240
 1222 IF(X-621)1223,1223,1224
 1223 ORDER1(JOBNO,5)=450
      GO TO 1240
 1224 IF(X-657)1225,1225,1226
 1225 ORDER1(JOBNO,5)=550
      GO TO 1240
 1226 IF(X-669)1227,1227,1228
 1227 ORDER1(JOBNO,5)=625
      GO TO 1240
 1228 IF(X-777)1229,1229,1230
 1229 ORDER1(JOBNO,5)=750
      GO TO 1240
 1230 IF(X-929)1231,1231,1232
 1231 ORDER1(JOBNO,5)=925
      GO TO 1240
 1232 ORDER1(JOBNO,5)=1100
C        CALL G05BBF
 1240 X=G05ABF(0.0,1000.0)
      IF(X-69)1241,1241,1242
 1241 ORDER1(JOBNO,6)=15
      GO TO 1265
 1242 IF(X-153)1243,1243,1244
 1243 ORDER1(JOBNO,6)=22
      GO TO 1265
 1244 IF(X-237)1245,1245,1246
 1245 ORDER1(JOBNO,6)=28
      GO TO 1265
 1246 IF(X-306)1247,1247,1248
 1247 ORDER1(JOBNO,6)=33
      GO TO 1265
 1248 IF(X-806)1249,1249,1250
 1249 ORDER1(JOBNO,6)=50
      GO TO 1265
 1250 IF(X-820)1251,1251,1252
 1251 ORDER1(JOBNO,6)=70
      GO TO 1265
 1252 IF(X-889)1253,1253,1254
 1253 ORDER1(JOBNO,6)=88
      GO TO 1265
 1254 IF(X-930)1255,1255,1256
 1255 ORDER1(JOBNO,6)=125
      GO TO 1265
 1256 IF(X-958)1257,1257,1258
 1257 ORDER1(JOBNO,6)=178
      GO TO 1265
 1258 IF(X-986)1259,1259,1260
 1259 ORDER1(JOBNO,6)=250
      GO TO 1265
 1260 ORDER1(JOBNO,6)=320
C        CALL G05BBF
 1265 X=G05ABF(0.0,1000.0)
      IF(X-285)1266,1266,1267
 1266 ORDER1(JOBNO,7)=1
      GO TO 9999
 1267 IF(X-478)1268,1268,1269
 1268 ORDER1(JOBNO,7)=2
      GO TO 9999
 1269 IF(X-649)1270,1270,1271
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1270  ORDER1(JOBNO,7)=3
      GO TO 9999
1271  IF(X-797)1272,1272,1273
1272  ORDER1(JOBNO,7)=4
      GO TO 9999
1273  IF(X-820)1274,1274,1275
1274  ORDER1(JOBNO,7)=5
      GO TO 9999
1275  IF(X-910)1276,1276,1277
1276  ORDER1(JOBNO,7)=6
      GO TO 9999
1277  IF(X-933)1278,1278,1279
1278  ORDER1(JOBNO,7)=7
      GO TO 9999
1279  IF(X-944)1280,1280,1281
1280  ORDER1(JOBNO,7)=8
      GO TO 9999
1281  IF(X-978) 1282,1282,1283
1282  ORDER1(JOBNO,7)=10
      GO TO 9999
1283  ORDER1(JOBNO,7)=21
C        CALL G05BBF
1285  X=G05ABF(0.0,1000.0)
      IF(X-220)1286,1286,1287
1286  ORDER1(JOBNO,4)=5
      GO TO 1300
1287  IF(X-627)1288,1288,1289
1288  ORDER1(JOBNO,4)=15
      GO TO 1300
1289  IF(X-873)1290,1290,1291
1290  ORDER1(JOBNO,4)=30
      GO TO 1300
1291  IF(X-921)1292,1292,1293
      GO TO 1300
1292  ORDER1(JOBNO,4)=45
1293  IF(X-937)1294,1294,1295
1294  ORDER1(JOBNO,4)=55
      GO TO 1300
1295  IF(X-969)1296,1296,1297
1296  ORDER1(JOBNO,4)=75
      GO TO 1300
1297  IF(X-985)1298,1298,1299
1298  ORDER1(JOBNO,4)=85
      GO TO 1300
1299  ORDER1(JOBNO,4)=162
C        CALL G05BBF
1300  X=G05ABF(0.0,1000.0)
      IF(X-48)1301,1301,1302
1301  ORDER1(JOBNO,5)=49
      GO TO 1320
1302  IF(X-96)1303,1303,1304
1303  ORDER1(JOBNO,5)=111
      GO TO 1320
1304  IF(X-380)1305,1305,1306
1305  ORDER1(JOBNO,5)=150
      GO TO 1320
1306  IF(X-555)1307,1307,1308
1307  ORDER1(JOBNO,5)=200
      GO TO 1320
1308  IF(X-714)1309,1309,1310
1309  ORDER1(JOBNO,5)=250
      GO TO 1320
1310  IF(X-777)1311,1311,1312
1311  ORDER1(JOBNO,5)=300
      GO TO 1320
1312  IF(X-904)1313,1313,1314
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x1

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 1313 ORDER1(JOBNO,5)=350
      GO TO 1320
 1314 IF(X-920)1315,1315,1316
 1315 ORDER1(JOBNO,5)=403
      GO TO 1320
 1316 ORDER1(JOBNO,5)=440
C        CALL G05BBF
 1320 X=G05ABF(0.0,1000.0)
      IF(X-76)1321,1321,1322
 1321 ORDER1(JOBNO,6)=12
      GO TO 1350
 1322 IF(X-137)1323,1323,1324
 1323 ORDER1(JOBNO,6)=22
      GO TO 1350
 1324 IF(X-214)1325,1325,1326
 1325 ORDER1(JOBNO,6)=30
      GO TO 1350
 1326 IF(X-384)1327,1327,1328
 1327 ORDER1(JOBNO,6)=45
      GO TO 1350
 1328 IF(X-461)1329,1329,1330
 1329 ORDER1(JOBNO,6)=71
      GO TO 1350
 1330 IF(X-491)1331,1331,1332
 1331 ORDER1(JOBNO,6)=99
      GO TO 1350
 1332 IF(X-506)1333,1333,1334
 1333 ORDER1(JOBNO,6)=123
      GO TO 1350
 1334 IF(X-567)1335,1335,1336
 1335 ORDER1(JOBNO,6)=140
      GO TO 1350
 1336 IF(X-739)1337,1337,1338
 1337 ORDER1(JOBNO,6)=165
      GO TO 1350
 1338 IF(X-798)1339,1339,1340
 1339 ORDER1(JOBNO,6)=193
      GO TO 1350
 1340 IF(X-815)1341,1341,1342
 1341 ORDER1(JOBNO,6)=229
      GO TO 1350
 1342 IF(X-879)1343,1343,1344
 1343 ORDER1(JOBNO,6)=354
      GO TO 1350
 1344 IF(X-889)1345,1345,1346
 1345 ORDER1(JOBNO,6)=515
      GO TO 1350
 1346 ORDER1(JOBNO,6)=635
C        CALL G05BBF
 1350 X=G05ABF(0.0,1000.0)
      IF(X-127)1351,1351,1352
 1351 ORDER1(JOBNO,7)=1
      GO TO 9999
 1352 IF(X-218)1353,1353,1354
 1353 ORDER1(JOBNO,7)=2
      GO TO 9999
 1354 IF(X-266)1355,1355,1356
 1355 ORDER1(JOBNO,7)=3
      GO TO 9999
 1356 IF(X-281)1357,1357,1358
 1357 ORDER1(JOBNO,7)=4
      GO TO 9999
 1358 IF(X-329) 1359,1359,1360
 1359 ORDER1(JOBNO,7)=5
      GO TO 9999
 1360 IF(X-472)1361,1361,1362
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      GO TO 9999
 1362 IF(X-520)1363,1363,1364
 1363 ORDER1(JOBNO,7)=7
      GO TO 9999
 1364 IF(X-567)1365,1365,1366
 1365 ORDER1(JOBNO,7)=12
      GO TO 9999
 1366 IF(X-582)1367,1367,1368
 1367 ORDER1(JOBNO,7)=15
      GO TO 9999
 1368 IF(X-646)1369,1369,1370
 1369 ORDER1(JOBNO,7)=20
      GO TO 9999
 1370 IF(X-757)1371,1371,1372
 1371 ORDER1(JOBNO,7)=31
      GO TO 9999
 1372 IF(X-805)1373,1373,1374
 1373 ORDER1(JOBNO,7)=45
      GO TO 9999
 1374 IF(X-869)1375,1375,1376
 1375 ORDER1(JOBNO,7)=62
      GO TO 9999
 1376 IF(X-933)1377,1377,1378
 1377 ORDER1(JOBNO,7)=90
      GO TO 9999
 1378 ORDER1(JOBNO,7)=190
      GO TO 9999
C        CALL G053BF
 1380 X=G05ABF(0,0,1000,0)
      IF(X-500)1381,1381,1382
 1381 ORDER1(JOBNO,4)=5
      GO TO 9993
 1382 IF(X-500)1383,1383,1384
 1383 ORDER1(JOBNO,4)=18
      GO TO 9993
 1384 IF(X-750)1385,1385,1386
 1385 ORDER1(JOBNO,4)=25
      GO TO 9993
 1386 IF(X-850)9995,9995,9994
 9995 ORDFR1(JOBNO,4)=37
      GO TO 9993
 9994 ORDER1(JOBNO,4)=140
C        CALL G058BF
 9993 X=G05ABF(0,0,1000,0)
      IF(X-83)9992,9992,9991
 9992 ORDER1(JOBNO,5)=55
      GO TO 1390
 9991 IF(X-208)9990,9990,0989
 9990 ORDER1(JOBNO,5)=130
      GO TO 1390
 9989 IF(X-250)9988,9988,9987
 9988 ORDER1(JOBNO,5)=132
      GO TO 1390
 9987 IF(X-375)9986,9986,9985
 9986 ORDER1(JOBNO,5)=180
      GO TO 1300
 9985 IF(X-500)9984,9984,9983
 9984 ORDER1(JOBNO,5)=233
      GO TO 1390
 9983 IF(X-710)9982,9982,1387
 9982 ORDER1(JOBNO,5)=300
      GO TO 1390
 1387 IF(X-835)1388,1388,1389
 1388 ORDER1(JOBNO,5)=425
      GO TO 1390
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 1389 ORDER1(JOBNO,5)=800
C        CALL G05BBF
 1390 X=G05ABF(0.0,1000.0)
      IF(X-56)1391,1391,1392
 1391 ORDER1(JOBNO,6)=8
      GO TO 1410
 1392 IF(X-178)1393,1393,1394
 1393 ORDER1(JOBNO,6)=25
      GO TO 1410
 1394 IF(X-290)1395,1395,1396
 1395 ORDER1(JOBNO,6)=53
      GO TO 1410
 1396 IF(X-346)1397,1397,1398
 1397 ORDER1(JOBNO,6)=87
      GO TO 1410
 1398 IF(X-458)1399,1399,1400
 1399 ORDER1(JOBNO,6)=105
      GO TO 1410
 1400 IF(X-514)1401,1401,1402
 1401 ORDER1(JOBNO,6)=132
      GO TO 1410
 1402 IF(X-626)1403,1403,1404
 1403 ORDER1(JOBNO,6)=150
      GO TO 1410
 1404 IF(X-682)1405,1405,1406
 1405 ORDER1(JOBNO,6)=168
      GO TO 1410
 1406 IF(X-849)1407,1407,1408
 1407 ORDER1(JOBNO,6)=195
      GO TO 1410
 1408 ORDER1(JOBNO,6)=230
C        CALL G05BBF
 1410 X=G05ABF(0.0,1000.0)
      IF(X-500)1411,1411,1412
 1411 ORDER1(JOBNO,7)=1
      GO TO 9999
 1412 IF(X-533)1413,1413,1414
 1413 ORDER1(JOBNO,7)=2
      GO TO 9999
 1414 IF(X-800)1415,1415,1416
 1415 ORDER1(JOBNO,7)=3
      GO TO 9999
 1416 IF(X-933)1417,1417,1418
 1417 ORDER1(JOBNO,7)=17
      GO TO 9999
 1418 ORDER1(JOBNO,7)=53
      GO TO 9999
C        CALL G05BBF
 1420 X=G05ABF(0.0,1000.0)
      IF(X-100)1421,1421,1422
 1421 ORDER1(JOBNO,4)=5
      GO TO 1445
 1422 IF(X-500)1423,1423,1424
 1423 ORDER1(JOBNO,4)=15
      GO TO 1445
 1424 IF(X-600)1425,1425,1426
 1425 ORDER1(JOBNO,4)=25
      GO TO 1445
 1426 IF(X-700)1427,1427,1428
 1427 ORDER1(JOBNO,4)=33
      GO TO 1445
 1428 IF(X-740)1429,1429,1430
 1429 ORDER1(JOBNO,4)=37
      GO TO 1445
 1430 IF(X-780)1431,1431,1432
 1431 ORDER1(JOBNO,4)=43
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      GO TO 1445
 1432 IF(X-840)1433,1433,1434
 1433 ORDER1(JOBNO,4)=50
      GO TO 1445
 1434 IF(X-940)1435,1435,1436
 1435 ORDER1(JOBNO,4)=65
      GO TO 1445
 1436 IF(X-960)1437,1437,1438
 1437 ORDER1 (JOBNO,4)=85
      GO TO 1445
 1438 IF(X-980)1439,1439,1440
 1439 ORDER1(JOBNO,4)=120
      GO TO 1445
 1440 ORDER1(JOBNO,4)=170
C       CALL G05BBF
 1445 X=G05ABF(0,0,1000,0)
      IF(X-36)1446,1446,1447
 1446 ORDER1(JOBNO,5)=45
      GO TO 1470
 1447 IF(X-54)1448,1448,1449
 1448 ORDER1(JOBNO,5)=100
      GOTO 1470
 1449 IF(X-108)1450,1450,1451
 1450 ORDER1(JOBNO,5)=120
      GO TO 1470
 1451 IF(X-199)1452,1452,1453
 1452 ORDER1(JOBNO,5)=140
      GO TO 1470
 1453 IF(X-217)1454,1454,1455
 1454 ORDER1(JOBNO,5)=160
      GO TO 1470
 1455 IF(X-298)1456,1456,1457
 1456 ORDER1(JOBNO,5)=180
      GO TO 1470
 1457 IF(X-461)1458,1458,1459
 1458 ORDER1(JOBNO,5)=208
      GO TO 1470
 1459 IF(X-571)1460,1460,1461
 1460 ORDER1(JOBNO,5)=250
      GO TO 1470
 1461 IF(X-791)1462,1462,1463
 1462 ORDER1(JOBNO,5)=343
      GO TO 1470
 1463 IF(X-845)1464,1464,1465
 1464 ORDER1(JOBNO,5)=459
      GO TO 1470
 1465 IF(X-936)1466,1466,1467
 1466 ORDER1(JOBNO,5)=572
      GO TO 1470
 1467 IF(X-954)1468,1468,1469
 1468 ORDER1(JOBNO,5)=693
      GO TO 1470
 1469 ORDER1(JOBNO,5)=990
C       CALL G05BBF
 1470 X=G05ABF(0,0,1000,0)
      IF(X-38)1471,1471,1472
 1471 ORDER1(JOBNO,6)=12
      GO TO 1495
 1472 IF(X-77)1473,1473,1474
 1473 ORDER1(JOBNO,6)=30
      GO TO 1495
 1474 IF(X-116)1475,1475,1476
 1475 ORDER1(JOBNO,6)=42
      GO TO 1495
 1476 IF(X-212)1477,1477,1478
 1477 ORDER1(JOBNO,6)=53
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      GO TO 1495
 1478 IF(X-290)1479,1479,1480
 1479 ORDER1(JOBNO,6)=89
      GO TO 1495
 1480 IF(X-386)1481,1481,1482
 1481 ORDER1(JOBNO,6)=102
      GO TO 1495
 1482 IF(X-577)1483,1483,1484
 1483 ORDER1(JOBNO,6)=140
      GO TO 1495
 1484 IF(X-787)1485,1485,1486
 1485 ORDER1(JOBNO,6)=205
      GO TO 1495
 1486 IF(X-846)1487,1487,1488
 1487 ORDER1(JOBNO,6)=273
      GO TO 1495
 1488 IF(X-904)1489,1489,1490
 1489 ORDER1(JOBNO,6)=412
      GO TO 1495
 1490 IF(X-962)1491,1491,1492
 1491 ORDER1(JOBNO,6)=575
      GO TO 1495
 1492 ORDER1(JOBNO,6)=790
C        CALL G05BBF
 1495 X=G05ABF(0,0,1000,0)
      IF(X-443)1496,1496,1497
 1496 ORDER1(JOBNO,7)=1
      GO TO 9999
 1497 IF(X-520)1498,1498,1499
 1498 ORDER1(JOBNO,7)=2
      GO TO 9999
 1499 IF(X-578)1500,1500,1501
 1500 ORDER1(JOBNO,7)=3
      GO TO 9999
 1501 IF(X-655)1502,1502,1503
 1502 ORDER1(JOBNO,7)=4
      GO TO 9999
 1503 IF(X-674)1504,1504,1505
 1504 ORDER1(JOBNO,7)=5
      GO TO 9999
 1505 IF(X-732)1506,1506,1507
 1506 ORDER1(JOBNO,7)=8
      GO TO 9999
 1507 IF(X-770)1508,1508,1509
 1508 ORDER1(JOBNO,7)=12
      GO TO 9999
 1509 IF(X-808)1510,1510,1511
 1510 ORDER1(JOBNO,7)=15
      GO TO9999
 1511 IF(X-885)1512,1512,1513
 1512 ORDER1(JOBNO,7)=22
      GO TO 9999
 1513 IF(X-981)1514,1514,1515
 1514 ORDER1(JOBNO,7)=70
      GO TO 9999
 1515 ORDER1(JOBNO,7)=283
 9999 CONTINUE
      ORDER1(JOBNO,8)=0,0
      RETURN
      END
      SUBROUTINE CASTDIM(ORDER1,ORDER2,DIESIZ,JOBNO)
       DIMENSION ORDER1(300,9),ORDER2(300,11),DIESIZ(119,3),DENSITY(29),
     1XMETLS(29)
      DATA DENSITY/8900E-9,8900E-9,7570E-9,7570E-9,7570E-9,7570E-9,
     18800E-9,8800E-9,8300E-9,8800E-9,8800E-9,8800E-9,8800E-9,8800E-9,
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     18850E-9,8850E-9,8380E-9,8380E-9,8380E-9,8380E-9,8380E-9,8380E-9/
      DATA XMETLS/2.46,2.46,13.8,13.8,13.8,13.8,2.05,2.05,2.05,2.05,2.05
     1,2.05,2.05,2.05,2.05,2.05,2.05,2.05,2.05,2.05,2.05,2.05,3.93,3.93,
     112.61, 12.61,12.61,12.35,12.35/
C     CALCULATION OF MIN DIMENSIONS
      III=JOBNO
       IL=0
      IF(ORDER1(III,5)-300)1700,1710,1710
 1700 LOUTDIA=ORDER1(III,5)+18
      GO TO 1712
 1710 LOUTDIA=ORDER1(III,5)+25
 1712 IF((ORDER1(III,3).LE.6).OR.(ORDER1(III,3).GE.28)) GO TO 1715
      LINDIA=ORDER1(III,5)-(ORDER1(III,4)*2+40)
      GO TO 1716
 1715 LINDIA=ORDER1(III,5)-(ORDER1(III,4)*2+70)
 1716 IF(LINDIA.GT.80)GO TO 1717
      ORDER1(III,8)=1
      GO TO 1
 1717 IF(ORDER1(III,5)-580)1760,1760,1770
 9999 WRITE(2,9099)DIESIZ(N,2)
 9099 FORMAT(1H ,6HSTOP 1,2X,F10.2)
      STOP
 1760 LGTH=ORDER1(III,6)+49
      GO TO 1800
 1770 IF(ORDER1(III,5)-900)1780,1780,1790
 1780 LGTH=ORDER1(III,6)+56
      GO TO 1800
 1790 LGTH=ORDER1(III,6)+62
C     DIE CHOICE
 1800 JK=1
      IF(LOUTDIA-313)1801,1801,1802
 1801 IF(LGTH.GT.648)GO TO 1805
        IF((LGTH*ORDER1(III,7))-1200)1802,1804,1804
 1802 GO TO 1805
 1804 GOTO 1806
C     NON BUSHDIE CHOICE
 1805 DO 9 N=29,119
      IF(LOUTDIA-DIESIZ(N,1))1808,1808,1810
 1808 ORDER2(III,3)=LINDIA
      GO TO 1811
 1810 CONTINUE
    9 CONTINUE
 1811 IF(DIESIZ(N,2)-LGTH)1855,1853,1856
 1853 ORDER2(III,2)=DIESIZ(N,1)
      ORDER2(III,1)=DIESIZ(N,3)
      ORDER2(III,4)=DIESIZ(N,2)
      ORDER2(III,5)=ORDER1(III,7)
      ORDER2(III,9)=N
      IF(IL.GT.0)GO TO 5351
      GO TO 5330
 1855 IF(DIESIZ(N,3).EQ.4)GO TO 1857

      DO 1858 ILT=N+1,119
      IF(DIESIZ(ILT,2)-LGTH)1860,1859,1859
 1859 N=ILT
       GO TO 1861
 1860 IF(DIESIZ(ILT,3)-4)1858,1862,1862
 1862 N=ILT
      GO TO 1857
 1858 CONTINUE
 1861 IF(DIESIZ(N,1).GT.1.5*ORDER1(III,5))GO TO 9979
      GO TO 1853
 9979 IF(DIESIZ(N,3).LT.4)GO TO 9978
      ORDER1(III,6)=ORDER1(III,6)/2
      ORDER1(III,7)=ORDER1(III,7)*2
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9978 ORDER1(III,8)=1.0
     GO TO 1
C    NUMBER OF RINGS REQN ON VERTICAL SECTION
1857 INMEDIA=DIESIZ(N,1)
      LGDIE=DIESIZ(N,2)
     DO 10 JJ=N+1,119
     LGDIE=LGDIE+DIESIZ(JJ,2)
     JK=JK+1
      INMEDIA=INMEDIA+DIESIZ(JJ,1)
     IF(LGTH-LGDIE)1821,1821,1822
1822 CONTINUE
  10 CONTINUE
1821 ORDER2(III,4)=LGDIE
     ORDER2(III,2)=INMEDIA/JK
      IF(ORDER2(III,2).GT.1.5*ORDER1(III,5))GO TO 9946
     IF(ORDER2(III,2).GT.1143)GO TO 5421
     IF(ORDER2(III,4).LT.660)GO TO 5422
     ORDER1(III,8)=1
     GO TO 1
5421 IF(ORDER2(III,2).GT.1397)GO TO 5423
     IF (ORDER2(III,4).LT.508)GO TO 5422
9946 ORDER1(III,8)=1
     GO TO 1
5423 IF(ORDER2(III,4).LT.381)GO TO 5422
     ORDER1(III,8)=1
     GO TO 1
5422 ORDER2(III,5)=ORDER1(III,7)
     IF(JK.GT.1)GO TO 9927
     ORDER2(III,6)=JK
     ORDER2(III,9)=N
     GO TO 5330
9927 ORDER2(III,6)=(JK-1)
     ORDER2(III,9)=N
      GO TO 5330
1856 DO 1863 IL=2,1000
     LCALGTH=(IL*LGTH)+((IL-1)*9)
     IF(LCALGTH.GT.DIESIZ(N,2))GO TO 1864
1863 CONTINUE
     GO TO 9999
1864 XX=ORDER1(III,7)/(IL-1)
     IYY=INT(XX)
     ORDER2(III,5)=IYY
     IF(FLOAT(IYY).NE.XX)ORDER2(III,5)=IYY+1
     ORDER1(III,7)=ORDER2(III,5)*(IL-1)
     ORDER2(III,9)=N
     ORDER2(III,1)=DIESIZ(N,3)
      ORDER2(III,2)=DIESIZ(N,1)
      ORDER2(III,4)=DIESIZ(N,2)
5330 ORDER1(III,9)=3.142*(ORDER1(III,5)**2/4- (ORDER1(III,5)
    1-(2*ORDER1(III,4)))**2/4)*ORDER1(III,6)*DENSITY(INT(ORDER1(III,3
    1)))
     ORDER2(III,8)=3.142*(ORDER2(III,2)**2/4-ORDER2(III,3)**2/4)*
    1ORDER2(III,4)*DENSITY(INT(ORDER1(III,3)))
     ORDER2(III,11)=ORDER2(III,8)-ORDER1(III,9)
     GO TO 1840
5331 ORDER1(III,9)=3.142*(ORDER1(III,5)**2/4- (ORDER1(III,5)
    1-(2*ORDER1(III,4)))**2/4) *ORDER1(III,6)*DENSITY(INT(ORDER1(III,3
    1)))
     ORDER2(III,8)=3.142*(ORDER2(III,2)**2/4-ORDER2(III,3)**2/4)*
    1ORDER2(III,4)*DENSITY(INT(ORDER1(III,3)))
     ORDER2(III,11)=ORDER2(III,8)-ORDER1(III,9)*(IL-1)
     GO TO 1840
C    CHOICE OF DIE ON BUSHMASTER SECTION
1806 IF(LGTH.GT.340.AND.LGTH.LT.500)GO TO 1805
      DO 11 L=1,28
     IF(LOUTDIA-DIESIZ(L,1))1830,1830,1831
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 1830 ORDER2(III,1)=1
      ORDER2(III,2)=DIESIZ(L,1)
      ORDER2(III,9)=L
      N=L
      GO TO 1833
 1831 CONTINUE
   11 CONTINUE
 1833 ORDER2(III,3)=LINDIA
      ORDER2(III,4)=648
      ORDER2(III,5)=INT(ORDER1(III,7)/INT(648/ORDER1(III,6)))
      ORDER1(III,9)=3.142*(ORDER1(III,5)**2/4- (ORDER1(III,5)
     1-(2*ORDER1(III,4)))**2/4)*ORDER1(III,6)*DENSITY(INT(ORDER1(III,3
     1)))
      ORDER2(III,8)=3.142*(ORDER2(III,2)**2/4-ORDER2(III,3)**2/4)*
     1ORDER2(III,4)*DENSITY(INT(ORDER1(III,3)))
      ORDER2(III,11)=ORDER2(III,8)-ORDER1(III,9)*INT(ORDER2(III,4)/
     1ORDER1(III,6))
C     MOLTEN METAL REQUIREMENT FOR ONE CASTING FROM A PARTICULAR ORDER
 1840 ORDER2(III,1)=DIESIZ(N,3)
      ORDER2(III,7)=ORDER2(III,8)*(100+XMETLS(INT(ORDER1(III,3))))/100
    1 RETURN
      END
      SUBROUTINE FNCHOS(ORDER1,ORDER2,STOCK,FNCINF,ICOUNT,VACHTIM,
     1TEMSCRAP,TEMSTOR,PRIOR,TIM,DAY)
      DIMENSION ORDER1(300,9),ORDER2(300,11),STOCK(29,6),FNCINF(7,5),
     1ICOUNT(119),VACHTIM(141),TEMSCRAP(29),TEMSTOR(300)
      INTEGER X,DAY
C     JOB CHOICE
C     LOOKFOR STANDBY JOB
      DO 9971 IBC=1,7
      IF(FNCINF(IBC,3).EQ.23.OR.FNCINF(IBC,3).EQ.24)
     1FNCINF(IBC,3)=1.0
 9971 CONTINUE
 1918 L=1
 1919 IF(FNCINF(4,2).EQ.1.0.AND.FNCINF(5,2).EQ.1.0)GO TO 753
      DO 1920 JMN=L,300
C       LOOK FOR STANDBY JOB
        X=ORDER2(JMN,9)
          IF((ORDER1(JMN,8).GT.0.0).OR.(ORDER1(JMN,1).EQ.0.0)
     1.OR.(ICOUNT(X).EQ.1))GO TO 1920
      GO TO 1950
 1920 CONTINUE
C     LOOK FOR PRIORITY JOB
  753 SETPRIOR=PRIOR
 1929 AA=1.0
      L=1
 1928 DO 1925 IMN=L,300
      X=ORDER2(IMN,9)
        IF((ORDER1(IMN,2).LT.SETPRIOR).OR.(ORDER1(IMN,8).GT.0.0)
     1.OR.(ICOUNT(X).GT.0))GO TO 1925
      IF(ORDER1(IMN,3).GT.AA)GO TO 1925
      J=IMN
      GO TO 1940
 1925 CONTINUE
      AA=AA+1.0
      IF(AA.GT.29.0)GO TO 776
      L=1
      GO TO 1928
  776 SETPRIOR=SETPRIOR-1.0
      IF(SETPRIOR.LE.0.0)GO TO 9999
      GO TO 1929
C     DETERMINE WHETHER TWO ELECT FNCES REQUIRED
 1940 IF(FNCINF(4,1)+FNCINF(5,1).GT.ORDER2(J,7))GO TO 1942
      ORDER1(J,8)=1
      L=J+1
      GO TO 1928
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 1942 IF(FNCINF(5,1).GE.ORDER2(J,7))GO TO 1980
      ORDER1(J,1)=1.0
      L=J+1
      GO TO 1928
C     PROCESS ORDER REQUIRING TWO FURNACES
 1950 FNCINF(4,4)=1.0
      FNCINF(5,4)=1.0
      IF(FNCINF(4,2).GT.0.0)GO TO 1952
      IF(FNCINF(5,2).LT.1.0)GO TO 1953
 1952 GO TO 753
C     CHECK PREVIOUS ALLOY
 1953 IF(FNCINF(4,3).GT.ORDER1(JMN,3))GO TO 1960
 1955 IF(FNCINF(5,3).GT.ORDER1(JMN,3))GO TO 1970
 1957 IF(FNCINF(4,3).LE.ORDER1(JMN,3))GO TO 9976
      FNCINF(4,3)=0.0
      GO TO 753
 9976 AMOLWT=ORDER2(JMN,7)
      IF((ORDER2(JMN,1).LT.4).OR.(ORDER2(JMN,6).EQ.0.0))
     1GO TO 1973
      KYM=INT(ORDER2(JMN,9))
      DO 905 KVM=KYM,KYM+INT(ORDER2(JMN,6))
      IF(ICOUNT(KVM).EQ.1)GO TO 901
  905 CONTINUE
      DO 1978 KZM=KYM,KYM+INT(ORDER2(JMN,6))
      ICOUNT(KZM)=1
 1978 CONTINUE
      N=5
      GO TO 903
  901 L=JMN+1
      GO TO 1919
 1973 ICOUNT(INT(ORDER2(JMN,9)))=1
      N=5
  903 FNCINF(4,2)=1
      FNCINF(4,3)=ORDER1(JMN,3)
      FNCINF(5,2)=1
      FNCINF(5,3)=ORDER1(JMN,3)
      FNCINF(4,4)=0
      FNCINF(5,4)=0
      ICOUNT(INT(ORDER2(JMN,9)))=1
C     CALL G05BBF
      X=G05ABF(0,0,1000,0)
      IF(ORDER1(JMN,3).GT.2)GO TO 1979
      IF(X.LT.11)GO TO 5018
      GO TO 5019
 1979 IF(ORDER1(JMN,3).GT.6)GO TO 5020
      IF(X.LT.15)GO TO 5018
      TEMSTOR(JMN  )=ORDER2(JMN,9)
      GO TO 5019
 5020 IF((ORDER1(JMN,3).GT.25).AND.(ORDER1(JMN,3).LT.27))GO TO 5021
      IF(X.LT.7)GO TO 5018
      TEMSTOR(JMN  )=ORDER2(JMN,9)
      GO TO 5019
 5021 IF(X.LT.10)GO TO 5018
 5019 TEMSTOR(JMN  )=ORDER2(JMN,9)
      ORDER2(JMN,5)=ORDER2(JMN,5)-1
      IF(ORDER2(JMN,5).GT.0.0)GO TO 3027
      ORDER1(JMN,8)=1
      J=JMN
       GO TO 2080
 5018 TEMSCRAP(INT(ORDER1(JMN,3)))=TEMSCRAP(INT(ORDER1(JMN,3)))+
     1ORDER2(JMN,8)
 3027 J=JMN
      GO TO 2080
C     FIND WASH HEAT
 1960 LN=1
      N=4
```

```
 1961 DO 1965 JI=LN,300
      IF(ORDER1(JI,8).GT.0.0)GO TO 1965
      IF((ORDER1(JI,3).GT.22.5).AND.(ORDER1(JI,3).LT.24.5))
     1GO TO 1962
 1965 CONTINUE
C     SCRUB HEAT REQUIRED
      J=0
      FNCINF(4,2)=1
      FNCINF(4,3)=1.0
      AMOLWT=0.5*FNCINF(4,1)
      TEMSCRAP(1)=AMOLWT
      LIJ=1
      GO TO 5120
 1962 IF(FNCINF(4,1).GE.ORDER2(JI,7))GO TO 1967
 1966 LN=JI+1
      GO TO 1961
 1967 KYM=INT(ORDER2(JI,9))
      IF(ICOUNT(KYM).EQ.1)GO TO 902
      AMOLWT =ORDER2(JI,7)
      IF((ORDER2(JI,1).LT.4).OR.(ORDER2(JI,6).EQ.0.0))
     1GO TO 5011
      DO 906 KWM=KYM,KYM+INT(ORDER2(JI,6))
      IF(ICOUNT(KWM).EQ.1)GO TO 902
  906 CONTINUE
      DO 5110 KZM=KYM,KYM+INT(ORDER2(JI,6))
 5110 ICOUNT(KZM)=1
      GO TO 5012
  902 LN=JI+1
      GO TO 1961
 5011 ICOUNT(INT(ORDER2(JI,9)))=1
 5012 FNCINF(4,2)=1.0
      FNCINF(4,3)=ORDER1(JI,5)
C      CALL G05BBF
      X=G05ABF(0.0,1000.0)
      IF(X.LT.10)GO TO 5106
      TEMSTOR(JI)=ORDER2(JI,9)
      ORDER2(JI,5)=ORDER2(JI,5)-1.0
      IF(ORDER1(JI,5).GT.0)GO TO 5108
      ORDER1(JI,8)=1
 5108 LIJ=25
      J=JI
      GO TO 5120
 5106 TEMSCRAP(23)=ORDER2(JI,8)
      LIJ=25
      J=JI
 5120 IF(STOCK(LIJ,3)-AMOLWT)5121,5123,5123
 5121 REMDER=AMOLWT-STOCK(LIJ,3)
      STOCK(LIJ,3)=0.0
      IF(STOCK(LIJ,2)-REMDER)5125,5126,5126
 5125 REMDER=REMDER-STOCK(LIJ,2)
      STOCK(LIJ,2)=0.0
      STOCK(LIJ,1)=STOCK(LIJ,1)-REMDER
      MX=LIJ
       GO TO 5180
 5126 STOCK(LIJ,2)=STOCK(LIJ,2)-REMDER
      MX=LIJ
       GO TO 5180
 5123 STOCK(LIJ,3)=STOCK(LIJ,3)-AMOLWT
      MX=LIJ
       GO TO 5180
 1970 MN=1
      N=5
 1971 DO1975 IJ=MN,300
      IF(ORDER1(IJ,8).GT.0.0)GO TO 1975
      IF((ORDER1(IJ,3).GT.22.5).AND.(ORDER1(IJ,3).LT.24.5))
     1GO TO 1972
```

```
 1975 CONTINUE
C       SCRUB HEAT REQUIRED.
        J=0
        FNCINF(5,2)=1
        FNCINF(5,3)=1.0
        AMOLWT=0.5*FNCINF(5,1)
        TEMSCRAP(1)=AMOLWT
        LIJ=1
        GO TO 5130
 1972   IF(FNCINF(5,1).GE.ORDER2(IJ,7))GO TO 1977
 1976   MN=IJ+1
        GO TO 1971
 1977   KYM=INT(ORDER2(IJ,9))
        IF(ICOUNT(KYM).EQ.1)GO TO 908
        AMOLWT=ORDER2(IJ,7)
        IF((ORDER2(IJ,1).LT.4).OR.(ORDER2(IJ,6).EQ.0.0))
     1GO TO 5162
        DO 907 KWM=KYM,KYM+INT(ORDER2(IJ,6))
        IF(ICOUNT(KUM).EQ.1)GO TO 908
  907   CONTINUE
        DO 5163 KZM=KYM,KYM+INT(ORDER2(IJ,6))
 5163   ICOUNT(KZM)=1
        GO TO 909
  908   MN=IJ+1
        GO TO 1971
 5162   ICOUNT(INT(ORDER2(IJ,9)))=1
  909   FNCINF(5,2)=1.0
        FNCINF(5,3)=ORDER1(IJ,3)
C        CALL G05BBF
        X=G05ABF(0.0,1000.0)
        IF(X.LT.10)GO TO 5165
        TEMSTOR(IJ)=ORDER2(J,9)
        ORDER2(IJ,5)=ORDER2(IJ,5)-1.0
        IF(ORDER2(IJ,5).GT.0)GO TO 5168
        ORDER1(IJ,8)=1
 5168   LIJ=23
        J=IJ
        GO TO 5130
 5165   TEMSCRAP(23)=ORDER2(IJ,8)
        LIJ=23
        J=IJ
 5130   IF(STOCK(LIJ,3)-AMOLWT)5171,5173,5173
 5171   REMDER=AMOLWT-STOCK(LIJ,3)
        STOCK(LIJ,3)=0.0
        IF(STOCK(LIJ,2)-REMDER)5175,5176,5176
 5175   REMDER=REMDER-STOCK(LIJ,2)
        STOCK(LIJ,2)=0.0
        STOCK(LIJ,1)=STOCK(LIJ,1)-REMDER
        MX=LIJ
        GO TO 5180
 5176   STOCK(LIJ,2)=STOCK(LIJ,2)-REMDER
        MX=LIJ
        GO TO 5180
 5173    STOCK(LIJ,3)=STOCK(LIJ,3)-AMOLWT
        MX=LIJ
        GO TO 5180.
 1980   DO 1990 N=1,7
         IF(N.LT.4.OR.N.GT.5)GO TO 922
        IF(FNCINF(N,4).GT.0.0)GO TO 1990
  922   IF(ORDER2(J,7).GT.FNCINF(N,1))GO TO 1992
        IF(FNCINF(N,2).LT.1.0)GO TO 1985
        IF(N.LT.7)GO TO 1992
        GO TO 2081
 1985   IF(FNCINF(N,3).LE.ORDER1(J,3))GO TO 1991
        GO TO 2030
 1992   IF(N.LT.6)GO TO 1990
```

```
 1975 CONTINUE
C     SCRUB HEAT REQUIRED.
       J=0
      FNCINF(5,2)=1
      FNCINF(5,3)=1.0
      AMOLWT=0.5*FNCINF(5,1)
      TEMSCRAP(1)=AMOLWT
      LIJ=1
      GO TO 5130
 1972 IF(FNCINF(5,1),GE,ORDER2(IJ,7))GO TO 1977
 1976 MN=IJ+1
      GO TO 1971
 1977 KYM=INT(ORDER2(IJ,9))
      IF(ICOUNT(KYM).EQ.1)GO TO 908
      AMOLWT=ORDER2(IJ,7)
      IF((ORDER2(IJ,1).LT.4).OR.(ORDER2(IJ,6).EQ.0.0))
     1GO TO 5162
      DO 907 KWM=KYM,KYM+INT(ORDER2(IJ,6))
      IF(ICOUNT(KWM).EQ.1)GO TO 908
  907 CONTINUE
      DO 5163 KZM=KYM,KYM+INT(ORDER2(IJ,6))
 5163 ICOUNT(KZM)=1
      GO TO 909
  908 MN=IJ+1
      GO TO 1971
 5162 ICOUNT(INT(ORDER2(IJ,9)))=1
  909 FNCINF(5,2)=1.0
      FNCINF(5,3)=ORDER1(IJ,5)
C      CALL G05BBF
      X=G05ABF(0.0,1000.0)
      IF(X.LT.10)GO TO 5165
      TEMSTOR(IJ)=ORDER2(J,9)
      ORDER2(IJ,5)=ORDER2(IJ,5)-1.0
      IF(ORDER2(IJ,5).GT.0)GO TO 5168
      ORDER1(IJ,8)=1
 5168 LIJ=23
      J=IJ
      GO TO 5130
 5165 TEMSCRAP(23)=ORDER2(IJ,8)
      LIJ=23
      J=IJ
 5130 IF(STOCK(LIJ,3)-AMOLWT)5171,5173,5173
 5171 REMDER=AMOLWT-STOCK(LIJ,3)
      STOCK(LIJ,3)=0.0
      IF(STOCK(LIJ,2)-REMDER)5175,5176,5176
 5175 REMDER=REMDER-STOCK(LIJ,2)
      STOCK(LIJ,2)=0.0
      STOCK(LIJ,1)=STOCK(LIJ,1)-REMDER
      MX=LIJ
      GO TO 5180
 5176 STOCK(LIJ,2)=STOCK(LIJ,2)-REMDER
      MX=LIJ
      GO TO 5180
 5173  STOCK(LIJ,3)=STOCK(LIJ,3)-AMOLWT
      MX=LIJ
      GO TO 5180
 1980 DO 1990 N=1,7
       IF(N.LT.4.OR.N.GT.5)GO TO 922
      IF(FNCINF(N,4).GT.0.0)GO TO 1990
  922 IF(ORDER2(J,7).GT.FNCINF(N,1))GO TO 1992
      IF(FNCINF(N,2).LT.1.0)GO TO 1985
      IF(N.LT.7)GO TO 1992
      GO TO 2081
 1985 IF(FNCINF(N,3).LE.ORDER1(J,3))GO TO 1991
      GO TO 2030
 1992 IF(N.LT.6)GO TO 1990
```

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 1990 CONTINUE
      GO TO 2081
 2020 L=J+1
      GO TO 1928
CC    COMMIT FURNACES TO ORDER UNDER CONSIDERATION
 1991 AMOLUT=ORDER2(J,7)
      IF((ORDER2(J,1).LT.4).OR.(ORDER2(J,6).EQ.0.0))
     1GO TO 5240
      KYM=INT(ORDER2(J,9))
      DO 910 KTM=KYM,KYM+INT(ORDER2(J,6))
      IF(ICOUNT(KTM).EQ.1)GO TO 911
  910 CONTINUE
      DO 5241 KJM=KYM,KYM+INT(ORDER2(J,6))
      ICOUNT(KJM)=1
 5241 CONTINUE
      GO TO 912
 5240 ICOUNT(INT(ORDER2(J,9)))=1
      GO TO 912
  911 GO TO 2020
  912 FNCINF(N,2)=1.0
      FNCINF(N,3)=ORDER1(J,3)
C     CALL G05FBF
      X=G05ABF(0.0,1000.0)
      IF(ORDER1(J,3).GT.2)GO TO 5250
      IF(X.LT.11)GO TO 5251
      TEMSTOR(J)=ORDER2(J,9)
      GO TO 5255
 5250 IF(ORDER1(J,3).GT.6) GOTO 5256
      IF(X.LT.15)GO TO 5251
      TEMSTOR(J)=ORDER2(J,9)
      GO TO 5255
 5256 IF((ORDER1(J,3).GT.25).AND.(ORDER1(J,3).LT.27))GO TO 5257
      IF(X.LT.7)GO TO 5251
      TEMSTOR(J)=ORDER2(J,9)
      GO TO 5255
 5257 IF(X.LT.10)GO TO 5251
      TEMSTOR(J)=ORDER2(J,9)
 5255 IF(ORDER2(J,5).GT.1.0)GO TO 5327
      ORDER1(J,8)=1
      GO TO 2080
 5327 ORDER2(J,5)=ORDER2(J,5)-1.0
      GO TO 2080
 5251 TEMSCRAP(INT(ORDER1(J,3)))=TEMSCRAP(INT(ORDER1(J,3)))+ORDER2(J,8)
      GO TO 2080
C     CHOSEN FURNACE ALREADY COMMITTED
C     LOOK FOR WASH HEAT
 2030 IF(SETPRIOR.GT.6)GO TO 2031
      IF((SETPRIOR.GT.1).AND.(AA.LT.22.5))GO TO 2020
      IF(J.LT.200)GO TO 2020
 2031 CONTINUE
 3020 JZ=1
  920 DO 2050 MJL=JZ,300
      IF(ORDER1(MJL,8)-1.0)2046,2050,2050
 9999 WRITE(2,9098)SETPRIOR
 9098 FORMAT(1H ,6HSTOP 2,2X,F10.2)
      STOP
 2046 IF((ORDER1(MJL,3).GT.22.5).AND.(ORDER1(MJL,3).LT.24.5))
     1GO TO 2049
      GO TO 2050
 2049 KYM=INT(ORDER2(MJL,9))
      IF(ICOUNT(KYM).EQ.1)GO TO 2050
      IF(ORDER2(MJL,7).GT.FNCINF(N,1))GO TO 2050
      IF((ORDER2(MJL,1).LT.4).OR.(ORDER2(MJL,6).EQ.0.0))
     1GO TO 5370
      DO 915 KPM=KYM,KYM+INT(ORDER2(MJL,6))
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     1(...)(KP4),ER,1)GO TO 2050
 915 CONTINUE
     DO 5371 KZM=KYM,KYM+INT(ORDER2(MJL,6))
     ICOUNT(KZM)=1
5371 CONTINUE
     GO TO 5373
5370 ICOUNT(INT(ORDER2(MJL,9)))=1
5373 FNCINF(N,2)=1.0
      FNCINF(N,3)=ORDER1(MJL,3)
     AMOLWT=ORDER2(MJL,7)
C    CALL G05BBF
     X=G05ABF(0.0,100.0)
     IF(X.LT.10)GO TO 5376
     TEMSTOR(MJL)=ORDER2(MJL,9)
     IF(ORDER2(MJL,5).GT.1.5)GO TO 5375
     ORDER1(MJL,8)=1.0
     GO TO 5374
5375 ORDER2(MJL,5)=ORDER2(MJL,5)-1
     GO TO 5374
5376 TEMSCRAP(23)=ORDER2(MJL,8)
5374 J=MJL
     JX=23
     MX=23
     GO TO 2080
2050 CONTINUE
C    SCRUB HEAT REQUIRED
     J=0
     AMOLWT=0.5*FNCINF(N,1)
     TEMSCRAP(1)=AMOLWT
     FNCINF(N,2)=1.0
     FNCINF(N,5)=1.0
     FNCINF(N,3)=1.0
C    DETERMINE CHARGE MAKE UP.
2080 IF(FNCINF(N,5).LT.1.0)GO TO 3061
     FNCINF(N,5)=0.0
     JX=1
     MX=1
3060 STOCK(28,2)=STOCK(28,2)+STOCK(29,2)
     STOCK(29,2)=0.0
     STOCK(28,3)=STOCK(28,3)+STOCK(29,3)
     STOCK(29,3)=0.0
     IF(STOCK(JX,3).GE.AMOLWT)GO TO 3063
     REMDER=AMOLWT-STOCK(JX,3)
     STOCK(JX,3)=0.0
     IF(STOCK(JX,2).GE.REMDER)GO TO 3066
     REMDER=REMDER-STOCK(JX,2)
     STOCK(JX,2)=0.0
     STOCK(MX,1)=STOCK(MX,1)-REMDER
     GO TO 5180
3066 STOCK(JX,2)=STOCK(JX,2)-REMDER
     GO TO 5180
3063 STOCK(JX,3)=STOCK(JX,3)-AMOLWT
     GO TO 5180
3061 LALLOY=INT(FNCINF(N,3))
     IF((LALLOY.GE.4).AND.(LALLOY.LE.6))GO TO 3070
     IF(LALLOY.GT.28)GO TO 3070
     IF(LALLOY.GT.10)GO TO 3074
     JX=LALLOY
     MX=LALLOY
     GO TO 3060
3074 IF(LALLOY.GT.11)GO TO 3075
     JX=11
     MX=8
     GO TO 3060
3075 IF(LALLOY.GT.16)GO TO 3076
     JX=LALLOY
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      MX=13
      GO TO 3060
 3076 IF(LALLOY.GT.20)GO TO 3077
      JX=LALLOY
      MX=18
      GO TO 3060
 3077 JX=LALLOY
      MX=LALLOY
      GO TO 3060
 3070 MX=LALLOY
      STOCK(MX,1)=STOCK(MX,1)-AMOLWT
 5180 IF(STOCK(MX,4).GT.0.0)GO TO 3078
      IF(MX.GT.1)GO TO 3272
      IF(STOCK(MX,1).GT.500)GO TO 3078
      STOCK(MX,4)=0.5
      GO TO 3071
 3272 IF(MX.GT.2)GO TO 3273
      IF(STOCK(MX,1).GT.1000)GO TO 3078
      STOCK(MX,4)=1.0
      GO TO 3071
 3273 IF(MX.GT.3)GO TO 3062
      IF(STOCK(MX,1).GT.1250)GO TO 3078
      STOCK(MY,4)=1.25
      GO TO 3071
 3062 IF(MX.GT.4)GO TO 3079
      IF(STOCK(MX,1).GT.1250)GO TO 3078
      STOCK(MX,4)=1.25
      GO TO 3071
 3079 IF(MX.GT.6)GO TO 3051
       IF(STOCK(MX,1).GT.500)GO TO 3078
      STOCK(MX,4)=0.5
      GO TO 3071
 3051 IF(MX.GT.7)GO TO 3274
      IF(STOCK(MX,1).GT.2500)GO TO 3078
      STOCK(MX,4)=2.5
      GO TO 3071
 3274 IF(MX.GT.8)GO TO 3052
      IF(STOCK(MX,1).GT.1300)GO TO 3078
      STOCK(MX,4)=1.3
      GO TO 3071
 3052 IF(MX.GT.10)GO TO 3053
      IF(STOCK(MX,1).GT.500)GO TO 3078
      STOCK(MX,4)=0.5
      GO TO 3071
 3053 IF(MX.EQ.13)GO TO 3054
      IF(MX.EQ.18)GO TO 3055
      IF(MX.GT.20)GO TO 3056
      GO TO 3058
 3054 IF(STOCK(MX,1).GT.3000)GO TO 3078
      STOCK(MX,4)=3.0
      GO TO 3071
 3055 IF(STOCK(MX,1).GT.1500)GO TO 3078
      STOCK(MX,4)=1.5
      GO TO 3071
 3056 IF(MX.GT.21)GO TO 3275
      IF(STOCK(MX,1).GT.500)GO TO 3078
      STOCK(MX,4)=0.5
      GO TO 3071
 3275 IF(MX.GT.22)GO TO 3057
      IF(STOCK(MX,1).GT.200)GO TO 3078
      STOCK(MX,4)=0.2
      GO TO 3071
 3057 IF(MX.GT.23)GO TO 3058
      IF(STOCK(MX,1).GT.1600)GO TO 3078
      STOCK(MX,4)=1.6
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      IF(STOCK(MX,1).GT.500)GO TO 3078
      STOCK(MX,4)=0.5
      GO TO 3071
 3270 IF(MX.GT.25)GO TO 3059
      IF(STOCK(MX,1).GT.1500)GO TO 3078
      STOCK(MX,4)=1.5
      GO TO 3071
 3059 IF(STOCK(MX,1).GT.500)GO TO 3078
      STOCK(MX,4)=0.5
 3071 STOCK(MX,5)=DAY
C     CALCULATION OF PROCESS TIMES
C     CALCULATION OF MELTING TIME
 3078 FNCINF(N,5)=0.0
      IF(N.GT.2.)GO TO 3081
      IF(FNCINF(N,3).GT.1)GO TO 3083
      TIMELT =74
      GO TO 3120
 3083 IF(FNCINF(N,3).GT.2)GO TO 3084
      TIMELT=71.4
      GO TO 3120
 3084 IF(FNCINF(N,3).GT.6)GO TO 3085
      TIMELT=84.0
      GO TO 3120
 3085 IF(FNCINF(N,3).GT.22)GO TO 3086
      TIMELT=67.7
      GO TO 3120
 3086 TIMELT=90.0
      GO TO 3120
 3081 IF(N.GT.4)GO TO 3091
      IF(FNCINF(N,3).GT.1)GO TO 3093
      TIMELT=38.5
      GO TO 3120
 3093 IF(FNCINF(N,3).GT.2)GO TO 3094
      TIMELT=38.5
      GO TO 3120
 3094 IF(FNCINF(N,3).GT.6)GO TO 3095
      TIMELT=38.5
      GO TO 3120
 3095 IF(FNCINF(N,3).G T.22)GO TO 3096
      TIMELT=33.0
      GO TO 3120
 3096 IF(FNCINF(N,3).G T.24)GO TO 3097
      TIMELT= 37.0
      GO TO 3120
 3097 TIMELT=31.0
      GO TO 3120
 3091 IF(N.GT.5)GO TO 3101
      IF(FNCINF(N,3).GT.6)GO TO 5601
      TIMELT=57.0
      GO TO 3120
 5601 IF(FNCINF(N,3).GT.22)GO TO 5602
      TIMELT=50.0
      GO TO 3120
 5602 IF(FNCINF(N,3).GT.24)GO TO 5603
      TIMELT= 55.0
      GO TO 3120
 5603 TIMELT=47.5
      GO TO 3120
 3101 IF(N.GT.6)GO TO 3110
      TIMELT=(AMOLWT*0.00194*0.885)*60
      GO TO 3120
 3110 TIMELT=110
C     CALCULATION OF SOLIDIFICATION TIME
 3120 IF(ORDER1(J,1).GT.0.0)GO TO 3122
      VACHTIM(N)=TIM+TIMELT
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3122 VACHTIM(4)=TIM+TIMELT
     VACHTIM(5)=TIM+TIMELT
3197 IF(ENGINE(N,3).LT.0.9)GO TO 9948
9955 IF(ORDER2(J,1).GT.1)GO TO 3121
     IF(ORDER2(J  ,2)-108)3123,3123,3125
3123 TIMDIE =17
     GO TO 3190
3125 IF(ORDER2(J  ,2)-131)3126,3126,3127
3126 TIMDIE =18
     GO TO 3190
3127 IF(ORDER2(J  ,2)-150)3128,3128,3129
3128 TIMDIE=20
     GO TO 3190
3129 IF(ORDER2(J  ,2)-160)3130,3130,3131
3130 TIMDIE=21
     GO TO 3190
3131 IF(ORDER2(J  ,2)-201)3132,3132,3133
3132 TIMDIE=30
     GO TO 3190
3133 IF(ORDER2(J  ,2)-253)3134,3134,3135
3134 TIMDIE=32
     GO TO 3190
3135 IF(ORDER2(J  ,2)-293)3136,3136,3137
3136 TIMDIE=34
     GO TO 3190
3137 TIMDIE=36
     GO TO 3190
3121 IF(ORDER2(J  ,1).GT.2)GO TO 3141
     IF(ORDER2(J  ,8)-95) 3142,3142,3143
3142 TIMDIE=20.4
     GO TO 3190
3143 TIMDIE=42.5
     GO TO 3190
3141 IF(ORDER2(J  ,1).GT.3)GO TO 3151
     IF(ORDER2(J  ,8)-275)3152,3152,3153
3152 IF(ORDER2(J  ,2)-508)3154,3154,3155
3154 TIMDIE=71.5
     GO TO 3190
3155 IF(ORDER2(J  ,2)-762)3156,3156,3157
3156 TIMDIE=86.5
     GO TO 3190
3157 TIMDIE=101.0
     GO TO 3190
3153 IF(ORDER2(J  ,8)-350)3160,3160,3161
3160 IF(ORDER2(J  ,2)-508)3162,3162,3163
3162 TIMDIE=80.0
     GO TO 3190
3163 IF(ORDER2(J  ,2)-762)3164,3164,3165
3164 TIMDIE=95.0
     GO TO 3190
3165 TIMDIE=110.0
     GO TO 3190
3161 IF(ORDER2(J  ,2)-508)3170,3170,3171
3170 TIMDIE=110.0
     GO TO 3190
3171 IF(ORDER2(J  ,2)-762)3172,3172,3173
3172 TIMDIE=125.5
     GO TO 3190
3173 TIMDIE=140.0
     GO TO 3190
3151 IF(ORDER2(J  ,8)-275)3180,3180,3181
3180 TIMDIE=80.0
     GO TO 3190
3181 IF(ORDER2(J  ,8)-450)3182,3182,3183
3182 TIMDIE=90.0
```

```
      GO TO 3190
 3183 IF(ORDER2(J   ,8)-700)3184,3184,3185
 3184 TIMDIE=127
      GO TO 3190
 3185 IF(ORDER2(J   ,8)-1200)3186,3186,3187
 3186 TIMDIE=164
      GO TO 3190
 3187 TIMDIE=170
 3190 IF(ORDER2(J,1).LT.4.0.OR.ORDER2(J,6).EQ.0.0)GO TO 5690
      KYM=ORDER2(J,9)
      DO 3196 KZM=KYM,KYM+INT(ORDER2(J,6)+0.5)
      VACHTIM(KZM+7)=VACHTIM(N)+TIMDIE
 3196 CONTINUE
      GO TO 9948
 5690 VACHTIM(INT(ORDER2(J,9))+7)=VACHTIM(N)+TIMDIE
 9948 IF(N.NE.4)GO TO 2081
      IF(FNCINF(4,4).NE.1.0)GO TO 2081
      GO TO 1955
 2081 DO 3040 JLJ=1,7
      IF(JLJ.LT.4.OR.JLJ.GT.5)GO TO 771
      IF(FNCINF(4,4).GT.0.1)GO TO 3040
  771 IF(FNCINF(JLJ,2).GT.0.1)GO TO 3040
      L=J+1
      GO TO 1928
 3040 CONTINUE
 9928 RETURN
      END
      SUBROUTINE MACHOS(ORDER1,ORDER2,VACHTIM,MACHINF,STOCK,
     1PRIOR,WTMACH,TIM)
      DIMENSION ORDER1(300,9),ORDER2(300,11),VACHTIM(141),MACHINF(15),
     1STOCK(29,6)
      SETPRIOR =PRIOR
C     CHOOSE A SUITABLE ORDER
 4011 JAK=1
 4010 DO 4000 JAJ=JAK,300
      IF(ORDER1(JAJ,2).LT.SETPRIOR)GO TO 4000
      IF(ORDER2(JAJ,10).LT.1.0)GO TO 4000
      GO TO 4005
 4000 CONTINUE
      SETPRIOR=SETPRIOR-1
      IF(SETPRIOR.LT.1.0)GO TO 9090
      GO TO 4011
C     CHOOSE A SUITABLE MACHINE
 4005 IF(ORDER2(JAJ,2).GT.456)GO TO 4013
      DO 4020 KAJ=1,8
      IF(MACHINF(KAJ).LT.1)GO TO 4070
 4020 CONTINUE
      IF(ORDER2(JAJ,2).GE.203)GO TO 4018
      JAK=JAJ+1
      GO TO 4010
 4018 DO 4030 KAJ=9,12
      IF(MACHINF(KAJ).LT.1)GO TO 4070
 4030 CONTINUE
      IF(ORDER2(JAJ,2).GE.304)GO TO 4032
      JAK=JAJ+1
      GO TO 4010
 4032 IF(MACHINF(13).EQ.1)GO TO 4035
      KAJ=13
      GO TO 4070
 4035 IF(MACHINF(14).EQ.1)GO TO 4037
      KAJ=14
      GO TO 4070
 4037 IF(ORDER2(JAJ,2).GE.380)GO TO 4041
      JAK=JAJ+1
      GO TO 4010
 4041 IF(MACHINF(15).EQ.1)GO TO 4075
```

```
4013 IF(ORDER2(JAJ,2).GT.760)GO TO 4051
     DO 4055 KAJ=9,15
     IF(MACHINE(KAJ).LT.1)GO TO 4070
4055 CONTINUE
     JAJ=JAJ+1
     GO TO 4010
4051 IF(ORDER2(JAJ,2).GT.1020)GO TO 4061
     DO 4065 KAJ=13,15
     IF(MACHINE(KAJ).LT.1)GO TO 4070
4065 CONTINUE
     JAK=JAJ+1
     GO TO 4010
4061 IF(MACHINE(15).LT.1)GO TO 4071
     GO TO 4075
4071 KAJ=15
4070 ORDER2(JAJ,10)=ORDER2(JAJ,10)-1
     MACHINE(KAJ)=1
     WTMACH=WTMACH+ORDER1(JAJ,9)
     J1=INT(ORDER1(JAJ,3))
     STOCK(J1,3)=STOCK(J1,3)+ORDER2(JAJ,11)
     IF(ORDER2(JAJ,10).GT.0)GO TO 4273
     IF(ORDER2(JAJ,5).GT.0)GO TO 4273
     ORDER1(JAJ,8)=1
C    TIME TAKEN TO MACHINE JOB
C    TIME TAKEN BY SMALL HORIZONTAL MACHINES
4273 IF(KAJ-8)4100,4100,4101
4100 IF(ORDER1(JAJ,3).LT.7.AND.ORDER1(JAJ,3).GT.2)GO TO 4110
     IF(ORDER1(JAJ,5).GT.106)GO TO 4103
4102 SKNMACH=25*ORDER2(JAJ,4)/648+30
     GO TO  4220
4103 IF(ORDER1(JAJ,5).GT.122)GO TO 4106
4105 SKNMACH=27*ORDER2(JAJ,4)/648+35
     GO TO 4220
4106 IF(ORDER1(JAJ,5).GT.142)GO TO 4108
4107 SKNMACH =29*ORDER2(JAJ,4)/648+40
     GO TO 4220
4108 IF(ORDER1(JAJ,5).GT.152)GO TO 4122
4109 SKNMACH=31*ORDER2(JAJ,4)/648+45
     GO TO 4220
4122 IF(ORDER1(JAJ,5).GT.193)GO TO  4112
4111 SKNMACH=33*ORDER2(JAJ,4)/648+50
     GO TO 4220
4112 IF(ORDER1(JAJ,5).GT.243)GO TO  4114
4113 SKNMACH=35*ORDER2(JAJ,4)/648+55
     GO TO 4220
4114 IF(ORDER1(JAJ,5).GT.283)GO TO  4116
4115 SKNMACH=37*ORDER2(JAJ,4)/648+60
     GO TO 4220
4116 SKNMACH=40*ORDER2(JAJ,4)/648+60
     GO TO 4220
4110 IF(ORDER1(JAJ,5).GT.106)GO TO  4203
4202 SKNMACH=38*ORDER2(JAJ,4)/648+30
     GO TO 4220
4203 IF(ORDER1(JAJ,5).GT.122)GO TO  4206
4205 SKNMACH=41*ORDER2(JAJ,4)/648+35
     GO TO 4220
4206 IF(ORDER1(JAJ,5).GT.142)GO TO  4208
4207 SKNMACH=44*ORDER2(JAJ,4)/648+40
     GO TO 4220
4208 IF(ORDER1(JAJ,5).GT.152)GO TO  4210
4209 SKNMACH=47*ORDER2(JAJ,4)/648+45
     GO TO 4220
4210 IF(ORDER1(JAJ,5).GT.193)GO TO  4212
4211 SKNMACH=50*ORDER2(JAJ,4)/648+50
```

```
4212 IF(ORDER1(JAJ,5).GT.243)GO TO  4214
4213 SKNMACH=53*ORDER2(JAJ,4)/648+60
     GO TO 4220
4214 IF(ORDER1(JAJ,5).GT.283)GO TO  4216
4215 SKNMACH=56*ORDER2(JAJ,4)/648+60
     GO TO 4220
4216 SKNMACH=60*ORDER2(JAJ,4)/648+60
4220 NAJ=INT(ORDER2(JAJ,4)/ORDER1(JAJ,6))
     NAJ=NAJ+1
     IF(ORDER1(JAJ,3).LT.7.AND.ORDER1(JAJ,3).GT.2)GO TO 4250
     IF(ORDER1(JAJ,4).LT.30)GO TO  4221
4222 PARTIM=10* NAJ
     GO TO 4265
4221 IF(ORDER1(JAJ,4).LE.20)GO TO 4225
4226 PARTIM =NAJ*8
     GO TO 4265
4225 IF(ORDER1(JAJ,4).LE.15)GO TO  4227
4228 PARTIM=NAJ*7
     GO TO 4265
4227 IF(ORDER1(JAJ,4).LE.12)GO TO  4229
4230 PARTIM=NAJ*6
     GO TO 4265
4229 IF(ORDER1(JAJ,4).LE.7)GO TO   4231
4232 PARTIM=NAJ*5
     GO TO 4265
4231 PARTIM=NAJ*4
     GO TO 4265
4250 IF(ORDER1(JAJ,4).LE.30)GO TO  4251
4252 PARTIM=15*NAJ
     GO TO 4265
4251 IF(ORDER1(JAJ,4).LE.20)GO TO  4255
4256 PARTIM=NAJ*12
     GO TO 4265
4255 IF(ORDER1(JAJ,4).LE.15)GO TO  4257
4258 PARTIM=NAJ*11
     GO TO 4265
4257 IF(ORDER1(JAJ,4).LE.12)GO TO  4259
4260 PARTIM=NAJ*9
     GO TO 4265
4259 IF(ORDER1(JAJ,4).LE.7)GO TO  4261
4262 PARTIM=NAJ*8
     GO TO 4265
4261 PARTIM=NAJ*6
     GO TO 4265
4265 TIMACH=SKNMACH*PARTIM
     GO TO 4277
C    TIME TAKEN ON HEAVY  HORIZONTAL AND VERTICAL MACHINES
C    PARTING TIME ASSUMED TO EQUAL HALF MACHINING TIME.
4101 SKNMACH=ORDER2(JAJ,11) *0.5+60
     PARTIM=  (INT(ORDER2(JAJ,4)/ORDER1(JAJ,6))+1)*0.5*SKNMACH
     TIMACH =SKNMACH+PARTIM
4277 VACHTIM(KAJ+126)=TIM+TIMACH
C    FOR THE PRESENT ASSUME ALL SCRAP LOCATED IN FOUNDRY
4275 DO4080 LAJ=1,15
     IF(MACHINF(LAJ).EQ.1)GO TO 4080
     JAK=JAJ+1
     GO TO 4010
4080 CONTINUE
4075 CONTINUE
9090 RETURN
     END
     SUBROUTINE HEXVENT(ORDER1,ORDER2,STOCK,FNCINF,ICOUNT,VACHTIM,
    1TEMSCRAP,TEMSTOR,MACHINF,TIM,WTCAST,NOCAST,NRK)
     DIMENSION ORDER1(300,9),ORDER2(300,11),STOCK(29,6),FNCINF(7,5),
    1ICOUNT(119),VACHTIM(141),TEMSCRAP(29),TEMSTOR(300),MACHINF(15)
```

```
5150 DO 5000 IDK=1,141
     IF(IDK.GT.7)GO TO  5002
5001 IF(FNCINF(IDK,2).LT.1.0)GO TO 5000
     SMALL=VACHTIM(IDK)
     LCOUNTER=IDK
     GO TO 5050
5002 IF (IDK.GT.126)GO TO 5011
     IF(ICOUNT(IDK-7).EQ.0)GO TO 5000
     SMALL=VACHTIM(IDK)
     LCOUNTER=IDK
     GO TO 5050
5011 IF(MACHINF(IDK-126).LT.1)GO TO 5000
     SMALL=VACHTIM(IDK)
     LCOUNTER=IDK
     GO TO 5050
5000 CONTINUE
     GO TO 9999
5050 DO 5070 MDK= IDK+1,141
     IF(MDK.GT.7)GO TO 5052
     IF(FNCINF(MDK,2).LT.1.0)GO TO 5070
     IF(SMALL.LE.VACHTIM(MDK))GO TO 5070
     SMALL=VACHTIM(MDK)
     LCOUNTER=MDK
5070 CONTINUE
5052 JDK=MDK
     DO 5080 KDK=JDK,141
     IF(KDK.GT.126)GO TO 5074
     IF(ICOUNT(KDK-7).EQ.0)GO TO 5080
     IF(SMALL.LE.VACHTIM(KDK))GO TO 5080
     SMALL=VACHTIM(KDK)
     LCOUNTER=KDK
5080 CONTINUE
5074 LRK=KDK
     DO 5090 MRK=LRK,141
     IF(MACHINF(MRK-126)-1)5090,5082,5082
9999 WRITE(2,9096)
9096 FORMAT(1H ,6HSTOP 4)
     STOP
5082 IF(SMALL.LE.VACHTIM(MRK))GO TO 5090
     SMALL=VACHTIM(MRK)
     LCOUNTER=MRK
5090 CONTINUE
     TIM=SMALL
     NRK=LCOUNTER
     IF(NRK.GT.7)GO TO 5102
5101 FNCINF(NRK,2)=0
     IF(FNCINF(NRK,3).LT.1.0)GO TO 5130
     JAX=INT(FNCINF(NRK,3))
     STOCK(JAX,2)=STOCK(JAX,2)+TEMSCRAP(JAX)
     TEMSCRAP(JAX)=0.0
     GO TO 5130
5102 IF(NRK.GT.126)GO TO 5106
     ICOUNT(NRK-7)=0
     DO 5107 MX=1,300
     IF(INT(TEMSTOR(MX))+7.NE.NRK)GO TO 5107
     ORDER2(MX,10)=ORDER2(MX,10)+1
     TEMSTOR(MX)=0.0
     UTCAST=UTCAST+ORDER2(MX,8)
     NOCAST=NOCAST+1
     IF(ORDER2(MX,6).LT.1.0)GO TO 5129
     DO 5128 JXX=INT(ORDER2(MX,9)),INT(ORDER2(MX,9)
    1+ORDER2(MX,6))
     ICOUNT(JXX)=0
5128 CONTINUE
     GO TO 5130
```

```
      GO TO 5130
 5107 CONTINUE
      GO TO 5130
 5106 MACHINF(NRK-120)=J
 5130 RETURN
      END
      FINISH
```

1x

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Section 2: APPENDIX III.

The Monte Carlo technique as used by the simulation model.

The Monte Carlo technique.

A simulation model, in providing the means for examining the relationship between decision making systems controlling a sequence of interdependent activities using theoretical techniques instead of resortion to an often expensive actual physical model of the situation, often requires a means of generating unlimited sample data. This could be achieved by feeding in 'real world' information, but because of the rapid rate at which many simulation models operate (particularly computerised versions), such an alternative might necessitate the availability of large proportions of such data. If not an impossible task, in many instances this would certainly constitute a somewhat inefficient procedure capable of upsetting the otherwise rythmic continuity of the model. In addition, alterations to allow study of modifications to the model, a feature for which simulation is often employed, might prove laborious.

To counter such limitations and thus provide an often necessary flexibility to the process, simulation models are often equipped with the means for self-generating essential feed data. Practices of this type are particularly suited to investigation of process plant design or modification of manufacturing systems where jobs arrive at a station in a production system and join the queue to await the service.

A common technique employed in these situations, to provide a theoretical counterpart for the 'real world' from which to draw sample data, is the Monte Carlo method. So called because of its analogy to games of chance, it employs random or pseudo-random numbers to portray 'real world' situations in numerical terms.

Monte Carlo type simulation comprises three principal stages.

The first of these involves study of the system to be simulated. This requires the collection of the necessary information on which to build the Monte Carlo routine. Although historical records provide knowledge of job arrivals, and often plant performance, the latter may be alternatively collected via personal observations or predictions by suppliers. But in all instances, caution is necessary to ensure both the relevance and accuracy of such information.

Mathematical formulation of the routine, based on data studies, provides the second stage of construction. Interpretation of this collected information is carried out through the development of a frequency distribution. This involves determining the variation of values for a particular parameter, plus their associated probabilities of occurrence. A typical example of a frequency distribution is shown in Diagram 1.

But it is more convenient to convert to a cumulation distribution shown in Diagram 2. This is accomplished by summing successive proportionate frequencies to produce a stepped ogive - in effect,a percentage or probability scale is developed. The ordinates are obviously drawn at the mid-point of the class width,and their lengths represent the probability of a particular value being chosen. It is pertinent to note, that to avoid undue ambiguity, it is usual to limit the steps on a cumulative frequency distribution to not more than fifteen.

The routine for data generation, which is the third and final stage in Monte Carlo type simulation, is operated by directing a stream of random numbers at the cumulative frequency distribution to obtain a sequence or pattern of values for the particular parameter. Such a random number stream, suitable for indicating the positions

Diagram 1.

Typical frequency distribution curve.

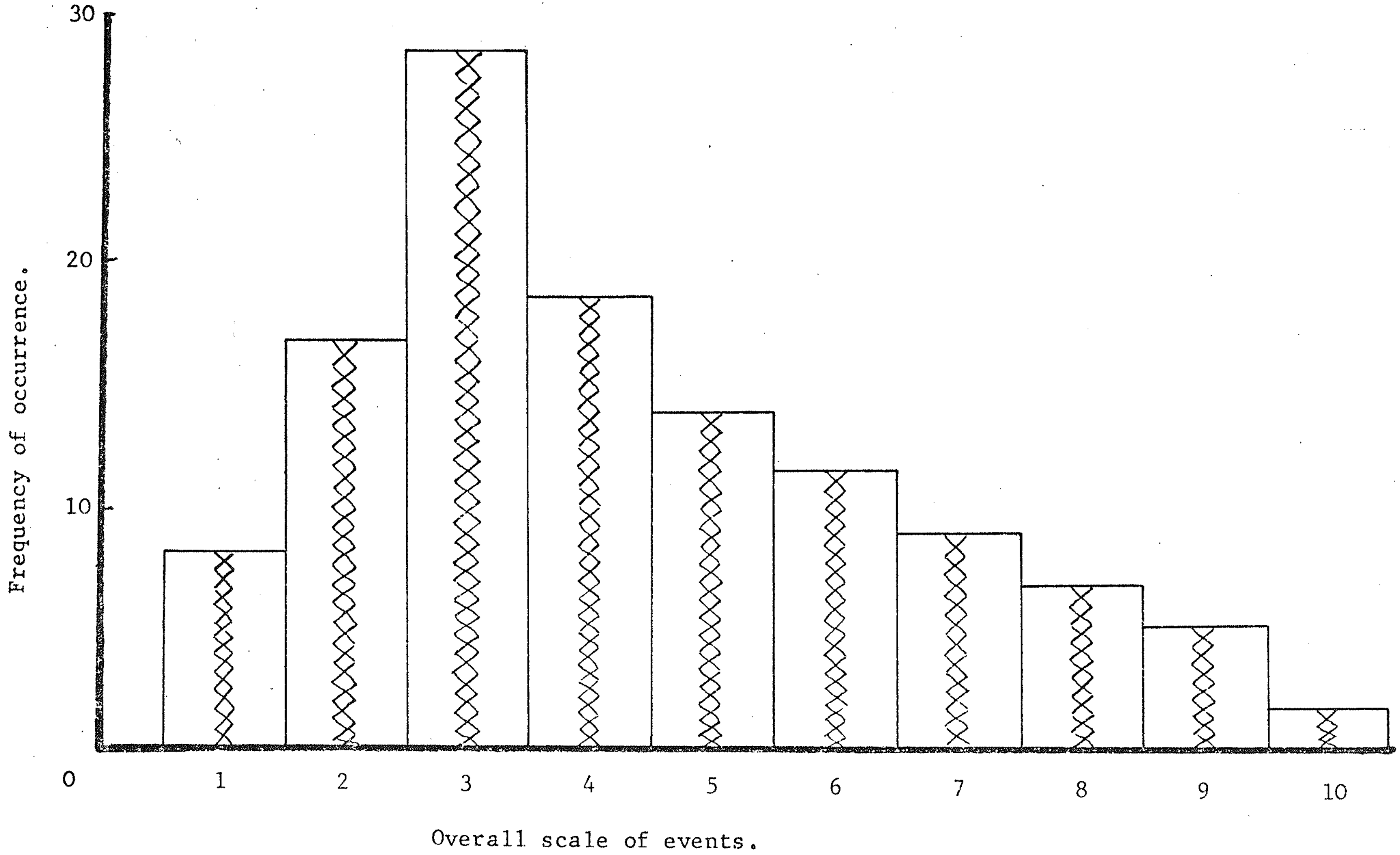
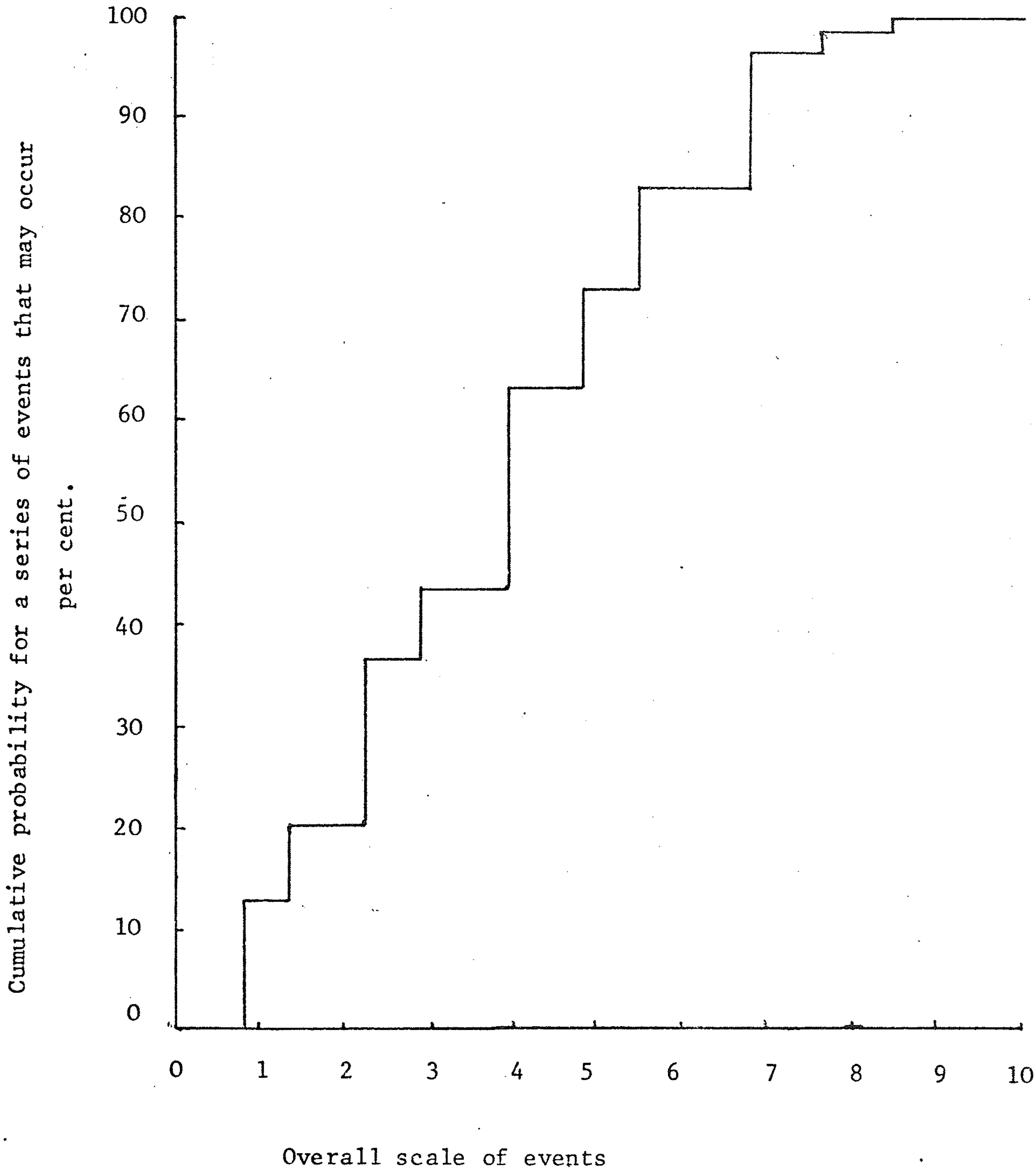


Diagram 2.

Typical cumulative frequency chart.

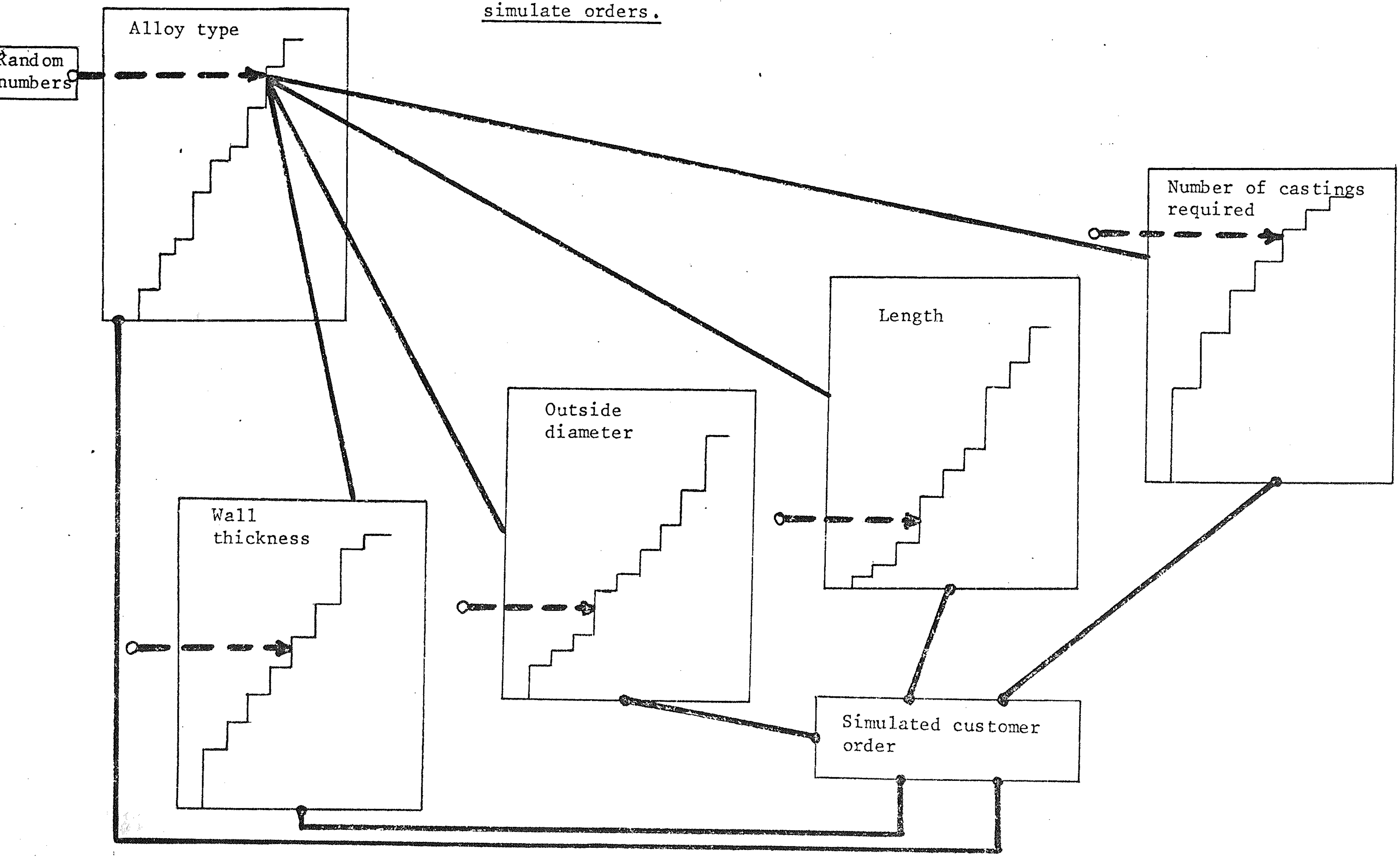


of contact on the stepped ogive and so identifying individual values, can be provided in a number of ways. The simplest is to spin a roulette wheel (hence Monte Carlo) or choose Bingo chips. However, to provide simulation models with the necessary continuity of operation, computers are used to generate a sequence of numbers - these are said to be pseudo-random. Although they are often utilised as a table form, in the majority of computerised simulation studies, it is more convenient to generate the random number as and when required by simply calling an appropriate programmed routine. Pseudo-random number generators produce a sequence of numbers which are random for a given cycle of numbers (perhaps several hundred thousand), but which will eventually recycle through the same numbers- they are reproducible sequences.

The Monte Carlo style order generation routine employed in the Spunalloys simulation model involves provision of a random number 1-1000, which initially identifies the alloy composition of the order. Depending on alloy identification depends the cumulative frequency distribution employed to decide appropriate wall thickness, outside diameter and number off parameters for the order. Again, random numbers having values 1-1000 determine these various dimensions. The programme dealing with order generation and using these techniques is illustrated in Diagram 3.

Diagram 3.

Use of the Monte Carlo technique to simulate orders.



Section 3: APPENDIX III.

Details of the copper base alloys cast at Spunalloys.

Identity of numbered alloys.

Alloy number	Alloy identity	Type of copper alloy
1	H.C.C.	Pure copper
2	4% Ni	Low nickel alloy
3	A.B.1	
4	A.B.2	
5	C.M.A.1	Aluminium bronze
6	C.M.A.2	
7	PB 1	
8	PB 2	
9	PB 3	Phosphor bronze
10	PB 4	
11	LPB 1	
12	LB 1	
13	LB 2	
14	LB 3	
15	LB 4	
16	LB 5	
17	LG 1	Leaded bronzes
18	LG 2	
19	LG 3	
20	LG 4	
21	G 1	
22	SAE 660	
23	B 43 MTL.	
24	CROWN MTL.	High nickel alloy
25	BRASS	
26	D.C.B. 3	Brass
27	S.C.B. 1	
28	H.T.B. 1	High tensile
29	H.T.B. 2	brass

SPECIFIED IMPURITY LEVELS FOR CASTINGS MADE IN COPPER BASE ALLOYS.

SPECIFICATION.	IMPORTANT MAXIMUM IMPURITY LEVELS.							
	Bi	Pb	P.	S.	Zn.	Si.	Fe.	Al.
BSS:1400. HCC.1.	0.0025:	0.001:						
BSS:1400. HCC.2.	0.005:	0.005:						
DHP:225/2.		0.00:	0.20:	0.02:				
BSS;1400. PB.1.		0.25:			0.05:	0.02:	0.10:	0.01:
BSS:1400. PB.2.		0.50:			0.30:	0.02:	0.15:	0.01:
BSS:1400. PB.3.		0.25:			0.05:	0.02:	0.15:	0.01:
BSS:1400. LPB.1.					2.00:			
BSS:1400. LB.1.			0.10:		1.00:			
BSS:1400. LB.2.			0.10:		0.75:	0.02:	0.15:	0.01:
BSS:1400. LB.3.			0.10:		1.00:			
BSS:1400. LB.4.			0.10:		2.00:			
BSS:1400. LB.5.			0.10:		1.00:			
BSS:1400. G.1.	0.03:		1.50:		1.50:	0.02:	0.2:	0.01:
BSS:1400. G.2.	0.03:		1.50:			0.02:	0.2:	0.01:
BSS:1400. G.3.	0.02:	0.5:	0.02:			0.01:	0.2:	0.01:
BSS:1400. LG.1.	Not more than 1.0 per cent total impurity.							
BSS: 1400.LG.2.	0.05:					0.02:	0.5:	0.01:
BSS:1400. LG.3.	0.05:					0.02:	0.5:	0.01:
BSS:1400. LG.4.	0.05:					0.02:	0.5:	0.01:
B.43:			0.45:				0.80:	
Crown metal:							0.50:	
12% Ni.Pb.Bronze.			0.20:				0.80:	
15% Ni.Pb.Bronze.			0.10:		0.50:		0.80:	
	Mg.			Sn.				
60:40 Brass.				0.80:			0.40:	0.30:
BS:1400.SCB.1.							0.75:	0.01:
BS:1400.SCB.2.				1.50:			0.50:	0.01:
BS:1400.HTB.1.		0.50:		1.50:		0.10:		
BS:1400.HTB.2.		0.50:		0.50:				
BS:1400.HTB.3.		0.20:		0.20:		0.10:		
BS:1400.AB.1.	0.05:	0.05:		0.10:	0.50:	0.25:		
BS:1400.AB.2.	0.05:	0.05:		0.10:	0.50:	0.25:		
BS.1400.CMA.1.		0.05:	0.05:	1.00:		0.15:		
BS:1400.CMA.2.		0.05:	0.05:	1.00:		0.15:		

Section 4: APPENDIX III.

Order book analysis base used by the simulation model to generate the order file via the Monte Carlo technique.

Note. The identity of the various parameters is in accordance with the key shown in section 1 of this appendix.

Alloy type parameter.

Alloy no.	Alloy group	Alloy identity	Proportion of total orders-per cent
1	1	H.C.C.	0.27
2	2	4% Ni.	6.10
3	7	A.B.1	2.23
4	7	A.B.2	5.00
5	7	C.M.A.1	0.18
6	7	C.M.A.2	0.18
7	3	PB 1	14.35
8	3	PB 2	8.90
9	3	PB 3	3.56
10	3	PB 4	2.56
11	3	LPB 1	0.52
12	3	LB 1	1.54
13	3	LB 2	11.20
14	3	LB 3	2.58
15	3	LB 4	1.00
16	3	LB 5	0.20
17	3	LG 1	0.39
18	3	LG 2	7.95
19	3	LG 3	0.20
20	3	LG 4	1.78
21	3	G 1	3.76
22	3	SAE 660	1.39
23	4	B 43	11.02
24	4	CROWN MTL.	0.07
25	5	BRASS	7.48
26	5	D.C.B. 3	0.44
27	5	S.C.B. 1	0.23
28	6	H.T.B. 1	3.05
29	6	H.T.B. 3	0.25

Length parameter.

Alloy group															
1	Dimension mm	125													
	Proportion %	100													
2		20	25	30	35	55	100	150	200	250	300				
		14.0	7.0	16.3	18.6	11.6	9.3	7.0	2.3	0	2.3				
3		30	50	70	90	110	130	150	170	190	225	275	350	550	800
		6.4	11.2	4.6	11.2	3.3	6.6	6.4	3.3	6.2	9.5	6.8	8.6	7.5	8.3
4		10	20	25	30	40	65	75	100	150	200	300	400		
		0	6.9	8.4	8.4	6.9	50.0	1.4	6.9	4.1	2.8	2.8	1.4		
5		20	25	35	55	85	115	130	150	180	200	250	350	450	650
		7.6	6.1	7.7	17.0	7.7	3.0	1.5	6.1	17.0	4.7	1.5	0	6.2	13.5
6		15	35	80	95	100	110	120	125	140	160	175	215	250	
		5.6	11.2	11.2	5.6	0	11.2	0	0	5.6	11.2	5.6	16.7	16.7	
7		25	35	50	65	75	85	95	110	170	250	325	500	650	800
		3.8	3.9	3.9	9.6	0	7.8	0	9.6	19.1	21.0	5.8	5.8	5.8	3.9

Wall thickness parameter.

Alloy group															
1	Dimension mm	25	30	40	80	180	220								
	Proportion %	50.0	0	0	0	50.0	0								
2		15	30	40	50	60	70	80	90	100	115	135	160		
		2.2	13.3	22.2	37.0	13.3	6.7	2.4	0	2.2	0	0	0		
3		10	20	30	40	50	60	70	100	140	250	300			
		5.6	45.2	15.4	9.3	10.5	5.8	2.8	3.3	1.4	0.47	0.23			
4		15	30	40	50	60	70	80	90	100	170				
		0	21.6	43.3	31.1	0	2.7	0	0	0	1.3				
5		10	20	40	50	60	70	80	90	100	120	150	180		
		22.0	42.7	22.6	4.8	1.6	0	3.2	1.6	0	0	0	0		
6		10	15	20	30	45	55	60	70	100	180				
		30.0	0	20.0	25.0	10.0	0	0	0	0	15.0				
7		10	20	30	35	40	45	55	75	95	145	170			
		10.0	40.0	10.0	10.0	4.0	4.0	6.0	10.0	2.0	2.0	2.0			

Outside diameter parameter.

Alloy group															
1	Dimen-sion mm	200	250	300	350	400									
	Propor-tion %	50.0	0	0	50.0	0									
2		125	175	225	275	325	375	450	550	690					
		0	16.3	23.2	16.3	4.7	11.6	16.3	2.3	9.3					
3		90	175	225	275	325	375	450	600	650	800	950	1150		
		15.1	14.0	20.4	9.9	8.2	5.0	7.6	9.0	2.6	5.0	2.4	0.9		
4		150	225	275	325	375	425	475	525	575	675	825	1050		
		6.0	2.4	9.5	6.0	12.0	7.2	19.0	0	3.6	1.2	10.8	22.4		
5		100	125	175	225	275	325	375	450	500					
		4.8	4.8	28.4	17.5	15.9	6.3	12.7	1.6	8.0					
6		100	150	170	190	220	250	350	500	650	800				
		8.3	12.5	4.2	12.5	0	12.5	21.0	12.5	0	16.7				
7		90	110	130	150	170	190	225	275	400	500	650	900		
		3.6	5.4	5.4	9.1	1.8	9.1	16.3	11.0	22.0	5.4	9.1	5.4		

Number of castings required per order parameter.

Alloy group															
1	Number off	1	2	3	4	5	6								
	Proportion %	0	0	0	0	0	100								
2		1	2	3	4	5	6	10	18	32	45	70	120		
		17.4	6.5	28.2	4.4	2.2	13.0	6.5	6.5	8.7	0	2.2	4.4		
3		1	2	3	4	5	7	10	15	20	35	60	150	200	
		42.0	20.	8.4	5.5	1.4	5.9	4.5	2.5	4.2	1.4	0.4	3.0	0.4	
4		1	2	3	4	5	6	7	8	12	30				
		28.5	19.3	17.1	14.8	2.3	9.0	2.3	1.1	3.4	2.3				
5		1	2	3	4	5	6	8	12	18	25	40	50	75	50
		12.7	9.5	4.8	1.5	4.8	14.3	4.8	4.7						
6		1	2	4	6	8	10	24	85						
		50.0	3.3	26.7	0	0	0	13.3	6.7						
7		1	2	3	4	5	6	7	8	10	13	18	25	115	200
		44.3	7.7	5.8	7.7	1.9	0	0	5.8	0	3.8	3.8	7.7	9.6	1.9

APPENDIX IV.

The Bridge Foundry mathematical model.

Section 1: 0-1 integer programming as used in the mathematical model.

Section 2: The 0-1 integer computer programme statements using ALGOL 60 language.

Section 3: Details of the data bank used by the mathematical model.

Section 1: APPENDIX IV.

0-1 integer programming as used in the mathematical model.

0-1 Integer Programming

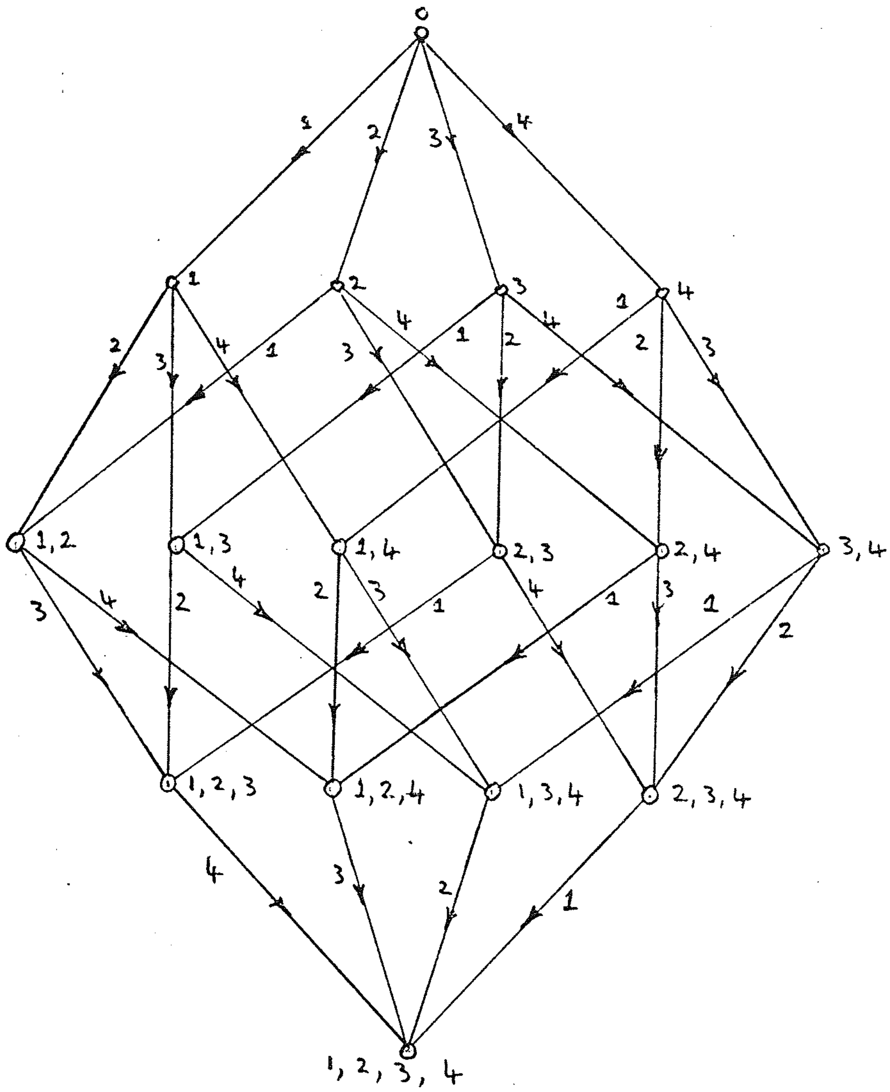
Since the objective functions in linear and nonlinear programming problems are continuous, each variable is free to take any value within its constraint domain (infinite number of values). Contrasting this, in integer linear (digit variables) programming problems, variables are constrained to a finite number of different values although the range of possible values for each variable may be quite large. However, in 0-1 integer programming problems, each variable can take on only one of two possible values. Thus, solution to such a problem will be to find that combination of 0-1 values for the variables which will optimize the objective function without violating any of the constraints.

The fact that in 0-1 problems each variable can only have one of two values, means that small problems can often be solved by inspection, however, large problems are not so clear cut and can have an enormous variety of solutions. This promoted the need for an efficient procedure for dealing with such large dimensioned programmes which was better than complete enumeration and which was not associated with large storage requirements. Such a procedure is the Balas Addition Algorithm, which combines a high rate of solution exclusion with modest storage requirements.

In this technique, all solutions are enumerated explicitly or implicitly. The efficiency of the procedure arises out of the fact that by employing a clever strategy for selecting a few solutions to be enumerated explicitly, many can be enumerated implicitly and computation thus reduced enormously. The algorithm is best considered via reference to the network of solutions to a four variable problem shown in Diagram 4.

Diagram 4.

Solution network.



Each node in the network specifies a solution. The number associated with a node represents the subscripts of variables that have values of 1 in that solution. The important concept of implicit enumeration is made apparent if a four variable 0-1 problem is imagined in which it has been found that $X_4 = 1$ is infeasible. This allows all solutions in which $X_4 = 1$ to be ignored and, hence, the nodes associated with such solutions to be eliminated from the network as shown in Diagram 5.

Similarly, suppose it is found that the solution $X_1 = 1$, $X_3 = 1$, all other variables = 0, is feasible (but not necessarily optimal). All solutions represented by nodes connected from below to node 1,3 can be ignored since they represent solutions in which additional variables other than X_1 and X_3 have been given values of 1. Because all coefficients in the objective function are positive, these solutions are less attractive. It can be said that they have been enumerated implicitly and they can be ignored.

Therefore, in the Balas procedure, sets of solutions are ignored as the enumeration proceeds, when, as suggested above:

i) completions of partial solutions are found to be infeasible; or

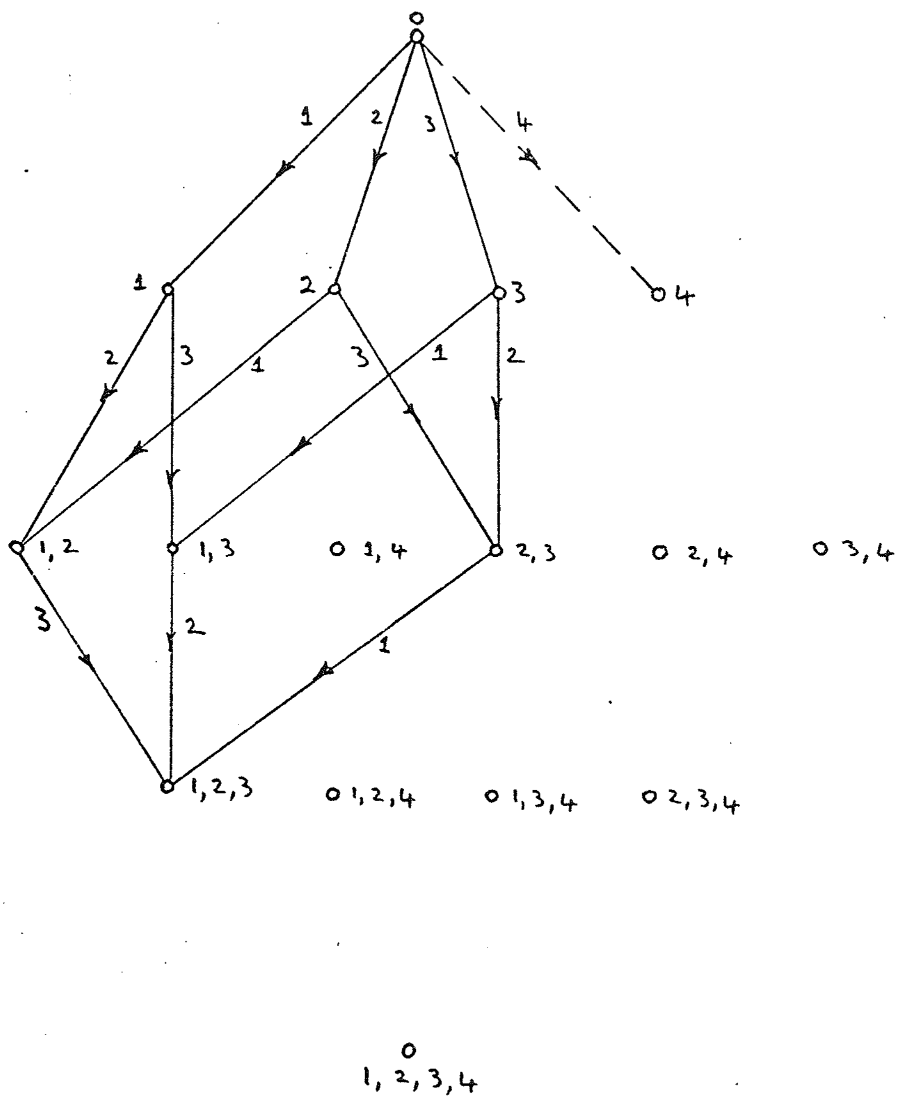
ii) completions of partial solutions are found to be feasible but less attractive.

Completions of a partial solution means a specification of 0 or 1 values for variables whose solution values are not specified in that partial solution. For example, consider the assumption in the four variable problem above that it is known that X_1 and X_3 must be 1. The partial solution has the following completions:

(1,0,1,0)
(1,1,1,0)
(1,1,1,1)

Diagram 5.

Solution network showing a partial solution.



Such a procedure for enumerating the 2^n solutions in an n variable 0-1 problem is superior to an intuitive 'cut and try' process because it is systematic and avoids redundancy. But, in an intuitive enumeration of the solutions, duplication of some solutions a number of times would be inevitable. Just as efficiency requires that redundancy in explicit enumeration be eliminated, so it requires that elimination of redundancy in implicit enumeration be a priority also.

Balas's method employs a 'backtracking' procedure to generate further nonredundant solutions once a feasible (but not necessarily optimal) partial solution has been found. In backtracking, one of the variables in the current partial solution is simply replaced with its complement. For example, again assume the partial solution $X_1 = X_3 = 1$ has been found, i.e., all other variables = 0 is feasible but not necessarily optimal. To proceed with the explicit-implicit enumeration of solutions, explicit examination of the solution $X_1 = 1$, $X_3 = 0$, might next be carried out. Clearly, among all possible completions of the partial solution $X_1 = 1$, $X_3 = 0$, completions of partial solution $X_1 = 1$, $X_3 = 1$, will not appear, and thus, redundancy will be avoided.

The algorithm commences by expressing all constraints in the form $g_i \geqslant 0$, i = 1,2,3,etc., and proceeds by first examining the solution (0,0,0,etc.). If this solution is infeasible, the procedure will be to generate a sequence of partial solutions by adding one variable at each stage and considering all completions of the partial solution at that stage. In this fashion, it is possible, by implicit enumeration, to eliminate many solution sets from future consideration. The variable to be added is selected on the basis of its contribution either to (a) reduction of infeasibility in the current solution, or (b) avoidance of redundancy.

The symbol S^k is used to represent the partial solution under consideration at stage k, hence, for example, $S^2 = (3,2)$, means at stage 2, $X_3 = X_2 = 1$. Obviously, because all variables in the objective function are positive, and the aim is to minimise, once a feasible solution has been found, any completion other than S^k is less attractive. This means that the remaining completions can be eliminated by implicit enumeration.

Further enumeration then proceeds using the 'backtracking' technique. One by one, variables in S^k are replaced by their complements, and again, partial solutions are enumerated either explicitly or implicitly. A minus sign before the subscript in the partial solution vector indicates that the variable designated has a value of 0. Hence, at each new stage, after identifying a new partial solution, attempts to fathom that solution by considering its completions, are carried out.

Implicit enumeration, therefore, involves generating a sequence of partial solutions and simultaneously considering all completions of each. As the calculations proceed, feasible solutions are discovered from time to time, and the best one yet found is kept in store as an incumbent. Variables in the set whose complements are examined, are chosen in an orderly fashion, moving left from the rightmost element. On completion of the examination (explicit and implicit enumeration), that element is said to be 'underlined'.

As the complement of each element is fathomed, any partial solution found to be better than the incumbent, replaces it. So more variables in the set become underlined, until eventually the leftmost element has its complement solutions enumerated. At this point, all solutions have now been considered and the incumbent is regarded as the optimal solution.

Thanks to its essentially enumerative nature and the scorekeeping method (underline) used, at any iteration, it can be proved that by insection of the current partial solution, the number of solutions enumerated so far, and their identity, can relatively easily be obtained. For example, if n = 24 and the calculations are stopped when $S = \{5,4,-\underline{2},\underline{3},9\}$, then all $2^{(24-3)}$ completions of $\{5,4,2\}$ have been accounted for, as have all $2^{(24-4)}$ completions of $\{5,4,-2,-3\}$. Thus, it is known precisely which $2^{21} + 2^{20}$ of the 2^{24} solutions have been enumerated, and the current incumbent is an optimal feasible solution with the restrictions: $[X_5 = 1,\ X_4 = 1]$ and either $[X_2 = 1]$ or $[X_2 = 0,\ X_3 = 0]$.

The main usefulness of the ability to calculate easily the number of enumerated solutions is in determining when to terminate the calculations if an optimal solution has not been found in a reasonable length of computing time.

Section 2: APPENDIX IV.

The 0-1 integer computer programme statements using ALGOL 60 language.

```
↑***************************************************************************

\LISTING ØF :LINK,SWANØUTPUT(35/ØUTP)   PRØDUCED ØN 15FEB78 AT 17.58.47

\ØUTPUT BY LISTFILE IN ':LINK,LINKPRØG1' ØN 15FEB78 AT 18.18.01 USING I441

DØCUMENT     SWANØUTPUT(35/ØUTP)

    ****     *    *    *  *     *  *    *
**  *       * *    *  *    *  *     *  *
**  ***    *   *    **      **       **
    *      *****    **      **       **
**  *      *   *   *  *    *  *     *  *
**  ****   *   *  *    *  *     *  *    *

       ***   ***   ****  ****    ***  *****   *
        *   *      *     *   *    *     *    **
        *    ***   ***   *    *   *     *     *
***     *       *  *     *    *   *     *     *
***  *  *   *   *  *     *   *    *     *     *
***   **     ***   ****  ****    ***    *    ***

\LISTING ØF :EAXXX.JSFØUN8(1/)  PRØDUCED ØN 29NØV77 AT 12.20.58

\ØUTPUT ØN UMRCC 4S BY ':EAXXX.JSEDIT1' ØN 15FEB78 AT 17.54.53 USING I436

DØCUMENT     JSFØUN8

'BEGIN'
 'INTEGER'CØUNT,N,M,U,W,F,I,J,K,IA,P,E,D;
 'REAL'Z,Q,MAX,R,INF,SAW,BALL,GRIND,LIN,TØSAW,TØBALL,TØGRIND,TØLIN,
      RESAW,REBALL,REGRIND,RELIN,REFILE,FEFILE,DISC,PRESS,REAM,
     TØFILE,TØFEFILE,TØDISC,TØPRESS,TØREAM,FILE,
     REFEFILE,REDISC,REPRESS,REREAM;
 'BØØLEAN'NULL,API,NØSØLN;
     'CØMMENT' READ IN JØB DATA AND DRESSING SHØP CAPACITIES;
  SELECTINPUT(10);
  U:=396;
  M:=4;
   'BEGIN'
     'REAL''ARRAY'DATA[1:U,1:10],SLACKS,TØTAL[1:M];
     'FØR'K:=1'STEP'1'UNTIL'U'DØ'
    'FØR'P:=1'STEP'1'UNTIL'10'DØ' DATA[K,P]:=READ;
    TØSAW:=READ;
    TØBALL:=READ;
    TØGRIND:=READ;
    TØLIN:=READ;
    TØFILE:=READ;
    TØFEFILE:=READ;
```

```
      TØPRESS:=READ;
      TØREAM:=READ;
      TØSAW:=TØSAW*0.875;
      TØBALL:=TØBALL*0.875;
      TØGRIND:=TØGRIND*0.875;
      TØLIN:=TØLIN*0.875;
      TØFILE:=TØFILE*0.875;
      TØFEFILE:=TØFEFILE*0.875;
      TØDISC:=TØDISC*0.875;
      TØPRESS:=TØPRESS*0.875;
      TØREAM:=TØREAM*0.875;
      N:=READ;W:=READ;F:=READ;
  'BEGIN'
          'INTEGER''ARRAY'MUST[1:W],CHØIC,S,V,X[1:N];
    'REAL''ARRAY'A[0:M,0:N],HØLD[1:N,1:9];
     'CØMMENT'READ IN IDENTITY ØF CØMPULSØRY JØBS;
      'FØR'K:=1'STEP'1'UNTIL'W'DØ'
       MUST[K]:=READ;
     'CØMMENT'CALCULATE DRESSING SHØP REQUIRMENTS FØR CØMPULSØRY JØBS;
            SAW:=BALL:=GRIND:=LIN:=FILE:=FEFILE:=DISC
            :=PRESS:=REAM:=0.0;
      'FØR'J:=1'STEP'1'UNTIL'U'DØ'
      'FØR'I:=1'STEP'1'UNTIL'W'DØ'
            'IF'J'EQUAL'MUST[I]'THEN'
   'BEGIN'
               SAW:=SAW+DATA[J,1];
               BALL:=BALL+DATA[J,2];
               GRIND:=GRIND+DATA[J,3];
               LIN:=LIN+DATA[J,4];
               FILE:=FILE+DATA[J,5];
               FEFILE:=FEFILE+DATA[J,6];
               DISC:=DISC+DATA[J,7];
               PRESS:=PRESS+DATA[J,8];
               REAM:=REAM+DATA[J,9];
               'END';
      'CØMMENT' READ IN IDENTITY ØF CHØICE JØBS;
      'FØR'K:=1'STEP'1'UNTIL'N'DØ'
       CHØIC[K]:=READ;
    I:=0;
    'FØR'J:=1'STEP'1'UNTIL'N'DØ'
  'BEGIN'
    I:=I+1;
    K:=CHØIC[J];
    HØLD[I,1]:=DATA[K,1];
    HØLD[I,2]:=DATA[K,2];
    HØLD[I,3]:=DATA[K,3];
    HØLD[I,4]:=DATA[K,4];
    HØLD[I,5]:=DATA[K,5];
    HØLD[I,6]:=DATA[K,6];
    HØLD[I,7]:=DATA[K,7];
    HØLD[I,8]:=DATA[K,8];
    HØLD[I,9]:=DATA[K,9];
  'END';
      'CØMMENT'CALCULATE DRESSING SHØP SLACK PERIØD;
            RESAW:=TØSAW-SAW;
            REBALL:=TØBALL-BALL;
            REGRIND:=TØGRIND-GRIND;

            RELIN:=TØLIN-LIN;
            REFILE:=TØFILE-FILE;
            REFEFILE:=TØFEFILE-FEFILE;

            REDISC:=TØDISC-DISC;
            REPRESS:=TØPRESS-PRESS;
            REREAM:=TØREAM-REAM;
```

```
      A[2,0]:=REGRIND+RELIN;
      A[3,0]:=REFILE;
      A[4,0]:=REFEFILE+REDISC+REPRESS+REREAM;
     'CØMMENT'ASSEMBLE REMAINDER ØF CØNSTAINT ARRAY;
      I:=0;
      'FØR'K:=1'STEP'1'UNTIL'N'DØ'
     'BEGIN'
      I:=I+1;
        A[1,I]:=HØLD[K,1]+HØLD[K,2];
        A[2,I]:=HØLD[K,3]+HØLD[K,4];
        A[3,I]:=HØLD[K,5];
        A[4,I]:=HØLD[K,6]+HØLD[K,7]+HØLD[K,8]+HØLD[K,9]
               'END';
 'CØMMENT' CALCULATE ZERØ CØLUMN;
           'FØR'J:=1'STEP'1'UNTIL'4'DØ'
              'BEGIN'
      TØTAL[J]:=0.0;
      'FØR'K:=1'STEP'1'UNTIL'N'DØ'
      TØTAL[J]:=TØTAL[J]+A[J,K];
      A[J,0]:=A[J,0]-TØTAL[J];
      'END';
     'CØMMENT' CALCULATE ØBJECTIVE FUNCTIØN;
      'FØR' K:=1'STEP'1'UNTIL'N'DØ'
        A[0,K]:=A[1,K]+A[2,K]+A[3,K]+A[4,K];
          A[0,0]:=0.0;
         'FØR'I:=0'STEP'1'UNTIL'M'DØ'
              'BEGIN'
              'FØR'J:=0'STEP'1'UNTIL'N'DØ' PRINT(A[I,J],5,2);
              NEWLINE(1)
              'END';
'CØMMENT'S HØLDS THE CURRENT PARTIAL SØLUTIØN IN ØRDER ØF ASSIGNMENT,
      V IS A STATE VECTØR ASSØCIATED WITH S;
API:='TRUE';
INF:=1000000000.0;
'IF'API'THEN'
'BEGIN'
      E:=0;
      'FØR'J:=1'STEP'1'UNTIL'N'DØ'
      'IF' X[J] =0 'THEN' V[J]:=0
      'ELSE'
      'BEGIN'
       E: =E+1 ;  S[E]: = J; V[J]:= 3 ;
      'FØR' I:=1'STEP'1'UNTIL'M'DØ'
        A[I,0]:=A[I,0]+A[I,J];
      'END';
      Z:=A[0,0];'GØTØ'   LØ;
      'END';
      'FØR'J:=1'STEP'1 'UNTIL'N 'DØ'S[J]:=V[J]:=0;
      Z:=0.0; E:=0 ;
  LØ: NØSØLN:='TRUE'; CØUNT:=0; A[0,0]:=INF;
'CØMMENT'ALL RELEVANT VARIABLES ARE NØW INITIALIZED ;
 START: CØUNT: = CØUNT +1;
  'IF'CØUNT'GREATER'100'THEN''GØTØ'RESULT;
      'FØR' I: =1'STEP'1'UNTIL'M 'DØ'
          'IF'A[I,0]'LESS'0.0 'THEN''GØTØ' FØRMT;
'CØMMENT'BEST CØMPLETIØN IF S IS FEASIBLE;
      'GØTØ'   INCUMBENT;
      FØRMT: NULL : = 'TRUE';
'CØMMENT'FØRMSET T ØF FREE VARIABLES TØ WHICH 1 MAY BE PRØFITABLY
      ASSIGNED;
      'FØR'J:=1 'STEP'1 'UNTIL'N 'DØ'
 'BEGIN'
        'IF''NØT'(V[J]=0'AND'A[0,J]+Z'LESS'A[0,0])'THEN''GØTØ'L1;
      'FØR'K:= I'STEP'1'UNTIL'M 'DØ'
       'IF'A[K,0]'LESS'0.0'AND'A[K,J]'GREATER'0.0'THEN'
       'BEGIN'NULL:='FALSE';V[J]:=1;'GØTØ'L1'END';
```

```
     L1:'END';
     'IF' NULL'THEN''GØTØ'NEWS;
'CØMMENT'IF T IS EMPTY THEN S IS FATHØMED;
     'FØR' K:=I 'STEP'1 'UNTIL' M 'DØ'
 'BEGIN'
     'IF'A[K,0]'NØTLESS'0.0'THEN''GØTØ'L2;
     Q: =A[K,0];
     'FØR' J: =1'STEP'1 'UNTIL' N 'DØ'
     'IF'V[J]=1'AND'A[K,J]'NØT LESS'0.0'THEN'Q:=Q+A[K,J];
     'IF'Q'LESS'0.0'THEN''GØTØ'NEWS;
'CØMMENT' IF Q IS NEGATIVE S IS FATHØMED;
 L2 : 'END';
     MAX:= -INF;
     'FØR' J:= 1'STEP'1 'UNTIL' N 'DØ'
  'BEGIN'
     'IF'V[J] 'NE' 1'THEN''GØTØ'L3;Q:=0.0;
     'FØR' I:=1 'STEP'1 'UNTIL'M 'DØ'
     'BEGIN'
      R := A[I,0] +A[I,J];
             'IF'R'LESS'0.0'THEN'Q:=Q+R;
     'END';
         'IF'MAX'NØT GREATER'Q'THEN'
      'BEGIN' MAX:= Q; D:= J 'END';
 L3:  'END';
     E: =E+1; S[E]: =D; V[D]:=3 ; IA:= 1 ;
'CØMMENT'AUGMENT S BY ASSIGNING  1 TØ X[D];
RESET: 'FØR' J:=1 'STEP'1 'UNTIL' N 'DØ'
     'IF' V[J] =1 'THEN'V[J]:= 0 ;
'CØMMENT' CLEAR T ;
     'FØR' I:= 1'STEP'1 'UNTIL' M 'DØ'
     A[I,0]:= A[I,0]+IA* A[I,D];
     Z:= Z+IA*  A[0,D];
'CØMMENT' RECALCULATE SLACKS AND ØBJECTIVE FUNCTIØN;
  'GØTØ'START;
 INCUMBENT: NØSØLN:= 'FALSE';
     'IF' Z 'GE' A[0,0] 'THEN''GØTØ'NEWS;
  A[0,0]:=Z;
     'FØR' J:= 1 'STEP'1 'UNTIL' N 'DØ'
     X[J] := 'IF'V[J] =3 'THEN' 1 'ELSE' 0 ;
     'FØR'I:=1 'STEP'1 'UNTIL' M 'DØ'
     SLACKS [I]:= A[I,0];
     NEWS: 'IF' E =0 'THEN''GØTØ'RESULT;
     L4: D: = S[E];
    'IF'D 'GT' 0 'THEN''GØTØ'UNDERLINE;
     V[-D]:=0; E:= E-1;  'CØMMENT' BACKTRACK;
'GØTØ'NEWS;
     UNDERLINE:  S[E]:= -D; V[D]:=2 ; IA:= -1 ;
'CØMMENT' ASSIGN 0 TØ X[D];
     'GØTØ'RESET;
     RESULT :
     'IF''NØT' NØSØLN 'THEN'
     'FØR' I:=1 'STEP'1 'UNTIL' M 'DØ'
     A[I,0]:= SLACKS[I];
WRITE BØØLEAN(NØSØLN);
NEWLINE(1);
 'FØR'I:=1'STEP'1'UNTIL'M'DØ'
PRINT(A[I,0],5,2);
NEWLINE(1);
PRINT(A[0,0],5,2);
NEWLINE(1);
PRINT(CØUNT,3,0);
NEWLINE(1);
 'FØR'J:=1'STEP'1'UNTIL'N'DØ'PRINT(X[J],3,0);
 NEWLINE(1);
 'FØR'J:=1'STEP'1'UNTIL'E'DØ'PRINT(S[J],3,0);
 NEWLINE(1);
```

```
'FØR'I:=1'STEP'1'UNTIL'N'DØ'PRINT(V[I],3,0);
        'END';
    'END';
   'END';
```


↑**

Section 3: APPENDIX IV.

Details of the data bank used by the mathematical model.

```
†*************************************************************************************

\LISTING ØF :LINK.SWANØUTPUT(38/ØUTP)   PRØDUCED ØN 15FEB78 AT 18.00.43

\ØUTPUT BY LISTFILE IN ':LINK.LINKPRØG1' ØN 15FEB78 AT 18.41.58 USING I441

DØCUMENT    SWANØUTPUT(38/ØUTP)

      ****      *     *     *   *     *   *     *
**    *       *  *     *   *     *   *     *   *
**    ***     *    *     **        **         **
      *       *****      **        **         **
**    *       *    *     *   *     *   *     *   *
**    ****    *    *   *     *   *     *   *     *

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           *    *        *      *    *    *       *     **
           *    ***      ***    *    *    *       *      *
***        *        *    *      *    *    *       *      *
***   *    *    *   *    *      *    *    *       *      *
***    **       ***      ****   ****      ***     *     ***

\LISTING ØF :EAXXX.JSSHED(3/)   PRØDUCED ØN 12ØCT77 AT 22.56.50

\ØUTPUT ØN UMRCC 4S BY ':EAXXX.JSEDIT1' ØN 15FEB78 AT 17.57.42 USING I436

DØCUMENT    JSSHED

74.9 ,  0.0 ,115.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
39.9 ,  0.0 , 53.2 ,  0.0 ,  0.0,   0.0,   0.0 ,  0.0 ,  0.0 ,0.0,
28.0 ,  0.0 , 27.2 ,  0.0 ,116.0 ,  0.0,   0.0 ,  0.0,   0.0 ,0.0,
33.2 ,  0.0 ,  0.0 , 24.8 ,  0.0 , 86.2 ,  0.0 ,  0.0,   0.0,0.0,
28.2 ,  0.0 ,  0.0 , 31.35,  0.0 ,  0.0 ,  0.0 ,  0.0,  78.3,0.0,
17.3 ,  0.0 , 20.0 , 12.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0,   0.0,0.0,
32.35,  0.0 , 32.35, 37.5 ,  0.0 ,  0.0 , 30.8 ,  0.0,  16.7,0.0,
 0.0 , 43.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0,  29.4,0.0,
 0.0 , 43.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0,  36.0,0.0,
16.3 ,  0.0 , 13.95,  0.0 , 42.6 ,  0.0 ,  0.0 ,  0.0,   0.0,0.0,
13.1 ,  0.0 ,  0.0 , 15.33, 40.9 ,  0.0 ,  0.0 ,  0.0,   0.0,0.0,
27.25,  0.0 , 19.75,  0.0 , 67.8 ,  0.0 ,  0.0 ,  0.0,   0.0,0.0,
33.57,  0.0 , 33.05,  0.0 , 57.9 ,  0.0 ,  0.0 ,  0.0,  13.0,0.0,
35.50,  0.0 , 22.72,  0.0 , 16.32,  0.0 ,  0.0 ,  0.0,   0.0,0.0,
30.22,  0.0 , 30.22,  0.0 ,  0.0 ,  0.0 ,  0.0,   0.0,   0.0,0.0,
10.0 ,  0.0 ,  0.0 , 14.0 , 48.0 ,  0.0 ,  0.0,   0.0,   0.0,0.0,
22.2 ,  0.0 , 22.82,  0.0 ,  0.0 ,  0.0 ,  0.0,   0.0,   0.0,0.0,
27.4 ,  0.0,  34.9 ,  0.0, 117.4 ,  0.0 ,  0.0,   0.0,   0.0,0.0,
39.3 ,  0.0,  40.9 ,  0.0, 203.8 ,  0.0 ,  0.0,   0.0,  10.37,0.0,
39.25,  0.0,  40.8 ,  0.0, 203.5 ,  0.0 ,  0.0,   0.0,  10.35,0.0,
45.90,  0.0,  31.9 ,  9.85, 73.1 ,  0.0 ,  0.0,   0.0 , 15.48,0.0,
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39.25, 0.0, 40.8, 0.0, 203.8, 0.0, 0.0, 0.0, 10.62, 0.0,
57.80, 0.0, 38.55, 56.4, 0.0, 0.0, 90.8, 0.0, 0.0, 0.0,
0.0, 36.25, 0.0, 0.0, 0.0, 0.0, 71.5, 0.0, 0.0, 0.0,
25.0, 0.0, 18.0, 0.0, 0.0, 0.0, 0.0, 0.0, 7.94, 0.0,
52.5, 0.0, 33.2, 0.0, 146.2, 0.0, 0.0, 0.0, 0.0, 0.0,
56.2, 0.0, 90.2, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
38.2, 0.0, 73.6, 0.0, 0.0, 0.0, 0.0, 0.0, 35.45, 0.0,
59.6, 0.0, 129.1, 0.0, 80.7, 0.0, 0.0, 0.0, 0.0, 0.0,
48.1, 0.0, 0.0, 67.7, 0.0, 54.6, 0.0, 0.0, 0.0, 0.0,
10.71, 0.0, 20.3, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
25.2, 0.0, 43.7, 0.0, 50.4, 0.0, 0.0, 0.0, 43.8, 0.0,
35.2, 0.0, 34.8, 0.0, 0.0, 0.0, 188.0, 0.0, 0.0, 0.0,
35.2, 0.0, 34.8, 0.0, 0.0, 0.0, 188.0, 0.0, 0.0, 0.0,
35.2, 0.0, 34.8, 0.0, 0.0, 0.0, 188.0, 0.0, 0.0, 0.0,
35.2, 0.0, 34.8, 0.0, 0.0, 0.0, 188.0, 0.0, 0.0, 0.0,
0.0, 35.35, 0.0, 0.0, 85.5, 0.0, 0.0, 0.0, 0.0, 0.0,
26.3, 0.0, 24.55, 0.0, 0.0, 45.1, 0.0, 0.0, 0.0, 0.0,
19.95, 0.0, 16.00, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
20.60, 0.0, 34.35, 0.0, 152.7, 0.0, 53.4, 0.0, 0.0, 0.0,
0.0, 35.2, 0.0, 0.0, 85.2, 0.0, 0.0, 0.0, 0.0, 0.0,
19.65, 0.0, 28.8, 0.0, 0.0, 38.0, 0.0, 0.0, 0.0, 0.0,
42.4, 0.0, 26.8, 0.0, 118.0, 0.0, 0.0, 0.0, 0.0, 0.0,
28.8, 0.0, 32.2, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
0.0, 70.6, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
55.0, 0.0, 0.0, 80.0, 0.0, 100.0, 0.0, 0.0, 0.0, 0.0,
72.0, 0.0, 44.7, 0.0, 0.0, 0.0, 0.0, 0.0, 27.2, 0.0,
37.0, 0.0, 49.0, 0.0, 0.0, 57.0, 0.0, 0.0, 0.0, 0.0,
20.0, 0.0, 24.8, 0.0, 47.2, 0.0, 0.0, 0.0, 22.4, 0.0,
33.0, 0.0, 32.8, 0.0, 0.0, 43.2, 0.0, 0.0, 0.0, 0.0,
14.55, 0.0, 24.1, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
23.0, 0.0, 38.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
22.0, 0.0, 0.0, 32.0, 0.0, 0.0, 40.0, 0.0, 0.0, 0.0,
21.6, 0.0, 0.0, 46.0, 0.0, 0.0, 31.6, 0.0, 0.0, 0.0,
45.0, 0.0, 0.0, 72.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
30.0, 0.0, 49.5, 0.0, 0.0, 90.0, 0.0, 0.0, 0.0, 0.0,
16.72, 0.0, 18.7, 0.0, 0.0, 155.7, 0.0, 0.0, 14.0, 0.0,
20.2, 0.0, 16.37, 19.64, 129.1, 0.0, 0.0, 0.0, 13.1, 0.0,
25.4, 0.0, 45.6, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
25.4, 0.0, 61.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
106.4, 0.0, 150.0, 0.0, 141.0, 0.0, 0.0, 0.0, 57.8, 0.0,
33.0, 0.0, 33.9, 0.0, 77.0, 0.0, 47.4, 0.0, 35.57, 0.0,
22.75, 0.0, 0.0, 47.0, 0.0, 26.6, 0.0, 0.0, 26.6, 0.0,
37.2, 0.0, 45.5, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
39.4, 0.0, 31.65, 13.12, 0.0, 0.0, 0.0, 0.0, 35.5, 0.0,
30.65, 0.0, 0.0, 52.8, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
74.4, 0.0, 67.5, 0.0, 0.0, 129.0, 0.0, 0.0, 0.0, 0.0,
60.6, 0.0, 61.1, 42.2, 0.0, 0.0, 0.0, 0.0, 57.8, 0.0,
60.6, 0.0, 61.1, 44.4, 49.9, 0.0, 0.0, 0.0, 68.1, 0.0,
46.4, 0.0, 0.0, 55.7, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
14.07, 0.0, 35.75, 0.0, 26.0, 0.0, 41.4, 0.0, 15.7, 0.0,
57.3, 0.0, 59.4, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
26.25, 0.0, 39.6, 0.0, 108.1, 0.0, 0.0, 0.0, 0.0, 0.0,
43.4, 0.0, 26.5, 0.0, 74.7, 0.0, 0.0, 0.0, 0.0, 0.0,
57.2, 0.0, 32.5, 0.0, 63.0, 0.0, 0.0, 0.0, 0.0, 0.0,
39.7, 0.0, 36.9, 0.0, 31.8, 0.0, 0.0, 0.0, 0.0, 0.0,
27.3, 0.0, 27.1, 0.0, 33.2, 0.0, 0.0, 0.0, 0.0, 0.0,
39.7, 0.0, 61.1, 9.45, 44.7, 0.0, 0.0, 0.0, 0.0, 0.0,
45.7, 0.0, 29.62, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
19.9, 0.0, 19.9, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
12.9, 0.0, 11.9, 0.0, 77.9, 0.0, 0.0, 0.0, 0.0, 0.0,
22.95, 0.0, 22.95, 0.0, 99.0, 0.0, 0.0, 0.0, 0.0, 0.0,
40.0, 0.0, 32.0, 0.0, 115.1, 0.0, 0.0, 0.0, 35.2, 0.0,
47.7, 0.0, 53.2, 0.0, 111.1, 0.0, 0.0, 0.0, 30.0, 0.0,
48.1, 0.0, 53.1, 0.0, 103.2, 0.0, 0.0, 0.0, 27.9, 0.0,
51.8, 0.0, 50.4, 0.0, 123.2, 0.0, 0.0, 0.0, 30.0, 0.0,
44.7, 0.0, 35.2, 0.0, 56.0, 0.0, 0.0, 0.0, 52.8, 0.0,
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37.0 , 0.0 , 22.2 , 0.0, 58.0 , 0.0 , 0.0, 0.0 , 0.0 ,0.0,
21.2 , 0.0 , 25.4 , 0.0, 0.0 , 0.0 , 0.0, 0.0 , 0.0 ,0.0,
34.3 , 0.0 , 0.0 , 0.0, 0.0 , 0.0 , 0.0, 0.0 , 0.0 ,0.0,
30.5 , 0.0 , 0.0 , 61.0, 0.0 , 0.0 , 0.0, 0.0 , 74.0 ,0.0,
36.0 , 0.0 , 0.0 , 28.8, 0.0 , 0.0 , 0.0, 0.0 , 64.7 ,0.0,
54.5 , 0.0 , 64.1 , 0.0, 0.0 , 0.0, 0.0, 0.0 , 72.1 ,0.0,
75.25, 0.0 , 64.8 , 0.0, 0.0 , 0.0, 0.0, 0.0 , 0.0 ,0.0,
18.9 , 0.0 , 0.0 , 23.4 , 0.0 , 0.0, 0.0, 0.0 , 0.0 ,0.0,
0.0 , 29.6 , 11.92, 18.4 ,104.3 , 0.0, 0.0, 0.0 , 5.27,0.0,
40.6 , 0.0 , 47.0 , 0.0 , 0.0 , 0.0, 0.0, 0.0 ,100.0 ,0.0,
31.5 , 0.0 , 30.3 , 0.0 , 0.0 , 0.0, 0.0, 0.0 , 0.0 ,0.0,
60.0 , 0.0 , 72.0 , 0.0 , 0.0 , 0.0, 0.0, 0.0 , 0.0 ,0.0,
32.35, 0.0 , 0.0 , 26.65, 0.0 , 0.0, 0.0, 0.0 , 0.0 ,0.0,
19.34, 0.0 , 0.0 , 27.60, 0.0 , 0.0, 0.0, 0.0 , 0.0 ,0.0,
32.7 , 0.0 , 33.23, 0.0 ,113.6 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
33.1 , 0.0 , 24.8 , 0.0 , 0.0 , 0.0 ,116.0 , 0.0 , 0.0,0.0,
35.3 , 0.0 , 27.1 , 0.0 , 0.0 , 0.0 , 92.8 , 0.0 , 0.0,0.0,
22.15, 0.0 , 31.6 , 0.0 , 69.8 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
0.0 , 0.0 , 19.2 , 0.0, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
11.20, 0.0 , 14.4 , 0.0, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
16.70, 0.0 , 15.2 , 0.0, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
29.6 , 0.0 , 35.1 , 20.3, 0.0 , 41.4 , 0.0 , 0.0 , 0.0,0.0,
0.0 , 96.5 , 0.0 , 47.1, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
30.5 , 0.0 , 40.3 , 0.0, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
30.5 , 0.0 , 39.6 , 0.0, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
33.6 , 0.0 , 56.0 , 0.0, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
41.6 , 0.0 , 47.6 , 0.0, 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
35.85, 0.0 , 25.12, 16.27, 98.3 , 0.0 , 0.0 , 0.0 , 25.0,0.0,
26.45, 0.0 , 18.37, 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
19.05, 0.0 , 23.65, 0.0 , 0.0 , 0.0 , 0.0, 0.0 , 0.0,0.0,
39.62, 0.0 , 58.1 , 0.0 , 62.1 , 0.0, 0.0, 0.0 , 0.0,0.0,
19.67, 0.0 , 0.0 , 29.15, 0.0 , 0.0 , 0.0, 0.0 , 0.0,0.0,
24.27 , 0.0 , 24.27, 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
26.6, 0.0 , 20.40, 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
24.05 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
28.4, 0.0 , 20.9 , 0.0 , 80.3 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
21.7, 0.0 , 18.5 , 0.0 , 80.3 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
22.3, 0.0 , 25.05, 0.0 , 71.5 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
21.87 , 0.0 , 18.6 , 0.0 , 90.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
22.1, 0.0 , 25.1 , 0.0 , 75.4 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
21.7, 0.0 , 18.75, 0.0 , 80.4 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
28.4, 0.0 , 20.9 , 0.0 , 80.4 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
150.7, 0.0 , 15.22, 0.0 , 74.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
36.8, 0.0 , 17.37, 0.0 ,140.22, 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
32.1, 0.0 , 32.40, 0.0 ,101.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
48.2, 0.0 , 35.7 , 0.0 ,212.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
0.0 , 39.6 , 13.32, 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
36.0 , 0.0 , 45.4 , 0.0 ,158.6 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
43.1 , 0.0 , 32.85, 0.0 , 78.0 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
48.4 , 0.0 , 39.75, 0.0 ,184.9 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
0.0 , 76.8 , 0.0 , 60.0 , 0.0 , 0.0 , 36.0 , 0.0 , 0.0,0.0,
0.0 , 56.0 , 32.0 , 0.0 , 64.0 , 0.0 , 40.0 , 0.0 , 0.0,0.0,
24.07, 0.0 , 20.5 , 0.0 ,142.7 , 0.0 , 0.0 , 0.0 , 0.0,0.0,
0.0 , 38.45, 0.0 , 32.4 , 69.2 , 0.0 , 0.0 , 0.0 , 47.2,0.0,
0.0 , 30.75, 29.65, 0.0 , 0.0 , 66.0 , 23.05, 0.0 , 27.45,0.0,
0.0 , 50.2 , 21.0 , 0.0 , 24.65, 0.0 , 0.0 , 0.0 , 22.21,0.0,
0.0 , 48.14, 21.3 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 21.23,0.0,
38.45, 0.0 , 39.42, 0.0 , 95.80, 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
47.40, 0.0 , 27.0 , 0.0 , 72.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
21.0 , 0.0 , 27.6 , 0.0 , 0.0 , 26.4 , 0.0 , 0.0 , 0.0 ,0.0,
39.9 , 0.0 , 29.9 , 0.0 , 78.6 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
48.0 , 0.0 , 36.0 , 0.0 ,146.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
39.9 , 0.0 , 42.1 , 0.0 , 73.1 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
31.0 , 0.0 , 23.8 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
79.4 , 0.0 , 74.6 , 64.3 , 0.0 , 0.0 , 0.0 , 0.0 , 0.0 ,0.0,
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21,3	0,0	0,0	26,3	0,0	75,5	0,0	0,0	0,0	0,0
0,0	68,2	0,0	125,5	0,0	70,9	0,0	0,0	57,3	0,0
17,1	0,0	0,0	48,8	0,0	59,8	0,0	0,0	0,0	0,0
38,75	0,0	0,0	57,6	0,0	0,0	0,0	0,0	39,9	0,0
22,30	0,0	54,0	0,0	111,5	0,0	0,0	0,0	0,0	0,0
23,65	0,0	86,4	0,0	0,0	0,0	0,0	0,0	64,8	0,0
41,50	0,0	23,15	0,0	31,0	0,0	0,0	0,0	0,0	0,0
19,02	0,0	0,0	0,0	84,0	0,0	0,0	0,0	0,0	0,0
20,15	0,0	23,03	0,0	56,4	0,0	0,0	0,0	14,97	0,0
25,4	0,0	33,0	0,0	57,6	0,0	0,0	0,0	0,0	0,0
15,87	0,0	0,0	23,0	0,0	50,4	0,0	0,0	66,2	0,0
43,6	0,0	0,0	71,5	0,0	90,7	0,0	0,0	0,0	0,0
36,44	0,0	74,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0
15,58	0,0	21,9	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37,0	0,0	0,0	10,0	118,5	0,0	0,0	0,0	0,0	0,0
17,55	0,0	41,8	28,4	0,0	0,0	0,0	0,0	50,2	0,0
48,0	0,0	101,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0
44,0	0,0	28,0	0,0	116,7	0,0	0,0	0,0	0,0	0,0
49,5	0,0	0,0	72,0	0,0	126,0	0,0	0,0	0,0	0,0
46,0	0,0	0,0	58,4	0,0	0,0	0,0	0,0	0,0	0,0
17,3	0,0	13,64	50,0	30,95	0,0	0,0	0,0	15,0	0,0
19,6	0,0	41,15	0,0	45,1	0,0	0,0	0,0	0,0	0,0
0,0	102,5	0,0	77,5	115,0	0,0	107,5	0,0	52,5	0,0
20,45	0,0	25,9	0,0	0,0	43,6	0,0	0,0	0,0	0,0
22,0	0,0	30,0	0,0	57,5	0,0	0,0	0,0	19,5	0,0
32,0	0,0	0,0	25,6	0,0	0,0	51,2	0,0	0,0	0,0
23,3	0,0	22,3	0,0	52,7	0,0	0,0	0,0	0,0	0,0
23,05	0,0	20,9	0,0	68,4	0,0	0,0	0,0	22,35	0,0
47,1	0,0	39,3	0,0	63,5	0,0	0,0	0,0	0,0	0,0
28,1	0,0	23,0	0,0	107,0	0,0	0,0	0,0	15,2	0,0
30,2	0,0	0,0	14,4	130,4	0,0	0,0	0,0	26,58	0,0
30,45	0,0	16,55	10,08	122,8	0,0	0,0	0,0	18,7	0,0
0,0	29,08	24,35	0,0	91,0	0,0	0,0	0,0	11,39	0,0
33,82	0,0	35,55	0,0	39,35	0,0	0,0	0,0	14,15	0,0
0,0	31,8	27,45	0,0	37,8	0,0	0,0	0,0	12,43	0,0
135,8	0,0	128,4	0,0	298,0	0,0	0,0	0,0	42,80	0,0
135,8	0,0	128,4	17,5	298,0	0,0	0,0	0,0	42,80	0,0
12,85	0,0	19,5	0,0	106,5	0,0	0,0	0,0	0,0	0,0
12,85	0,0	19,07	0,0	106,5	0,0	0,0	0,0	0,0	0,0
11,7	0,0	37,85	0,0	81,2	0,0	0,0	0,0	86,5	0,0
33,35	0,0	33,35	0,0	88,2	0,0	0,0	0,0	0,0	0,0
19,0	0,0	31,6	0,0	38,0	0,0	0,0	0,0	10,55	0,0
9,9	0,0	22,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16,95	0,0	21,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16,95	0,0	34,75	0,0	0,0	0,0	0,0	0,0	0,0	0,0
16,95	0,0	21,50	0,0	0,0	0,0	0,0	0,0	0,0	0,0
6,04	0,0	14,48	0,0	0,0	0,0	0,0	0,0	0,0	0,0
47,1	0,0	0,0	70,7	0,0	138,8	0,0	0,0	0,0	0,0
0,0	36,9	0,0	31,6	0,0	80,7	0,0	0,0	0,0	0,0
0,0	36,9	0,0	25,45	0,0	80,7	0,0	0,0	0,0	0,0
0,0	36,9	0,0	28,10	0,0	80,7	0,0	0,0	0,0	0,0
0,0	36,9	0,0	27,65	0,0	80,7	0,0	0,0	0,0	0,0
0,0	36,9	0,0	31,60	0,0	72,0	0,0	0,0	0,0	0,0
0,0	42,1	0,0	19,1	0,0	35,15	0,0	0,0	0,0	0,0
31,2	0,0	0,0	45,8	0,0	80,20	0,0	0,0	0,0	0,0
29,0	0,0	0,0	28,0	0,0	33,0	0,0	0,0	0,0	0,0
33,1	0,0	0,0	46,1	0,0	67,7	0,0	0,0	0,0	0,0
45,2	0,0	0,0	57,0	0,0	95,0	0,0	0,0	0,0	0,0
43,6	0,0	0,0	63,1	0,0	218,0	0,0	0,0	0,0	0,0
26,55	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
35,25	0,0	0,0	100,1	0,0	75,0	0,0	0,0	36,4	0,0
81,5	0,0	0,0	120,0	0,0	141,5	0,0	0,0	45,6	0,0
35,65	0,0	0,0	98,0	0,0	72,7	0,0	0,0	35,6	0,0
34,80	0,0	0,0	72,0	0,0	93,6	0,0	0,0	0,0	0,0
26,15	0,0	0,0	53,5	0,0	134,0	0,0	0,0	58,83	0,0
28,8	0,0	24,0	0,0	31,9	0,0	0,0	0,0	0,0	0,0

70,0	0,0	0,0	110,0	0,0	175,0	150,0	0,0	80,0	0,0
55,0	0,0	0,0	73,4	0,0	0,0	110,0	0,0	62,4	0,0
0,0	44,0	0,0	35,0	0,0	163,0	0,0	0,0	33,0	0,0
93,5	0,0	41,7	43,8	102,4	0,0	0,0	0,0	0,0	0,0
32,8	0,0	0,0	67,6	0,0	127,1	0,0	0,0	0,0	0,0
43,6	0,0	0,0	63,1	0,0	272,0	0,0	0,0	0,0	0,0
42,8	0,0	0,0	48,0	0,0	0,0	140,5	0,0	0,0	0,0
57,8	0,0	126,8	0,0	0,0	0,0	0,0	0,0	49,6	0,0
33,6	0,0	0,0	118,2	0,0	0,0	0,0	0,0	43,0	0,0
28,15	0,0	0,0	48,7	0,0	0,0	19,77	0,0	0,0	0,0
34,3	0,0	0,0	49,7	0,0	185,0	140,5	0,0	0,0	0,0
25,7	0,0	0,0	71,9	133,7	0,0	106,2	0,0	58,21	0,0
54,0	0,0	0,0	97,0	0,0	0,0	0,0	0,0	0,0	0,0
37,9	0,0	0,0	81,3	227,5	0,0	117,2	0,0	64,05	0,0
23,6	0,0	0,0	48,7	0,0	0,0	46,2	0,0	0,0	0,0
54,9	0,0	53,9	0,0	0,0	0,0	0,0	0,0	48,8	0,0
45,0	0,0	0,0	45,0	0,0	0,0	0,0	0,0	0,0	0,0
53,8	0,0	0,0	254,0	0,0	0,0	92,3	0,0	0,0	0,0
32,85	0,0	0,0	133,0	0,0	0,0	0,0	0,0	18,6	0,0
0,0	83,2	0,0	30,25	0,0	49,2	28,4	94,6	0,0	0,0
0,0	62,3	0,0	0,0	0,0	43,6	43,6	0,0	0,0	0,0
0,0	75,8	0,0	30,3	0,0	64,4	53,0	94,6	0,0	0,0
59,6	0,0	0,0	149,0	0,0	170,5	0,0	89,5	68,1	0,0
47,3	0,0	0,0	61,8	0,0	140,0	0,0	0,0	0,0	0,0
35,4	0,0	0,0	167,0	0,0	83,4	70,7	0,0	78,3	0,0
14,4	0,0	0,0	33,0	0,0	27,6	0,0	0,0	18,5	0,0
0,0	0,0	0,0	0,0	57,6	0,0	0,0	0,0	17,7	0,0
0,0	0,0	0,0	0,0	57,6	0,0	0,0	0,0	42,0	0,0
14,4	0,0	0,0	20,4	114,0	0,0	0,0	0,0	19,5	0,0
10,77	0,0	15,23	0,0	87,0	0,0	0,0	0,0	14,58	0,0
21,6	0,0	19,8	0,0	0,0	0,0	0,0	0,0	20,7	0,0
51,5	0,0	0,0	118,2	118,2	0,0	0,0	0,0	27,4	0,0
37,3	0,0	0,0	57,5	181,0	0,0	0,0	0,0	17,05	0,0
39,4	0,0	0,0	118,2	92,6	0,0	0,0	0,0	27,4	0,0
28,8	0,0	23,2	0,0	100,0	0,0	0,0	0,0	17,2	0,0
16,4	0,0	29,75	0,0	59,4	0,0	0,0	0,0	0,0	0,0
26,8	0,0	21,6	0,0	99,1	0,0	0,0	0,0	0,0	0,0
41,8	0,0	39,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0
42,7	0,0	0,0	96,1	0,0	90,7	0,0	64,1	0,0	0,0
39,75	0,0	37,3	0,0	186,5	0,0	70,8	0,0	0,0	0,0
18,0	0,0	20,1	0,0	216,5	0,0	0,0	0,0	0,0	0,0
42,9	0,0	40,75	0,0	0,0	0,0	0,0	0,0	0,0	0,0
43,7	0,0	23,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
37,2	0,0	48,0	0,0	0,0	0,0	0,0	0,0	86,4	0,0
60,0	0,0	48,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
28,15	0,0	32,82	0,0	0,0	0,0	0,0	0,0	22,5	0,0
15,35	0,0	15,35	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,0	48,0	0,0	0,0	0,0	14,0	0,0	0,0	0,0	0,0
0,0	46,2	0,0	34,6	0,0	0,0	0,0	0,0	0,0	0,0
0,0	42,6	0,0	13,4	0,0	10,42	0,0	0,0	0,0	0,0
23,45	0,0	26,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0
18,91	0,0	33,8	0,0	0,0	0,0	0,0	0,0	41,4	0,0
0,0	43,2	0,0	20,85	0,0	0,0	0,0	0,0	0,0	0,0
51,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	61,4	0,0
28,35	0,0	31,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0
48,4	0,0	36,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0
27,1	0,0	41,7	0,0	0,0	0,0	0,0	0,0	37,55	0,0
37,2	0,0	33,6	0,0	0,0	0,0	0,0	0,0	86,4	0,0
37,2	0,0	48,0	0,0	0,0	0,0	0,0	0,0	50,4	0,0
0,0	43,2	0,0	20,9	0,0	0,0	0,0	0,0	0,0	0,0
28,0	0,0	27,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22,35	0,0	22,35	0,0	0,0	105,0	41,75	0,0	0,0	0,0
0,0	95,7	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
96,3	0,0	49,8	0,0	0,0	0,0	0,0	0,0	18,83	0,0
65,7	0,0	0,0	94,5	205,5	209,8	0,0	411,0	0,0	0,0

```
  0.0 , 65.0 ,  0.0 , 19.5 , 45.4 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 28.88,  0.0 , 25.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 14.4 ,0.0,
 24.80,  0.0 , 26.1 ,  0.0 , 47.8 ,  0.0 ,  0.0 ,  0.0 , 36.1 ,0.0,
 24.8 ,  0.0 , 26.1 ,  0.0 , 47.8 ,  0.0 ,  0.0 ,  0.0 , 36.1 ,0.0,
 34.35,  0.0 , 41.6 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 40.2 ,0.0,
 35.35,  0.0 ,  0.0 , 56.25,  0.0 ,  0.0 ,  0.0 ,  0.0 , 31.4 ,0.0,
 61.7 ,  0.0 , 78.2 ,  0.0 ,  0.0 , 86.4 ,  0.0 ,  0.0 , 53.5 ,0.0,
  0.0 , 93.5 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 48.8 ,  0.0 , 51.6 ,  0.0 ,  0.0 , 57.0 ,  0.0 ,  0.0 , 35.3 ,0.0,
 57.0 ,  0.0 ,  0.0 ,134.0 ,  0.0 ,150.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 36.0 ,  0.0 ,  0.0 ,105.0 ,  0.0 ,151.8 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 36.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 97.6 ,  0.0 ,  0.0 ,169.5 ,  0.0 ,292.5 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 41.7 ,  0.0 , 39.82,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 34.55,0.0,
  0.0 ,  0.0 , 56.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 46.8 ,  0.0 , 39.6 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 40.0 ,  0.0 ,  0.0 , 51.7 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 23.35,0.0,
 36.0 ,  0.0 ,  0.0 ,170.0 ,  0.0 ,200.7 ,  0.0 ,  0.0 ,  0.0 ,0.0,
127.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 24.3 ,  0.0 , 26.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 26.0 ,  0.0 , 26.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 24.0 ,0.0,
 22.0 ,  0.0 ,  0.0 , 28.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 24.0 ,0.0,
 30.9 ,  0.0 , 29.6 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 19.3 ,0.0,
  0.0 ,  0.0 , 68.4 ,  0.0 ,  0.0 , 30.6 ,  0.0 ,  0.0 , 17.2 ,0.0,
  0.0 ,114.0 , 92.7 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 26.50,  0.0 ,  0.0 , 70.6 ,  0.0 ,104.1 ,  0.0 ,  0.0 ,  0.0 ,0.0,
  0.0 ,108.0 ,  0.0 ,  9.9 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 83.7 ,  0.0 , 64.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 70.2 ,0.0,
 65.7 ,  0.0 ,  0.0 , 94.5 ,414.5 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 49.7 ,  0.0 , 64.9 ,  0.0 ,  0.0 ,138.7 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 48.7 ,  0.0 , 68.6 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 66.45,0.0,
 37.2 ,  0.0 , 27.6 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 , 20.6 ,0.0,
 24.65,  0.0 , 33.35,  0.0 ,198.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 64.8 ,  0.0 ,  0.0 , 50.4 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 20.6 ,  0.0 ,  0.0 , 45.1 ,154.4 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 50.8    0.0 ,  0.0 , 80.5 ,372.5 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 41.75,  0.0 , 23.65,  0.0 , 24.45,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 36.0 ,  0.0 , 20.75,  0.0 , 19.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 19.0 ,  0.0 , 33.35,  0.0 ,163.2,   0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 48.2 ,  0.0 , 47.40,  0.0 , 31.2,   0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
  0.0 , 51.6 , 28.15,  0.0 , 84.8 ,  0.0 ,  0.0 ,  0.0 , 56.2 ,0.0,
 39.8 ,  0.0 , 30.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 14.3 ,  0.0 , 10.0 ,170.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 16.5 ,  0.0 , 14.4 ,  0.0 ,127.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 45.6 ,  0.0 , 42.5 ,  0.0 ,191.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 19.18,  0.0 , 12.15,  0.0 ,127.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 20.25,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
  0.0 , 33.25, 35.45,  0.0 , 87.5 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
  0.0 , 60.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 24.0 ,  0.0 , 32.4 ,  0.0 ,  0.0 , 22.8 , 76.7 ,  0.0 , 39.0 ,0.0,
 24.55,  0.0 , 24.0 ,  0.0 , 99.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 22.7 ,  0.0 , 36.65,  0.0 ,111.3 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
  0.0 ,  0.0 ,  0.0 ,  0.0 ,129.8 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 22.42,  0.0 , 23.65,  0.0 ,127.5 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 20.2 ,  0.0 , 15.82,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 33.77,  0.0 , 35.65 ,  0.0 ,128.9 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 33.75,  0.0 , 27.0, 0.0 ,191.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 35.6 ,  0.0 , 28.5, 0.0  202.20   0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 35.6    0.0 , 28.5, 0.0 ,158.2    0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 35.6    0.0 , 28.5, 0.0 ,158.2 ,  0.0 ,  0.0 ,  0.0 ,  0.0 ,0.0,
 14.5,0.0,10.23,0.0,0.0,0.0,51.2,0.0,0.0,0.0,
 29.3,0.0,38.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
 30.6,0.0,40.5,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
 0.0,53.0,0.0,51.8,0.0,0.0,75.8,0.0,0.0,0.0,
 19.6,0.0,26.8,0.0,80.2,0.0,0.0,0.0,0.0,0.0,
 23.3,0.0,17.5,0.0,85.8,0.0,0.0,0.0,0.0,0.0,
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18.3,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
52.0,0.0,43.2,0.0,103.0,0.0,0.0,0.0,0.0,0.0,
40.0,0.0,29.8,0.0,204.0,0.0,0.0,0.0,0.0,0.0,
51.2,0.0,42.4,0.0,230.0,0.0,0.0,0.0,0.0,0.0,
38.6,0.0,0.0,88.6,154.5,0.0,0.0,0.0,31.8,0.0,
45.0,0.0,0.0,153.0,0.0,0.0,0.0,0.0,0.0,0.0,
38.6,0.0,0.0,88.5,152.2,0.0,0.0,0.0,0.0,0.0,
53.9,0.0,0.0,254.0,0.0,0.0,92.2,0.0,0.0,0.0,
37.8,0.0,0.0,158.2,0.0,0.0,70.8,0.0,0.0,0.0,
28.4,0.0,0.0,45.5,63.8,0.0,0.0,0.0,18.2,0.0,
11.5,0.0,10.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
12.0,0.0,0.0,12.0,0.0,51.6,0.0,0.0,0.0,0.0,
32.8,0.0,0.0,133.0,0.0,0.0,0.0,0.0,0.0,0.0,
35.6,0.0,28.5,0.0,203.0,0.0,0.0,0.0,0.0,0.0,
35.6,0.0,28.5,0.0,154.1,0.0,0.0,0.0,0.0,0.0,
35.6,0.0,28.5,0.0,203.0,0.0,0.0,0.0,0.0,0.0,
 35.6,0.0,28.5,0.0,154.1,0.0,0.0,0.0,0.0,0.0,
21.8,0.0,23.0,0.0,111.8,0.0,0.0,0.0,0.0,0.0,
30.0,0.0,31.6,0.0,101.8,0.0,0.0,0.0,0.0,0.0,
22.5,0.0,23.7,0.0,126.0,0.0,0.0,0.0,0.0,0.0,
39.7,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
0.0,43.1,0.0,12.6,0.0,0.0,0.0,0.0,0.0,0.0,
0.0,43.1,0.0,12.6,0.0,0.0,0.0,0.0,0.0,0.0,
0.0,43.1,0.0,12.6,0.0,0.0,0.0,0.0,0.0,0.0,
48.0,0.0,0.0,24.0,0.0,0.0,0.0,0.0,0.0,0.0,
48.0,0.0,0.0,11.0,14.0,0.0,0.0,0.0,0.0,0.0,
40.0,0.0,33.2,0.0,155.8,0.0,0.0,0.0,0.0,0.0,
28.9,0.0,0.0,31.7,0.0,36.0,0.0,0.0,0.0,0.0,
14.6,0.0,24.0,0.0,25.3,0.0,0.0,0.0,0.0,0.0,
0.0,0.0,0.0,31.6,33.3,0.0,0.0,0.0,0.0,0.0,
0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
38.3,0.0,0.0,76.5,88.2,0.0,0.0,180.0,0.0,0.0,
38.3,0.0,0.0,76.5,88.2,0.0,0.0,0.0,0.0,0.0,
26.1,0.0,0.0,43.2,43.2,0.0,0.0,101.0,0.0,0.0,
37.2,0.0,48.0,0.0,0.0,0.0,0.0,0.0,50.7,0.0,
30.5,0.0,15.75,10.05,123.0,0.0,0.0,0.0,18.7,0.0,
85.1,0.0,0.0,50.7,0.0,63.4,0.0,0.0,0.0,0.0,
85.1,0.0,0.0,50.7,0.0,63.4,0.0,0.0,0.0,0.0,
85.1,0.0,0.0,50.7,0.0,63.4,0.0,0.0,0.0,0.0,
59.8,0.0,0.0,126.8,0.0,0.0,0.0,0.0,0.0,0.0,
85.1,0.0,0.0,50.7,0.0,63.4,0.0,0.0,0.0,0.0,
29.9,0.0,61.4,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
18.8,0.0,13.6,55.4,0.0,0.0,0.0,0.0,0.0,0.0,
47.1,0.0,48.0,53.1,0.0,0.0,0.0,0.0,0.0,0.0,
2650.0,1920.0,2100.0,3600.0,5200.0,2100.0,1200.0,400.0,960.0;
68,63,58;
379,199,394,389,356,187,389,156,199,394,243,389,
360,389,371,368,373,374,375,376,208,187,
89,350,170,24,173,128,340,367,172,
41,353,357,21,242,231,348,349,366,348,
349,373,374,355,172,41,351,129,389,372,
367,379,19,78,375,376,129,389,128,381,
362,212,
168,7,21,206,348,114,93,117,350,24,
170,364,24,93,369,239,304,271,272,348,
114,24,173,385,386,365,180,239,304,358,
359,352,166,93,157,54,179,189,25,253,
8,100,24,173,268,377,365,180,382,377,
378,159,117,354,169,70,187,110,
387,370,380,361,130,352,20,190,
178,396;

↑****************************************************************
```

APPENDIX V.

Performance analysis of the simulation model.

Section 1: Output resulting from the inclusion of numerous write statements in the programme - employed to ensure correct simulation (a key is included).

Section 2: Typical customer order data generated by the Monte Carlo technique - ORDER1 and ORDER2 arrays.

Section 3: Selection of information from the order file (ORDER1 and ORDER2 arrays) after a simulated production run of 9 weeks using a nine week lead time.

Section 4: Details of the process times used in the simulation model.

Section 5: Results from a 3 month simulation run using a nine week lead time and showing output level and stock level details.

Section 1: APPENDIX V.

Output resulting from the inclusion of numerous write statements in the programme - employed to ensure correct simulation (a key is included).

Note. A full and complete key to this data would be both extensive and complex without serving any satisfactory purpose. However, to facilitate adequate interpretation a simple but limited key is provided. The section of file shown is not wholly continuous but has been suitably edited to economise on space while at the same time retaining the salient features.

Key to the identity to the output employed to ensure correct simulation.

THIS FNCE	= Indicates that the sub-routine FNCHOS has been called.
ROUTE1	= Considers whether or not the job under consideration requires two furnaces.
ROUTE2	= The job under consideration requires two furnaces hence furnace availability and suitability (alloy contamination) is appraised.
ROUTE3	= The job under consideration only requires one furnace hence a suitable furnace is sought.
CONTAM4	= A job requiring two furnaces is under consideration but furnace no. 4 is contaminated.
CONTAM5	= Same as CONTAM4 except involves furnace no. 5.
CONTAM	= A job requiring a single furnace has a sufficiently high priority to warrant a WASH or SCRUB heat being assigned to the furnace designated which is found to be contaminated.
WASH HEAT FOUND	= A suitable order (correct weight) for a high nickel alloy (Alloy no. 23 or 24) has been found hence the availability of the appropriate die/s is determined.
SCRUB	= A suitable WASH heat has not been found hence a pure copper charge is assigned to decontaminate the furnace.
THIS MACH	= Indicates that the sub-routine MACHOS has been called.

THIS TIME = Indicates that the sub-routine NEXVENT has been called - the current time of day (mins.) for the simulation is also indicated here.

The various values shown indicate a variety of data such as stock details, die,furnace and cutting machine identity, various time parameters and details of the order under consideration.

```
WASH HEAT FOUND   393
WASH HEAT FOUND   398
  -4570.27      0.00      0.00      1.00      1.00      0.00
  -4570.27      0.00      0.00      1.00      1.00      0.00
     3.0     597.0     420.0     229.0       1.0       0.0     297.8     286.6      71.0       1.0     255.0
  398      37.00     95.00    500.00      0.00     25.00     23
THIS MACH
THIS TIME      107.00
   116.50    46
THIS TIME      116.50
   144.00     4
     0.00
THIS FNCE   PRIOR     1.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   9456.78      0.00      0.00      0.00      0.00      0.00
   9456.78      0.00      0.00      0.00      0.00      0.00
     4.0     647.0     480.0     197.0       1.0       1.0     265.6     259.2      81.0       0.0     249.5
   19      38.50     80.00    500.00      0.00      2.00      2
THIS MACH
THIS TIME      144.00
   149.50    48
THIS TIME      149.50
   171.74     6
     0.00
THIS FNCE   PRIOR     1.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   8685.52      0.00      0.00      0.00      0.00      0.00
   8685.52      0.00      0.00      0.00      0.00      0.00
     2.0     387.0     250.0     216.0     182.0       0.0     139.7     124.1      46.0       0.0      82.4
   26      69.36     42.50    365.00      0.00     25.00     25
THIS MACH
       15         2      0.00    268.51         1
```

```
   182.50      4
     0.00
 THIS FNCE   PRIOR     1.00
 ROUTE1
 ROUTE3
 ROUTE1
 ROUTE3
 ROUTE1
 ROUTE3
 ROUTE1
 ROUTE3
   14107.92      0.00      244.76      0.00      0.00      0.00
   14107.92      0.00      244.76      0.00      0.00      0.00
       2.0     286.0      182.0     210.0       1.0       0.0      72.1      70.7      31.0      0.0      59.
   27        33.00       42.50     500.00      0.00     14.00    14
 THIS MACH
 THIS TIME        182.50
   190.00     63
 THIS TIME        190.00
   203.00     31
 THIS TIME        203.00
   203.90     52
 THIS TIME        203.90
   206.00      3
     0.00
 THIS FNCE   PRIOR     1.00
 ROUTE1
 ROUTE3
 ROUTE1
 ROUTE3
    9374.26      0.00      0.00      0.00      0.00      0.00
    9374.26      0.00      0.00      0.00      0.00      0.00
       2.0     381.0     210.0     114.0       1.0       0.0      82.5      80.5      45.0      1.0      66.7
    3        38.50      42.50     500.00      0.00      2.00    2
 THIS MACH
           3          3      0.00    303.04        1
           6          4      0.00    315.00        1
 THIS TIME        206.00
   215.40     91
 THIS TIME        215.40
   215.50      4
     0.00
 THIS FNCE   PRIOR     1.00
 ROUTE1
```

```
ROUTE1
ROUTE3
  8615.07      0.00      0.00      0.00      0.00      0.00
  8615.07      0.00      0.00      0.00      0.00      0.00
     1.0     273.0     180.0     648.0     180.0       0.0     202.4     179.7      24.0       0.0     131.9
   6     31.00     34.00    500.00      0.00     25.00    25
THIS MACH
THIS TIME      215.50
  219.00      5
    0.00
THIS FNCE  PRIOR    1.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
 14085.41      0.00    244.76      0.00      0.00      0.00
 14085.41      0.00    244.76      0.00      0.00      0.00
     4.0     673.0     555.0     127.0       1.0       0.0     129.8     127.2      84.0       1.0     117.8
  13     50.00     80.00    750.00      0.00     15.00    15
THIS MACH
THIS TIME      219.00
  220.00      7
    0.00
THIS FNCE  PRIOR    1.00
ROUTE1
ROUTE3
CONTAM
WASH HEAT FOUND    16
WASH HEAT FOUND    53
WASH HEAT FOUND    66
WASH HEAT FOUND   140
WASH HEAT FOUND   154
WASH HEAT FOUND   158
WASH HEAT FOUND   163
WASH HEAT FOUND   164
WASH HEAT FOUND   170
WASH HEAT FOUND   171
WASH HEAT FOUND   175
WASH HEAT FOUND   195
 -4737.53      0.00      0.00      1.00      1.00      0.00
 -4737.53      0.00      0.00      1.00      1.00      0.00
     2.0     330.0     190.0     318.0       1.0       0.0     167.5     160.9      39.0       0.0     146.0
 105    410.00     42.50    630.00      0.00     23.00    23
```

```
THIS MACH
THIS TIME      220.00
   225.40      1
     0.00
THIS FNCE  PRIOR      1.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
  14085.41      0.00     77.50      0.00      0.00      0.00
  14085.41      0.00     77.50      0.00      0.00      0.00
      1.0     172.0      82.0     648.0      19.0       0.0     104.5     102.4      15.0       0.0      70.8
   30       67.70     30.00    180.00      0.00     15.00     13
THIS MACH
THIS TIME      225.40
   228.00    117
THIS TIME      228.00
   232.80      2
     0.00
THIS FNCE  PRIOR      1.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
ROUTE1
ROUTE3
  12161.90     70.00    545.26      0.00      0.00      0.00
  12161.90     70.00    545.26      0.00      0.00      0.00
      2.0     299.0     130.0     267.0       3.0       0.0     131.0     115.1      33.0       0.0      87.7
   36       84.00     42.50    180.00      0.00      4.00      4
```

```
   283.50      4
     0.00
THIS FNCE  PRIOR     1.00
ROUTE1
ROUTE3
   8412.71      0.00       0.00       0.00       0.00       0.00
   8412.71      0.00       0.00       0.00       0.00       0.00
      1.0     273.0      180.0      648.0      179.0        0.0      202.4      179.7      24.0      1.0      131.9
    6      31.00      34.00     500.00       0.00      25.00     25
THIS MACH
        6          5       0.00     592.50          1
THIS TIME       283.50
   283.61     53
THIS TIME       283.61
   286.00     68
THIS TIME       286.00
   287.00     52
THIS TIME       287.00
   293.10      1
     0.00
THIS FNCE  PRIOR     1.00
ROUTE1
ROUTE3
CONTAM
WASH HEAT FOUND     16
WASH HEAT FOUND     53
WASH HEAT FOUND     66
WASH HEAT FOUND    140
WASH HEAT FOUND    154
WASH HEAT FOUND    158
  -5608.69      0.00       0.00       1.00       1.00       0.00
  -5608.69      0.00       0.00       1.00       1.00       0.00
      2.0     381.0      240.0      114.0        4.0        0.0       72.1       69.4      45.0      0.0      54.1
  158      90.00      42.50     180.00       0.00      25.00     23
THIS MACH
        3          6       0.00     590.14          1
       26          7       0.00     386.43          1
THIS TIME       293.10
   300.00     59
THIS TIME       300.00
   303.04    129
THIS MACH
       11          3       0.00     440.10          1
THIS TIME       303.04
```

```
THIS TIME      305.40
  314.00     77
THIS TIME      314.00
  314.50      3
    0.00
THIS FNCE  PRIOR     1.00
ROUTE1
ROUTE3
  8412.71        0.00     359.25      0.00      0.00      0.00
  8412.71        0.00     359.25      0.00      0.00      0.00
     3.0      349.0      280.0     1054.0      60.0       0.0      339.1      301.1      52.0      0.0      217.
    11      31.00       80.00     500.00       0.00     25.00    25
THIS MACH
THIS TIME      314.50
  314.50      4
    0.00
THIS FNCE  PRIOR     1.00
ROUTE2
ROUTE1
ROUTE3
THIS MACH
THIS TIME      314.50
  315.00    130
THIS MACH
THIS TIME      315.00
  316.80      2
    0.00
THIS FNCE  PRIOR     1.00
ROUTE2
ROUTE1
ROUTE3
  8412.71        0.00     287.14      0.00      0.00      0.00
  8412.71        0.00     287.14      0.00      0.00      0.00
     2.0      279.0      150.0       83.0       3.0       0.0       34.0       30.2      29.0      1.0      29.5
    50      90.00       20.40     180.00       0.00     25.00    25
THIS MACH
THIS TIME      316.80
  319.00      5
    0.00
THIS FNCE  PRIOR     1.00
ROUTE2
CONTAM4
 -5782.97        0.00       0.00      1.00      1.00      0.00
 -5782.97        0.00       0.00      1.00      1.00      0.00
```

```
WASH HEAT FOUND   286
WASH HEAT FOUND   298
WASH HEAT FOUND   305
WASH HEAT FOUND   310
WASH HEAT FOUND   319
WASH HEAT FOUND   321
WASH HEAT FOUND   323
WASH HEAT FOUND   327
WASH HEAT FOUND   345
WASH HEAT FOUND   347
WASH HEAT FOUND   352
WASH HEAT FOUND   382
WASH HEAT FOUND   390
WASH HEAT FOUND   393
WASH HEAT FOUND   402
WASH HEAT FOUND   405
WASH HEAT FOUND   410
WASH HEAT FOUND   421
WASH HEAT FOUND   422
WASH HEAT FOUND   427
WASH HEAT FOUND   453
WASH HEAT FOUND   461
WASH HEAT FOUND   464
WASH HEAT FOUND   471
WASH HEAT FOUND   482
WASH HEAT FOUND   485
WASH HEAT FOUND   489
SCRUB
  25000.00      70.00      66.28      0.00      0.00      0.00
  25000.00      70.00      66.28      0.00      0.00      0.00
      0.0        2.0      349.0     232.0     398.0       4.0       0.0     190.8     187.0     41.0     0.0
     0       38.50      17.00     500.00      0.00      2.00    23
THIS MACH
THIS TIME        108.50
   109.00     127
THIS MACH
THIS TIME        109.00
   110.00       7
     0.00
THIS FNCE   PRIOR      2.00
ROUTE1
ROUTE3
ROUTE1
```

```
 -5957.24     0.00      0.00      1.00      1.00      0.00
     4.0     825.0     640.0      89.0      -1.0       0.0     174.3     167.7      95.0       5.0     144.
  140      55.00     80.00    750.00      0.00     25.00    23
THIS MACH
THIS TIME      319.00
   323.10    22
THIS TIME      323.10
   328.74   140
THIS MACH
         5        14      1.00    787.91          1
        30         4      0.00    440.74          1
THIS TIME      328.74
   328.87     6
     0.00
THIS FNCE  PRIOR     1.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   9314.79      0.00      0.00      0.00      0.00      0.00
   9314.79      0.00      0.00      0.00      0.00      0.00
     4.0     647.0     480.0     197.0       1.0       1.0     265.6     259.2      81.0       1.0     249.5
   19      84.01     80.00    365.00      0.00      2.00     2
THIS MACH
THIS TIME      328.87
   330.00     7
     0.00
THIS FNCE  PRIOR     1.00
ROUTE1
ROUTE3
   8311.64      0.00      0.00      0.00      0.00      0.00
   8311.64      0.00      0.00      0.00      0.00      0.00
     3.0     483.0     340.0     445.0       4.0       0.0     388.2     344.7      61.0       0.0     282.2
   18     110.00     80.00    680.00      0.00     25.00    25
THIS MACH
THIS TIME      330.00
   345.50     3
     0.00
THIS FNCE  PRIOR     1.00
ROUTE1
ROUTE3
CONTAM
WASH HEAT FOUND     16
WASH HEAT FOUND     53
WASH HEAT FOUND     66
```

```
  348.50     31
THIS TIME        348.50
  349.00     63
THIS TIME        349.00
  349.00     91
THIS TIME        349.00
  352.30    127
THIS MACH
       6             1      0.00     461.50         1
      24             8      0.00     463.77         1
THIS TIME        352.30
  356.00      4
    0.00
THIS FNCE  PRIOR       1.00
ROUTE2
ROUTE1
ROUTE3
THIS MACH
THIS TIME        356.00
  359.30     40
THIS TIME        359.30
  365.41    128
THIS MACH
THIS TIME        365.41
  372.50     46
THIS TIME        372.50
  373.50    117
THIS TIME        373.50
  374.00      5
    0.00
THIS FNCE  PRIOR       1.00
ROUTE2
  5504.20       0.00       0.00       0.00       0.00       0.00
  5504.20       0.00       0.00       0.00       0.00       0.00
     3.0       572.0      245.0      406.0        5.0        0.0     765.1     749.8     70.0     3.0     329.2
  48         50.00      125.50     750.00       0.00       8.00     8
THIS MACH
THIS TIME        374.00
  356.00      4
    0.00
THIS FNCE  PRIOR       1.00
ROUTE1
ROUTE3
  8241.18       0.00       0.00       0.00       0.00       0.00
```

```
 -6650.62      0.00       0.00       1.00       1.00       0.00
 -6650.62      0.00       0.00       1.00       1.00       0.00
      2.0     381.0      240.0      114.0        3.0        0.0       72.1       69.4       45.0        1.0       54.1
 158      90.00     42.50     180.00       0.00      23.00      23
ROUTE1
ROUTE3
  7865.04      0.00       0.00       0.00       0.00       0.00
  7865.04      0.00       0.00       0.00       0.00       0.00
      1.0     273.0      180.0      648.0        3.0        0.0      202.4      179.7       24.0        0.0      121.2
 159      76.65     34.00     365.00       0.00      25.00      25
ROUTE1
ROUTE3
CONTAM
WASH HEAT FOUND      16
 -7220.14      0.00       0.00       1.00       1.00       0.00
 -7220.14      0.00       0.00       1.00       1.00       0.00
      4.0     825.0      580.0      229.0        1.0        1.0      569.5      548.0       95.0        1.0      486.1
  16     110.00    127.00     680.00       0.00      23.00      23
THIS MACH
          1          13       0.00     681.98          1
          6           1       0.00     109.00          1
         11           2       0.00     157.06          1
         16          14       0.00    1230.77          1
         18           9       0.00     573.55          1
         26           3       0.00      93.53          1
         36           4       0.00     107.07          1
         48          10       3.00     515.00          1
         50           5       1.00      71.48          1
        158           6       0.00      97.04          1
        192           7       0.00     104.57          1
        390          11       0.00     552.89          1
          5          12       0.00     459.18          1
         12          15       1.00     328.74          1
   90.        90.        37.   0.00E 00        50.        77.   0.11E 03   0.00E 00   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.11E 03   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.11E 03   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.13E 03   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.15E 03   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.18E 03
 0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.24E 03   0.24E 03   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00
 0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00   0.00E 00
```

```
          0         0         0         0         0         0         0         0         0         0
          0         0         0         1         0         0         0         0         0         0
          0         1         0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0         0         0
          0         0         0         0         1         1         0         0         0         0
          0         0         0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         1         1         1
          1         1         1         0         1         1         1         1         1         1
THIS TIME        0.00
     0.00     4
     0.00
THIS FNCE  PRIOR      2.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   2915.02       0.00      55.07       0.00       0.00       0.00
   2915.02       0.00      55.07       0.00       0.00       0.00
       4.0      948.0      842.0      216.0        1.0        1.0      289.1      283.3      102.0        0.0      273.0
     9      33.00      90.00     500.00       0.00      18.00     18
THIS MACH
        50          8       0.00      71.48          1
THIS TIME        0.00
    33.00     4
     0.00
THIS FNCE  PRIOR      2.00
ROUTE1
ROUTE3
   7865.04       0.00     203.01       0.00       0.00       0.00
   7865.04       0.00     203.01       0.00       0.00       0.00
       3.0      349.0      280.0     1054.0       59.0        0.0      339.1      301.1       52.0        0.0      217.1
    11      31.00      80.00     500.00       0.00      25.00     25
THIS MACH
THIS TIME       33.00
    37.00     5
     0.00
THIS FNCE  PRIOR      2.00
ROUTE1
ROUTE3
   9231.13       0.00       0.00       0.00       0.00       0.00
   9231.13       0.00       0.00       0.00       0.00       0.00
       2.0      279.0       84.0      165.0        1.0        0.0       83.7       81.7       30.0        0.0       72.8
    20      38.50      42.50     500.00       0.00       2.00      2
THIS MACH
```

```
     50.00        5
      0.00
THIS FNCE   PRIOR      2.00
ROUTE1
ROUTE3
  13734.96         0.00      322.25        0.00        0.00        0.00
  13734.96         0.00      322.25        0.00        0.00        0.00
       4.0       673.0       555.0       257.0         1.0         1.0       262.7       257.4        84.0         0.0       229.1
    23         50.00       80.00       750.00        0.00       14.00      14
THIS MACH
THIS TIME          50.00
     64.00        4
      0.00
THIS FNCE   PRIOR      2.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   7865.04         0.00      -17.62        0.00        0.00        0.00
   7865.04         0.00      -17.62        0.00        0.00        0.00
       2.0       387.0       250.0       216.0       180.0         0.0       139.7       124.1        46.0         0.0        82.4
    26         31.00       42.50       500.00        0.00       25.00      25
THIS MACH
THIS TIME          64.00
     71.48      131
THIS MACH
THIS TIME          71.48
     71.48      134
THIS MACH
THIS TIME          71.48
     75.50        3
      0.00
THIS FNCE   PRIOR      2.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
  13734.96         0.00      101.62        0.00        0.00        0.00
  13734.96         0.00      101.62        0.00        0.00        0.00
       1.0       172.0        82.0       648.0        18.0         0.0       104.5       102.4        15.0         0.0        70.8
    30         33.00       30.00       500.00        0.00       13.00      13
THIS MACH
THIS TIME          75.50
     76.65        6
      0.00
```

```
  11837.96      70.00      632.94       0.00       0.00       0.00
  11837.96      70.00      632.94       0.00       0.00       0.00
       2.0      368.0       143.0      248.0       67.0        0.0      192.9      169.5       44.0        0.0      109.4
    34     110.00       42.50      680.00       0.00       4.00      4
THIS MACH
THIS TIME       110.00
   110.40     36
THIS TIME       110.40
   110.65     31
THIS TIME       110.65
   118.00     37
THIS TIME       118.00
   123.00    109
THIS TIME       123.00
   132.00      4
     0.00
THIS FNCE   PRIOR      2.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   7645.06       0.00        0.00       0.00       0.00       0.00
   7645.06       0.00        0.00       0.00       0.00       0.00
       1.0      273.0       180.0      648.0      177.0        0.0      202.4      179.7       24.0        0.0      131.9
     6      31.00       34.00      500.00       0.00      25.00     25
THIS MACH
        20          1        0.00     219.91          1
        50          3        0.00     203.48          1
       159          4        0.00     319.00          1
THIS TIME       132.00
   132.50     52
THIS TIME       132.50
   137.06    128
THIS MACH
       158          2        0.00     234.10          1
THIS TIME       137.06
   137.50     53
THIS TIME       137.50
   138.50     22
THIS TIME       138.50
   144.00     59
THIS TIME       144.00
   147.00      3
     0.00
THIS FNCE   PRIOR      2.00
```

```
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   9221.37        0.00       0.00       0.00       0.00       0.00
   9221.37        0.00       0.00       0.00       0.00       0.00
      2.0      381.0      210.0      114.0        1.0        0.0       82.5       80.5       45.0        0.0       66.
   3       38.50      42.50     500.00       0.00       2.00       2
THIS MACH
        11          5       0.00     284.06          1
        26          6       0.00     240.53          1
        30          7       0.00     259.00          1
THIS TIME        147.00
   147.00     68
THIS TIME        147.00
   151.15      6
     0.00
THIS FNCE   PRIOR     2.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   7645.06.       0.00     440.41       0.00       0.00       0.00
   7645.06        0.00     440.41       0.00       0.00       0.00
      3.0      349.0      280.0     1054.0       58.0        0.0      339.1      301.1       52.0        0.0      217.1
   11      92.57      80.00     365.00       0.00      25.00      25
THIS MACH
THIS TIME        151.15
   155.00      5
     0.00
THIS FNCE   PRIOR     2.00
ROUTE1
ROUTE3
   2430.03        0.00       0.00       0.00       0.00       0.00
   2430.03        0.00       0.00       0.00       0.00       0.00
      4.0      951.0      820.0      330.0       24.0        2.0      540.1      529.2      102.0        0.0      468.3
   1       50.00     127.00     750.00       0.00      18.00      18
THIS MACH
THIS TIME        155.00
   163.00      4
     0.00
THIS FNCE   PRIOR     2.00
ROUTE1
```

```
    193,65     46
THIS TIME        193,65
    194,00      4
      0,00
THIS FNCE  PRIOR      2,00
ROUTE2
ROUTE1
ROUTE3
THIS MACH
       273          8        0,00     343,63          1
THIS TIME        194,00
    197,00     31
THIS TIME        197,00
    203,48    129
THIS MACH
         6          3        0,00     512,48          1
THIS TIME        203,48
    205,00      5
      0,00
THIS FNCE  PRIOR      2,00
ROUTE2
CONTAM4
  -7737,08       0,00       31,16       1,00       1,00       0,00
  -7737,08       0,00       31,16       1,00       1,00       0,00
  -7889,72       0,00        0,00       1,00       1,00       0,00
  -7889,72       0,00        0,00       1,00       1,00       0,00
       2,0      330,0      170,0      318,0       -1,0        0,0      183,8      176,9       39,0        0,0      160,9
 273          55,00      42,50     750,00       0,00      25,00      23
THIS MACH
THIS TIME        205,00
    216,50     40
THIS TIME        216,50
    218,50      3
      0,00
THIS FNCE  PRIOR      2,00
ROUTE1
ROUTE3
   7530,02       0,00        0,00       0,00       0,00       0,00
   7530,02       0,00        0,00       0,00       0,00       0,00
       1,0      273,0      180,0      648,0      176,0        0,0      202,4      179,7       24,0        0,0      131,9
   6          31,00      34,00     500,00       0,00      25,00      25
THIS MACH
THIS TIME        218,50
    219,91    127
THIS MACH
```

```
      36          1        0.00     326.99         1
THIS TIME       219.91
  220.00      7
    0.00
THIS FNCE   PRIOR     2.00
ROUTE1
ROUTE3
ROUTE1
ROUTE3
   7390.30      0.00      0.00      0.00      0.00      0.00
   7390.30      0.00      0.00      0.00      0.00      0.00
      2.0     387.0     250.0     216.0     179.0       0.0     159.7     124.1      46.0       0.0      82.4
   26      110.00       42.50     680.00       0.00      25.00   25
THIS MACH
THIS TIME       220.00
  222.00    117
THIS TIME       222.00
  228.00     52
THIS TIME       228.00
  234.10    128
THIS MACH
       3          2        0.00     331.14         1
THIS TIME       234.10
  237.00    102
THIS TIME   .   237.00
  240.33    132
THIS MACH
THIS TIME       240.33
  242.00      4
    0.00
THIS FNCE   PRIOR     2.00
ROUTE2
ROUTE1
ROUTE3
THIS MACH
THIS TIME       242.00
  243.72      6
    0.00
THIS FNCE   PRIOR     2.00
ROUTE2
ROUTE1
ROUTE3
   7356.25      0.00      0.00      0.00      0.00      0.00
   7356.25      0.00      0.00      0.00      0.00      0.00
      2.0     279.0     150.0      85.0       1.0       0.0      34.0      30.2      29.0       0.0      29.5
```

Section 2: APPENDIX V.

Typical customer order data generated by the Monte Carlo technique - ORDER1 and ORDER2 arrays.

Note. See Appendix III Section 1 for the identity of the various parameters indicated.

0.00	1.00	18.00	45.00	412.00	60.00	3.00	0.00	27.40		
3.00	445.00	282.00	445.00	1.00	1.00	371.98	364.51	56.00	0.00	337.
0.00	1.00	13.00	25.00	412.00	120.00	18.00	0.00	32.10		
3.00	445.00	322.00	445.00	9.00	1.00	296.14	290.19	56.00	0.00	258.
0.00	1.00	23.00	35.00	300.00	50.00	3.00	0.00	12.90		
2.00	330.00	190.00	318.00	1.00	1.00	167.26	160.93	39.00	0.00	148.
0.00	1.00	9.00	14.00	150.00	80.00	2.00	1.00	0.00		
0.00	0.00	82.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
0.00	1.00	13.00	14.00	728.00	140.00	1.00	0.00	38.69		
4.00	123.00	660.00	247.00	1.00	19.00	-732.61	-717.90	93.00	0.00	-754.
0.00	1.00	9.00	85.00	103.00	80.00	120.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
0.00	1.00	25.00	30.00	250.00	50.00	6.00	0.00	5.21		
2.00	279.00	150.00	85.00	6.00	1.00	34.05	30.24	29.00	0.00	25.
0.00	1.00	14.00	14.00	525.00	20.00	8.00	0.00	3.96		
3.00	572.00	457.00	216.00	4.00	1.00	180.51	176.68	69.00	0.00	172.
0.00	1.00	7.00	65.00	200.00	20.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
0.00	1.00	25.00	15.00	150.00	45.00	190.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
0.00	1.00	13.00	25.00	868.00	40.00	1.00	0.00	23.86		
4.00	939.00	798.00	465.00	1.00	1.00	285.07	279.34	102.00	0.00	255.
0.00	1.00	15.00	14.00	300.00	208.00	11.00	0.00	23.03		
2.00	330.00	232.00	318.00	11.00	1.00	123.55	121.06	39.00	0.00	98.0
0.00	1.00	8.00	35.00	412.00	180.00	3.00	0.00	65.67		
3.00	445.00	302.00	445.00	3.00	1.00	335.32	328.58	56.00	0.00	262.9
0.00	1.00	23.00	45.00	250.00	125.00	2.00	0.00	32.06		
2.00	286.00	120.00	210.00	2.00	1.00	102.25	98.39	31.00	0.00	66.3
0.00	1.00	25.00	75.00	250.00	45.00	62.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0.00	1.00	8.00	25.00	300.00	40.00	18.00	0.00	7.60		
2.00	330.00	210.00	318.00	6.00	1.00	145.36	142.44	39.00	0.00	134.8
0.00	1.00	2.00	55.00	350.00	45.00	25.00	0.00	20.42		
2.00	381.00	170.00	114.00	25.00	1.00	94.94	92.66	45.00	0.00	72.2
0.00	1.00	25.00	5.00	350.00	22.00	31.00	0.00	1.00		
2.00	381.00	300.00	114.00	31.00	1.00	46.61	41.39	45.00	0.00	40.3
0.00	1.00	18.00	25.00	40.00	208.00	7.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0.00	1.00	23.00	45.00	450.00	50.00	6.00	0.00	25.34		
3.00	483.00	320.00	445.00	2.00	1.00	420.82	404.90	61.00	0.00	379.5
0.00	1.00	25.00	30.00	200.00	45.00	1.00	0.00	6.04		
2.00	279.00	100.00	165.00	1.00	1.00	82.97	73.68	30.00	0.00	67.6
0.00	1.00	14.00	14.00	350.00	160.00	4.00	0.00	20.81		
2.00	387.00	282.00	216.00	4.00	1.00	107.03	104.88	46.00	0.00	84.0
0.00	1.00	8.00	25.00	103.00	40.00	120.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
0.00	1.00	2.00	75.00	200.00	53.00	3.00	1.00	0.00		

0.00	1.00	25.00	15.00	350.00	22.00	90.00	0.00	2.91		
2.00	381.00	230.00	114.00	90.00	1.00	56.42	50.10	45.00	0.00	47.19
0.00	1.00	7.00	55.00	300.00	40.00	3.00	0.00	14.90		
2.00	430.00	150.00	318.00	1.00	1.00	193.81	189.92	39.00	0.00	175.02
0.00	1.00	13.00	25.00	412.00	140.00	18.00	0.00	37.45		
3.00	445.00	322.00	445.00	9.00	1.00	296.14	290.19	56.00	0.00	252.74
0.00	1.00	23.00	140.00	300.00	132.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	3.00	25.00	140.00	205.00	70.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	65.00	350.00	120.00	1.00	0.00	74.74		
2.00	387.00	140.00	216.00	1.00	1.00	198.54	194.35	46.00	0.00	119.62
0.00	1.00	7.00	85.00	150.00	208.00	17.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	25.00	200.00	250.00	1.00	1.00	0.00		
0.00	0.00	110.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	23.00	45.00	450.00	22.00	5.00	0.00	11.15		
3.00	483.00	320.00	445.00	1.00	1.00	420.82	404.90	61.00	0.00	393.76
0.00	1.00	25.00	15.00	250.00	165.00	31.00	0.00	0.09		
1.00	273.00	160.00	648.00	10.00	1.00	202.36	179.70	24.00	0.00	170.42
0.00	1.00	25.00	5.00	150.00	45.00	62.00	0.00	0.02		
1.00	172.00	100.00	648.00	4.00	1.00	94.07	83.53	15.00	0.00	83.27
0.00	1.00	25.00	30.00	150.00	45.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	200.00	250.00	2.00	1.00	0.00		
0.00	0.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	200.00	120.00	1.00	0.00	8.64		
2.00	286.00	132.00	210.00	1.00	1.00	95.56	93.44	31.00	0.00	84.80
0.00	1.00	8.00	55.00	412.00	448.00	120.00	0.00	243.22		
4.00	129.00	262.00	623.00	120.00	24.00	-228.54	-223.95	73.00	0.00	-467.17
0.00	1.00	4.00	33.00	208.00	205.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	14.00	623.00	140.00	9.00	0.00	33.00		
4.00	53.00	555.00	257.00	9.00	25.00	-553.33	-542.21	84.00	0.00	-575.22
0.00	1.00	25.00	5.00	150.00	165.00	15.00	0.00	0.02		
1.00	172.00	100.00	648.00	5.00	1.00	94.07	83.53	15.00	0.00	83.48
0.00	1.00	28.00	18.00	300.00	150.00	3.00	0.00	20.05		
2.00	330.00	194.00	318.00	3.00	1.00	167.59	149.17	39.00	0.00	129.12
0.00	1.00	13.00	35.00	40.00	313.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	2.00	55.00	350.00	27.00	3.00	0.00	12.25		
2.00	381.00	170.00	114.00	3.00	1.00	94.94	92.66	45.00	0.00	80.41
0.00	1.00	25.00	30.00	150.00	71.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	4.00	65.00	100.00	205.00	12.00	1.00	0.00		

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	0.00	0.00
0.00	1.00	14.00	3.00	250.00	180.00	2.00	0.00	3.69		
2.00	299.00	204.00	267.00	2.00	1.00	90.00	88.19	33.00	0.00	84.50
0.00	1.00	8.00	14.00	525.00	600.00	28.00	1.00	0.00		
0.00	97.00	457.00	206.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	23.00	21.00	250.00	50.00	2.00	0.00	6.69		
2.00	279.00	168.00	165.00	2.00	1.00	59.15	56.91	30.00	0.00	50.23
0.00	1.00	18.00	3.00	1150.00	120.00	1.00	0.00	11.42		
4.00	1201.00	110.00	216.00	[illegible]	2.00	340.67	333.83	111.00	0.00	322.41
0.00	1.00	23.00	35.00	350.00	50.00	2.00	0.00	15.53		
2.00	381.00	240.00	114.00	2.00	1.00	72.12	69.39	45.00	0.00	54.06
0.00	1.00	8.00	25.00	200.00	180.00	2.00	0.00	21.77		
2.00	299.00	110.00	267.00	2.00	1.00	145.59	142.67	33.00	0.00	120.89
0.00	1.00	14.00	85.00	150.00	313.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	525.00	180.00	1.00	0.00	35.60		
3.00	572.00	457.00	406.00	[illegible]	1.00	338.91	332.10	70.00	0.00	296.49
0.00	1.00	13.00	14.00	150.00	140.00	9.00	0.00	0.05		
1.00	172.00	32.00	648.00	2.00	1.00	104.49	102.40	15.00	0.00	102.18
0.00	1.00	25.00	15.00	200.00	45.00	2.00	0.00	3.29		
2.00	279.00	130.00	165.00	2.00	1.00	74.54	66.19	30.00	0.00	62.90
0.00	1.00	23.00	45.00	350.00	50.00	1.00	0.00	19.08		
2.00	381.00	220.00	114.00	[illegible]	1.00	79.70	76.68	45.00	0.00	57.60
0.00	1.00	14.00	35.00	200.00	80.00	2.00	0.00	12.77		
2.00	279.00	90.00	165.00	[illegible]	1.00	81.17	79.54	30.00	0.00	66.77
0.00	1.00	4.00	33.00	130.00	58.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	30.00	200.00	354.00	6.00	1.00	0.00		
0.09	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	35.00	623.00	40.00	43.00	0.00	22.76		
4.00	673.00	513.00	127.00	46.00	1.00	170.00	166.59	84.00	0.00	143.82
0.00	1.00	10.00	25.00	103.00	80.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	3.00	14.00	200.00	120.00	1.00	0.00	8.64		
2.00	286.00	132.00	210.00	[illegible]	1.00	95.36	93.44	31.00	0.00	84.30
0.00	1.00	8.00	14.00	200.00	20.00	7.00	0.00	1.44		
2.00	279.00	132.00	83.00	7.00	1.00	35.37	34.66	29.00	0.00	33.22
0.00	1.00	4.00	50.00	250.00	205.00	4.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	14.00	40.00	448.00	17.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	28.00	25.00	300.00	58.00	18.00	0.00	10.50		
2.00	330.00	180.00	318.00	9.00	1.00	179.91	160.13	39.00	0.00	149.63
0.00	1.00	13.00	25.00	40.00	760.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	75.00	210.00	45.00	3.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

0.00	1.00	4.00	65.00	343.00	102.00	70.00	0.00	43.84		
2.00	368.00	143.00	248.00	70.00	1.00	192.95	169.55	44.00	0.00	125.71
0.00	1.00	7.00	14.00	412.00	120.00	2.00	0.00	18.49		
3.00	445.00	344.00	445.00	1.00	1.00	250.15	245.12	56.00	0.00	226.64
0.00	1.00	13.00	55.00	40.00	313.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	4.00	15.00	343.00	42.00	2.00	0.00	4.91		
2.00	368.00	243.00	248.00	1.00	1.00	128.17	112.63	44.00	0.00	107.71
0.00	1.00	2.00	55.00	150.00	17.00	3.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	23.00	21.00	300.00	28.00	3.00	0.00	4.56		
2.00	330.00	218.00	518.00	1.00	1.00	141.01	135.68	39.00	0.00	131.12
0.00	1.00	25.00	15.00	141.00	140.00	6.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	23.00	35.00	350.00	28.00	3.00	0.00	8.58		
2.00	381.00	240.00	414.00	3.00	1.00	72.12	69.39	45.00	0.00	60.81
0.00	1.00	8.00	25.00	150.00	120.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	14.00	45.00	300.00	250.00	1.00	0.00	79.32		
2.00	330.00	170.00	318.00	1.00	1.00	179.46	175.35	39.00	0.00	94.53
0.00	1.00	18.00	14.00	412.00	40.00	4.00	0.00	6.16		
3.00	445.00	344.00	445.00	1.00	1.00	250.15	245.12	56.00	0.00	238.96
0.00	1.00	25.00	55.00	200.00	229.00	7.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	3.00	15.00	343.00	700.00	1.00	0.00	81.92		
3.00	349.00	243.00	1054.00	1.00	1.00	447.56	393.29	52.00	0.00	311.37
0.00	1.00	8.00	35.00	200.00	313.00	2.00	1.00	0.00		
0.00	0.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	9.00	14.00	40.00	20.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	35.00	200.00	40.00	7.00	0.00	6.39		
2.00	279.00	90.00	165.00	7.00	1.00	81.17	79.54	30.00	0.00	73.16
0.00	1.00	10.00	14.00	200.00	760.00	17.00	1.00	0.00		
0.00	0.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	45.00	143.00	448.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	3.00	170.00	343.00	412.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	45.00	412.00	448.00	120.00	0.00	204.57		
4.00	445.00	282.00	625.00	120.00	7.00	520.78	510.32	73.00	0.00	305.74
0.00	1.00	3.00	50.00	250.00	140.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	6.00	14.00	515.00	208.00	9.00	0.00	41.14		
3.00	572.00	457.00	406.00	9.00	1.00	338.91	332.10	70.00	0.00	290.96
0.00	1.00	14.00	14.00	200.00	40.00	120.00	0.00	0.07		
1.00	222.00	132.00	648.00	2.00	1.00	145.03	142.71	20.00	0.00	141.56
[illegible]	[illegible]	35.00	35.00	925.00	15.00	2.00	0.00	12.99		

0.00	1.00	7.00	25.00	150.00	208.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	15.00	40.00	30.00	3.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	28.00	140.00	150.00	58.00	17.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	35.00	525.00	160.00	2.00	0.00	75.87		
3.00	572.00	415.00	216.00	2.00	1.00	236.11	231.37	69.00	0.00	155.50
0.00	1.00	13.00	45.00	250.00	40.00	1.00	0.00	10.20		
2.00	279.00	120.00	165.00	1.00	1.00	73.84	72.36	30.00	0.00	62.15
0.00	1.00	25.00	15.00	111.00	45.00	12.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	2.00	75.00	300.00	295.00	3.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	14.00	250.00	120.00	1.00	0.00	10.96		
2.00	286.00	182.00	210.00	1.00	1.00	72.10	70.65	31.00	0.00	59.69
0.00	1.00	7.00	14.00	200.00	80.00	4.00	0.00	5.76		
2.00	279.00	132.00	165.00	4.00	1.00	70.32	68.91	30.00	0.00	63.15
0.00	1.00	23.00	21.00	550.00	33.00	2.00	0.00	10.19		
3.00	597.00	468.00	229.00	1.00	1.00	227.30	218.71	71.00	0.00	208.51
0.00	1.00	7.00	35.00	200.00	313.00	2.00	1.00	0.00		
0.00	0.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	85.00	200.00	160.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	5.00	350.00	229.00	31.00	0.00	10.40		
3.00	305.00	300.00	507.00	3.00	1.00	11.37	10.10	50.00	0.00	-0.31
0.00	1.00	18.00	25.00	350.00	208.00	1.00	0.00	39.54		
2.00	330.00	240.00	318.00	1.00	1.00	145.36	142.44	39.00	0.00	102.90
0.00	1.00	12.00	45.00	103.00	100.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	3.00	412.00	140.00	2.00	0.00	4.75		
3.00	445.00	366.00	445.00	1.00	1.00	201.12	197.08	56.00	0.00	192.33
0.00	1.00	7.00	35.00	623.00	160.00	2.00	0.00	91.04		
4.00	448.00	515.00	257.00	2.00	3.00	-113.24	-110.97	84.00	0.00	-202.01
0.00	1.00	6.00	15.00	345.00	58.00	70.00	0.00	6.79		
2.00	368.00	243.00	248.00	35.00	1.00	126.17	112.63	44.00	0.00	105.84
0.00	1.00	2.00	35.00	150.00	23.00	14.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	14.00	25.00	350.00	313.00	17.00	0.00	70.32		
3.00	305.00	260.00	507.00	17.00	1.00	90.93	89.10	50.00	0.00	18.79
0.00	1.00	9.00	120.00	150.00	250.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	2.00	23.00	250.00	173.00	4.00	0.00	25.26		
2.00	299.00	134.00	267.00	4.00	1.00	136.64	133.36	33.00	0.00	108.10
0.00	1.00	13.00	14.00	40.00	40.00	17.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
[illegible]	[illegible]	[illegible]	24.00	150.00	50.00	1.00	1.00	0.00		

0.00	0.00	132.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	15.00	250.00	45.00	3.00	0.00	4.18		
2.00	279.00	180.00	165.00	3.00	1.00	55.58	49.35	30.00	0.00	45.18
0.00	1.00	4.00	25.00	343.00	575.00	1.00	0.00	108.73		
3.00	349.00	223.00	1054.00	1.00	1.00	514.03	451.70	52.00	0.00	342.97
0.00	1.00	2.00	95.00	200.00	27.00	25.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	3.00	15.00	459.00	140.00	70.00	0.00	22.18		
3.00	492.00	350.00	432.00	35.00	1.00	330.86	290.74	62.00	0.00	268.56
0.00	1.00	8.00	14.00	150.00	250.00	2.00	1.00	0.00		
0.00	0.00	82.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	14.00	200.00	208.00	4.00	0.00	14.98		
2.00	299.00	132.00	267.00	4.00	1.00	135.56	132.84	33.00	0.00	117.87
0.00	1.00	25.00	55.00	150.00	165.00	6.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	8.00	55.00	412.00	448.00	1.00	0.00	243.22		
4.00	389.00	262.00	623.00	1.00	8.00	363.34	356.04	73.00	0.00	117.82
0.00	1.00	8.00	45.00	300.00	40.00	3.00	0.00	12.69		
2.00	330.00	170.00	318.00	1.00	1.00	179.46	175.85	39.00	0.00	163.16
0.00	1.00	14.00	65.00	412.00	180.00	3.00	0.00	112.25		
3.00	445.00	242.00	445.00	3.00	1.00	437.78	428.98	56.00	0.00	316.73
0.00	1.00	14.00	25.00	350.00	313.00	1.00	0.00	70.32		
3.00	305.00	260.00	507.00	1.00	1.00	90.93	89.10	50.00	0.00	18.79
0.00	1.00	25.00	15.00	150.00	165.00	45.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	14.00	40.00	20.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	23.00	21.00	200.00	50.00	10.00	0.00	5.23		
2.00	279.00	118.00	165.00	10.00	1.00	76.20	73.31	30.00	0.00	68.09
0.00	1.00	2.00	35.00	150.00	17.00	6.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	14.00	200.00	180.00	3.00	0.00	12.96		
2.00	299.00	132.00	267.00	3.00	1.00	135.56	132.84	33.00	0.00	119.88
0.00	1.00	2.00	65.00	400.00	78.00	6.00	0.00	47.50		
3.00	445.00	200.00	445.00	2.00	1.00	503.71	491.61	56.00	0.00	444.12
0.00	1.00	23.00	35.00	750.00	15.00	3.00	0.00	10.44		
4.00	625.00	640.00	89.00	3.00	1.00	174.27	167.68	95.00	0.00	157.24
0.00	1.00	18.00	35.00	300.00	600.00	2.00	0.00	153.87		
3.00	349.00	190.00	1054.00	2.00	1.00	637.19	624.39	52.00	0.00	470.52
0.00	1.00	8.00	35.00	103.00	448.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	15.00	250.00	71.00	1.00	0.00	6.59		
2.00	279.00	180.00	165.00	1.00	1.00	55.58	49.35	30.00	0.00	42.76
0.00	1.00	13.00	14.00	200.00	250.00	3.00	1.00	0.00		
0.00	0.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	103.00	208.00	1.00	1.00	0.00		
[illegible]	[illegible]	[illegible]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.00	279.00	132.00	165.00	1.00	1.00	70.32	68.91	30.00	0.00	[illegible]
0.00	1.00	8.00	85.00	200.00	250.00	9.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	3.00	14.00	200.00	120.00	7.00	0.00	8.64		
2.00	286.00	132.00	210.00	7.00	1.00	95.36	93.44	31.00	0.00	84.80
0.00	1.00	7.00	14.00	728.00	120.00	120.00	0.00	33.17		
4.00	782.00	660.00	247.00	120.00	3.00	306.52	300.37	93.00	0.00	267.20
0.00	1.00	14.00	14.00	525.00	760.00	2.00	1.00	0.00		
0.00	450.00	457.00	865.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	8.00	45.00	150.00	140.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	4.00	25.00	208.00	575.00	2.00	0.00	0.11		
1.00	233.00	88.00	648.00	2.00	1.00	204.10	179.35	21.00	0.00	179.24
0.00	1.00	23.00	35.00	400.00	55.00	4.00	0.00	11.72		
3.00	445.00	290.00	445.00	1.00	1.00	366.28	352.43	56.00	0.00	340.70
0.00	1.00	7.00	14.00	150.00	80.00	11.00	0.00	0.05		
1.00	172.00	82.00	648.00	1.00	1.00	104.49	102.40	15.00	0.00	101.97
0.00	1.00	8.00	35.00	300.00	20.00	4.00	0.00	5.13		
2.00	330.00	190.00	518.00	1.00	1.00	163.51	160.02	39.00	0.00	154.90
0.00	1.00	13.00	65.00	300.00	20.00	4.00	0.00	8.45		
2.00	330.00	130.00	518.00	1.00	1.00	206.37	202.23	39.00	0.00	193.78
0.00	1.00	8.00	65.00	525.00	160.00	7.00	0.00	132.28		
3.00	572.00	355.00	216.00	7.00	1.00	306.50	300.35	69.00	0.00	168.07
0.00	1.00	4.00	5.00	45.00	58.00	3.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	14.00	65.00	103.00	40.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	250.00	208.00	1.00	0.00	19.00		
2.00	299.00	182.00	267.00	1.00	1.00	105.99	103.87	33.00	0.00	84.86
0.00	1.00	13.00	25.00	200.00	20.00	1.00	0.00	2.42		
2.00	279.00	110.00	83.00	1.00	1.00	38.49	37.72	29.00	0.00	35.30
0.00	1.00	1.00	110.00	88.00	63.00	3.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	10.00	14.00	103.00	180.00	190.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	25.00	200.00	250.00	3.00	1.00	0.00		
0.00	0.00	110.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	14.00	525.00	60.00	7.00	0.00	11.87		
3.00	572.00	457.00	216.00	7.00	1.00	180.51	176.68	69.00	0.00	164.82
0.00	1.00	15.00	14.00	728.00	448.00	3.00	0.00	123.82		
4.00	307.00	660.00	589.00	3.00	16.00	-1418.27	-1389.78	93.00	0.00	-1513.60
0.00	1.00	23.00	65.00	1100.00	15.00	2.00	0.00	28.06		
4.00	1161.00	930.00	165.00	1.00	1.00	575.81	554.04	110.00	0.00	525.98
0.00	1.00	13.00	25.00	200.00	140.00	2.00	0.00	16.94		
2.00	286.00	110.00	210.00	2.00	1.00	103.44	101.17	31.00	0.00	84.24
0.00	1.00	12.00	25.00	525.00	140.00	3.00	0.00	48.59		
[illegible]	572.00	435.00	216.00	3.00	1.00	210.41	205.98	69.00	0.00	157.60

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	3.00	25.00	572.00	12.00	3.00	0.00	3.90		
3.00	597.00	452.00	229.00	3.00	1.00	235.70	207.12	71.00	0.00	203.22
0.00	1.00	3.00	14.00	150.00	20.00	120.00	0.00	0.05		
1.00	172.00	82.00	648.00	3.00	1.00	104.49	102.40	15.00	0.00	100.71
0.00	1.00	23.00	45.00	63.00	50.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	12.00	45.00	103.00	250.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	4.00	53.00	180.00	140.00	4.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	412.00	448.00	17.00	0.00	69.02		
4.00	519.00	344.00	623.00	17.00	6.00	663.71	650.38	73.00	0.00	581.36
0.00	1.00	25.00	15.00	150.00	12.00	90.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	55.00	250.00	140.00	3.00	0.00	41.52		
2.00	286.00	100.00	210.00	3.00	1.00	106.56	104.22	31.00	0.00	62.70
0.00	1.00	7.00	45.00	40.00	140.00	9.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	14.00	200.00	313.00	1.00	1.00	0.00		
0.00	0.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	25.00	103.00	250.00	7.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	4.00	65.00	208.00	140.00	70.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	195.00	150.00	160.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	15.00	350.00	140.00	6.00	0.00	18.52		
2.00	387.00	280.00	216.00	6.00	1.00	114.27	101.47	46.00	0.00	82.95
0.00	1.00	18.00	45.00	250.00	208.00	3.00	0.00	53.05		
2.00	299.00	120.00	267.00	3.00	1.00	141.26	138.42	33.00	0.00	85.37
0.00	1.00	23.00	45.00	925.00	125.00	6.00	0.00	137.64		
4.00	960.00	795.00	216.00	6.00	3.00	451.90	434.81	103.00	0.00	297.17
0.00	1.00	2.00	45.00	500.00	125.00	3.00	0.00	71.57		
3.00	527.00	340.00	216.00	3.00	1.00	250.84	244.82	66.00	0.00	173.25
0.00	1.00	3.00	15.00	343.00	102.00	3.00	0.00	11.94		
2.00	368.00	243.00	248.00	3.00	1.00	128.17	112.63	44.00	0.00	100.69
0.00	1.00	2.00	23.00	150.00	17.00	6.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	350.00	180.00	28.00	0.00	23.41		
3.00	305.00	282.00	507.00	28.00	1.00	48.29	47.32	50.00	0.00	23.90
0.00	1.00	9.00	14.00	525.00	80.00	1.00	0.00	15.82		
3.00	572.00	457.00	216.00	1.00	1.00	180.51	176.68	69.00	0.00	160.86
0.00	1.00	14.00	14.00	40.00	448.00	17.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	8.00	25.00	40.00	80.00	120.00	1.00	0.00		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.00	0.00	0.00	0.00	0.00	0.00

0.00	1.00	10.00	45.00	623.00	760.00	1.00	1.00	0.00		
0.00	351.00	493.00	818.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	12.00	14.00	250.00	600.00	7.00	0.00	54.81		
3.00	349.00	182.00	1054.00	7.00	1.00	659.32	646.07	52.00	0.00	591.26
0.00	1.00	9.00	14.00	150.00	208.00	1.00	1.00	0.00		
0.00	0.00	82.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	5.00	5.00	130.00	58.00	1.00	1.00	0.00		
0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	15.00	150.00	165.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	14.00	250.00	600.00	17.00	1.00	0.00		
0.00	0.00	132.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	200.00	60.00	2.00	0.00	5.76		
2.00	279.00	132.00	165.00	2.00	1.00	70.32	68.91	30.00	0.00	63.15
0.00	1.00	9.00	14.00	200.00	140.00	28.00	0.00	0.07		
1.00	222.00	132.00	648.00	7.00	1.00	145.03	142.71	20.00	0.00	142.42
0.00	1.00	13.00	85.00	103.00	250.00	2.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	13.00	14.00	412.00	140.00	2.00	0.00	21.57		
3.00	445.00	344.00	445.00	1.00	1.00	250.15	245.12	56.00	0.00	223.56
0.00	1.00	7.00	14.00	623.00	80.00	5.00	0.00	18.86		
4.00	89.00	555.00	257.00	5.00	15.00	-544.06	-533.13	84.00	0.00	-551.99
0.00	1.00	25.00	5.00	150.00	45.00	20.00	0.00	0.02		
1.00	172.00	100.00	648.00	1.00	1.00	94.07	83.53	15.00	0.00	83.27
0.00	1.00	8.00	3.00	350.00	120.00	1.00	0.00	3.45		
2.00	387.00	304.00	216.00	1.00	1.00	87.59	85.63	46.00	0.00	82.18
0.00	1.00	8.00	25.00	412.00	60.00	3.00	0.00	16.05		
3.00	445.00	322.00	445.00	1.00	1.00	296.14	290.19	56.00	0.00	274.14
0.00	1.00	14.00	14.00	728.00	20.00	17.00	0.00	5.53		
4.00	761.00	660.00	79.00	17.00	1.00	79.98	78.37	93.00	0.00	72.85
0.00	1.00	7.00	65.00	40.00	600.00	28.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	11.00	25.00	250.00	60.00	9.00	0.00	9.33		
2.00	279.00	160.00	165.00	9.00	1.00	60.80	59.58	30.00	0.00	50.25
0.00	1.00	18.00	14.00	300.00	208.00	120.00	0.00	25.03		
2.00	530.00	232.00	318.00	120.00	1.00	123.55	121.06	39.00	0.00	98.04
0.00	1.00	25.00	15.00	150.00	12.00	5.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	18.00	14.00	250.00	600.00	1.00	0.00	54.81		
3.00	349.00	182.00	1054.00	1.00	1.00	659.32	646.07	52.00	0.00	591.26
0.00	1.00	8.00	45.00	525.00	208.00	1.00	0.00	124.22		
3.00	572.00	395.00	406.00	1.00	1.00	490.19	480.35	70.00	0.00	356.12
0.00	1.00	18.00	14.00	250.00	208.00	7.00	0.00	0.09		
1.00	273.00	182.00	648.00	2.00	1.00	189.26	185.46	24.00	0.00	185.19
0.00	1.00	15.00	65.00	150.00	448.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	448.00	1.00	1.00	0.00		

0.00	1.00	9.00	45.00	200.00	180.00	120.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	15.00	25.00	40.00	160.00	1.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	25.00	5.00	350.00	354.00	6.00	0.00	16.08		
3.00	305.00	300.00	507.00	6.00	1.00	11.37	10.10	50.00	0.00	-5.98
0.00	1.00	23.00	35.00	450.00	50.00	3.00	0.00	20.19		
3.00	483.00	340.00	445.00	1.00	1.00	378.38	364.07	61.00	0.00	343.88
0.00	1.00	13.00	14.00	728.00	80.00	3.00	0.00	22.11		
4.00	95.00	660.00	156.00	5.00	16.00	-475.44	-465.89	93.00	0.00	-488.00
0.00	1.00	13.00	14.00	442.00	80.00	3.00	0.00	12.33		
3.00	445.00	344.00	445.00	1.00	1.00	250.15	245.12	56.00	0.00	232.80
0.00	1.00	9.00	14.00	350.00	180.00	1.00	0.00	23.41		
3.00	305.00	282.00	507.00	1.00	1.00	48.29	47.32	50.00	0.00	23.90
0.00	1.00	13.00	25.00	300.00	100.00	2.00	0.00	19.01		
2.00	330.00	210.00	318.00	1.00	1.00	145.56	142.44	39.00	0.00	123.43
0.00	1.00	25.00	15.00	200.00	354.00	3.00	1.00	0.00		
0.00	0.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	23.00	65.00	400.00	22.00	5.00	0.00	13.32		
3.00	445.00	230.00	445.00	1.00	1.00	466.59	448.94	56.00	0.00	435.62
0.00	1.00	25.00	5.00	300.00	12.00	8.00	0.00	0.47		
2.00	330.00	250.00	318.00	2.00	1.00	109.37	97.13	39.00	0.00	94.66
0.00	1.00	4.00	5.00	208.00	58.00	5.00	0.00	1.40		
2.00	279.00	128.00	165.00	5.00	1.00	68.62	60.30	30.00	0.00	58.90
0.00	1.00	18.00	35.00	525.00	20.00	2.00	0.00	9.48		
3.00	372.00	415.00	216.00	1.00	1.00	236.11	231.37	69.00	0.00	221.88
0.00	1.00	2.00	65.00	350.00	33.00	3.00	0.00	17.09		
2.00	381.00	150.00	114.00	3.00	1.00	100.16	97.76	45.00	0.00	80.66
0.00	1.00	7.00	14.00	525.00	40.00	2.00	0.00	7.91		
3.00	572.00	457.00	216.00	1.00	1.00	180.31	176.68	69.00	0.00	168.77
0.00	1.00	14.00	55.00	150.00	100.00	4.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	28.00	5.00	233.00	195.00	1.00	0.00	5.85		
2.00	299.00	153.00	267.00	1.00	1.00	130.31	115.98	33.00	0.00	110.13
0.00	1.00	7.00	25.00	250.00	80.00	1.00	0.00	12.44		
2.00	279.00	160.00	165.00	1.00	1.00	60.80	59.58	30.00	0.00	47.14
0.00	1.00	18.00	25.00	412.00	180.00	11.00	0.00	48.15		
3.00	445.00	322.00	445.00	1.00	1.00	296.14	290.19	56.00	0.00	242.04
0.00	1.00	13.00	14.00	350.00	313.00	1.00	0.00	40.71		
3.00	305.00	282.00	507.00	1.00	1.00	48.29	47.32	50.00	0.00	6.61
0.00	1.00	8.00	14.00	525.00	20.00	2.00	0.00	3.96		
3.00	572.00	457.00	216.00	1.00	1.00	180.31	176.68	69.00	0.00	172.73
0.00	1.00	3.00	170.00	900.00	140.00	1.00	0.00	413.24		
4.00	411.00	490.00	210.00	1.00	17.00	-332.93	-292.56	102.00	0.00	-705.80
0.00	1.00	28.00	140.00	180.00	58.00	17.00	1.00	0.00		
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	1.00	7.00	3.00	525.00	313.00	2.00	0.00	13.55		

Section 3: APPENDIX V.

Selection of information from the order file (ORDER1 and ORDER2 arrays) after a simulated production run of 9 weeks using a nine week lead time.

Note. The identity of the various parameters is in accordance with the key shown in Appendix I Section 3.

0.00	7.00	7.00	2.00	0.00	2.00	2.00	123.55	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	7.00	7.00	120.00	0.00	4.00	120.00	95.89	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	4.00	2.00	6.00	0.00	2.00	3.00	203.41	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	3.00	14.00	5.00	1.00	3.00	1.00	335.32	1.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	8.00	15.00	120.00	0.00	3.00	59.00	180.31	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	1.00	23.00	5.00	1.00	3.00	0.00	420.82	1.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	7.00	2.00	15.00	0.00	2.00	5.00	189.74	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	5.00	7.00	1.00	0.00	2.00	1.00	52.05	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	6.00	25.00	1.00	0.00	3.00	1.00	138.23	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	1.00	23.00	6.00	1.00	3.00	1.00	420.82	1.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	8.00	25.00	2.00	0.00	2.00	2.00	139.73	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	7.00	7.00	3.00	0.00	2.00	1.00	123.55	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	5.00	18.00	1.00	0.00	3.00	1.00	347.34	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	6.00	8.00	1.00	0.00	4.00	1.00	446.96	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	7.00	13.00	2.00	0.00	3.00	1.00	180.31	0.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	1.00	23.00	10.00	1.00	1.00	1.00	257.16	1.00
STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST

STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	2.00	23.00	1.00	1.00	4.00	1.00	190.48	1.00
0.00	4.00	4.00	1.00	0.00	2.00	1.00	61.79	0.00
0.00	3.00	13.00	7.00	1.00	4.00	1.00	265.93	4.00
0.00	6.00	28.00	1.00	0.00	4.00	1.00	274.74	0.00
0.00	2.00	23.00	3.00	1.00	3.00	0.00	314.64	1.00
0.00	7.00	12.00	2.00	0.00	3.00	2.00	174.98	0.00
0.00	7.00	25.00	62.00	0.00	1.00	15.00	165.85	0.00
0.00	8.00	17.00	9.00	0.00	2.00	9.00	70.32	0.00
0.00	7.00	10.00	2.00	0.00	3.00	1.00	335.32	0.00
0.00	3.00	18.00	2.00	0.00	2.00	2.00	63.00	0.00
0.00	7.00	10.00	1.00	0.00	2.00	1.00	107.03	0.00
0.00	5.00	18.00	1.00	0.00	4.00	1.00	392.33	0.00
0.00	2.00	23.00	3.00	1.00	2.00	1.00	183.80	1.00
0.00	7.00	3.00	4.00	0.00	3.00	4.00	148.54	0.00
0.00	6.00	2.00	16.00	0.00	3.00	4.00	476.93	0.00
0.00	3.00	18.00	2.00	0.00	3.00	2.00	659.32	0.00

STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	7.00	18.00	17.00	0.00	3.00	17.00	180.31	0.00
0.00	5.00	8.00	1.00	0.00	3.00	1.00	210.21	0.00
0.00	8.00	25.00	2.00	0.00	3.00	1.00	260.66	0.00
0.00	5.00	18.00	2.00	0.00	3.00	2.00	180.31	0.00
0.00	3.00	7.00	1.00	0.00	4.00	1.00	107.50	0.00
0.00	6.00	12.00	9.00	1.00	3.00	1.00	148.93	4.00
0.00	8.00	28.00	3.00	0.00	4.00	3.00	567.09	0.00
0.00	8.00	4.00	2.00	0.00	2.00	1.00	128.17	0.00
1.00	3.00	23.00	1.00	1.00	4.00	0.00	898.15	1.00
0.00	3.00	14.00	5.00	0.00	2.00	5.00	52.05	0.00
0.00	6.00	11.00	3.00	0.00	2.00	3.00	72.10	0.00
0.00	8.00	28.00	3.00	0.00	4.00	3.00	130.97	0.00
0.00	8.00	25.00	1.00	0.00	2.00	1.00	74.54	0.00
1.00	2.00	8.00	1.00	1.00	4.00	0.00	1206.89	1.00
0.00	1.00	11.00	120.00	0.00	3.00	60.00	296.14	0.00
0.00	1.00	13.00	4.00	0.00	4.00	4.00	306.52	0.00

STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	1.00	23.00	2.00	1.00	2.00	1.00	79.70	1.00
0.00	5.00	7.00	120.00	0.00	2.00	120.00	225.22	0.00
0.00	4.00	7.00	1.00	0.00	4.00	1.00	219.79	0.00
0.00	5.00	7.00	4.00	0.00	4.00	4.00	246.89	0.00
0.00	2.00	25.00	31.00	0.00	1.00	10.00	202.36	0.00
0.00	6.00	8.00	1.00	0.00	2.00	1.00	76.52	0.00
0.00	5.00	8.00	11.00	0.00	3.00	11.00	250.15	0.00
0.00	5.00	23.00	2.00	1.00	3.00	1.00	366.28	2.00
0.00	6.00	2.00	10.00	0.00	3.00	2.00	447.61	0.00
0.00	5.00	23.00	2.00	1.00	4.00	1.00	569.52	1.00
0.00	2.00	8.00	2.00	1.00	3.00	1.00	180.31	2.00
0.00	3.00	8.00	4.00	0.00	2.00	4.00	26.18	0.00
0.00	2.00	23.00	3.00	1.00	3.00	0.00	420.82	1.00
0.00	5.00	13.00	2.00	0.00	3.00	2.00	659.32	0.00
0.00	8.00	8.00	28.00	0.00	3.00	24.00	690.72	0.00
0.00	3.00	14.00	2.00	1.00	3.00	1.00	90.93	1.00

STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	7.00	10.00	7.00	0.00	2.00	7.00	52.05	0.00
0.00	7.00	4.00	22.00	1.00	3.00	1.00	436.09	1.00
0.00	2.00	8.00	2.00	1.00	2.00	1.00	123.55	1.00
0.00	4.00	18.00	120.00	0.00	4.00	120.00	446.96	0.00
0.00	2.00	4.00	2.00	0.00	2.00	1.00	177.04	0.00
0.00	4.00	13.00	2.00	0.00	4.00	2.00	306.52	0.00
0.00	2.00	14.00	1.00	0.00	3.00	1.00	296.14	0.00
0.00	6.00	8.00	1.00	0.00	3.00	1.00	48.29	0.00
0.00	8.00	27.00	31.00	0.00	2.00	31.00	114.27	0.00
0.00	1.00	2.00	1.00	1.00	3.00	1.00	229.18	1.00
0.00	2.00	8.00	1.00	0.00	2.00	1.00	70.32	0.00
0.00	5.00	18.00	1.00	0.00	4.00	1.00	191.79	0.00
0.00	5.00	4.00	12.00	0.00	3.00	12.00	199.18	0.00
0.00	3.00	14.00	120.00	0.00	3.00	30.00	250.15	0.00
0.00	3.00	9.00	1.00	0.00	2.00	1.00	106.36	0.00
0.00	4.00	25.00	62.00	0.00	3.00	31.00	113.22	0.00

STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	3.00	10.00	1.00	1.00	2.00	1.00	295.62	1.00
0.00	8.00	18.00	11.00	0.00	2.00	7.00	81.17	0.00
0.00	8.00	25.00	62.00	0.00	3.00	31.00	260.66	0.00
0.00	3.00	10.00	1.00	1.00	4.00	1.00	539.48	1.00
1.00	4.00	18.00	1.00	1.00	4.00	0.00	834.28	1.00
0.00	8.00	14.00	2.00	0.00	2.00	2.00	81.17	0.00
0.00	4.00	8.00	7.00	1.00	2.00	1.00	70.32	2.00
0.00	3.00	14.00	1.00	1.00	2.00	1.00	107.03	1.00
0.00	5.00	23.00	3.00	1.00	3.00	1.00	366.28	1.00
0.00	1.00	11.00	1.00	0.00	2.00	1.00	153.13	0.00
0.00	8.00	7.00	120.00	0.00	3.00	105.00	174.98	1.00
0.00	8.00	23.00	1.00	0.00	4.00	1.00	571.38	0.00
0.00	5.00	23.00	4.00	1.00	4.00	1.00	172.23	2.00
0.00	2.00	7.00	1.00	1.00	2.00	1.00	105.99	1.00
0.00	8.00	14.00	1.00	0.00	2.00	1.00	70.32	0.00
0.00	4.00	18.00	1.00	1.00	2.00	1.00	135.56	1.00

0.00 2.00 13.00 4.00 0.00 3.00 2.00 180.31 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 1.00 2.00 8.00 1.00 3.00 1.00 415.73 2.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 5.00 18.00 28.00 0.00 3.00 14.00 347.34 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 4.00 25.00 4.00 0.00 2.00 4.00 95.70 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 3.00 13.00 3.00 1.00 3.00 1.00 180.31 2.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 3.00 25.00 45.00 0.00 1.00 15.00 155.55 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 4.00 2.00 3.00 0.00 3.00 3.00 476.93 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 3.00 13.00 1.00 0.00 3.00 1.00 443.80 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 4.00 25.00 6.00 0.00 3.00 2.00 138.23 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 8.00 25.00 45.00 0.00 1.00 3.00 188.69 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 2.00 25.00 62.00 0.00 2.00 62.00 132.00 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 7.00 8.00 2.00 0.00 2.00 2.00 83.25 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 5.00 7.00 7.00 0.00 4.00 7.00 246.89 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 3.00 7.00 2.00 0.00 2.00 2.00 70.32 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 5.00 14.00 28.00 0.00 3.00 28.00 759.87 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

0.00 1.00 14.00 28.00 0.00 2.00 28.00 107.03 0.00
STANDBY PRIORITY ALLOY NO OFF AVAILABLE SECTION NO OFF WT MOLTEN ROUGH CAST

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   0.00     2.00     7.00    2.00      0.00      3.00     1.00   180.31      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     4.00    14.00    2.00      0.00      2.00     2.00    81.17      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     2.00     7.00    4.00      1.00      3.00     1.00   338.91      3.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   1.00     2.00    10.00    2.00      1.00      4.00     0.00  1035.24      2.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     5.00    13.00   48.00      0.00      4.00    48.00   659.53      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     2.00    25.00    6.00      0.00      3.00     6.00   698.47      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     5.00    23.00    3.00      1.00      3.00     1.00   378.38      1.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     4.00    23.00    2.00      1.00      4.00     1.00   438.48      2.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     2.00     7.00    3.00      0.00      2.00     1.00   123.55      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     6.00    25.00    3.00      0.00      2.00     3.00    76.89      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     4.00    13.00    2.00      0.00      2.00     2.00    95.36      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     2.00    23.00    2.00      1.00      2.00     1.00    59.15      2.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     4.00    18.00    1.00      1.00      3.00     1.00   180.31      1.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     8.00    25.00    1.00      0.00      2.00     1.00    56.42      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     3.00    18.00    2.00      0.00      3.00     1.00   371.98      0.00
STANDBY  PRIORITY  ALLOY  NO OFF  AVAILABLE  SECTION  NO OFF  WT MOLTEN  ROUGH CAST

   0.00     2.00     7.00    9.00      0.00      1.00     1.00   104.49      0.00
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STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	8.00	8.00	2.00	0.00	3.00	1.00	335.32	0.00
0.00	3.00	14.00	2.00	1.00	2.00	1.00	145.59	1.00
0.00	7.00	7.00	9.00	1.00	4.00	1.00	567.63	3.00
0.00	4.00	3.00	70.00	0.00	2.00	70.00	128.17	0.00
0.00	2.00	9.00	1.00	0.00	2.00	1.00	52.05	0.00
0.00	2.00	7.00	1.00	0.00	2.00	1.00	193.81	0.00
0.00	1.00	4.00	4.00	1.00	2.00	1.00	105.23	1.00
0.00	6.00	23.00	2.00	1.00	3.00	1.00	378.38	2.00
0.00	3.00	13.00	1.00	1.00	2.00	1.00	225.22	1.00
0.00	4.00	18.00	3.00	1.00	4.00	1.00	243.63	2.00
0.00	6.00	23.00	4.00	0.00	4.00	2.00	302.24	2.00
0.00	6.00	15.00	2.00	0.00	3.00	1.00	250.15	0.00
0.00	8.00	25.00	1.00	0.00	4.00	1.00	855.54	0.00
1.00	3.00	12.00	1.00	1.00	4.00	0.00	866.71	1.00
0.00	6.00	23.00	1.00	1.00	4.00	1.00	485.21	1.00
0.00	3.00	4.00	2.00	0.00	3.00	2.00	116.56	0.00

STANDBY	PRIORITY	ALLOY	NO OFF	AVAILABLE	SECTION	NO OFF	WT MOLTEN	ROUGH CAST
0.00	4.00	14.00	1.00	1.00	3.00	1.00	335.32	1.00
0.00	3.00	23.00	3.00	1.00	2.00	1.00	141.01	1.00
0.00	8.00	9.00	11.00	0.00	4.00	10.00	527.56	1.00
0.00	4.00	7.00	17.00	1.00	1.00	1.00	104.49	1.00
0.00	1.00	9.00	1.00	0.00	2.00	1.00	99.84	0.00
0.00	1.00	8.00	120.00	0.00	1.00	40.00	104.49	0.00
0.00	3.00	14.00	3.00	1.00	2.00	1.00	103.24	3.00
0.00	5.00	14.00	4.00	1.00	3.00	1.00	148.93	2.00
0.00	8.00	18.00	1.00	0.00	2.00	1.00	52.05	0.00
0.00	6.00	7.00	3.00	1.00	2.00	1.00	163.31	2.00
0.00	7.00	23.00	3.00	1.00	3.00	1.00	420.82	1.00
0.00	2.00	13.00	2.00	1.00	2.00	1.00	92.13	2.00
0.00	1.00	14.00	1.00	0.00	4.00	1.00	442.42	0.00
0.00	7.00	23.00	32.00	1.00	3.00	1.00	168.89	15.00
0.00	8.00	7.00	1.00	1.00	4.00	1.00	740.48	1.00
0.00	7.00	8.00	1.00	1.00	4.00	1.00	191.79	1.00

Section 4: APPENDIX V.

Details of the process times used in the simulation model.

Process time data used in simulation model.

Unfortunately, circumstances did not allow the author to develop an independent process time data base for use by the simulation model. Although it is recognised that some activity in this direction would be necessary for the findings of the model to be totally satisfactory, this was not a feasible proposition because of the limited time scale available for the project and the considerable cost which would have been involved. Instead, reliance had to be placed on alternative sources of information, however, one of these, it is felt, can be employed with complete confidence in its authenticity.

Shipley, in a comprehensive study to evaluate the economic consequences of reorganising the melting plant at Spunalloys, made a detailed survey of melting procedure which included analysis of process times. He accomplished this by careful sifting of company information, supplemented by a proportion of carefully planned personal observations using a stop-watch etc. But Shipley's interests did not extend to the casting machines or the machine shop, hence, for these production centres, information supplied by the company was the sole source of process time data. In spite of the obvious dubious nature of certain aspects of such information (particularly that supplied by operatives), it was decided to proceed with the investigation because of the soundness of the melting shop figures.

With reference to melting times, the seven furnaces employed in the model can be divided into two groups, those using oil and gas to provide the necessary heat and electric furnaces. Although various factors such as amount of preheat, operator ability and performance, condition of crucible or furnace lining, physical properties of the metal charge, tapping temperature required and miscellaneous shop floor delays, affect melting time, it was felt by Shipley, that over an extended time period, delays such as these can be averaged out.

Consequently, with respect to the gas and oil group of furnaces, he found that a linear regression analysis, based on numerous observed data, and with charge weight as the independent variable, gave acceptable results. In contrast to this group, the coreless induction furnaces rely principally on the degree of electromagnetic couple achieved between coil and charge for degree of heat input and, therefore, extent of melting time. Further, because less than maximum capacity charges only engage a proportion of the induction coil, small charges do not melt significantly faster than large ones. Certainly, charge make-up (dense ingots as distinct from light swarf) is more of a deciding factor, with respect to duration of melting, than is charge weight.

In both cases, Shipley considered that charge variation (make-up and total weight), together with all other possible delay variables mentioned above, would average out, allowing general melt times based on a satisfactory quantity of observed data, to be used. However, with respect to the electric furnaces, distinction between the various alloy types was found to be a significant factor.

Shipley also compiled metal loss figures for the various alloys, taking into account both melting losses and metal spillage- averages were again calculated from observed and collected data. No distinction was made between electric furnaces and oil and gas fired ones, although it is felt, that a minor weakness probably exists here.

Casting and solidification times, on the other hand, as mentioned previously, had to be supplied by the company. Variation here, was based on casting section and size of casting (outside diameter dimension for Bushmaster since a standard length is involved, and weight for the others). Average die setting and cleaning times, according to the company, are also included in these figures.

Likewise, process times for the machine shop were also supplied by Spunalloys although these were less complete than the casting and solidification times. This meant calling upon the experience of operatives to fill in the various gaps- less than satisfactory approximations to say the least. Cutting rates depend on type of machine, hence, machining duration is compiled by summing proof machining time, based on type of machine and its size, plus an allowance for cutting off (increased if rough casting contains more than one finished casting), and an allowance for cleaning down and setting-up (again supposedly averaged).

All these values, as used by the model, are shown in the tables below.

Process times - furnaces

Furnace number	Furnace description	Alloy group	Time to melt and superheat- mins.
1 & 2	180 kg coreless elect. induction furnaces.	1	74.0
		2	71.4
		3	67.7
		4	90.0
		5	90.0
		6	90.0
		7	84.0
3 & 4	500 kg coreless elect. induction furnaces.	1	38.5
		2	38.5
		3	33.0
		4	37.0
		5	31.0
		6	31.0
		7	38.5
5	750 kg coreless elect. induction furnace.	1	57.0
		2	57.0
		3	50.0
		4	55.0
		5	47.5
		6	47.5
		7	57.0
6 & 7	680 kg gas fired and 365 kg oil fired furnaces.	Equation derived from regression analysis $y = (0.00194x + 0.885)60$	

Process times - casting sections

Section description.	Distinguishing parameter.	Partitions.	Setting time- mins.	Casting time- mins.
Bushmaster	Rough casting	93 - 108	12.0	5.0
	outside diameter	109 - 130	12.0	6.0
	- mm.	131 - 150	12.0	8.0
		151 - 160	12.0	9.0
		161 - 200	18.0	12.0
		201 - 250	18.0	14.0
		251 - 290	18.0	16.0
		291 - 320	18.0	18.0
Non stand-	Rough casting	0 - 65	12.0	8.4
ard	weight- kg.	66 - 150	30.0	12.5
Heavy	Rough casting	0 - 275 kg.		
horizontal	weight - kg. and	0 - 508 mm.	50.0	21.5
	rough casting	509 - 760 mm.	50.0	36.5
	outside diameter	761 - mm.	50.0	51.0
	- mm.	276 - 350 kg.		
		0 - 508 mm.	50.0	30.0
		509 - 760 mm.	50.0	45.0
		761 - mm.	50.0	60.0
		351 - 450 kg.		
		0 - 508 mm.	60.0	50.0
		509 - 760 mm.	60.0	65.5
		761 - mm.	60.0	80.0
Heavy	Rough casting	0 - 275	40.0	40.0
vertical	weight- kg.	276 - 450	40.0	50.0
		451 - 700	60.0	67.0
		701 - 1200	90.0	74.0
		1201 - 1800	90.0	80.0

Process times - cutting machines.

Machine number	Machine description	Alloy group	Machining			Parting	
			Rough casting O.D.- mm.	Setting time - mins.	Machining time for standard 620 mm length - mins.	Wall thickness - mm.	Time - mins.
1 - 8	Small horizontal lathes	1 - 6	85 - 105	30.0	25.0	0 - 7.0	4.0
			107 - 122	35.0	27.0	7.5 - 12.0	5.0
			123 - 142	40.0	29.0	12.5 - 15.0	6.0
			143 - 152	45.0	31.0	15.5 - 20.0	7.0
			153 - 193	50.0	33.0	20.5 - 30.0	8.0
			194 - 243	55.0	35.0	30.5 -	10.0
			244 - 283	60.0	37.0		
			284 - 303	60.0	40.0		
		7	85 - 106	30.0	38.0	0 - 7.0	6.0
			107 - 122	35.0	41.0	7.5 - 12.0	8.0
			123 - 142	40.0	44.0	12.5 - 15.0	9.0
			143 - 152	45.0	47.0	15.5 - 20.0	11.0
			153 - 193	50.0	50.0	20.5 - 30.0	12.0
			194 - 243	55.0	53.0	30.5 -	15.0
			244 - 283	60.0	56.0		
			284 - 303	60.0	60.0		
9 - 12	Large horizontal lathes			60.0	Machining time = Cast wt. - Proof wt. x 0.6 Parting time = 0.5 x machining time		
13 - 15	Vertical borers			60.0	Machining time = Cast wt. - Proof wt. x 0.6 Parting time = 0.5 x machining time		

Section 5: APPENDIX V.

Results from a 3 month simulation run using a nine week lead time and showing output level and stock level details.

```
#####   #####   #####    #          0000000000000000000000000000000000000000000
    #   #   #   #        #          0000                          000000000000
   #    #   #   #        #          0000                          000000000000
  #     #   #   #####    #####      0000          MOP             000000000000
 #      #   #       #    #   #      0000                          000000000000
 #      #   #       #    #   #      0000                          000000000000
 #      #####   #####    #####      0000000000000000000000000000000000000000000
```

```
#LISTING OF :EPP7056.SPUNREC(4/)    PRODUCED ON 20MAR78 AT 14.11.45

#G8.62M AT ASTON    IN ':EPP7056,MOPBE' ON 20MAR78 AT 16.01.20 USING  U14

DOCUMENT    SPUNREC


MONTH    1      WEEK    1
 CASTWEIGHT  NO CAST  MACHINED WEIGHT

  38179.71      192         3422.68
 INGOT WT  SCRAP WT  SWARF WT

   500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

 -2319.25      0.00     76.53
 INGOT WT  SCRAP WT  SWARF WT

  2315.38      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

 -2951.90      0.00   5184.78
 INGOT WT  SCRAP WT  SWARF WT

   500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

   500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

  5871.64      0.00    749.65
 INGOT WT  SCRAP WT  SWARF WT

  4000.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

  1500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

  1500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

     0.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

     0.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

  5000.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

     0.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

     0.00      0.00      0.00
```

```
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 4000.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 1500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  600.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 3129.23      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 1000.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 5000.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 1500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  500.00      0.00      0.00
MONTH     1     WEEK     2
 CASTWEIGHT  NO CAST  MACHINED WEIGHT

 42605.21       193          6851.17
 INGOT WT  SCRAP WT  SWARF WT

   500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

 -2055.13      0.00   1047.80
 INGOT WT  SCRAP WT  SWARF WT

  2267.94      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

 -6238.28      0.00   9710.98
 INGOT WT  SCRAP WT  SWARF WT

   500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

   500.00      0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT
```

3827.57 0.00 2864.96
INGOT WT SCRAP WT SWARF WT

-2824.25 0.00 247.80
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

429.53 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

3418.66 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

4000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

600.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

3129.23 0.00 501.55
INGOT WT SCRAP WT SWARF WT

1000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

5000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

cx1

500.00	0.00	0.00
MONTH 1	WEEK 3	
CASTWEIGHT	NO CAST	MACHINED WEIGHT
40919.51	178	7164.73
INGOT WT	SCRAP WT	SWARF WT
500.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
-55.13	0.00	2664.73
INGOT WT	SCRAP WT	SWARF WT
2267.94	0.00	188.25
INGOT WT	SCRAP WT	SWARF WT
-6238.28	0.00	10828.12
INGOT WT	SCRAP WT	SWARF WT
500.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
500.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
3827.57	0.00	2997.91
INGOT WT	SCRAP WT	SWARF WT
-5969.50	0.00	497.94
INGOT WT	SCRAP WT	SWARF WT
597.25	0.00	1110.01
INGOT WT	SCRAP WT	SWARF WT
-192.01	0.00	676.12
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	70.76
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
2365.79	0.00	863.01
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	47.35
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
3500.04	0.00	101.04
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

600.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

2499.34 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

5000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
MONTH 1 WEEK 4
CASTWEIGHT NO CAST MACHINED WEIGHT

43468.98 189 8815.25
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1944.87 0.00 3281.75
INGOT WT SCRAP WT SWARF WT

2267.94 0.00 188.25
INGOT WT SCRAP WT SWARF WT

-4489.55 0.00 11389.94
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

3827.57 0.00 3052.50
INGOT WT SCRAP WT SWARF WT

-4356.50 0.00 810.74
INGOT WT SCRAP WT SWARF WT

597.25 0.00 978.13
INGOT WT SCRAP WT SWARF WT

-192.01 0.00 676.12
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 130.01

INGOT WT SCRAP WT SWARF WT

2895.03 0.00 551.84
INGOT WT SCRAP WT SWARF WT

0.00 0.00 119.88
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

915.13 0.00 797.89
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

600.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

3003.17 0.00 54.06
INGOT WT SCRAP WT SWARF WT

1000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

5000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
WEIGHT OF WORK IN PROGRESS

42926.79
MONTH 2 WEEK 1
CASTWEIGHT NO CAST MACHINED WEIGHT

49447.60 203 6990.47
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1944.87 259.20 2156.21
INGOT WT SCRAP WT SWARF WT

1673.05	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
-5969.31	0.00	14882.19
INGOT WT	SCRAP WT	SWARF WT
500.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
800.45	0.00	148.91
INGOT WT	SCRAP WT	SWARF WT
2594.50	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
-542.74	0.00	441.61
INGOT WT	SCRAP WT	SWARF WT
597.25	0.00	809.10
INGOT WT	SCRAP WT	SWARF WT
307.99	0.00	623.71
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	141.62
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	139.01
INGOT WT	SCRAP WT	SWARF WT
5692.83	0.00	306.57
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	175.81
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	60.44
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
1635.16	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
1500.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
600.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
1940.36	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
1000.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT

```
INGOT WT   SCRAP WT   SWARF WT

  500.00       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT

  500.00       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT

 1500.00       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT

  500.00       0.00       0.00
MONTH    2      WEEK     2
CASTWEIGHT   NO CAST   MACHINED WEIGHT

 49465.62        199            4589.48
INGOT WT   SCRAP WT   SWARF WT

  817.50     182.50       0.00
INGOT WT   SCRAP WT   SWARF WT

 1944.87     186.48     396.10
INGOT WT   SCRAP WT   SWARF WT

 1508.84       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT

-8960.77     148.14   18744.51
INGOT WT   SCRAP WT   SWARF WT

  500.00       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT

  800.45       0.00     148.91
INGOT WT   SCRAP WT   SWARF WT

-1895.49       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT

 2394.62       0.00     207.51
INGOT WT   SCRAP WT   SWARF WT

  597.25       0.00     678.74
INGOT WT   SCRAP WT   SWARF WT

  807.99       0.00     571.29
INGOT WT   SCRAP WT   SWARF WT

    0.00       0.00     141.62
INGOT WT   SCRAP WT   SWARF WT

    0.00       0.00     139.01
INGOT WT   SCRAP WT   SWARF WT

 3492.38       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT

    0.00       0.00     675.52
INGOT WT   SCRAP WT   SWARF WT

    0.00       0.00      60.44
INGOT WT   SCRAP WT   SWARF WT

    0.00       0.00       0.00
INGOT WT   SCRAP WT   SWARF WT
```

```
   0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

1886.16      0.00    468.32
INGOT WT  SCRAP WT  SWARF WT

   0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

   0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

1500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 600.00*145417542738854876915866043418645858 7646.48        0.00
INGOT WT  SCRAP WT  SWARF WT

1151.23      0.00     57.60
INGOT WT  SCRAP WT  SWARF WT

1000.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

4867.59      0.00     84.04
INGOT WT  SCRAP WT  SWARF WT

 500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

1500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 500.00      0.00      0.00
MONTH     2      WEEK     3
 CASTWEIGHT  NO CAST  MACHINED WEIGHT

 46497.77     195          5002.36
 INGOT WT  SCRAP WT  SWARF WT

  817.50   182.50      0.00
 INGOT WT  SCRAP WT  SWARF WT

 1301.79     0.00    381.02
 INGOT WT  SCRAP WT  SWARF WT

 1651.82     0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

*10896.23  148.14  23875.26
 INGOT WT  SCRAP WT  SWARF WT

  500.00     0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

  800.45     0.00    148.91
 INGOT WT  SCRAP WT  SWARF WT

 3116.96     0.00      0.00
 INGOT WT  SCRAP WT  SWARF WT

 2069.15     0.00    148.99
```

```
INGOT WT  SCRAP WT  SWARF WT

  613.58      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  807.99      0.00    571.29
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00    141.62
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00    278.02
INGOT WT  SCRAP WT  SWARF WT

 3014.16      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00    214.06
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 1886.16      0.00    938.84
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

    0.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 1500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  600.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

-5654.40      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 1000.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 4501.28      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

 1500.00      0.00      0.00
INGOT WT  SCRAP WT  SWARF WT

  500.00      0.00      0.00
MONTH     2     WEEK     4
 CASTWEIGHT  NO CAST  MACHINED WEIGHT
```

40085.51	183	6148.76
INGOT WT	SCRAP WT	SWARF WT
1000.00	250.00	0.00
INGOT WT	SCRAP WT	SWARF WT
1637.21	0.00	1475.21
INGOT WT	SCRAP WT	SWARF WT
2076.42	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
-12454.57	317.69	27998.05
INGOT WT	SCRAP WT	SWARF WT
500.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
800.45	0.00	148.91
INGOT WT	SCRAP WT	SWARF WT
3550.89	0.00	145.88
INGOT WT	SCRAP WT	SWARF WT
1826.21	0.00	148.99
INGOT WT	SCRAP WT	SWARF WT
654.69	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
807.99	0.00	571.29
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	141.62
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	258.18
INGOT WT	SCRAP WT	SWARF WT
4164.11	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	15.59
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
1886.16	0.00	938.84
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
0.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT
1500.00	0.00	0.00
INGOT WT	SCRAP WT	SWARF WT

600.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

-6525.33 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

2410.38 0.00 282.23
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
WEIGHT OF WORK IN PROGRESS

112987.01
MONTH 3 WEEK 1
CASTWEIGHT NO CAST MACHINED WEIGHT

34520.41 160 5033.64
INGOT WT SCRAP WT SWARF WT

910.00 285.00 0.00
INGOT WT SCRAP WT SWARF WT

1637.21 0.00 1475.21
INGOT WT SCRAP WT SWARF WT

1458.13 0.00 0.00
INGOT WT SCRAP WT SWARF WT

-14436.52 317.69 32742.57
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

800.45 0.00 148.91
INGOT WT SCRAP WT SWARF WT

4732.43 0.00 107.05
INGOT WT SCRAP WT SWARF WT

1756.19 0.00 374.90
INGOT WT SCRAP WT SWARF WT

467.75 0.00 0.00
INGOT WT SCRAP WT SWARF WT

807.99 0.00 571.29
INGOT WT SCRAP WT SWARF WT

0.00 0.00 141.62
INGOT WT SCRAP WT SWARF WT

0.00 0.00 258.18
INGOT WT SCRAP WT SWARF WT

4249.89 0.00 282.65
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1781.50 0.00 398.77
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

600.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

-6305.68 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1236.02 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00
MONTH 3 WEEK 2
CASTWEIGHT NO CAST MACHINED WEIGHT

32940.81 152 5681.55
INGOT WT SCRAP WT SWARF WT

-1927.50 250.00 0.00
INGOT WT SCRAP WT SWARF WT

1637.21 0.00 1461.35
INGOT WT SCRAP WT SWARF WT

2039.84 0.00 0.00
INGOT WT SCRAP WT SWARF WT

-15765.02 317.69 37285.09

INGOT WT SCRAP WT SWARF WT

c1

500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

800.45 0.00 148.91
INGOT WT SCRAP WT SWARF WT

3884.79 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1887.05 0.00 0.00
INGOT WT SCRAP WT SWARF WT

566.30 0.00 0.00
INGOT WT SCRAP WT SWARF WT

807.99 0.00 571.29
INGOT WT SCRAP WT SWARF WT

0.00 0.00 141.62
INGOT WT SCRAP WT SWARF WT

0.00 0.00 258.18
INGOT WT SCRAP WT SWARF WT

4730.85 0.00 282.65
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 66.03
INGOT WT SCRAP WT SWARF WT

1781.50 35.39 70.14
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

0.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

1500.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

600.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

-4607.94 0.00 577.82
INGOT WT SCRAP WT SWARF WT

1000.00 0.00 0.00
INGOT WT SCRAP WT SWARF WT

31.65 0.00 40.03
INGOT WT SCRAP WT SWARF WT

500.00 0.00 0.00

```
 INGOT WT   SCRAP WT   SWARF WT

   500.00       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

  1500.00       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

   500.00       0.00       0.00
MONTH    3     WEEK     3
 CASTWEIGHT  NO CAST   MACHINED WEIGHT

 33750.43       153           5414.87
 INGOT WT   SCRAP WT   SWARF WT

 -5377.50     250.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

  1637.21       0.00    1410.89
 INGOT WT   SCRAP WT   SWARF WT

  1735.84       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

-16683.26     317.69   40986.11
 INGOT WT   SCRAP WT   SWARF WT

   500.00       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

   800.45       0.00     148.91
 INGOT WT   SCRAP WT   SWARF WT

  2734.38       0.00      86.30
 INGOT WT   SCRAP WT   SWARF WT

  1674.47       0.00     305.82
 INGOT WT   SCRAP WT   SWARF WT

   769.12       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

   807.99       0.00     474.19
 INGOT WT   SCRAP WT   SWARF WT

     0.00       0.00     141.62
 INGOT WT   SCRAP WT   SWARF WT

     0.00       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

  4952.61       0.00     282.65
 INGOT WT   SCRAP WT   SWARF WT

     0.00       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

     0.00       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

     0.00       0.00       0.00
 INGOT WT   SCRAP WT   SWARF WT

     0.00       0.00      66.03
 INGOT WT   SCRAP WT   SWARF WT
```

2607.33	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
0.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
0.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
1500.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
600.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
-3425.69	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
1000.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
-1138.37	0.00	101.96	
INGOT WT	SCRAP WT	SWARF WT	
500.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
500.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
1500.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
500.00	0.00	0.00	
MONTH 3	WEEK 4		
CASTWEIGHT	NO CAST	MACHINED WEIGHT	
34873.93	172		4154.13
INGOT WT	SCRAP WT	SWARF WT	
-7362.50	250.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
1637.21	0.00	1398.38	
INGOT WT	SCRAP WT	SWARF WT	
1735.84	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
-17867.55	317.69	45174.62	
INGOT WT	SCRAP WT	SWARF WT	
500.00	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
800.45	0.00	148.91	
INGOT WT	SCRAP WT	SWARF WT	
4219.57	0.00	0.00	
INGOT WT	SCRAP WT	SWARF WT	
2586.59	0.00	374.90	
INGOT WT	SCRAP WT	SWARF WT	
971.95	0.00	62.05	
INGOT WT	SCRAP WT	SWARF WT	

```
   807.99       0.00      474.19
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00      141.62
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

  4771.05       0.00      282.65
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00      119.68
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00       66.03
INGOT WT    SCRAP WT    SWARF WT

  2320.35       0.00      936.64
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

     0.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

  1500.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

   600.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

 -2227.97       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

  1000.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

 -3011.76       0.00      131.90
INGOT WT    SCRAP WT    SWARF WT

   500.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

   500.00       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

  1321.70       0.00        0.00
INGOT WT    SCRAP WT    SWARF WT

   500.00       0.00        0.00
WEIGHT OF WORK IN PROGRESS

    136151.83
MONTH     4      WEEK     1      DAY     1
MONTH     4      WEEK     1      DAY     2
MONTH     4      WEEK     1      DAY     3
MONTH     4      WEEK     1      DAY     4
```

APPENDIX VI.

Background theory to the statistical analysis work carried out in the thesis.

Statistical analysis.

Statistical methods are concerned with the study of variation. A set of observations of a situation or measurements of a particular parameter always involves a degree of scatter or variation the nature of which can be shown by a frequency distribution. This enables the degree of spread and the manner in which the results are distributed over the range to be appreciated. Such a construction is known as a frequency distribution chart and is illustrated in Appendix iii, Section 2.

If the number of obsevations is very large and the group division much narrower, a smooth curve results showing the Probability Distribution for all values. The value corresponding to the centre of the distribution is known as the Arithmetic Mean, whilst the most usual measure of spread is known as the Standard Deviation. These are calculated as:

$$\text{Arithmetic Mean } x = \overline{x}/N$$

$$\text{Standard Deviation } s = \sqrt{\left\{\sum_{i=1}^{N} (x_i - x)^2/(N-1)\right\}}$$

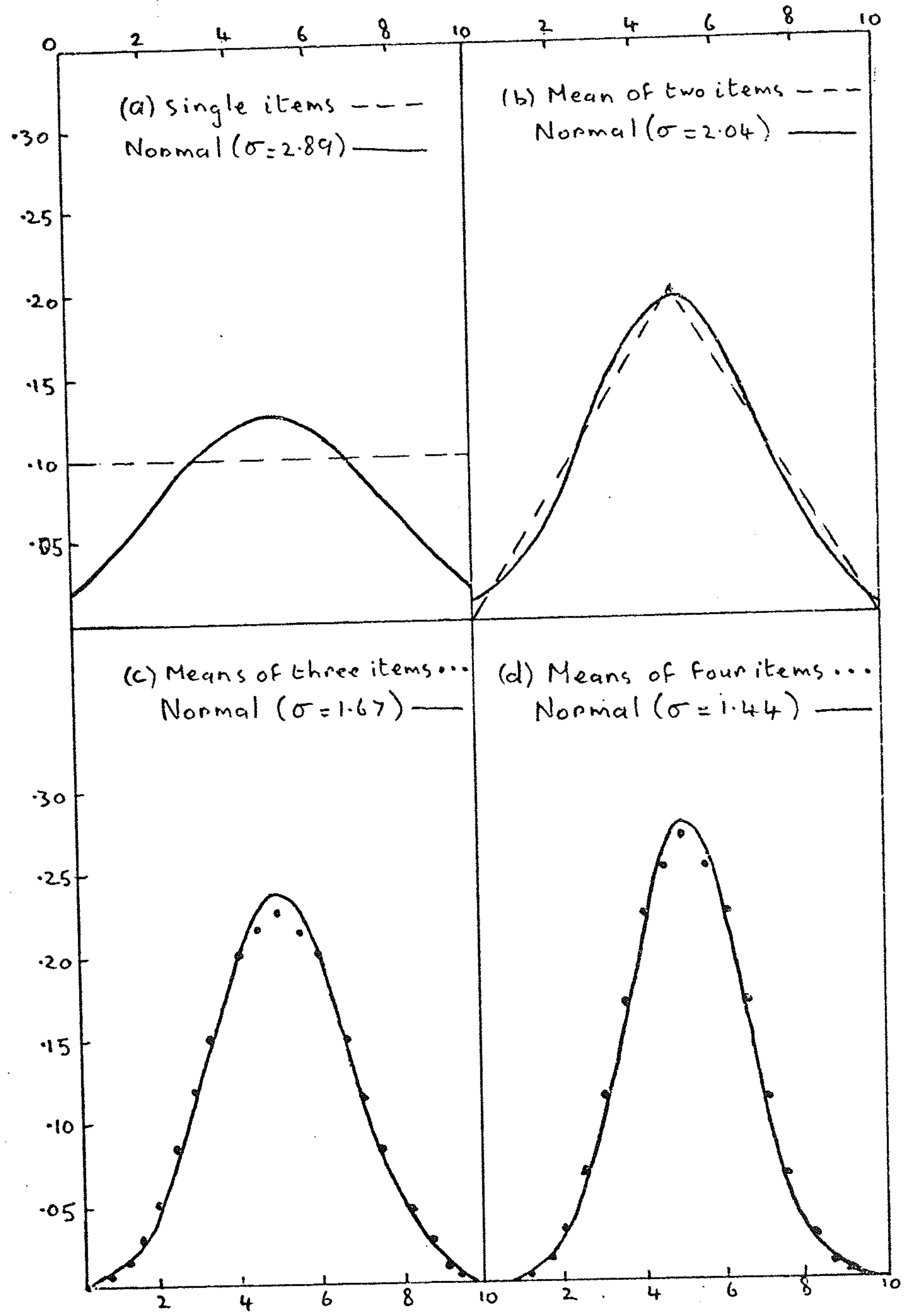
where x = values of the data set

N = number of values in the data set.

The most commonly used of the theoretical distributions is the Normal or Gaussian distribution which gives a bell-shaped probability curve. Many of the distributions found in observational and experimental work are of roughly the Normal type, but uses of the Normal distribution are by no means limited to data which are exactly, or very nearly, Normal. This is of the utmost importance, since simple relationships enable the probability of a particular value or range of values to be quickly calculated. Further, it can be proved that with almost any original distribution, the distribution of sample averages tends rapidly to the Normal form as the sample size increases as shown in Diagram 6.

Diagram 6.

Distribution of means of samples from a Rectangular distribution compared with a Normal distribution.



From an original distribution which is very far from Normal, averages of even three or four observations are distributed quite close to the Normal form.

Similar results are found with other distributions which are far from Normal. Since distributions encountered in practice are usually much closer to Normality, it is safe to assume that the means of small samples, even of three, are distributed in nearly the Normal form. Most of the common statistical tests are based on the assumption that the data are Normally distributed, an assumption which cannot often be verified, but since in most cases the quantities required are averages, the tests are of general applicability.

For mean μ and standard deviation σ, it can be shown that the mean of a random sample of n is also Normally distributed with mean μ and standard deviation $\sigma/\sqrt{n}$. If $\mu = 100$ and $\sigma = 5$, then for samples of four the standard deviation of the mean is $5/\sqrt{4} = 2.5$ and practically all samples will have mean values in the range $100 \pm 3\text{x}2.5$, i.e., between 92.5 and 107.5.

Such a postulation necessitates accurate knowledge of both mean and standard deviation of the Population. Because of this, a commoner situation is the reverse of it. Especially in experimental work when only a small set of data is available, the properties of the Population are required to be deduced from those of the sample. It is easy to calculate the mean and standard deviation of the sample which can then be used as estimates, though perhaps uncertain estimates, of the corresponding properties of the Population. However, these statistics do not prove that the correct form of distribution is being used and it is necessary to assume, usually from knowledge of the same or a similar type of situation, the probable form of the Population. Often, the assumption is that the Population is Normal, and while this may not be strictly true, it may often be justified in that it leads to valid conclusions for the reasons given earlier.

The Variance of a Population is the mean squared deviation of the individual values from the Population mean and is denoted by σ^2; s^2 is used for variance deduced from sample data.

In a sample of N drawn from a Population with mean μ, the variance of the Population is estimated by

$$s^2 = \frac{\sum(x-\mu)^2}{N}$$

In general, μ is not known and an estimate $\bar{x}$, based on the sample, must be used. It can be shown that the sum of the squared deviations from the arithmetic mean is less than that from any other value, i.e., $(x-a)^2$ is a minimum when $a = \bar{x}$.
Thus, $(x-\bar{x})^2$ is less than $(x-\mu)^2$, so that if $\bar{x}$ is substituted for μ variance is underestimated. It can be shown that this bias is removed by using (N-1) in place of N as the divisor, i.e.,

$$s^2 = \frac{\sum(x-\bar{x})^2}{N-1}$$

This gives the best estimate of the Population variance from the data available. (N-1) represents the number of Degrees of Freedom of the estimate of the variance, i.e., the number of independent comparisons that can be made among N observations.

The extent to which single observations vary about the Population mean is measured by the standard deviation. If a number of samples, each containing n observations, are taken, the means will be distributed about μ with a certain standard deviation which is less than that of the original data. The standard deviation of the mean (or any other statistic) is usually known as its Standard Error. The larger the number in the sample the more precise is the estimate of the mean, i.e., the smaller is the standard error of the mean.

It can be shown, independently of any assumption about the form of the parent Population, that the standard error of the mean of n obsevations is given by

$$\sigma_m = \sigma/\sqrt{n}$$

where σ is the standard deviation of the parent Population. This shows how the precision of the mean is related to the sample size, e.g., if n is increased by four times the standard error of the mean is halved.

When an average is calculated from a limited sample of variable data the result is subject to error. The degree of uncertainty in the result can conveniently be described by a 'confidence interval' within which the true value is almost certainly contained.

If the form of the distribution is known, and if the true mean and standard deviation are also known, it is possible to make straightforward probability statements about the value of the mean of a number of observations. For a Normal Population the probability that the mean of n observations will lie within the range $\mu - 3\sigma/\sqrt{n}$ to $\mu + 3\sigma/\sqrt{n}$ is 0.997. When μ is unknown but $\bar{x}$ is known it may be asserted that

$$\bar{x} - 3\sigma/\sqrt{n} < \mu < \bar{x} + 3\sigma/\sqrt{n}$$

with 99.7% Confidence Limits. The value dictating the confidence limits (3 above) is often shown as u.

Usually, σ is not known exactly, only an estimate s based on a limited number of degrees of freedom (ϕ) is available, and it is necessary to use this estimate in calculating the confidence limits. Since s itself is subject to some uncertainty, the confidence limits for μ are further apart than they would be if σ were known exactly. This uncertainty is allowed for by using in place of u, the quantity t. For a large number of degrees of freedom, say more than 20, the uncertainty in s is comparitively small and t is practically identical to u, but as the number of degrees of freedom become smaller t becomes progressively larger than u. The relationship between confidence limits and u and t are both available in table form covering very wide limits.

A problem that frequently arises is to assess the magnitude of the difference between two mean values. The method of comparing the two is to calculate the difference between two observed means $\bar{x}_1$ and $\bar{x}_2$, and the standard error of the difference. These values are used to calculate the confidence limits for the true difference $\mu_1 - \mu_2$. If the lower limit is greater than zero, it can be assumed that μ_1 is greater than μ_2. If the limits are too wide to lead to sufficiently reliable conclusions, more observations must be taken.

Problems such as these, described as Tests of Significance, are usually solved using a Null Hypothesis which states that no difference exists between two mean values μ_1 and μ_2 - the Hypothesis is then either accepted or rejected.

The t - Test is the test invariably involved in the significance of means, since μ_1 and μ_2 are rarely known, $\bar{x}_1$ and $\bar{x}_2$ having to suffice.

Let the group means $\bar{x}_1$ and $\bar{x}_2$ be based on n_1 and n_2 independent observations from Populations with standard deviations σ_1 and σ_2 respectively. The standard error of $\bar{x}_1 - \bar{x}_2$ is given by

$$S.E.\ (\bar{x}_1 - \bar{x}_2) = (\sigma_1^2/n_1 + \sigma_2^2/n_2)^{\frac{1}{2}}$$

and when only s_1 and s_2 are known this becomes

$$S.E\ (\bar{x}_1 - \bar{x}_2) = ((s_1^2/(n-1) + s_2^2/(n_2-1))^{\frac{1}{2}}$$

The ratio of the difference between the two sample means $\bar{x}_1 - \bar{x}_2$ to the standard error of this difference is

$$t = \frac{(\bar{x}_1 - \bar{x}_2)}{S.E.}$$

In other words, the Null Hypothesis regarding differences of mean values can only be rejected if

$$(\bar{x}_1 - \bar{x}_2) - t x S.E. > 0$$

But this test only applies if the two Populations have the same variance. This necessitates the use of the F - Test for comparing two variances σ_1^2 and σ_2^2 from the estimates s_1^2 and s_2^2 based on ϕ_1 and ϕ_2 degrees of freedom respectively. If the alternative to the Null Hypothesis is $\sigma_1^2 > \sigma_2^2$, the ratio $F = s_1^2/s_2^2$ is calculated. If this ratio is larger than the appropriate value, again available in table form, the Hypothesis is accepted. Such an event would preclude confident use of the t - Test.

APPENDIX VII.

0-1 integer computer programme statements using ADVANCED FORTRAN language.

```
↑***********************************************************************

\LISTING ØF :LINK,SWANØUTPUT(30/ØUTP)   PRØDUCED ØN 15FEB78 AT 17.55.27

\ØUTPUT BY LISTFILE IN '!:LINK,LINKPRØG1' ØN 15FEB78 AT 18.10.50 USING I441

DØCUMENT     SWANØUTPUT(30/ØUTP)



      ****    *      *      *   *      *   *     *
**    *        *  *     *    *      *   *     *  *
**    ***     *     *     **        **        **
      *       *****       **        **        **
**    *       *     *   *    *      *   *     *  *
**    ****    *     *   *    *   *     *    *     *




         ***     ***     ****    ****      ***    *****     *
          *   *          *         *    *   *        *     **
          *      ***     ***       *     *   *        *      *
***       *        *     *         *     *   *        *      *
***    *  *    *   *     *         *    *    *        *      *
***      **      ***     ****      ****        ***       *     ***



\LISTING ØF :EAXXX,JSFØRTBRIB(8/)    PRØDUCED ØN 25JAN78 AT 19.17.30

\ØUTPUT ØN UMRCC 4S BY '!:EAXXX,JSEDIT1' ØN 15FEB78 AT 17.51.23 USING I436

DØCUMENT     JSFØRTBRIB

      PRØGRAM TØRG(DATA,ØUTPUT,TAPE1=DATA,TAPE2=ØUTPUT)
      INTEGER CØUNT,D,E,F,M,P,U,W,ZEN,ZEM
      INTEGER MUST(99), CHØIC(99), S(99), V(99), X(99)
      REAL MAX,INF,LIN
      REAL A(20 ,99 ), DATA(396,10),SLACKS(10), TØTAL(20),
     *HØLD(68,9)
      LØGICAL NULL,API,NØSØLN
      M=10
      U=347
      INF=1E10
      API=.TRUE.
C     INPUT JØB DATA AND DRESSING SHØP CAPACITIES
      READ(1 ,501 ) ((DATA(K,P),P=1,9),K=1,U)
      READ(1 ,502 ) TØSAW , TØBALL, TØGRIN, TØLIN , TØFILE,
     *               TØFEFI, TØDISC, TØPRES, TØREAM
      TØSAW  = TØSAW  * 0.875
      TØBALL = TØBALL * 0.875
      TØGRIN = TØGRIN * 0.875
      TØLIN  = TØLIN  * 0.875
      TØFILE = TØFILE * 0.875
      TØFEFI = TØFEFI * 0.875
      TØDISC = TØDISC * 0.875
```

```
      TØPRES = TØPRES * 0.875
      TØREAM = TØREAM * 0.875
      READ(1 ,503 ) N,W,F
C     INPUT IDENTITY ØF CØMPULSØRY JØBS
      READ(1 ,504 ) (MUST(K),K=1,W)
      SAW=0.0
      BALL=0.0
      GRIN=0.0
      LIN=0.0
      FILE=0.0
      FEFI=0.0
      DISC=0.0
      PRES=0.0
      REAM=0.0
      ZEN = N + 1
      ZEM = M + 1
      DØ 100 J = 1,U
         DØ 100 I = 1,W
            IF (J.NE.MUST(I)) GØ TØ 100
               SAW  = SAW  + DATA(J,1)
               BALL = BALL + DATA(J,2)
               GRIN = GRIN + DATA(J,3)
               LIN  = LIN  + DATA(J,4)
               FILE = FILE + DATA(J,5)
               FEFI = FEFI + DATA(J,6)
               DISC = DISC + DATA(J,7)
               PRES = PRES + DATA(J,8)
               REAM = REAM + DATA(J,9)
100         CONTINUE
C     INPUT IDENTITY ØF CHØICE JØBS
      READ(1 ,505 ) (CHØIC(K),K=1,N)
      I=0
      DØ110 J=1,N
      K=CHØIC(J)
      I=I+1
      HØLD(I,1)=DATA(K,1)
      HØLD(I,2)=DATA(K,2)
      HØLD(I,3)=DATA(K,3)
      HØLD(I,4)=DATA(K,4)
      HØLD(I,5)=DATA(K,5)
      HØLD(I,6)=DATA(K,6)
      HØLD(I,7)=DATA(K,7)
      HØLD(I,8)=DATA(K,8)
      HØLD(I,9)=DATA(K,9)
110   CØNTINUE
C     DRESSING SHØP SLACK PERIØD
      A(1,ZEN) = TØSAW  - SAW
      A(2,ZEN) = TØBALL - BALL
      A(3,ZEN) = TØGRIN - GRIN
      A(4,ZEN) = TØLIN  - LIN
      A(5,ZEN) = TØFILE - FILE
      A(6,ZEN) = TØFEFI - FEFI
      A(7,ZEN) = TØDISC - DISC
      A(8,ZEN) = TØPRES - PRES
      A(9,ZEN) = TØREAM - REAM
C     ASSEMBLE REMAINDER ØF THE CØNSTRAINT ARRAY
      I=0
      DØ 130 K=1,N
      I=I+1
      A(1,I)=HØLD(K,1)
      A(2,I)=HØLD(K,2)
      A(3,I)=HØLD(K,3)
      A(4,I)=HØLD(K,4)
      A(5,I)=HØLD(K,5)
      A(6,I)=HØLD(K,6)
      A(7,I)=HØLD(K,7)
```

```
      A(8,I)=HØLD(K,8)
      A(9,I)=HØLD(K,9)
 130  CØNTINUE
C     CALCULATE THE FIRST CØLUMN
      DØ 150 J = 1,9
         TØTAL(J) = 0.0
         DØ 140 K = 1,N
 140        TØTAL(J) = TØTAL(J) + A(J,K)
 150     A(J,ZEN) = A(J,ZEN) - TØTAL(J)
C     CALCULATE JØB CHØICE RØW
      A(M,ZEN) = F - N
      DØ 160 K = 1,N
 160     A(M,K) = 1.0
C     EVALUATE THE ØBJECTIVE FUNCTIØN
      DØ 170 K = 1,N
         A(ZEM,K) = 0.0
         DØ 170 I = 1,9
 170        A(ZEM,K) = A(ZEM,K) + A(I,K)
      A(ZEM,ZEN) = 0.0
      WRITE(2 ,506 ) A(ZEM,ZEN), (A(ZEM,J),J=1,N),
     *               ((A( I ,ZEN), (A( I ,J),J=1,N)),I=1,M)
C     S HØLDS PARTIAL THE PARTIAL SØLUTIØN IN ØRDER ØF ASSIGNMENT,
C     V IS THE STATE VECTØR ASSØCIATED WITH S
      IF (.NØT.API) GØ TØ 200
         E = 0
         DØ
            IF (X(J).EQ.0   ) GØ TØ 180
               E = E + 1
               S(E) = J
               V(J) = 3
               DØ 175 I = 1,M
 175              A(I,ZEN) = A(I,ZEN) + A(I,J)
               GØ TØ 190
 180        V(J) = 0
 190        CØNTINUE
         Z = A(ZEM,ZEN)
         GØ TØ 220
 200  DØ 210 J = 1,N
 210  S(J)=0
      V(J)=0
      E=0
      Z=0.0
 220  NØSØLN = .TRUE.
      CØUNT  = 0
      A(ZEM,ZEN) = INF
C     ALL RELAVANT VARIABLES ARE NØW INITIALIZED
 230  CØUNT = CØUNT + 1
      IF(CØUNT.GT.750000)GØ TØ 400
      DØ 240 I = 1,M
         IF (A(I,ZEN).LT.0.0) GØ TØ 250
 240     CØNTINUE
C     BEST CØMPLETIØN IF S IS FEASIBLE
      GØTØ 350
 250  NULL = .TRUE.
C     FØRMSET T ØF FREE VARIABLES TØ WHICH 1 MAY BE PRØFITABLY ASSIGNED
      DØ 270 J = 1,N
         IF (.NØT.( (V(J).EQ.0 ) .AND.
     *      ((A(ZEM,J)+Z).LT.A(ZEM,ZEN))))GØ TØ 270
          DØ 260 K = I,M
             IF (.NØT.((A(K,ZEN).LT.0.0)
     *          .AND. (A(K, J ).GT.0.0)))GØ TØ 260
                NULL = .FALSE.
                V(J) = 1
                GØ TØ 270
 260         CØNTINUE
 270     CØNTINUE
```

```
      IF (NULL) GØ TØ 380
C     IF T IS EMPTY THEN S IS FATHØMED
      DØ 290 K = I,M
          IF (A(K,ZEN).GE.0.0) GØ TØ 290
              Q = A(K,ZEN)
              DØ 280 J = 1,N
                  IF ((V(J).EQ.1).AND.(A(K,J).GT.0.0)) Q = Q + A(K,J)
280               CØNTINUE
              IF (Q.LT.0.0) GØ TØ 380
C         IF Q IS NEGATIVE, S IS FATHØMED
290       CØNTINUE
      MAX = -INF
      DØ 310 J = 1,N
          IF (V(J).NE.1) GØ TØ 310
              Q = 0.0
              DØ 300 I = 1,M
                  R = A(I,ZEN) + A(I,J)
                  IF (R.LT.0.0) Q = Q + R
300               CØNTINUE
              IF (MAX.GT.Q) GØ TØ 310
                  MAX = Q
                  D   = J
310       CØNTINUE
      E    = E + 1
      S(E) = D
      V(D) = 3
      IA   = 1
C     AUGMENT S BY ASSIGNING 1 TØ X(D)
320   DØ 330 J = 1,N
          IF (V(J).EQ.1) V(J) = 0
330       CØNTINUE
C     CLEAR T
      DØ 340 I = 1,M
340       A(I,ZEN) = A(I,ZEN) + IA * A(I,D)
      Z = Z + IA * A(ZEM,D)
C     RECALCULATE SLACKS AND ØBJECTIVE FUNCTIØN
      GØ TØ 230
350   NØSØLN = .FALSE.
      IF (Z.GE.A(ZEM,ZEN))GØ TØ 380
          A(ZEM,ZEN) = Z
          DØ 360 J = 1,N
              IF (V(J).EQ.3) X(J) = 1
              IF (V(J).NE.3) X(J) = 0
360           CØNTINUE
          DØ 370 I = 1,M
370           SLACKS(I) = A(I,ZEN)
380   IF (E.EQ.0) GØ TØ 400
          D = S(E)
          IF (D.GT.0) GØ TØ 390
              V(-D) = 0
              E     = E-1
C             BACK TRACK
              GØ TØ 380
390       S(E) = -D
          V(D) = 2
          IA   = -1
C         ASSIGN 0 TØ X(D)
          GØ TØ 320
400   IF (NØSØLN) GØ TØ 420
          DØ 410 I = 1,M
410           A(I,ZEN) = SLACKS(I)
420   WRITE(2, 509) NØSØLN
      WRITE(2, 510) (A(I,ZEN),I=1,M)
      WRITE(2, 511)  A(ZEM,ZEN),CØUNT
      WRITE(2, 512) (X(J),J=1,N)
501   FØRMAT(F6.2,8F7.2)
```

```
  502   FØRMAT(9F7.1)
  503   FØRMAT(3I3)
  504   FØRMAT(7I4)
  505   FØRMAT(7I4)
  506   FØRMAT(T9,F10.3,/,(T9,10(F10.3,2X)/),/,T9,F10.3,/,
       *(T9,10(F10.5,2X)/))
  509   FØRMAT(L5)
  510   FØRMAT(10F10.3)
  511   FØRMAT(F10.3,I8)
  512   FØRMAT(1H ,68I1)
        STØP
        END

↑**************************************************************************
```