THE APPLICATION OF SYSTEM DYNAMICS TO PROBLEMS IN THE STEEL INDUSTRY

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The proposed paper will develop issues raised in the attach paper "System Dynamics as a Potential Aid to Capacity Planning in the Steel Industry".

In particular more emphasis will be placed on the model (together with the results) than is apparent in the attached paper.

Consideration can, therefore, be given to the model in various ways:-

(i) Using noise input for demand as at present.

(ii) Using a cyclical function for demand input to compare with the results at (i), the hypothesis being that the problems faced by the industry are worse when demand is cyclical.

(iii) Introducing specific cost/revenue performance measures which realistically represent the effects of experiments (i) and (ii). Continuous discounting of money flows can be explored, for example.

(iv) Considering profitability dynamically, rather than with single cumulative performance measures as in (iii). The high fixed cost element of many process industries renders them extremely vulnerable when cash inflow is reduced because of depressed demand. In the steel industry such a situation does generate large losses, but compare this with the oil industry where prices are quickly raised, to sustain the cash flow, giving compensation on the price side for what is lost because of reductions in volume throughput.

(v) Enhancing the model to ensure that demand for steel is generated internally. This would incorporate the process whereby consumers and stockholders of steel overbook in response to lengthening delivery delays and fear of the imminence of order prohibition.

The paper will,therefore, address a number of interrelated issues which face the steel industry in general and the U.K. steel industry in particular, but which centre upon the complex problems manifested by a mismatch between demand and production capacity.

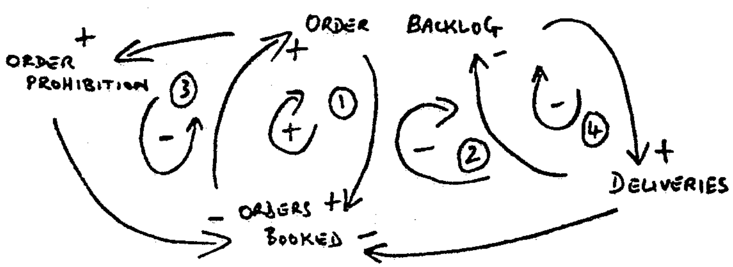
SYSTEM DYNAMICS AS A POTENTIAL AID TO CAPACITY PLANNING IN THE U.K. STEEL INDUSTRY

Any firm or industry which experiences marked cyclical fluctuations in both output and demand can provide a testimony of the damaging effects such oscillations have on profitability. Perhaps none more so than the British Steel Corporation (B.S.C.) whose record in this respect is rather poor. For such industries, therefore, any methods which management science can provide as a means of analysis of the causes and effects of such cycles are to be welcomed. It is suggested in this paper that system dynamics provides an important framework for analysing the causes of cyclical behaviour in economic systems and that it is this area of application which possesses the greatest chance for successful demonstrations of its use. It is probably for this reason that work using the methods of system dynamics has concentrated, in Gt Britain, on economic systems.

Being at the end of a long chain of supply, the steel industry experiences demand fluctuations which are amplified in the manner first demonstrated by J W Forrester.[1] An examination of Figure 1 (in the Appendix) reveals the typical four year business cycle insofar as it relates to steel production and consumption. It is interesting to note that the amplitude of the fluctuations in production exceed those of consumption and also that the year 1970 marks an occasion when, for the first time, the lowest point in the cycle is below that of the previous lowest point.

This cyclical behaviour has attracted the attention of at least two economists, one in Gt Britain[2] and one in Sweden.[3] Both these studies rely on econometric methods to investigate hypothese concerning the steel cycle. In the first study, Christopher Blake formulates a linear model, consisting of three equations, which is fitted to the data using multivariate least squares techniques. On the supply side deliveries to the home market are explained in terms of new orders booked and a factor to account for changes in the backlog of orders on hand. Clearly to use the language of system dynamics, this is a typical example of the way in which a level variable can influence a rate variable to form a negative feedback loop which performs the task of regulating deliveries in the face of changes in new orders booked. Fieldwork carried out by the author at several works making sheet steel products confirms the existence of the above relationship, although it should be added that the B.S.C. imparts its own controls when order backlogs become too high by prohibiting further new orders.

This is illustrated in the influence diagram below. The positive loop (No 1) exists to push up order backlogs through the practice of over-ordering when lead times are extended, a reaction all too prevalent by consumers of steel and a practice that is extremely difficult to eradicate without formal controls. The speed of reaction around loop 1 is much greater than can be counteracted by the beneficial (to the industry) effects of loop 2 and hence the necessity of imposing loop 3 on the system is seen by the industry as unavoidable.



Two aspects of this feature in the study deserve some mention. Firstly, it is impossible for the linear model produced by Blake to take account of the ceiling on order backlogs which the industry imposes and yet, in the methods of system dynamics, this would be simple, amounting to the formulation of an appropriate equation using the CLIP function in DYSMAP[4], for example. Secondly, merely constructing an influence diagram like the simple one above forces the management scientist to focus attention on the important issues and the most important one in this case is to find the

reason why the speed of reaction around loop 2 is slow, thereby unleashing the harmful effects of loop 1 and subsequently loop 3. One possible reason for this slowness is suggested later.

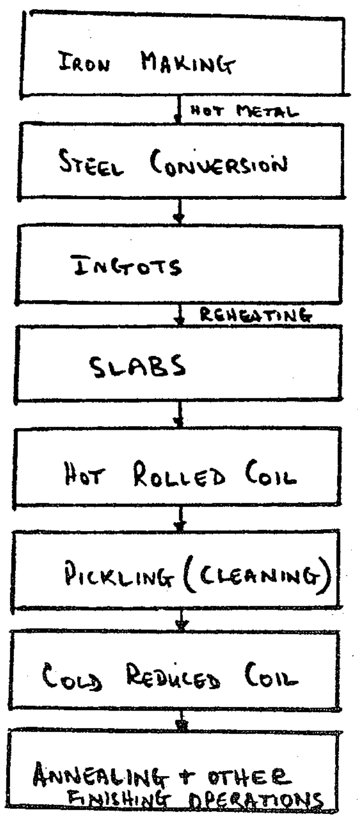
Certainly the influence diagram can be taken as a starting point for an examination of the reasons behind the growth of imports of cold reduced sheet steel into Gt Britain in recent years.

The demand hypothesis given by Blake[5] is presented as a form which has been described as proportional plus inertia control[6] and which is a common enough formulation for such situations. This is the same approach to steel demand taken by Vinell[7] in his comprehensive study of demand-generated cycles using Swedish data. Following this formulation, orders booked to steel mills consist of replacement for present consumption together with a quantity designed to adjust any discrepancies between actual and desired inventory levels. Clearly the stock adjustment element of demand can be either positive or negative and plays a significant role in the demand acceleration effect which it is the purpose of Blake's study to explain.

However, these studies, in common with econometric studies generally, are handicapped by the need to have time series data available on the variables in question or at least to be able to manufacture a proxy for such data from that which is available. In this respect Blake has set about creating a series of data on changes in the crucial order backlog variable by deriving it from the data that was available on both new orders booked and deliveries of finished steel.

It could well be a lack of data which has resulted in the apparently shallow treatment accorded the supply side of the system in these analyses of the steel cycle. Certainly demand acceleration is important but the processes generating it are now fairly well understood and widely documented in system dynamics studies as well as in work utilising alternative paradigms. Yet, the delay in supply response is an aspect of system performance which the industry itself has considerable control over and which, therefore, may repay intensive investigation. After all, some part of the demand acceleration effect is caused by buyers in, for example, consumer goods firms using their wealth of experience when determining purchase quantities and the buyers need only go back to the last big upturn in the steel cycle (in 1973/74 in Gt Britain) to recall a period of order prohibition being introduced by the B.S.C.

The diagram below illustrates the processes which form the main route through a modern integrated sheet steel works. By and large the prevalent means of steel manufacture is the basic oxygen process (B.O.S.) whereby oxygen is blown over molten iron (hot metal) to rid it of unwanted impurities in the charge.

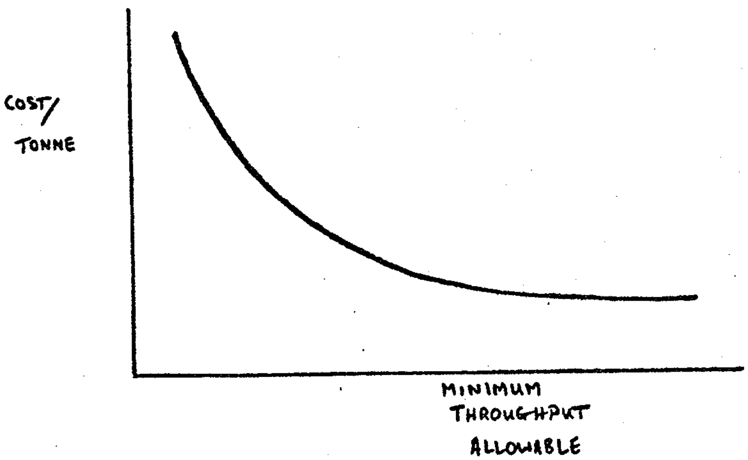


The production process is continuous until the steel reaches the slabbing stage and it is only from this point onwards that material is in any way related to a customer order. Shortages of slabs, therefore, can be seen as leading directly to order filling delays although it is possible to stock slabs over and above the normal two to four weeks supply if space can be found and the finance for stockbuilding is available. It is not usual to hold significant stocks of ingots as they require reheating before entering the slabbing mill.

The manufacturing lead time is approximately four weeks from launch of the order at the slabbing stage to production of cold reduced coil steel and, providing the stocks of slabs are adequate, orders will be launched more or less in sequence. It would appear, therefore, that supply inflexibility has to concentrate on the so-called "heavy-end" of the industry and the preparation of molten iron in blast furnaces in particular.

Figure 2 shows how the average number of furnaces in blast has fallen over the years while the output per furnace per annum has significantly increased. This is not solely due to the reduction in the number of furnaces but rather to their increasing hearth diameter, shown in Figure 3, which allows a larger burden to be input at each charge.

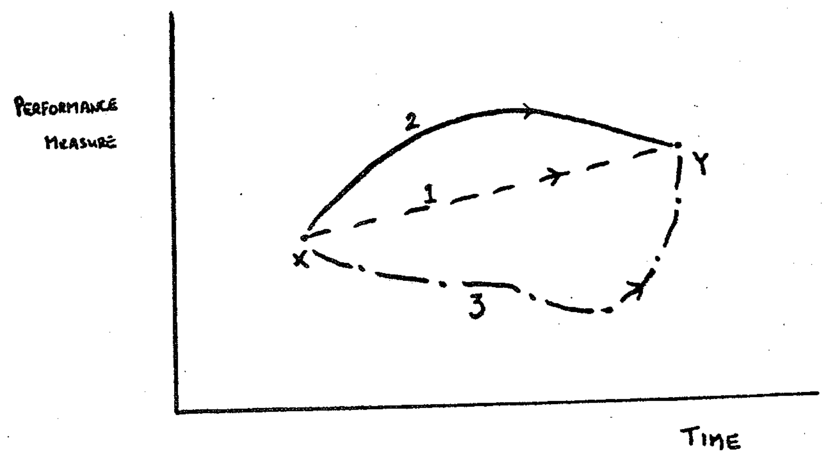
Several studies [8, 9] have pointed to the cost advantages of large-scale operations in iron-making and there is no doubt that an average cost curve of the type depicted below represents the typical shape of the scale curve, although there is some doubt as to the exact point at which it begins to flatten out. This is largely because of the lack of data on the few very large furnaces which exist, primarily in Japan.



In presenting their ten year development plan in 1973[10] the British Steel Corporation sought to press home the cost advantages of large scale operations by advocating an extension of capacity at the two main works in the flat products sector (Llanwern and Port Talbot) with an associated concentration of "heavy-end" production at these sites. Indeed work on one large blast furnace had already been started at Port Talbot and this was designed to replace three smaller furnaces. At Llanwern two large furnaces were to be supplemented by another in the mid-1970's. This furnace would then be the largest in Europe.

The planning work which went behind the formulation of the ten year development plan was never formally published, although it is known that considerable modelling work was undertaken.

Discounted cash flow analysis was used to cost out the various alternative investment strategies open to the Corporation and thereby provide a single numerical measure of the "performance" of each. Informal conversations with people involved in the modelling work have revealed that the analysis was done largely on a trend basis and little, if any, account appears to have been taken of the important cyclical behaviour of the industry, to which reference has already been made. Although, it is not the major point of this paper to elaborate unduly on such issues, it does appear a little shortsighted to ignore dynamic behaviour altogether. It is to be expected that management would wish to know if they were to progress from state X to state Y by routes 1, 2 or 3 in the diagram below. Indeed, if route 3 turned out to be the case then state Y may never be attained.



Returning to the subject of blast furnace size, it is clear that economies of scale exist on the cost side but against this it is surely necessary to give consideration to the notion of supply inflexibility resulting from the use of large furnaces. It is a metallurgical fact that blast furnaces require a periodic relining of refractory materials, the interval between relines being variable but of the order of between 4 million and 6 million tonnes throughput. It is hardly likely that it is cost-effective to have a spare blast furnace used only when one of the others at a particular works is out for relining and hence there is an apparent danger that distortion of the reline programme for the furnaces could result in grave supply difficulties at particular points in the demand cycle. If this were to occur on a demand upturn the consequences could be disastrous in terms of revenue foregone. This is reinforced by the knowledge that a furnace requires a period of two to three months or more to achieve maximum operating efficiency when it has been started up from cold.

The British Steel Corporation's commercial managing director has publicly admitted[11] that in 1974 the Corporation were unable to meet orders because of a bunching of blast furnace relines. He suggested that when demand rose (as it did for much of 1973) commercial pressures led to every last drop of steel being forced out of furnaces but he gave an assurance that in future maintenance schedules for the furnaces would be rigidly adhered to.

On top of the need to periodically reline the furnaces is the question of whether a furnace should be taken out of blast when demand is depressed. Discussions with executives involved has revealed that such decisions are taken at a very high level in the Corporation. Certainly one was taken out in the downturn of 1971 but, given the speed with which demand can change in the industry and the slow build-up to maximum efficiency when starting a furnace from cold, any such decision is fraught with dangers. Yet there is extremely little variation in the output that is possible from a blast furnace. Alteration of

the burden (charging materials) can lead to a variation of the order of 10%-15% in output, but that is all. Often a practice known as "granulating" occurs by which molten iron is just poured into the ground and not converted into steel.

Given the picture painted in figures 4 and 5 there is obviously a pressing need for an investigation of supply difficulties in the steel industry in Gt Britain with the issues above in relation to blast furnace sizes and capacity planning being one focus of attention. It is suggested that the methods of system dynamics can assist in this policy making analysis and the results of some initial computer runs are now elaborated. Figure 6 shows the results of a model formulated to illustrate the effects on some important variables when molten iron is manufactured in a configuration of five blast furnaces with a grand total output of 253,000 tonnes per month. As blast furnaces are brought out for relining (at months 42, 50 and 66 in this run) fluctuations in orders on hand, slab stocks and steel deliveries are set up. While this may not be a particularly counter-intuitive result at least it does serve to give a demonstration that supply, as well as demand, can create undesirable fluctuations. In this model there are no demand acceleration effects taken into account since its purpose is to examine the supply side only. Orders booked are a random noise function.

An alternative configuration, (Fig 7.) consisting of three large blast furnaces, again with a grand total output of 253,000 tonnes per month, produces fluctuations that are slightly more severe. In this run blast furnaces are taken out for relining at months 33, 43 and 59. Each reline means the loss of use of the furnace for some 3 to 4 months, together with the reduced output on heating up from cold, as previously mentioned.

One important measure to come from those two runs is the number of months on which it was necessary to activate the order prohibition control arising when the number of orders on hand exceeds the desirable maximum. In the case of the five blast furnace configuration it was on just one occasion while for the three blast furnace configuration it was necessary on seven occasions. Both runs were over a period of 80 months. In terms of potential home demand that goes unfulfilled this is surely significant and conversations with some British Steel stockholders, who are normally purchasers of large quantities of steel, reveal that when this happens an enormous amount of goodwill is lost. Perhaps of more significance, however, is that buyers for the stockholders then begin sourcing abroad for their steel. They cannot do otherwise for steel stockholding is a very competitive business.

A further series of runs has been conducted to assess the effects of demand input in the form of a sine wave. This, perhaps, more accurately reflects the vagaries of the motor vehicle industry in particular, in their need for steel. One interesting feature to emerge comes from a comparison of revenues obtained under the separate configurations. Revenue is accounted for by the simplistic approach of including a variable representing the Selling Price Per Tonne (SPPT) of steel. A third-order delay is used to model the delay with which payments are received following the issue of invoices. Revenue falls to a minimum of 10.7 E6 money units with three blast furnaces operating but to a minimum of only 11.84 E6 money units with five operating. The position is more starkly illustrated if an increasing demand trend of 10 E3 tonnes monthly i superimposed onto the stationary sine wave. The minimum revenue rate achieved then is 10.68 E6 money units with three furnaces and 11.84 E6 with five.

With the model of the industry in its present stage of development it would be misleading to recount any further results since they might be construed as definitive policy recommendations but it is hoped that, at the very least, this paper has served notice that system dynamics models are of help with decisions regarding the desirable scale of steel making operations by incorporating, as they can, three extremely important matters in such decisions - cost, revenues and dynamic behaviour. The focus to date has been far too strongly concentrated on the first.

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FIG.2 AVERAGE NUMBER OF FURNACES IN BLAST AND OUTPUT PER FURNACE PER ANNUM (=- - -) (SOURCE:I.S.S.B.)

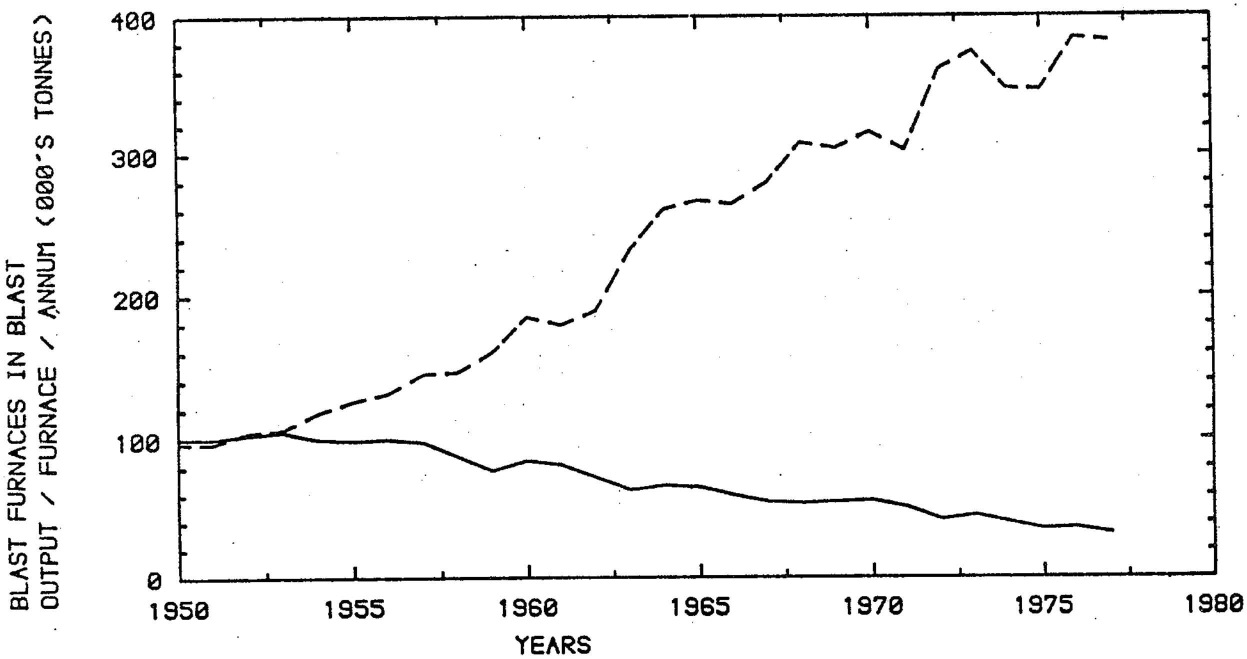


FIG.1 CRUDE STEEL PRODUCTION (1950-77) AND FINISHED STEEL CONSUMPTION =- - - - (1960-77) (SOURCE: ECONOMIC TRENDS)

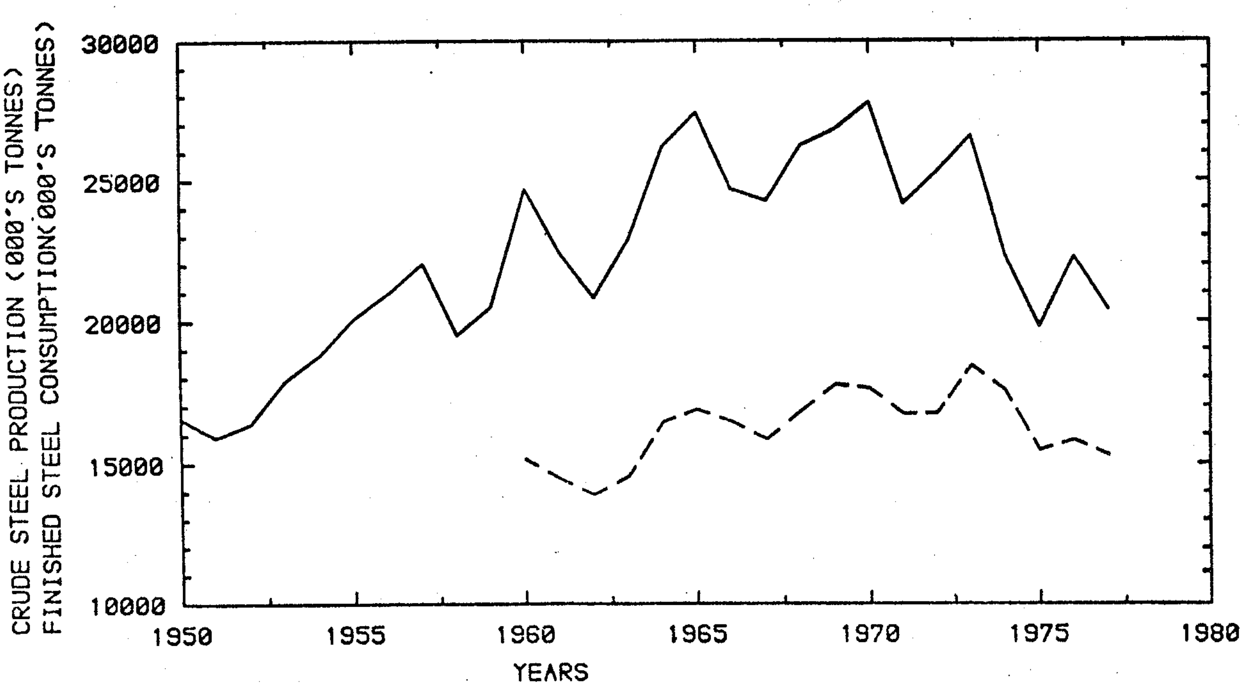


FIG. 4 ORDERS ON HAND FROM CONSUMERS AND STOCKHOLDERS FOR NON-ALLOY SHEET STEEL (JAN 1967-DEC 1974) (SOURCE:I.S.S.B.)

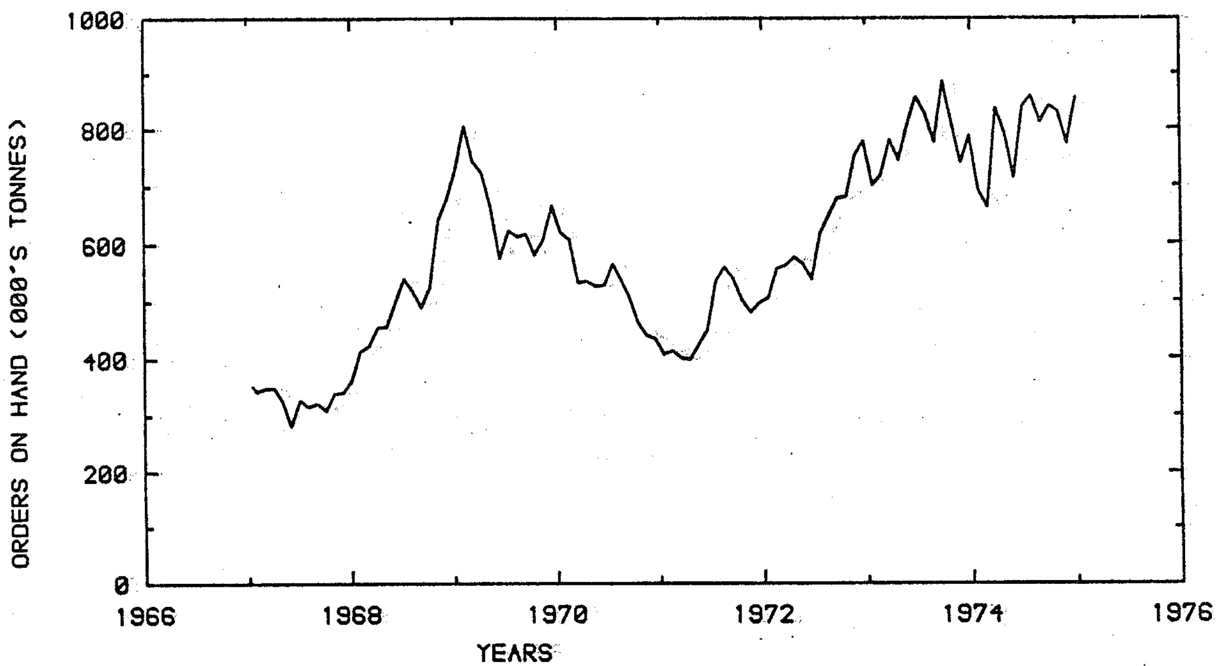
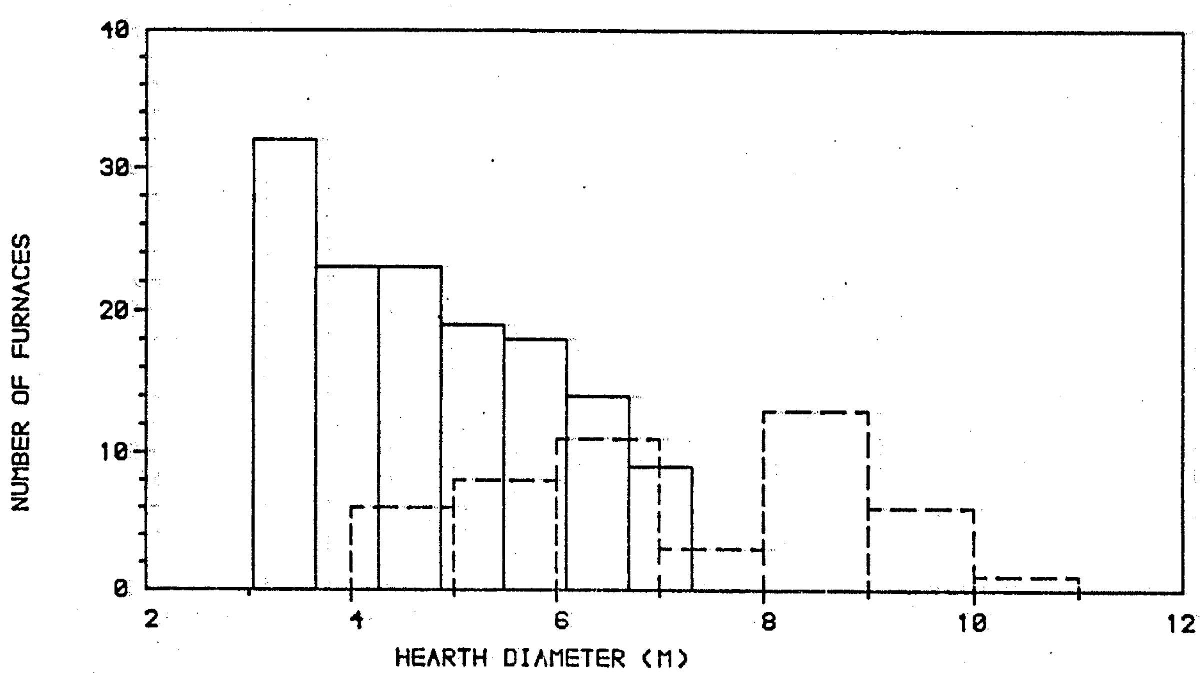


FIG.3 FREQUENCY DISTRIBUTION OF BLAST FURNACE HEARTH DIAMETERS IN 1955 AND 1977 (=- - - -) (SOURCE:I.S.S.B.)



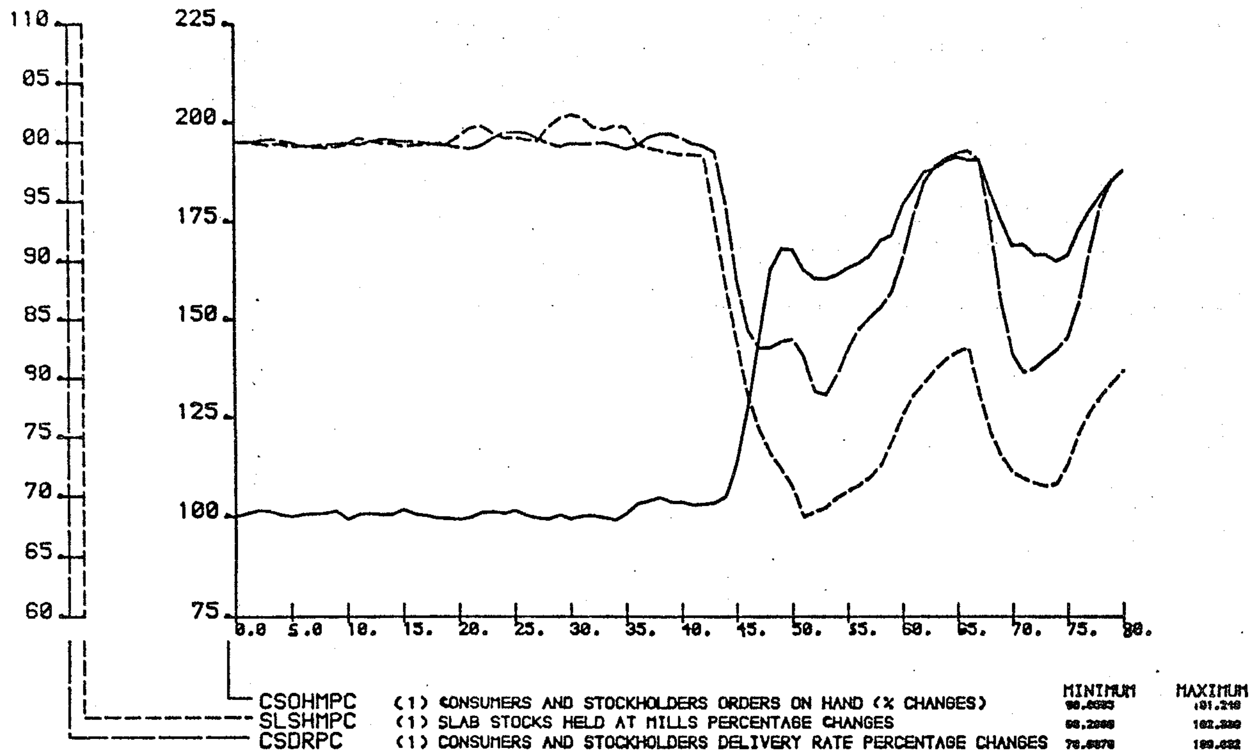


FIG.6 FIVE BLAST FURNACES--NOISE INPUT
STRIP MILLS SECTOR

FIG.5 MEAN LEAD TIMES FOR COLD-REDUCED SHEET STEEL
(SOURCE--INDUSTRIAL PURCHASING NEWS)