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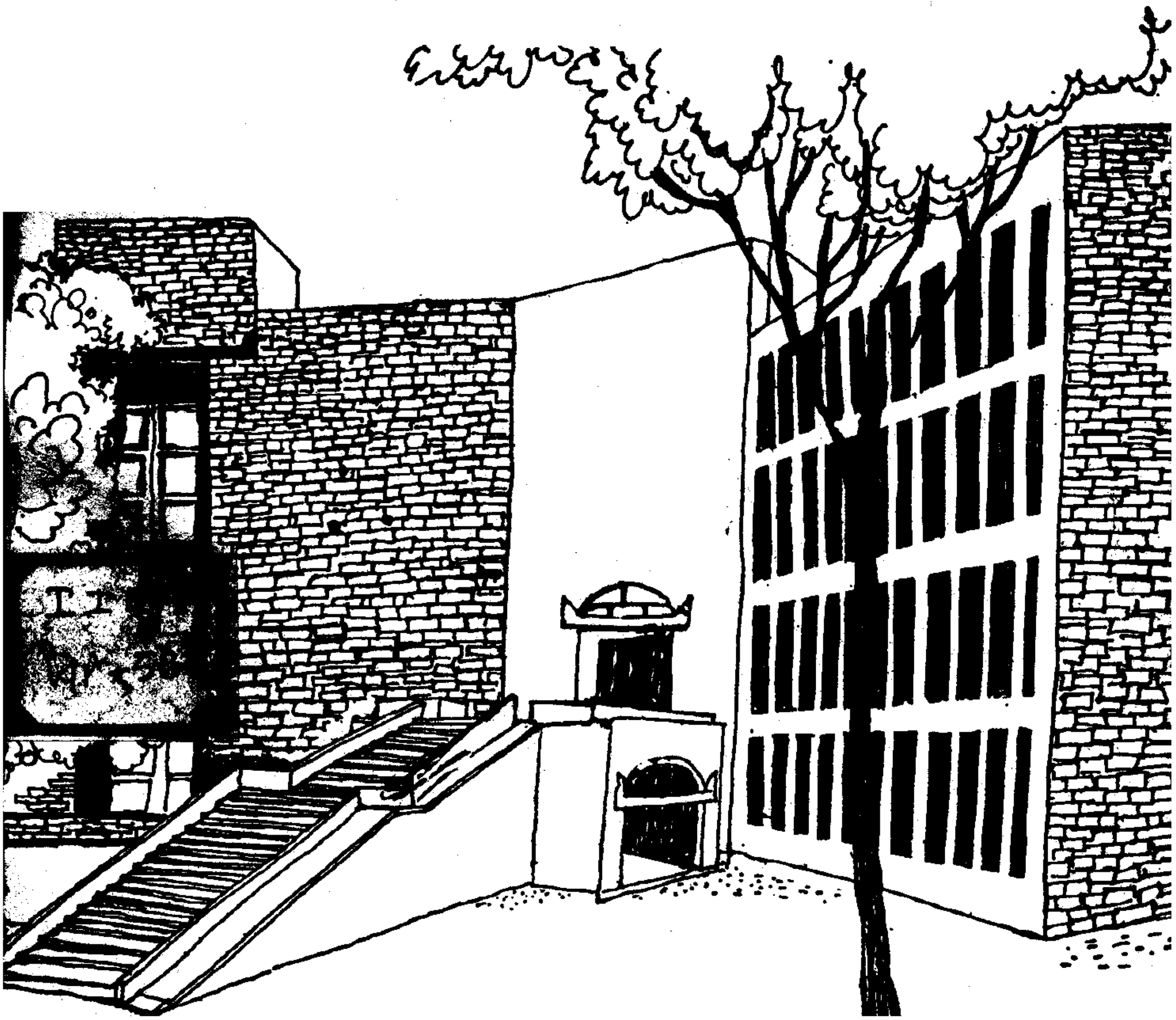

INDUSTRIAL GROWTH STRATEGY:
IMPLICATIONS FOR SPONGE IRON

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I. Introduction

The Central Planner of the country, such as the Planning Commission or the Industrial Licensing Authority must determine the optimal growth strategy for an industry. The growth strategy for an industry is the manner in which the industry is allowed to expand over an apriori fixed time horizon. Given the currently existing set of plants, their locations, process technologies, and capacities, the Planner must decide on the following issues:

i) Which among an identified set of potential locations should be chosen for locating new plants? These new plants are required to cater to known and growing demands of markets for the product.

ii) What is (are) the best choice of process technology (technologies) for each location? This is important since in most industries a choice of various basic process technologies exists.

iii) What should be the capacity of each of the new plants, and how should this be built-up over time?

iv) How much raw material from each raw material source should be moved to each of the plants. This is the question of allocation of raw materials.

v) What should be the allocation of product from the plants, both old and new, to the markets? Here old plants are those in operation at the beginning of the planning horizon, while new plants refer to those that are added during the planning horizon.

A growth strategy is optimal if it helps to achieve a certain pre-defined objective or a set of objectives as well as or better than does any other strategy. Often such complex planning problems have a multiplicity of objectives, such as minimisation of capital investments and other financial resources; minimisation of consumption of various types of raw materials and services required for production; minimisation use of infrastructural facilities such as transportation for movement of raw materials and product, etc. The basic promise is that if resource consumption for producing a given level of output is minimised, the resources thus saved can be gainfully used for other purposes, or in cases where the resources have no alternative uses, their use can be prolonged over longer periods. Since many of these objectives are measured in mutually non-commensurate units such as Rupees of Capital Outlay, tons of coal consumed, ton - km. of railway frieght etc, etc., it is customary while modelling such problems to use a single objective, for instance cost minimisation as a proxy of the real objective of minimising diverse types of resources. The objectives discussed above are all quantifiable, and with some approximation translatable into monetary measures. For this reason they can be incorporated through formal modelling, using techniques such as those available in Operations Research.

The planner must in addition incorporate in his decision making various other objectives which may not be amenable to straight-forward quantification. Amongst these are included : need for regional dispersal of plants; avoidance of wasteful investments for instance due to creation of gross over-capacity for the industry as a whole; creation of employment opportunities; avoidance of excessive growth of already developed areas of the country; minimisation of balance of payment deficits, etc. Since the effect of planning decisions for a particular industry on many of these 'soft' objectives is not always quantifiable, the planner may not be able to explicitly incorporate them in a formal model. This does not however imply that objective modelling of such complicated problems can be dispersed with. In the absence of objective and formal models, the decision maker tends to make policy decisions that often appear to be arbitrary. This is not surprising, since the enormity of the problem would result in his making decisions sequentially on the above five issues, where an integrated approach in which all decisions on all the five areas are made simultaneously is most appropriate. The sequential approach to decision making in such situations in which for instance the plant locations are first decided, followed by decisions on process technology at each location, and so on, usually leads to sub-optimality. This is because in the sequential approach, much pertinent information could be precluded from consideration, because of the large volume of information.

Thus while formal modelling is a good defense against perceived arbitrariness of planning decisions, unless it can implicitly incorporate the 'soft' objectives of the decision maker, it is inadequate as a practical tool. In this paper we present methodology and results of a planning model, where the soft objectives of the planner have been incorporated into the model through policy interventions. The model is demonstrated using the Indian sponge iron industry, primarily because it is a virgin industry with substantial growth potential in the coming years, so that some interesting and useful conclusions may emerge for the planner. Thus the formulation and solution method have made use of certain peculiarities of the industry. However the broad framework itself is general and can be applied to any process industry.

The primary contribution of the model and the solution procedure is that the planner is able to see the implications of his policy interventions. The model also enables examination of the sensitivity of his decisions to the problem data such as demands for the product and prices of various raw materials. This gives an idea of the robustness of various decisions with respect to problem uncertainities. In the context of administered pricing of various key raw materials and services, this aspect also has policy implications for the planner.

Optimal solution to the issues of plant location, process selection, capacity planning and allocation of raw materials and allocation of the product are important for the viability of the industry as well as from a resource concentration aspect. The latter is being increasingly emphasised at various forums. Poor plant location or an inappropriate choice of process at a location can hamper the viability of the plant. Poor decisions on capacity utilisation, both of which are undesirable. Finally poor allocation patterns can put undue stress on an already overloaded transport system. It is for these reasons that formal models become indespensible.

II. Sponge Iron in Indian Steel Scenario

India ranks amongst the lowest in the world in terms of per capita steel consumption. Since steel consumption reflects investment in the capital goods industry, which must continually grow for the economic development of a country, there is substantial need as well as scope for increasing the steel consumption in the country.

The principal route for steel making is through conventional integrated steel plants, where iron ore is converted into pig iron in a Blast Furnace. The molten pig iron is refined into steel using either the Basic Oxygen process or the Open Hearth Process. The resulting molten steel is cast into ingots, and then rolled into semis such as billets, blooms or slabs, which are in turn rolled into finished products such as wires, rods and bars. With the advent of continuous casting, the molten steel is directly cast into semis, and then finish rolled to get usable products. While advanced industrial nations have phased out the Open Hearth process for steel refining, and have gone in a big way into oxygen blown converters, in India over 50% of the steel production is through the Open Hearth process and only 10% of the steel produced is through oxygen steel making. The Blast Furnace route relies on use of coking coals. In India coking coals are of poor quality and their reserves are fast depleting. Moreover the Blast Furnace route is economically viable at relatively large capacities of over one Million tons per annum (Mtpa), and the full economies of scale can be realised only at 3-4 Mtpa, for which demands may not be readily available. This route also involves heavy investments of the order of several thousands of crores of Rupees, and long gestation periods.

The alternative route to steel manufacture which until recently has been one of recycling, involves melting and refining of steel scrap in an Electric Arc Furnace (EAF). The molten steel is formed into ingots or is continuously cast as in the case of conventional integrated steel plants. The EAF steel industry, also referred to as the mini steel industry has been plagued with the problems of lack of availability of steel scrap and consequent price escalations, as well as irregular availability of electric power. However in recent years, sponge iron, also called Directly Reduced (DR) iron has been found to be an effective partial substitute of scrap steel as a feed stock to EAFs. With the advent of sponge iron, the DR - EAF route to steel making has become a viable alternative to the conventional Blast Furnace route. The former does not require use of coking coals, which are fast depleting in the country; requires modest investments by comparison, and has much shorter gestation periods. Moreover capacity can be augmented in small increments to match the growth in demand for steel. Given these benefits, the Government has begun to encourage growth of the sponge iron industry in a big way. These plants will help ease the raw material problem being faced by EAFs, and reduce imports of steel scrap, which has been about 12 lakh tons in the year '83-84, if we include old ships that are imported for the purpose of being broken, in order to supply the resulting steel scrap to EAFs. Integrated DR-EAF plants are also conceivable in the future.

The demand for steel in the country, which was 8 Million tons (Mt) in '79-80 is expected to increase to over 18 Mt by '89-90. The share of EAF's in the total steel production, which was about 22% in 1982, is expected to increase in the coming years as sponge iron becomes increasingly available to EAFs, resulting in their better capacity utilisation, which is at present about 50%. At present there are two operating sponge iron plants in the country, which are primarily for demonstrational purpose.

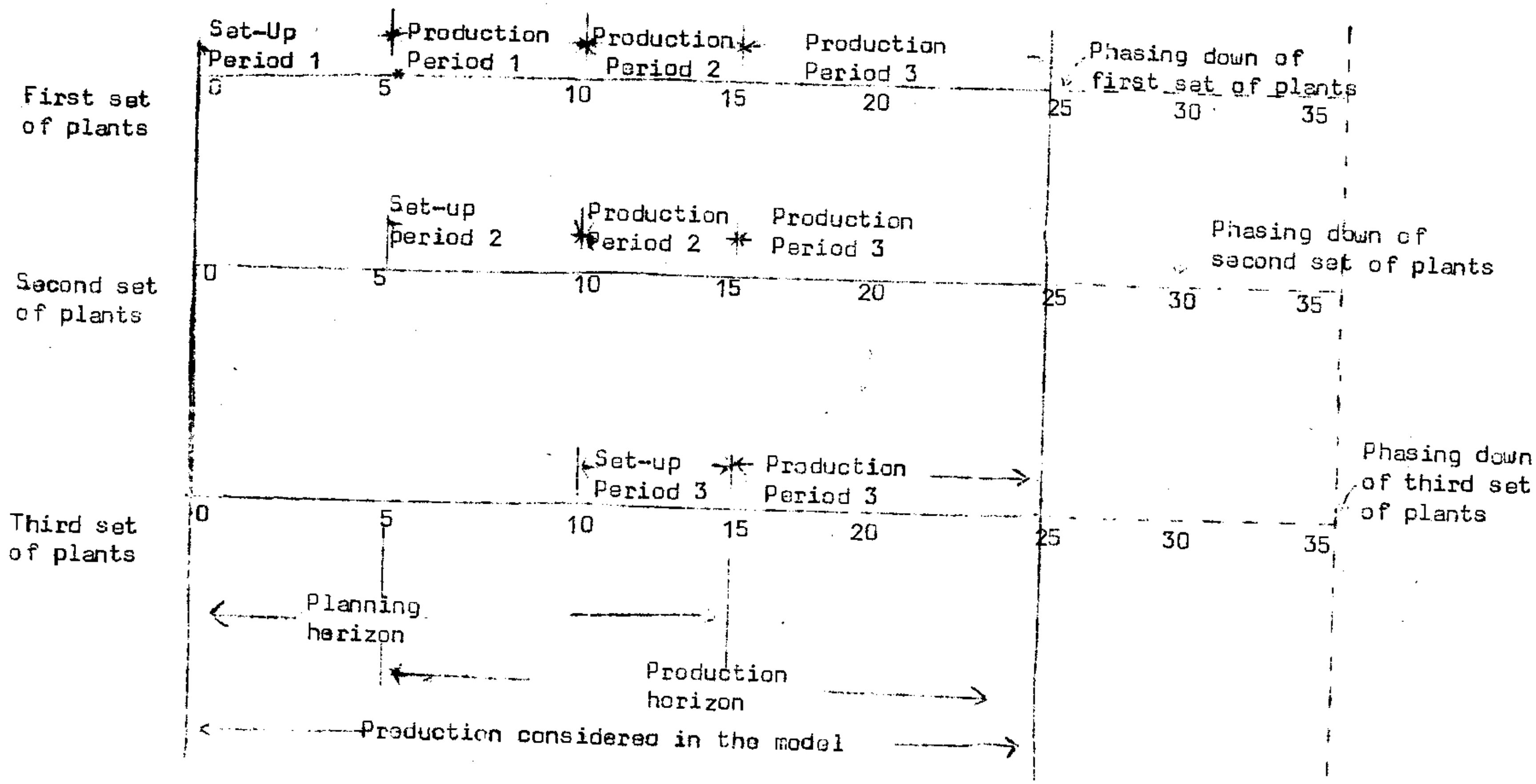
III. Framework of the Model

It is in this context that planning the growth of this industry is a problem being currently faced by the central planner. In the conceivable future the major users of sponge iron are likely to be EAFs. Sponge iron can also be used in conventional integrated steel plants, for example as a coolant in the Basic Oxygen Furnace. Thus the creation of sponge iron capacity showed match the demand for sponge iron from EAFs. It is unlikely that EAF capacity would increase substantially over the existing level, in the coming years, primarily because of the shortage of power being faced in many states. Thus the increased sponge iron availability in the coming years is likely to lead to better capacity utilisation of existing EAFs. This is the basis on which demand forecasts for sponge iron have been arrived at in the present study. The 189 EAF plants in the country with a total installed capacity of about 4.5 Mtpa have been agglomorated into 31 market centres for the purpose of the model.

Sponge iron, which is essentially a purified form of iron (about 90% Fe) is produced by removing oxygen from iron ore (about 65% Fe) in a reducing atmosphere. There are two commercially successful processes for sponge iron manufacture : (i) the coal-based rotary kiln process that uses iron ore lumps and non-coking coal as the primary raw materials, and (ii) the gas-based vertical shaft process that uses iron ore lumps, iron ore pellets and Natural gas as the primary raw materials. The former is available in two module sizes of 1.0 and 1.5 lakh tpa. The latter is available in two module sizes of 4.0 and 6.0 lakh tpa. Additional capacity at a location can be had by installing more modules. We have also identified the sources for non-coking coal; four sources for iron ore lumps and two sources for iron ore pellets. Natural gas is available from Bombay High, Gujarat and Assam. In addition, gas from Godavari basin is also likely to be available in the coming years. The gas from Bombay High would be piped to Babrala in Uttar Pradesh once the HBJ pipeline is commissioned. Gas would be available at any point along the route of the pipeline. Owing to the large number of gas-based fertilizer plants in Gujarat, gas from Gujarat is unlikely to be available for sponge iron manufacture, while Assam is not considered a suitable state for location of sponge iron plants since it does not have any EAFs, and additionally because of the bottlenecks in rail transport in that region. Limestone, which is another raw material required for coal based sponge iron manufacture was not explicitly included in the model since it is widely available in the country. Instead it was incorporated in the conversion cost for coal-based sponge iron.

Based on the above, it was possible to identify 25 potential locations for coal based sponge iron manufacture and 8 potential locations for gas-based sponge iron manufacture. The basis for this choice was nearness to markets or sources of raw materials or both. Table 1 gives the market-center-wise estimated demand for sponge iron till the turn of the century, after which the demand is expected to stabilize at that level. Table 2 lists the sources for major raw materials and the potential locations for the sponge iron plants. Table 3 gives the base level prices for various raw materials, as used in the model.

The model does not assume any capacity limitations for transport of material from source to destination. However this is not restrictive since any sectors where transportation bottlenecks are present can be taken care of by incorporating approximate transportation constraints. Market prices are assumed to reflect the worth of each resource to the nation and are used in the objective function. If social costs are available, these can be used instead. The problem in using social costs is the inability in most cases to quantify them. Such a quantification requires assessment of the total costs and benefits to the society for each resource employed. There are two problems associated with such a quantification. The first is in identification of the costs and benefits, especially in the presence of externalities. A second problem is their measurement. A single indistinguishable product results from all the processes, so that each market may be supplied from one or more location-process combinations. Plants are set up during the planning horizon, which is divided into three set-up periods of five years each; corresponding roughly to the gestation period for setting up those plants. Plants set up in a particular set-up period become operative at the end of the set-up period and are available for full stream production. Annual allocation of product from plants to markets remain unchanged until the system undergoes a 'perturbation' through addition of new plants at the end of set-up periods. Such periods of unaltered allocation are referred to here as production periods. Figure 1 shows a schematic of the set-up and production periods, where the life of a module is assumed as twenty years from the time of commissioning.



* These numbers represent years.

Figure 1. Schematic Illustration of Planning & Production Periods

Demands for sponge iron from each market in each production period is given. These demands may not change during a production period but may increase to new levels at the end of each production period. The existing small capacity of sponge iron plants, mainly in the form of experimental and demonstrational plants are ignored in the model although this can be readily incorporated in the model. Capital costs for the 2nd, 3rd and 4th modules of a particular process and size at a location cost respectively 75%, 70% and 65% of the corresponding capital cost for the first module. This accounts for economies of scale in the investment cost, since some common infrastructural facilities such as utilities, housing etc. will require only less than proportional incremental investment.

With these assumptions, the model which is described in Appendix was developed. The peculiarities of the particular industry have lead to certain modifications of the model. Since the envisaged peak production of sponge iron of 2.5 Mtpa is much less than the reserves, the constraints representing supply of raw materials become redundant. This enables for each potential location, supply of raw materials from that source which is closest to it. Consequently terms representing raw material cost plus frieght and handling can be included in the cost of conversion and transportation of the product after suitable incorporation of the specific consumption norms. This composite cost is referred to here as convertation cost. The constraints representing material balances can also be dropped now since this is implicitly incorporated in the convertation cost. Since the worldwide capacity utilisation for the sponge iron industry is only about 30%, representing surplus capacity created, export of sponge iron is discarded as a possibility. Moreover since India has an abundance of all the raw materials required for sponge iron manufacture, import of sponge iron is also not considered worthwhile, given the policy of self reliance of the country. These modifications give a closed economy version of the model presented in the appendix. Consequently the mode of transport for raw materials and product has been assumed as railways, although other modes can be incorporated in the model if found appropriate.

Excessive geographic concentration of sponge iron capacity is avoided by preventing no more than one gas-based module at a location from being set up. From an implementation point of view an average of no more than two coal based modules per set-up period are permitted. Based on experience with coal-based modules world-wide, no more than a total of four modules at a location are allowed. These modifications, when incorporated on the model in Appendix result in a large sized mixed (0-1) integer linear program with 3069 continuous variables, 548 (0-1) integer variables and 721 constraints. The (0-1) integer variables represent non-selection and selection respectively of various modules at each location during each set-up period. The continuous variables represent the amount of product manufactured from a particular technology, that is moved from each plant to each market during each production period. This can be used to back-calculate movements of raw materials.

The objective function in the model is the sum of Fixed cost and convertation cost. This can be interpreted as the value of all the resources consumed in order to make sponge iron available in the demanded quantities by the EAFs over the next twenty-five years, which is the horizon for the model. The fixed cost includes fixed investment cost less salvage value at the end of the model horizon, salaries and wages, fixed overhead costs and an appropriate component of the working capital requirements. The convertation cost represents the present value of the cost of transporting raw materials from respective nearest sources to plants and of product from plants to markets plus all other variable costs of production. All costs are taken at their present value, and a discounting factor of 3% has been used after assuming prices at constant money value, to account for the time value of money. The maximum allowable excess capacity for the industry as a whole was set at 10%, and at most 10 locations out of the 25 potential locations were allowed to be selected to prevent too thin a spreading of resources. Atmost one technology was allowed at locations where both technologies were feasible, to enable regional dispersal. Only one modular size within a technology was permitted at a location to avoid keeping spares for various module sizes. This was done from an operational point of view.

The model was solved using an algorithm specifically designed for the purpose. This is based on a suitable decomposition scheme and provides good solutions very rapidly. The algorithm was coded in FORTRAN IV and implemented on a PDP 11/10 computer. The solutions discussed in the following section resulted after between 90 to 150 minutes of CPU time.

IV. Solutions under various Governmental Policies

Four different policies have been considered, and the solution obtained in each case. These policies are illustrative and not exhaustive. The purpose of using them is to demonstrate how various governmental policies can be handled by the model. All the policies can be handled by the model. All the policies were solved for the base level of prices and demands.

Policy 1 is one of no intervention, which implies that the Planner does not restrict the solution in any manner. This is opposed to the remaining three policies, where based on certain governmental considerations, certain options are straightaway ruled out. Policy 2 requires regional dispersal of plants, which would result for instance by allowing no more than two coal based modules at a location. Thus all variables corresponding to the third and fourth coal based modules at a location are set to zero to start with. Policy 3 disallowes gas-based sponge iron plants in the country. This policy may be required if the Government envisages other more important uses for Natural gas. In policy 4, setting up sponge iron plants in the Eastern zone is disallowed. This may be necessary, since a large percentage of steel making capacity today is in Eastern India. Since the steel consuming centers are spread all over the country, it is meaningful from a national point of view, to prevent through deliberate policy, new steel-related capacities from being set up in Eastern India.

Table 4 summarises the solutions obtained by solving the model under the above four policies. In all the four policies, no gas-based module was chosen. Thus the solution to policy 1 and policy 3 are identical. In both cases only six locations were selected. If the maximum number of modules is restricted to two, thus forcing regional dispersal, ten locations are chosen. The objective function value for this alternative is Rs 2976.5 crores, which is only Rs. 42 crores more than the objective function value for the policy of no intervention. This is not a large difference, and thus the policy of regional dispersal may be worth-while. Policy 4 results in a total cost of Rs. 3200 crores, which is about Rs. 250 crores more than the total cost of policy 1. The Planner may nevertheless pursue this policy should he feel that reversing the concentration of steel-making capacity in Eastern India is worth even though it costs the country about Rs 250 crores more.

V. Sensitivity Parameters

We now discuss solutions to the model under various levels of problem parameters for which there was some uncertainty. All these solutions correspond to the policy of no intervention. Such a sensitivity analysis enables the planner to determine if the solutions to the model are robust with respect to changes in the values of various problem parameters. These include changes in demands, changes in costs of raw materials, changes in freight rates and simultaneous variation of several of these.

The base level demands for the third production period shown in Table 1 have been estimated on the assumption that 50% of the Ferrous input to EAFs would be sponge iron and that all the existing EAFs would reach full capacity utilisation by then. For the first two production periods the market-wise yearly demands would be respectively 25% and 50% of the corresponding base level demands for the third period. In this way the growth in sponge iron usage would match the increasing acceptance to use sponge iron amongst EAF operators. Three other demand scenarios were considered. The first is an optimistic scenario where the yearly demands for the three periods respectively are 25%, 60% and 72% of the base level demands for the third period. The second is a pessimistic scenario where the percentages are respectively 25, 40 and 75%. Finally the third scenario assumes that the demands for the three periods respectively are 15, 30 and 50% of the third period base level demands. All the these demands sensitivities were made using base level raw material prices and freight rates. The results are shown in Table 5. At all locations only coal based modules have been picked up. The locations Durg, Asansol, Tadali and Korba appear in all the scenarios and are thus fairly robust with respect to demand .

The base level price of gas was assumed to be Rs 1400/1000 Nm^3 at source, and the base-level pumping cost as Rs0.5/1000 Nm^3/Km. For base level demands as well as prices of all other raw materials, the gas price and pumping cost were varied over a range, as shown in Table 6, to see the effect on the solution. The price of Rs 1400/1000 Nm^3 represents the Naptha replacement price of gas, while the price of gas. Finally a price of Rs. 0/1000 Nm^3 was also considered, since at present much of the gas produced is being flared away for want of alternative uses for it. Apart from the base level pumping cost of Rs 0.5/1000 Nm^3/Km, a pumping cost of Rs 0.1/1000 Nm^3/Km was also considered to see if the solution changed. The results are presented in Table 6. These results indicate that even at a price of

Rs 700/1000 Nm^3 for Natural gas, no gas-based plant is preferred. For the gas price of Rs 0/1000 Nm^3, only one gas-based module is picked up, and that too in the third period.

The Government has been considering a gas price of Rs 2100/1000 Nm^3 for the Fertilizer industry, which falls in the priority sector. For sponge iron, even at prices as low as Rs 700/1000 Nm^3, gas-based process does not appear very suitable from the perspective of the country as a whole. The price at which gas would be made available to the sponge iron industry is yet to be finalised by the Government. However it is unlikely to be less than Rs 1400/1000 Nm^3. One reason why gas-based modules are not picked up in the solution even when the gas price is reduced is that having relatively large modular capacities, concentration of capacity at a location is in-built into them, resulting in need for considerable movement of raw material, finished product or both.

For the three cases of a doubling in the price of coal; a 50% reduction in the price of iron ore pellets, and a doubling in the price of iron ore lumps, and in each case keeping all other parameters at their base levels, the location of plants and location-wise set-up period-wise process selection and capacity buil-up are same as in the base case.

Apart from the base level freight costs, which was based on prevailing Railway tariff rates, three other levels of freight costs representing respectively 50% increase, 25% increase and 25% decrease compared to the base level were used to solve the model, keeping prices of all raw materials at their respective base levels. The results, presented in Table 7, show that the solution changes quite marked by for increase in freight costs. Thus for instance Bara Jamda was picked up by the solution only in the third period for base freight costs, at higher freight costs it is picked up earlier. This is to be expected since Bara Jamda is located very close to raw materials for the coal-based process, so that when freight costs become high, the locations shift closer to sources of these raw materials whose specific consumption is greater than unity.

Simultaneous variation in several problem parameters was considered, by identifying six scenerios for the prices of various raw materials. Base level demands and freight rates were maintained in all cases. The six scenerios are listed in Table 8. The solutions to the model for these cases are presented in Table 9. Scenerio the base case does not yield any gas based plants. Scenerio 4, which is the worst scenerio for both processes yields a gas-based plant in Bombay in the third period. For the remaining scenerios representing the best on realistic best scenerios for the gas-based process, so that the price of gas is Rs 700/1000 Nm^3 or less, one or more gas-based modules are picked up by the solution. The coal-based locations are very robust with respect to various scenerios and thus those locations are not very sensitive to the prices of various raw materials.

VI Concluding Remarks

An important problem of concern to the Central Planner that of planning for optimal growth strategy for an industry was discussed above. An opeational Research model is formulated to aid the decision maker to arrive at the best combination of plant location, location-wise process technology, location-wise process technology-wise capacity and its time phasing, and allocation of raw materials and product. The model has enabled incorporation of policy, decisions, and also an extensive sensitivity analysis of the solution to various problem parameters over which there was some uncertainty. Application of the model to India sponge Iron industry and policy implications provides the Planner the rational basis for optimal growth strategy.

Near optimal or good solutions to models such as the one proposed here in the context of the Indian sponge iron industry could provide a rational basis for crucial decisions regarding in industrial planning. In the specific example of this industry for instance we find that while the Government has licensed gas-based plants at Bombay and Hazira, as Table 10 shows, gas-based plants do not appear in our results under conditions of likely prices of various raw materials. A review and rethinking for optimal growth strategy for sponge iron industry thus is needed and the central planning from the national view point can be aided by the framework proposed in this paper.

Table 1

Market Center-wise demand for Sponge iron

Sl. No.	Market Center	Demand for Sponge iron (10^4 tons.)		
		1990-91	1995-96	2000-2001
1	Delhi	8.8025	17.605	35.21
2	Hisar	1.0375	2.075	4.15
3	Ambala	0.885	1.77	3.54
4.	Ludhiana	3.8475	7.695	15.39
5	Jaipur	2.475	4.95	9.9
6	Lucknow	3.4325	6.865	13.73
7	Muzaffarnagar	1.7375	3.475	6.95
8	Tatanagar	2.0275	4.055	8.11
9	Ranchi	1.175	2.35	4.7
10	Bara Jamda	0.0525	0.105	0.21
11	Calcutta	10.705	21-41	42.82
12	Rajkot	0.4125	0.825	1.65
13	Ahmedabad	0.845	1.69	3.38
14	Baroda	1.3075	2.615	5.23
15	Raipur	1.7775	3.555	7.11
16	Gwalior	0.565	1.13	2.26
17	Indore	1.9125	3.825	7.65
18	Jabalpur	0.1825	0.365	0.73
19	Bombay	9.37	18.74	37.48
20	Nagpur	2.485	4.97	9.94
21	Aurangabad	0.35	0.70	1.40
22	Kolhapur	0.6775	1.355	2.71
23	Waltair	0.8075	1.615	3.23
24	Secunderabad	1.16	2.32	4.64
25	Kothagudam	2.44	4.88	9.76
26	Bangalore	2.65	5.3	10.6
27	Hospet	0.5575	1.115	2.23
28	Bhadravati	1.48	2.96	5.92
29	Calicut	1.275	2.55	5.1
30	Madras	2.1175	4.235	8.47
31	Tiruchirapalli	0.245	0.49	0.98
	Total	68.795	137.59	275.18

Table 2

List of sources for Major Raw Materials and List of Potential Locations for Sponge Iron Plants

A. List of sources of Major Raw Materials :

1. Non-coking coal :

   Mamguru, Talcher, Tadali, Asansol, Neyveli Korba, Amnla, Anuppur, Mahdaiya, Brkakara

2. Iron ore lumps :

   Bara Jamda, Vasco da Gama, Bellary, Dalli-Rajhara

3. Iron ore pellets :

   Vasco da Gama, Dalli-Rajhara

4. Gas :

   Bombay High, Godavari Basin

B. List of Potential Locations for Sponge Iron Plants :

Kothagudem (c)*, Bara Jamda (c), Chandil (c), Hazira (c,g)*, Bombay (c,g), Hospet (c), Purulia (c), Delhi (c), Ludhiana (c), Calcutta (c), Bhadravati (c), Madras (c), Unnao (c,g), Baroda (c,g), Ujjain (c,g), Shahjahanpur (c,g), Babrala (c,g), Narasapur (c,g), Vasco da Gama (c), Durg (c), Asansol (c), Talcher (c), Tadali (c), Neyveli (c), Korba (c).

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* (c) indicates that only coal-based plants are possible at that location;

(c,g) indicates that both coal-based and gas-based plants are possible at that location.

Table 3 Prices of Raw Materials at Respective Sources*

Sl. No.	Raw Material	Price of Raw Material (Rs)
1	Non Coking coal	370/T
2	Iron ore lumps	85/T
3	Iron ore pellets	400/T
4	Natural Gas**	1400/1000 Nm^3
5	Limestone	270/T
6	Electric Power	0.45/KWh
7	Water***	1.5/m^3

* Source: Discussions with Ipitata Sponge Iron Limited Jamshedpur and MECON, Ranchi

** Considerable uncertainty in the price of gas exists. Moreover, the cost of pumping gas may range from Rs. 0.10/1000 Nm^3/Km to as high as Rs. 0.50/1000 Nm^3/Km.

*** Includes cost of pumping the water.

Table 4

Solution to the DMMSLPA Problem: Policy-wise Comparison
(Base Prices and Demands)

	Policy 1 No Intervention				Policy 2 Regional dispersal of plants				Policy 3 No gas based plants				Policy 4 No plants in Eastern India			
	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3
1. *Locations*																
Kothagudem					C			1					C			4
Bara Jamda	C*			4**	C		2		C			4				
Chandil					C			2								
Hospet	C			2					C			2	C	1	1	2
Calcutta					C			2								
Madras					C			2								
Unnao													C			3
Vasco					C			2					C	2	2	
Durg	C	2	2		C	2			C	2	2					
Asansol	C	1	1	2	C	1	1		C	1	1	2				
Tadali	C			1	C		2		C			1	C	2	2	
Korba	C	2	2		C	2			C	2	2					
2. Z (Rs. Cr)	2934.8				2976.5				2934.8				3200.3			
$-V^{+}$ (Rs. Cr)	2089.6				2067.9				2089.6				2360.9			
$-F^{++}$ (Rs. Cr)	845.2				908.6				845.2				839.4			

* Represents Coal based process; size of module: 1.5 lakh tpa

** This represents the no. of modules of the process installed at a location during period t.

\+ V: Variable Cost Component of Z; ++ F: Fixed Cost Component of Z

Table 5

Solution to the DMMSLPA Problem under Various Sponge Iron Demand Scenarios
(Base level Prices for all Inputs, No Policy Intervention)

	Base level demands				Scenario 1 Yearly marketwise demands in the three periods are respectively 25%, 60% and 125% of base demands for third period				Scenario 2* Yearly marketwise demands in the three periods are respectively 25%, 40% and 75% of base demands for the third period				Scenario 3* Yearly marketwise demands in the three periods are respectively 15%, 30% and 50% of base demands for the third period			
1. Location	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3
Bara Jamda	C			4	C			4					C			2
Hospet	C			2					C			1				
Madras					C			1								
Vasco					C			2								
Durg	C	2	2		C	2	2		C	2	2		C	2	2	
Asansol	C	1	1	2	C	1	3		C	2	2					
[illegible]	C			1	C			4				1				
Korba	C	2	2		C	2	2		C	2	2		C	2	1	1
2. Z (Rs. Cr)	2934.8				3515.1				2394.4				1642.5			
-V (Rs. Cr)	2089.7				2519.0				1663.3				1143.6			
-F (Rs. Cr)	845.8				996.1				731.1				498.9			

* For these two scenarios the constraints on over capacity for the country as a whole were removed since using an over capacity factor of 10% lead to no feasible solutions.

Table 6

Solution to the DMMSLPA Problem under Various Levels of Gas Prices and Gas Pumping Rates

(Base level market-center-wise demands for all the three period, base level prices for all raw materials except gas, No policy intervention)

Price of gas (Rs/1000 Nm^3)	1400				1400				700				0.0				0.0			
Gas pumping Rs/1000 Nm^3/Km	0.5				0.1				0.1				0.5				0.1			
1. Location	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3
Bara Jamda	C			4	C			4	C			4	C			4	C			4
Bombay													G			1	G			1
Hospet	C			2	C			2	C			2								
Durg	C	2	2		C	2	2		C	2	2		C	2	2		C	2	2	
Asansol	C	1	1	2	C	1	1	2	C	1	1	2	C	1	1	2	C	1	1	2
Tadali	C			1	C			1	C			1	C			1	C			1
Korba	C	2	2		C	2	2		C	2	2		C	2	2		C	2	2	

2. Z (Rs. Cr)	2934.8	2934.8	2934.8	2923.4	2919.0
-V (Rs. Cr)	2089.7	2089.7	2089.7	2066.7	2062.4
-F (Rs. Cr)	845.1	845.1	845.1	856.7	856.6

Table 7

Solution to the DMMSLPA Problem for Various Freight Costs
(Base level demands, base level prices of all raw materials;
No policy intervention)

	Base Freight rates			Freight rates 50% higher than Base freight values			Freight rates 25% higher than base values			Freight rates 25% lower than Base values		
1. Location	t=1	t=2	t=3	t=1	t=2	t=3	t=1	t=2	t=3	t=1	t=2	t=3
Bara Jamda			4*	2	2		2	2				4
Chandil						1						
Hospet			2									2
Madras						1			1			
Vasco						1			1			
Durg	2	2		2	2		2	2		2	2	
Asansol	1	1	2			4			4	1	1	2
Tadali			1						1			1
Korba	2	2		1	1	2	1	1	2	2	2	
2. Z (Rs. Cr)		2934.8			3327.3			3120.5			2735.8	
-V (Rs. Cr)		2089.7			2470.6			2266.2			1890.6	
-F (Rs. Cr)		845.1			856.6			854.4			845.2	

+ All modules are coal-based modules

Table 8

Six Scenarios when more than one Problem Parameter is changed for which the DMMSLPA Problem was Solved

Scenario	Description	Price of Natural gas at source Rs/1000Nm^3	Cost of pumping gas Rs/10[illegible] Nm^3/Km	Price of coal at source Rs/T	Price of iron ore pellets at source /T	Price of iron ore lumps at source Rs/T
I	Base Prices for all raw materials	1400	0.5	370	400	85
II	Best scenario for gas-based process; worst scenario for coal-based processes	0.0	0.1	740	200	85
III	Best scenario for both coal and gas-based processes	0.0	0.1	370	200	85
IV	Worst scenario for both coal and gas-based processes	1400*	0.5	740	400	170
V	Realistic best scenario fpr gas-based process; worst scenario for coal-based process	700	0.5	740	200	85
VI	Realistic best scenario for gas-based process; best scenario for coal-based process	700	0.5	370	200	85

* Since the Government has not yet decided the prices at which Natural Gas would be made available for the sponge iron industry, a price of Rs.1400/1000Nm^3 has been taken as the price for the worst scenario for gas-based sponge iron manufacture. Beyond this price, for instance at a price of Rs. 2100/1000Nm^3, gas based sponge iron manufacture becomes unviable even from the point of view of the individual investor.

Table 9

Solution to the DMMSLPA Problem for Various Scenarios of Table 8

(Joint Sensitivity Analysis)

(Base level market-center-wise demands for all three periods, over capacity factor of 10% for each production period, No policy intervention)

	Scenario1 Base prices for all raw materials				Scenario2 Best Scenario for gas-based process, worst scenario for coal-vased process				Scenario 3 Bestscenario for both coal and gas based processes				Scenario 4 Worst scenario for both coal and gas-based processes				Scenario 5 Realistic best scenario for gas-based process; worst scenario for coal-based process				Scenario 6 Realistic best scenario for gas-based process; best scenario for coal-based process			
1. Location	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3	Process	t=1	t=2	t=3
Kothagudem																								
Bara Jamda	C			4	C			3					C			4	C			3	C			4
Hazira					G			1	G			1					G			1	G			1
Bombay					G	1			G	1			G			1	G	1			G			1
Calcutta																								
Madras																								
Unnao					G		1		G		1						G		1					
Ujjain					G		1		G		1													
Durg	C	2	2		C	2		2	C	2		2	C	2	2		C	2		2	C	2	2	
Asansol	C	1	1	2					C		3		C	1	1	2					C	1	1	2
Tadali	C			1									C			1					C			1
Korba	C	2	2		C			1	C			1	C	2	2		C			4	C	2	2	
2. Z (Rs. Cr)	2934.8				2886.6				2642.1				3962.7				3352.4				2934.6			
-V (Rs. Cr)	2089.7				2079.7				1835.1				3106.1				2543.4				2078.0			
-F (Rs. Cr)	845.1				806.9				807.0				856.6				809.0				856.6			

Table 10 Details of Licenses issued for Sponge Iron Manufacture in India*

Sl. No.	Company	Location	Process	Installed Capacity tpa	Remarks
1	Sponge Iron India Limited	Kothagudem (Andhra Pradesh)	SL/RN	30,000	In Operation
2	Orissa Sponge Iron Limited	Keonjhar (Orissa)	ACCAR	150,000	In Operation
3	Ipitata Sponge Iron Limited	Joda (Orissa)	TDR	90,000	Project being implemented
4	Bihar Sponge Iron Limited	Chandil (Bihar)	SL/RN	150,000	"
5	Gujarat Industrial Development Corp. Limited	Hazira (Gujarat	Gas-based	400,000	Gas to be obtained from Bombay High. To be implemented.
6	State Industries & Investment Corp. of Maharastra Limited	Alibagh (Bombay)	Gas-based	400,000	Gas to be obtained from Bombay High. To be implemented.

* Source : Discussions with Department of Steel, Government of India

APPENDIX

The Operational Research model that was solved is a mathematical translation of the following physical model.

Minimise the following sum:

Fixed cost + cost of raw materials, freight and handling + conversion cost at plant + freight of product + cost of import of sponge iron - (Revenue from export of sponge iron - cost of export of sponge iron).

The following constraints should be satisfied:

1. Domestic demand for sponge iron must be met through indigenous production and imports.
2. Export commitments must be met from indigenous production.
3. Indigenous production cannot exceed installed capacity
4. Imports cannot exceed availability in the foreign markets
5. There can be atmost one first module for each technology, size and location, although this first module may have been installed in any of the three set-up periods. Likewise atmost one second, third and fourth modules are possible.
6. The modules installed must follow precedence constraints. The second module cannot be installed before the first, for instance. This is necessary since we assume the second module capital cost is 75% of that of the first module. In the absence of this constraint, cost minimisation will attempt to instal the second module before the first.
7. There can be atmost four coal-based and atmost one gas-based modules at a location
8. Only one technology - size type is allowed at a location
9. To prevent too thin a spreading of resources (and incidentally to help fasten search for the optimal solution), atmost 10 location from among 25 potential locations may be chosen.
10. No more raw material than is available at each source can be supplied to the plants.
11. The raw materials reaching each plant must be in proper proportion to the output of sponge iron from the plant This proporwill depend on the specific consumption norms for that technology.

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