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DETERMINATION OF THE OPTIMUM CAPACITY OF THE FULLY INTEGRATED IRON AND STEEL PLANTS AND ITS PARTS [1]

by

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1/ The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the secretariat of UNIDO. The document is presented as submitted by the authors, without re-editing.

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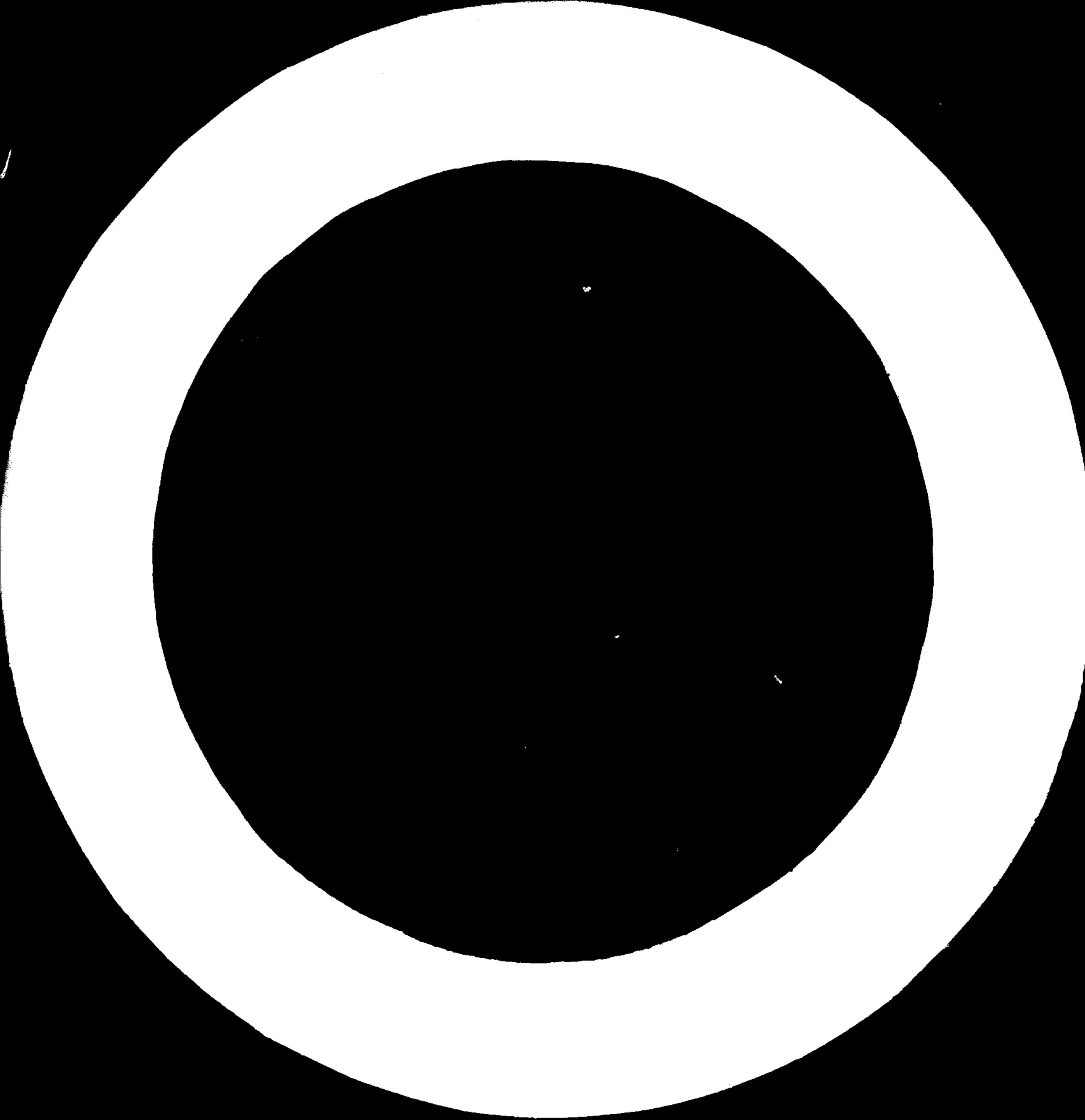

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The capacity of a steelworks manifests itself in two ways, the rate of production and the diversity of products. A particular combination of these characteristics may match the required output of the works at some point in time, but generally the actual capacity of the works is either insufficient to meet the possible demands it is in a position to satisfy, or too great in which case plant is under-utilised. The optimum capacity is that which, over the working life span of the plant, minimises the effects of missed opportunities on the one hand and of idle plant on the other. Although expressed as an annual output of steel or as the dimensions of a piece of plant the optimum capacity is in fact the economic parameter representing the size of enterprise having the highest possible profit within the given terms of reference. It follows that optimum capacity is one of the main parameters defining the course of action in the strategic plan for the development of an integrated iron and steel industrial project because the plant, of fixed capacity once installed, has a useful life measured in decades.

The long term implications of such a plan require that all foreseeable contingencies and circumstances are considered and weighed against each other. As a result the optimum capacity of a works is seen to depend on a number of criteria set by economic, sociological, political and technological considerations relevant to the situation.

The technological factors relate mainly to capacity as such, so that it is convenient to deal with these first. The capacity of a works is itself determined by the capacity of the individual process units of which it is composed. The capacity of a process is here defined as the annual output of the major element of plant in the process when operating under normal conditions of skill and management. These conditions vary from situation to situation. For a given situation they fix the basic technological parameters of the process, relating annual output to the designed performance of the plant and determining the operating requirements of the process. It is assumed in this paper that these parameters have already been defined for each process considered and that the processes themselves are technologically suitable for the materials fed to them and for the products so produced.

Economic criteria become relevant as soon as a process is considered for commercial exploitation. The sociological and political implications arise at a national level and are especially important in developing countries where the success of an iron and steel project cannot always be demonstrated on commercial grounds alone.

These criteria are identified and their effects on the capacity of the works then discussed. Some of the criteria govern specific parts of the plant. Others affect it in its entirety. To give order to the treatment of the subject, the analysis is visualized as a number of concentric shells, each representing a particular sphere of influence. The innermost shell represents the individual processes, the next the complete works, then the national economic framework, and finally the life span of the enterprise. This is a simplified treatment which ignores the fact that many of the criteria are applicable to situations in more than one shell. However, the method demonstrates the way in which the optimum capacity can be determined, enabling planners to extend the principles to more complex applications.

2. Application of the criteria

The capacity of a steel works is, as already mentioned, a combination of rate of production and diversity of products. Some of the criteria encourage the planner to consider high production rates and a wide diversity of products, while others require him to restrict his view on one or other of these characteristics. The criteria which have to be considered are

Economics of scale

Relationship of capital to operating costs

Yields of processes

Unsatisfied demand

Variation in demand

Product mix

Shortage of resources

Sociological benefits

Political strategy

Profitability

Before attempting to define these, it is essential to find a suitable scale of measurement by which each may be quantified. Direct evaluation in terms of tonnage of steel required, number of men employed, variety of products offered or increase in national prestige achieved is of little use since it is impossible to interrelate such dimensions. The planner must find some common ground for comparison. This he can do by studying the effects of each criterion on the costs of the enterprise and hence convert them into their cost equivalent.

Some components of cost of a process are represented by a single sum, such as capital costs of plant, while others are recurring charges, for instance manning costs. Before proceeding further, some relationship between these two types of cost must be set up for it is not always clear which of two or more processes of the same technical feasibility represents the best investment when either capital or operating costs are considered separately. One process may have a low annual operating cost and a high capital cost an alternative may have a high operating cost but require little capital - the use of existing or secondhand equipment requiring minor modification may fall into this category.

It is necessary therefore to establish a parameter which incorporates both types of cost. This can be done by regarding capital as a commodity which is hired for an annual charge. This charge must necessarily include for:

(a) Depreciation (that is, it must take into account the life of the asset).

(b) A satisfactory profit margin (a measure of the value of capital)

(c) The absence of profit during the construction period.

(d) A measure of the risk involved in the investment.

The addition of this annual charge to the annual operating cost or conversion cost gives a new parameter by which alternative processes can be compared realistically. This single parameter is here termed comprehensive cost. It is used as illustrated in Figure 2. 1. The various elements of operating a hypothetical process - raw materials, fuel and consumables, and man power - are summated together with the capital charge giving the total comprehensive cost. In this case it has been expressed as the cost per tonne. There are small perturbations due to the pattern of shift working and a major perturbation as the charges on the capital required for a complete new unit arise. The dotted line indicates the comprehensive cost curve that would result if the process was constrained to single shift work, when injections of capital are required more frequently as the capacity of the process is increased.

It is not always possible to quantify a particular criterion before applying it. Sociological and political factors often fall into this category. It is however possible by costing alternative courses of action one of which relates to the application and the other to withholding of the relevant criterion to determine by difference the effect of it in monetary terms.

The criteria can now be studied in some detail to establish how each will influence the capacities of the processes of which the steelwork is composed.

Economics of scale

It is a characteristic of process economics that the capital charge per unit of capacity decreases as the size of the plant increases. This is true not only of a range of machines for one process but also of large complexes such as power stations, oil refineries and steelworks. At any time, there is usually an asymptotic level below which costs can not fall however much the capacity is increased but this is due to the currently accepted maximum unit size built. Examples are obvious in the transport field both in aircraft and in oil tankers.

The largest economic size may at any one time be controlled by a limit to technological development, a lack of adequate manufacturing facilities or insufficient capacity of supporting installations, such as airports and oil terminals.

Figure 2. 2 shows the comprehensive cost of a process plotted against designed capacity. Each point on the curve represents the cost of operating the process at that designed capacity. The basic significance of this criterion can best be illustrated by considering an example of, say, two steelworks. One has a capacity E and the other a capacity e, such that the comprehensive cost per tonne of steel of the first works is 10% greater than the cost at a very large works while that of the second works is 50% greater. In the case of the larger works it may well be that this 10%extra cost is less than the cost of shipping steel from a very large works in another country so that in spite of the lower capacity this is the cheaper way of obtaining steel in the country concerned. In the case of the smaller works, it is probable that even allowing for the cost of shipping steel from another country, the home produced steel is more expensive. This works must then be justified on other grounds.

Relationship of capital to operating costs

The comparison of processes by studying their comprehensive costs takes account of both the capital and operating elements of their economic make up. Both capital and operating costs vary from country to country, so that the economics of scale of a process will depend on the location of the plant. Often a process known to be competitive at a given capacity in a developed country is found to be uneconomic in a developing one. In a developed country, capital is cheap, risk low and labour expensive. The planner in a developing country is likely to find that the reverse is true.

Yields of processes

The yield of a process, that is the ratio of output to input, is fixed by the technological characteristics ascribed to the process. It is of interest here when alternative chains of processes are studied. The yields across each chain are unlikely to be the same so that for the same output different inputs will be required.

The rolling and finishing processes of a steelworks need most study on this account for the demand from these determines the capacities of the earlier processes in the chain. Also, due to technological restraints, it is not always possible to build plant for these processes to the precise capacity required so that it may be more economic to forgo the full use of the capacity available in a finishing process than to expand the capacity of an earlier rolling process.

Unsatisfied demand

Ironically, world capacity for steel production exceeds current consumption so that in a global sense the demand can be satisfied. It is the economic imbalance between the producing and consuming countries which generates the unsatisfied demand. To the planner, the unsatisfied demand consists of two parts, that which is truly unsatisfied and that which is currently satisfied by the sacrifice of foreign exchange or other resources which could be put to a more effective use.

The unsatisfied demand can be defined as the total demand of the area under study less the capacity of the existing facilities in that area to satisfy it.

Variation in demand

The unsatisfied demand is a measure of the state of the market at any point in time. While this is a useful criterion on which to judge the choice of products and possible capacities of plant, it does not give an overall picture of the opportunities available. For strategic planning purposes, it is necessary to study the growth of markets and the changing levels of demand throughout the life span of the project.

The rate at which the market grows effects the utilization of the plant installed. This, in turn, has a bearing on the capacity of the plant. A rapid growth in a market followed by a steady demand will justify a larger capacity plant than a situation where the growth to the same level is gradual over a number of years. Growth rates must therefore be predicted. With a basic commodity like steel, these can be evaluated by studying the growth of the user industries, for example the construction industry as a user of rolled sections, reinforcing bar and galvanised sheet, mechanical engineering industries as consumers of merchant bars, castings and forgings or the food industry as a user of tinplate.

An example of the variation in unsatisfied demand for galvanised sheet is illustrated in Figure 2.3. The growth of the total demand is shown and the capacities of currently planned works set against this. The unsatisfied demand is shown shaded to illustrate how its pattern differs from the steady increase in total demand.

Product mix

Product mix affects capacity in two ways. It has a direct effect on the process making the finished product. It also has an impact on the chain of processes which are required to make the particular product.

The first effect is due to the range of products made in a process. In two different situations, the same range of products may be required but in one case the preponderence of the demand is for those at the lighter end of the range while in the second case the average weight of the products is nearer the heavier end. Due to the product range, the same plant may be required in each case, but its capacity will be greater in the second case than in the first.

Clearly, the difference in capacity caused by a shift in the average weight of the product mix has repercussions back up the chain of processes. This is a minor example of the second effect product mix has on capacity.

The main impact on the chain of process is caused by the disparity in capacities of plant in different processes. A number of products may each be produced on a different finishing process, but have originated from a common earlier process. Often this earlier process has a minimum economic capacity which it is impossible to absorb through a single product outlet. The planner must study the other possible products to see whether demands for these exist. If the one product has to bear the full costs of the under-utilised earlier process, it may prove more economic to ignore the particular market for which the product is intended and reduce the capacity of the works accordingly.

Shortage of resources

Shortage of resources may exercise either a temporary or permanent restraint on the capacity of the steelworks. These restraints are essentially economic, for it is technologically possible to overcome shortages of natural resources by transportation and manpower shortages by offering sufficient rewards and by direction of labour.

Permanency of a restraint in this context implies that it will prevail for the life span of the project. A temporary restraint can be expected to be withdrawn at some time during the period under study. For example, a dam built for hydro electric power generation may relieve the water shortage experienced during the dry season.

Resources are taken to include raw materials, fuel, power and water. All types of manpower whether unskilled, skilled, technical or managerial that are necessary to the plan are considered to be resources. Similarly financial resources, both internal capital and foreign exchange or credit, are included.

Sociological benefits

The establishment of an iron and steel industry in a developing country is often an unrewarding venture when viewed from a purely commercial standpoint. Other criteria must justify the action. Improvement in the sociological status of the population is one of these. It is apparent in increased purchasing power, higher levels of education and a betterment in the standard of living. This can only be achieved by improving the earning power of the individual, that is by upgrading the value of his work output. For a developing country this can be achieved by industrialisation, iron and steel being one of the first industries to establish.

It would appear from the advantages to be gained that industrialisation is desirable at any cost and it therefore becomes an overriding criterion. But it would be irresponsible to proceed without a knowledge of the price to be paid for advancing the standards of the country. The natural laws do not allow something for nothing so it is necessary to know the cost in order to be able to check that the increased earning power of the people can in the long term repay the investment.

Political strategy

Political implications of industrialisation are very much the intranational effects of the national concern for sociological improvement. Developing countries established originally on a heritage of natural resources now need to exploit the resources of their manpower as well to balance the costs of imports. The principal purpose of political economic strategy is the saving of foreign exchange. This applies both to the capital expenditure incurred during the building of the project and to the savings of imports once production commences. Trade agreements and regional economic alliances are other aspects of political strategy which are directed to the same end. Where these exist, their effect on the plan must be evaluated.

Profitability

It is accepted that the business man expects a profitable return on his investment when he initiates industrial development, that is, he wishes to make effective use of his money. Motives in the public sector are more complex involving political and sociological criteria but, nevertheless, it is equally vital that the financial resources employed should be used to most effect. The political and sociological considerations may influence the economic terms of reference by which profitability is measured but, even so, overall profitability should still be the yardstick of the effective use of money.

The comprehensive cost enables the planner to evaluate the effects of criteria in steady state or static conditions. Profitability is an assessment of the dynamic efficiency of a plan, a criterion for the performance of the enterprise through time. One measure of profitability is the discounted rate of return of the net-of-tax cash flows generated by the enterprise. This parameter - which is gaining in acceptance - provides a single index by which the complex pattern of inflows and outgoings of money associated with a strategic plan can be represented. It has the advantage that it can then be used to rank alternative strategies.

3. Primary processes

The chain of processes required for converting iron ore into finished steel products can be conveniently, if artificially, broken in two parts, one part consisting of those processes culminating in the production of liquid steel and the other in those which convert the liquid steel into the final products. For the purposes of this paper, the two groups of processes are referred to as primary and secondary respectively.

Figure 3.1 shows a range of alternative processes for extracting iron from ore, followed by the associated alternative steelmaking processes. This is not an exhaustive list, but it gives an idea of the chains of primary processes that the planner may have to consider.

The capacity of the primary processes is governed to some extent by the availability of raw materials and sources of power available. For instance, the proposal to set up a steelworks may have been based on a locally available source of iron ore which is of limited size. One solution is to build a works of such a capacity that the supply of iron ore is exhausted in, say, 20 years. It does not follow that this is the most economic plan for not only is development of the works restricted but also the cost of producing steel may be greater than that from a works of a larger capacity in which the local ore is supplemented by imported material, due to the economics of scale favouring the larger works.

Iron and steelmaking processes show pronounced economies of scale due to the plant maker's ability to provide a single unit of plant with any one of a very wide range of capacities. The time taken to develop a range of plant sizes and to master the operating techniques for each level of output varies from process to process. Thus, not all processes are developed to the same extent. This is particularly noticeable among the ironmaking processes where the present capacity of the kilns of the various direct reduction processes is markedly less than that of modern blast furnaces. In the capital intensive processes such as these, the economies of scale are small once capacities in excess of the maximum available in one unit of plant are reached. One process may, therefore, be cheaper than another at low capacities but the second cheaper at higher capacities because the latter enjoys economies of scale over a wide range of capacity.

The planner, wishing to study a range of capacity, may be faced with one chain of processes up to a certain level and a different chain thereafter. Figure 3.2 illustrates this point showing the comprehensive costs of ironmaking by the Elkem and blast furnace processes. In the upper pair of curves, the Elkem process is the cheaper at capacity levels below 280,000 tonnes per year, while in the lower pair of curves, it is cheaper only below an annual capacity of 60,000 tonnes.

The two curves have been drawn to show the significance of another criterion, that of the interaction between capital charges and operating costs. The upper curves represent the costs of iron production in a developing country in, say, Africa, where the basic capital expenditure is increased by freight and insurance charges and the additional costs of erection on a remote site. The lower curves relate to the same processes and plant in a European country where labour rates are higher and the principal raw material has to be imported.

These curves emphasise the point that the choice of process at a particular capacity level may not apply universally although the same technological conditions prevail.

Care must be exercised in making such comparisons to ensure that the processes are making the same product. Both the processes illustrated produce liquid iron and thus the same steelmaking process may be applied to their product. If however one process produces sponge iron and the other hot metal, then the changeover point from one process to the other will be affected by the steelmaking processes for it is seldom that two different processes have identical comprehensive costs over a wide range of capacity. The comparison is only valid when the chains of processes have been extended far enough to produce a common product, in this latter case, liquid steel.

4. Secondary processes

The capacity of the secondary processes is largely controlled by two factors - market demands and design characteristics of plant. The criteria associated with the market are unsatisfied demand, variation in demand and product mix. Only the first and last criteria are discussed here. The design characteristics are represented by the technological criteria of yield and economics of scale.

Figure 4. 1 shows a forecast of unsatisfied demand for bloom and billet products. In this case, the demands are large and may exceed the capacities determined by other criteria. The planner must therefore consider the advantages of specialising in one product range in contrast to the spread of risk by diversifying the capacity of the steelworks over a number of product types. For example the magnitude of the demand for rods and bars shown in the figure is such that a medium size works could be set up specifically to satisfy this particular demand. Usually the markets are small and various so that a number of different product groups have to be considered if a reasonable size of works is to result.

It is necessary to take care in the selection of the products to be made because, due to the earlier processes in the chain, they fall into groups. This is illustrated in Figure 4. 2. The demand for a product may have to be ignored because it is the only unsatisfied one of a group all of which are necessary to absorb the output of an early process in the chain. The galvanised sheet already mentioned is a typical example. This is one of the products derived from the hot strip mill as shown in Figure 4. 2. Without markets for the other products, an annual demand of 300,000 tonnes of galvanised sheet must be forecast to justify a Steckel mill while a semi-continuous mill will require a market of 1.5 million tonnes a year.

Product mix also influences the capacity of individual processes. It is not sufficient to identify a market only as a tonnage, it is necessary to know the range of products that are required and the distribution of demand through that range. A mill capable of producing a certain range of products will have a larger capacity if most of the demand is for the larger sizes than if it is for the smaller ones. This is illustrated in Figure 4.3 which shows the comprehensive cost curves for rod mills when the average sizes of the products rolled are 20, 25 and 30 mm. diameter. At the lower average size the output for a fully continuous mill is 380,000 tonnes per year while at the higher average the annual output is 550,000 tonnes.

A significant difference between plant for the primary and secondary processes is the greater flexibility there exists in the former for designing to suit a given capacity. It is difficult to design mills to specific capacities. The capacity of a mill is largely determined by the type of product it is to produce and its own configuration. There are usually three or four different; configurations of mill suitable for producing any one product. Each of these will cover a range of capacity but they do not together necessarily form a complete spectrum. Consequently, the economics of scale curve cannot be drawn as a continuous line. Figure 4.4 illustrates this effect for hot strip mills. The dotted lines are the cost curves of the lowest capacity mills in each group when running below capacity. Costs along these parts of the curves are always above

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DETERMINATION OF THE OPTIMUM CAPACITY OF THE FULLY INTEGRATED IRON AND STEEL PLANT AND ITS PARTS[1/]

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SUMMARY

Optimum capacity describes the size of the most profitable enterprise established to satisfy given terms of reference. It is one of the main parameters which is determined in the strategic planning stage of any development.

Strategic planning, being of a long-term nature, has to take account of all foreseeable circumstances. As a result, technological, economic, sociological and political factors have all to be assessed during the determination of optimum capacity.

Technological factors determine the capacity of individual process units, that is, their output under conditions of skill and management which can be considered as normal in a given situation. The capacity of a complete works is determined by that of its individual process units.

* This is a summary of a paper issued under the same title as ID/WG.14/48.

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. The document is presented as submitted by the author, without re-editing.

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those on the economics of scale curve, so that the planner is in a potentially disadvantageous position if he is constrained to work a plant in an under utilised condition.

Another facet of this problem is that sometimes the duty of the plant dictates its power and dimensional requirements to such an extent that the minimum size plant has an inherently large capacity. Mills capable of converting ingots into slabs, blooms and billets are of this type. For low tonnages they contribute a large capital charge to the comprehensive cost so that the alternative process of continuous casting which can be designed to cater for smaller capacities has been installed in many new works. The planner has thus alternative methods of processing which are directly inter changeable in terms of input and product. They are not however comparable in yield as is shown in Figure 4.5. These differences of yield must be taken into account during the assessment of alternative routes. They may also be a determining factor in the choice of the process route when the final selection of optimum plant capacities is made.

5. The complete works

The previous articles have dealt with the complete chain of processes in two parts. The primary processes gather the various raw materials together to produce the single product of liquid steel which is then diversified through the secondary processes into the range of finished products. For each part it is possible to prepare a minimum comprehensive cost envelope over a range of capacity. Such curves are given in Figures 5. 1 and 5. 2.

Figure 5. 1, the curve for the primary processes, has three parts, the first two relate to different process chains as portrayed earlier in Figure 3. 2. In this example, it is assumed that these represent strategies based on home ore exploitation and that the home ore reserves are small. Thus, the maximum capacity works that can be considered under these strategies is about 400, 000 tonnes per year. The third part represents the effect on the second chain of processes of supplementing the home ore with imported material at capacity levels above that which can be served by the home supply alone. Interpreting the curve, it is undesirable to consider annual capacity levels of less than 70 - to 80, 000 tonnes because the diseconomies of small scale production on the first process are becoming significant at these tonnages. The next point of decision is the maximum capacity that can be served by home ore alone. Beyond this point the cost of unit production increases and only falls below the earlier figure at a capacity of 480, 000 tonnes as the economies of scale continue to take effect. The figure has been simplified by the assumption that only one quality of steel is to be produced. Within the accuracy required for this type

of analysis, this is a reasonable assumption for common steels. High performance and alloy steels are best treated separately.

The curve for the secondary processes is more complex. It is again an envelope of a number of cost curves of different process chains but as can be seen the various chains contribute to the envelope at several points and in no logical order. One of the main problems in preparing this curve is the determination of the basis for it. In the primary processes the raw materials have prices which contribute to the total costs of processing but for the secondary processes the input is liquid steel the price of which is not determined until figure 5. 1 has been prepared. One method of avoiding the delay of producing these curves in sequence is to calculate the comprehensive costs of conversion only for the secondary processes. The conversion costs are not truly comparable because each chain has a different yield. For each finished product there is a different amount of steel required per unit of output. The planner can overcome this disparity by using the process chain with the best yield as a datum against which all the others can be debited for the excess increment of steel they require. For this purpose an estimate of the cost of steel will be sufficiently accurate because the error which may arise is now of the second order.

Scrap and energy credits can be included to the benefit of processes provided there is a reasonable possibility of their being consumed elsewhere in the complete integrated works. It is not wise at this stage of the analysis to assume sales of such by-products to outside markets, unless an established demand is known to exist.

The combination of Figures 5.1 and 5.2 gives a minimum comprehensive cost envelope for the complete chain of processes in the integrated iron and steel plant. Minor adjustments are necessary when the two are combined to take account of fuel, energy and scrap balances. For example, more or less scrap may arise in the secondary processes than is required in the steelmaking process for minimum cost operation. The imbalance of scrap has to be charged to the processes either as imported scrap if insufficient is arising or as a write off of part of the production of the secondary processes if there is a surfeit. An alternative strategy is the adoption of a different steelmaking practice which does absorb the amount of scrap arising but which may not be the minimum cost practice itself. The combination of this practice with the efficient use of the scrap arising may be the most economic overall solution.

The planner now has a selection of strategies extending over a range of capacity limited only by the total market available to him. The maximum level of production may be attained in, say, ten years from the original commissioning date, by which time the demands can be very large. So the planner must now consider what criteria may restrict the size of works to be built.

Shortage of resources will restrict the optimum capacity in a number of ways. Perhaps the most immediate is the possible shortage of capital with which to finance the project. If the shortage is marginal, the planner may consider adopting a strategy having minimum capital cost. This strategy will probably be more costly overall than that based on minimum comprehensive cost because of the higher operating costs that attend the lower capital investment. Bearing in mind that financial shortages are temporary in nature, an alternative to reducing the economic efficiency of the processes is to adopt the cheapest comprehensive solution but to build only part of the works initially. The planner must now analyse how the capital is divided between the major process groups. Figure 5. 3 shows this breakdown of a typical process chain for a works having an annual capacity of 125,000 tonnes. The planner may consider a works consisting first of the rolling mills using imported slabs, blooms or billets as feedstock. The next stage may be the steelplant using imported pig or reduced iron with the ironmaking facilities added later still. The phasing of the iron and steelplant is only possible if a cold charge is fed to the steel process. For hot charged processes, both iron and steelmaking plants must be built at the same time.

Restricted supplies of raw material have already been discussed. Services to the works must also be checked for adequacy. If the natural sources are insufficient then they must be supplemented in some way. Power or fuel deficiences can be made good by importing oil, gas or solid fuel and feeding them to a generating plant in the case of power. A shortage of water, on the other hand, may be best overcome by increased recirculation of that available. Clearly both solutions add cost to the process but this may be more economic than a reduction in capacity. The planner must review any plans for development of service facilities, for co-operative action between the planners concerned may result in a combined strategic plan which is more profitable than the individual plans for each project.

Manpower may also be in short supply not necessarily in general quantity but in specific skills both technological and managerial. This can be overcome by the employing of expatriate labour or by initial training of nationals. Both courses again add to the costs. Here an alternative which the planner may wish to evaluate is the use of automatic plant to reduce the demand on labour. The control equipment required varies little with the size of the plant so that its costs would increase the economies of scale to the disadvantage of the small capacity works with which the planner in a developing country is normally concerned. This strategy has the further drawback that skilled labour of a different kind is now required for maintenance of the complex control systems that result from automation.

6. National influences

The criteria which have been studied so far may be termed commercial. They are the conditions and factors which govern the decisions of the business man. The basic nature of iron and steel production has led many countries to regard the industry as a national responsibility, leading to state ownership. Furthermore, an iron and steel plant is regarded as offering a developing country a good start on the long journey towards industrialisation. The planner is then often confronted with additional criteria of a sociological or political nature. These may justify an otherwise uneconomic proposition or reduce the effectiveness of an otherwise sound plan.

The most common situation found when studying the viability of establishing an integrated steelworks in a developing country, is that the relationship between capital and operating costs, coupled with adverse economies of scale, makes the comprehensive cost of production higher than that achieved in an industrial country and much higher than that of the marginally costed products which are available on the high seas. Despite this, a government may consider that a home industry is justified because of the sociological benefits it bestows. The planner will probably be unable to obtain a measure of these benefits. But he can, by comparing the home costs of production with import prices, establish the cost of these benefits in terms of government subsidies or of a rise in the general cost of living by the introduction of tariff barriers on imports. This information must be presented so that the government can decide whether the benefit justifies the cost.

A government may also wish to encourage overmanning of the works so that as large a labour force as possible gains industrial experience. Besides evaluating the cost of the additional labour, the planner must decide whether overmanning increases or decreases the efficiency of operation of the plant, that is, has any effect on its capacity. Small increases above the manning levels fixed by technological requirements may result in an improvement especially in a new works. The difficult figure to assess is the level above which further overmanning causes performance to drop and hence decreases the effective capacity of the plant.

Political strategy may also have considerable influence on the planner's decisions. For instance the capacity of a steelworks designed to serve a region rather than a particular country is dependent upon the degree of co-operation that can be achieved between the countries of the region. If co-operation is not forthcoming then the market available may be cut drastically. Figure 6.1 shows the growth of demand for steel products in a region made up of perhaps ten or twelve developing countries. Five countries are shown to make sizeable demands upon the output of the projected works, while the rest make only a small call on it. Suppose the economic criteria indicate Country 'C' to be the best location for the regional steelworks. That country's share of the market is shown shaded in the figure to accentuate the dependence of the size of the project on the markets in the other countries.

Regional co-operation on industrial projects may prove extremely difficult due to existing politico-economic ties which have been created under non-industrial conditions or are due to historic causes. A recent study showed

Liberia to be the most economic location for a West African regional steelworks. Liberia is a member of the U. S. dollar area. The majority of the other members of the region have either sterling or franc economies, so that the purchasing countries are faced with a foreign exchange problem, having nothing suitable to barter in return. Trade agreements and other politico-economic associations have to be re-negotiated. Figure 6. 2. lists the important monetary, trade and development links between the various countries and illustrates the complex inter-relationships that exist.

The varying degrees by which these criteria affect the strategies considered present the planner with a bewildering number of alternatives. He must methodically test each advantage or restriction in turn. Only in this way can he build up an understanding of the part each criterion is to play in the determination of the optimum capacity.

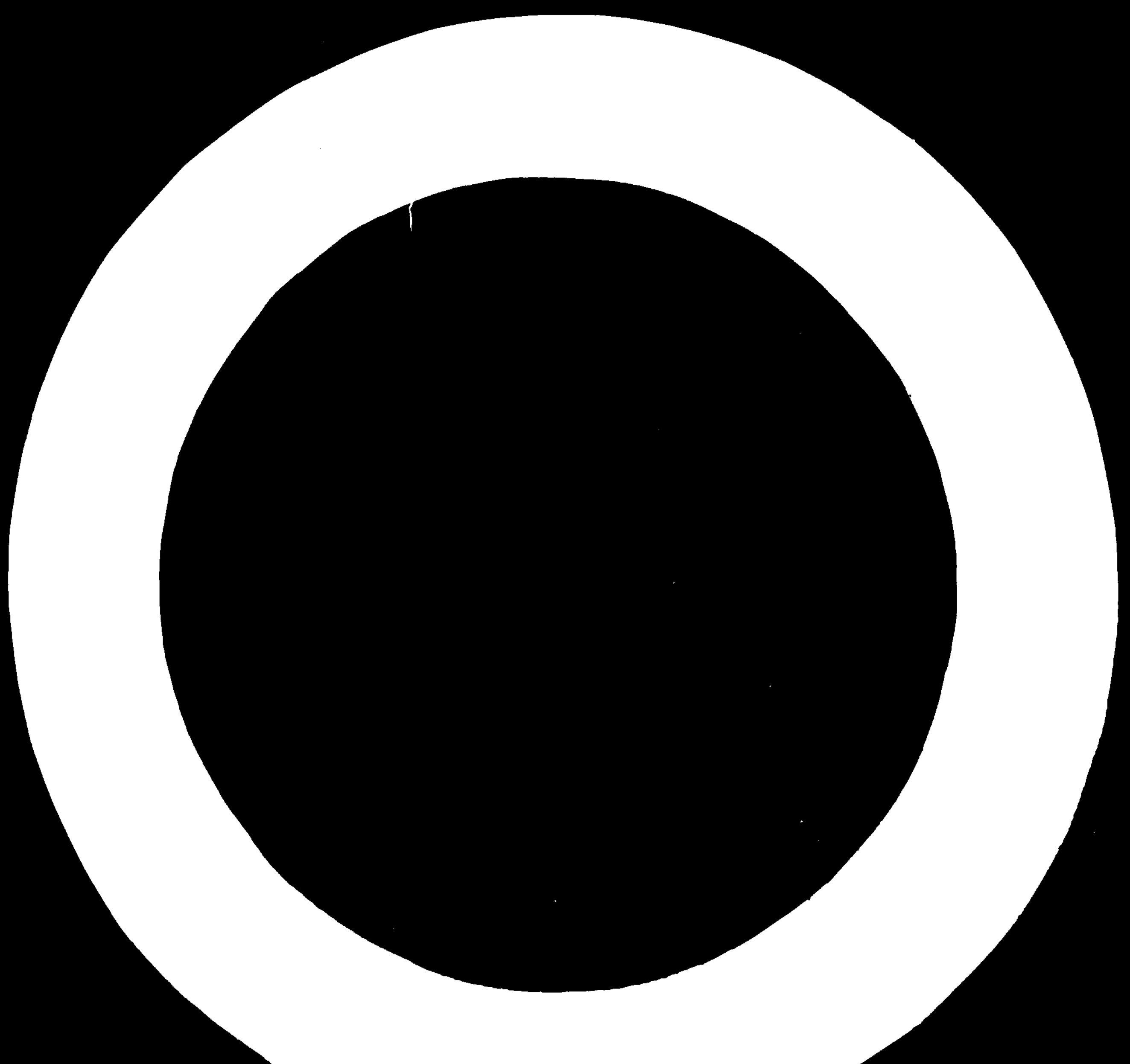
By this stage in the analysis, the planner will have constructed a number of strategies, each representing the most economic level of production or capacity for a given course of action, the courses of action being governed by the criteria applied. The tests of possible advantages or restrictions enable him to gauge the relative importance of each criterion and so select a short list of strategies for detailed study.

7. The effect of time

Definition of the steelworks has so far been studied in two dimensions, capacity and cost. The third dimension, that of time, brings into relief the changing character of the criteria which have already been studied and adds the final criterion of profitability.

The criterion most sensitive to time is the unsatisfied demand. Its relationship to the time scale of the project is so important that it has been presented as a separate criterion - variation in demand. If the capacity of a steelworks were adjusted to match the pattern of unsatisfied demand throughout its operational life, then this would be the truly optimum condition. This is not economically practical due to the economics of scale on capital plant favouring large units of capacity and to the difficulties of selling surplus capacity profitably. The interplay between these criteria enables the planner to reduce the number of strategies from which the optimum capacity may be determined to perhaps ten or twelve which must be tested by the final criterion of profitability.

The rate of growth of demand determines the date at which new facilities are planned to come into operation. The planner is here concerned to balance the lost opportunity of sales before this date against the under utilised state of the plant once commissioned. This is illustrated in Figure 7.1 It may be that the planner can afford to plan to install the plant at a time when demand exceeds its capacity but usually the unsatisfied demand is an incentive to action by competitors or in the case of a national market is a continued strain



on foreign exchange. Hence it is frequently necessary to anticipate demand by installing plant which in its early years will be under utilised. There are few situations in developing countries where the growth of demand is so rapid that plants enjoying the full economies of scale are required.

The overall pattern of demand is composed of the sum of the demands for the individual products. The demand for each different product can be satisfied by providing a unit of productive capacity as shown in Figure 7. 1. These capacities in turn can be summated to fulfil the whole market and be converted into a demand for liquid steel as in Figure 7. 2. In this example, there is a choice between a capacity based on billet products - rods, bars and light sections - and a higher figure when sheet products are included. The respective demands for liquid steel are 260,000 and 490,000 tonnes per year.

Suppose that the blast furnace and basic oxygen steelmaking processes form the most economic chain for the production of liquid steel, and further that three is the maximum practical number of vessels in the steel plant. Two levels of steelmaking capacity are now available in each strategy. For example, in the strategy based on a market of rods, bars and light sections only, two of the three steelmaking vessels can be installed initially. These would provide a capacity of 130,000 tonnes of liquid steel a year, one making steel while the other is relined. When the demand for steel rises sufficiently the third vessel can be installed so that two vessels are in operation while the third is being relined, raising the capacity of 260,000 tonnes. Steelmaking capacity to satisfy the demand for steel is shown by the dotted lines on Figure 7. 2. In both strategies, two vessels are installed initially in 1973. The third vessel is installed in the smaller works in 1980 and in 1982 in the larger one. The plant having the lower capacity has the better utilisation, an advantage which has to be set against the loss of markets and the economics of scale which favour the larger capacity plant.

The equivalent demand for hot metal at the lower capacity can be supplied by a 5m. blast furnace. This is a small furnace so that it is improbable that two furnaces of 3.5m. each to match the staging of the steel plant would be economically justified. The final capacity may be only marginally above the level at which a kiln process such as the Elkem mentioned in Article 3 is viable. In such cases, the planner must compare the phased development of ironmaking using a number of Elkem furnaces with the single 5m. blast furnace.

The hot metal requirement for the higher capacity case can be supplied from a 7m. furnace, or from two of 5 metres installed in phase with the steel plant. The choice between these various ironmaking strategies again depends on weighing the underutilisation of plant against lost markets and economies of scale.

Profitability has been defined as a measure of the effective use of money. Comprehensive cost comparisons have already enabled the planner to select the minimum cost courses of action to satisfy each demand. However, it is evident from the study of the pattern of demand, that the economic effects of time must also be taken into account. This is the function of the final criterion of profitability.

Figure 7.3 illustrates the pattern of financial development where all the plant has had to be installed at the outset. During the first four years losses are incurred mainly due to the expenditure on capital plant. Once production commences, revenue is generated and there is an inflow of money. If a phased programme of development as typified by the build-up of capacity in Figure 7.2 is adopted, a different pattern of cash flows results. In the latter case, less cash flows out in the early years due to the reduced initial expenditure but again less flows in in later years when further capital expenditure absorbs the operating surplus or "profit before depreciation" as it is described in Figure 7.3. The total capital expenditure and the total profit before depreciation when summated over the time span of the project may be the same in each case but the timing of its deployment is different. The planner can determine which strategy is the most profitable by comparing the discounted rates of the cash flows.

Profitability defined in this way favours the phased development of industrial projects so that its main influence on the optimum capacity is to ascribe to it a number of values, each relevant to a phase of the development plan. This applies to the capacity of parts of the complex, the complete integrated works being the current aggregation of the parts. It follows that the capacity of the whole works is seldom completely in balance, that is truly integrated, until it has reached its fully developed state.

8. Optimum capacity

The planner has now selected the most profitable strategy which satisfies the criteria laid down or intrinsic to the situation. The details of the selected strategy form the long term plan for the development of the works and are the basis of its design, the capacity of the works so specified being at any time during its life the optimum. There is no need to leave space in the layout of the works for plant not included in the plan for the final optimum capacity. Nor should the plant manufacturers be permitted to build in spare capacity into their designs, because such as is desirable has been included through the application of the technological criteria.

Fifteen or twenty years is a long period to forecast so that it is improbable that all the factors and parameters used in the comparisons will remain as predicted. The types of change which are most likely to affect the plan are technological innovation, shifts in the market demand and shortages of resources, whether funds, manpower, materials or services. The plan must be kept under review so that these changes in the criteria can be evaluated. Unless a major change occurs, the plan should not need re-appraising more often than once in three to five years. If the development of the works is planned in phases, then it is as well to make a re-appraisal before proceeding on each phase. If a revision is contemplated due to, say, the introduction of a new process, the planner must remember that there is now a heritage of plant and other facilities which for the purposes of his new comparisons is free. No allowance for it has to be made in the comprehensive cost and hence the operating cost is the only component applicable to the existing processes. The plant can be treated in this way because it is there whether it is used or not under any revised plan. Admitted it may have some resale value, but thisis usually small and can be ignored for comparative purposes, although it must be included in the profitability calculations.

The concept of optimum capacity implies the discipline of following the long term plan. So there is little scope for deviation from or expansion above the capacity already planned. There are however opportunities for expanding by setting up contiguous industries. These may make use of waste products such as slag or by-products such as tar and naphtha. Extension of the process chains into specialised steel products is another method. Pipes, tubes and wire products are the most usual opportunities for this type of expansion.

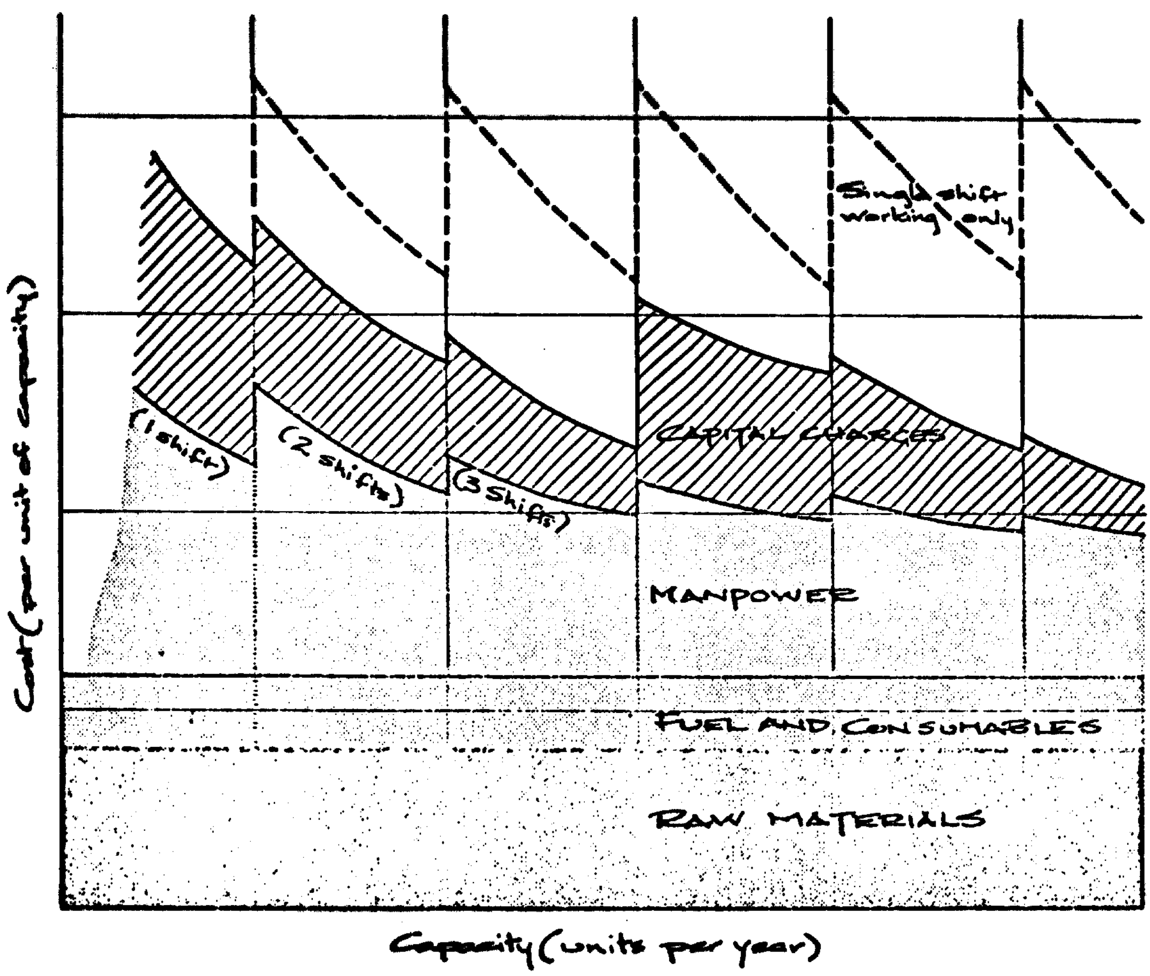
In brief, the planner by assessing the market demand, the availability of resources and processes, and the state of the environment over the proposed life span of the project can set up a number of alternative strategies. These can be evaluated in economic terms and the strategy showing the greatest profitability selected. This strategy specifies the performance required of each process in the chain through time so that the optimum capacity of the entire integrated steelworks together with those of its constituent parts can be determined.

9. Acknowledgements

The authors wish to acknowledge the assistance of their colleagues in the Industrial Planning Group of W. S. Atkins & Partners in the preparation of this paper. In particular they wish to thank Dr. S. K. Ghosh for the data he prepared as a basis for the illustrations.

Figure 2.1

Comprehensive cost



<u>Figure 2.2</u>

<u>The economics of scale</u>

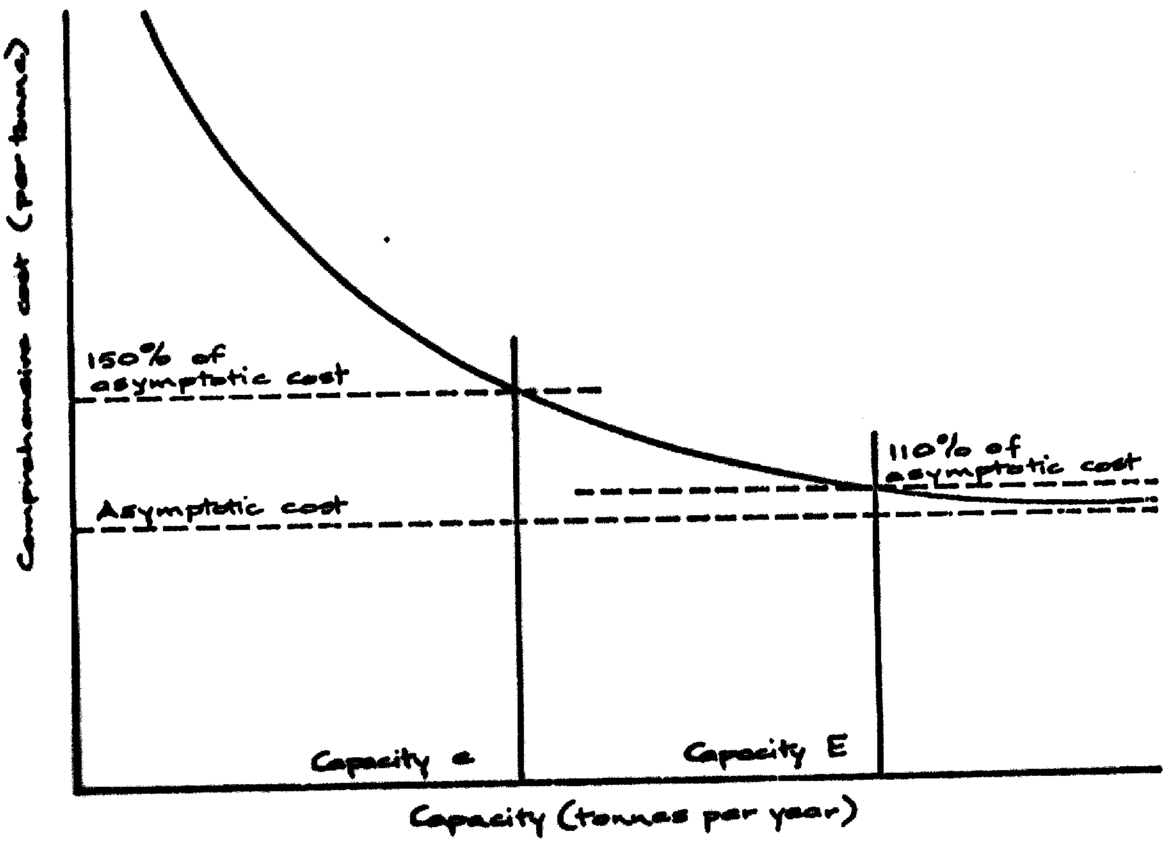


Figure 2.3

Galvanised sheet: supply and demand

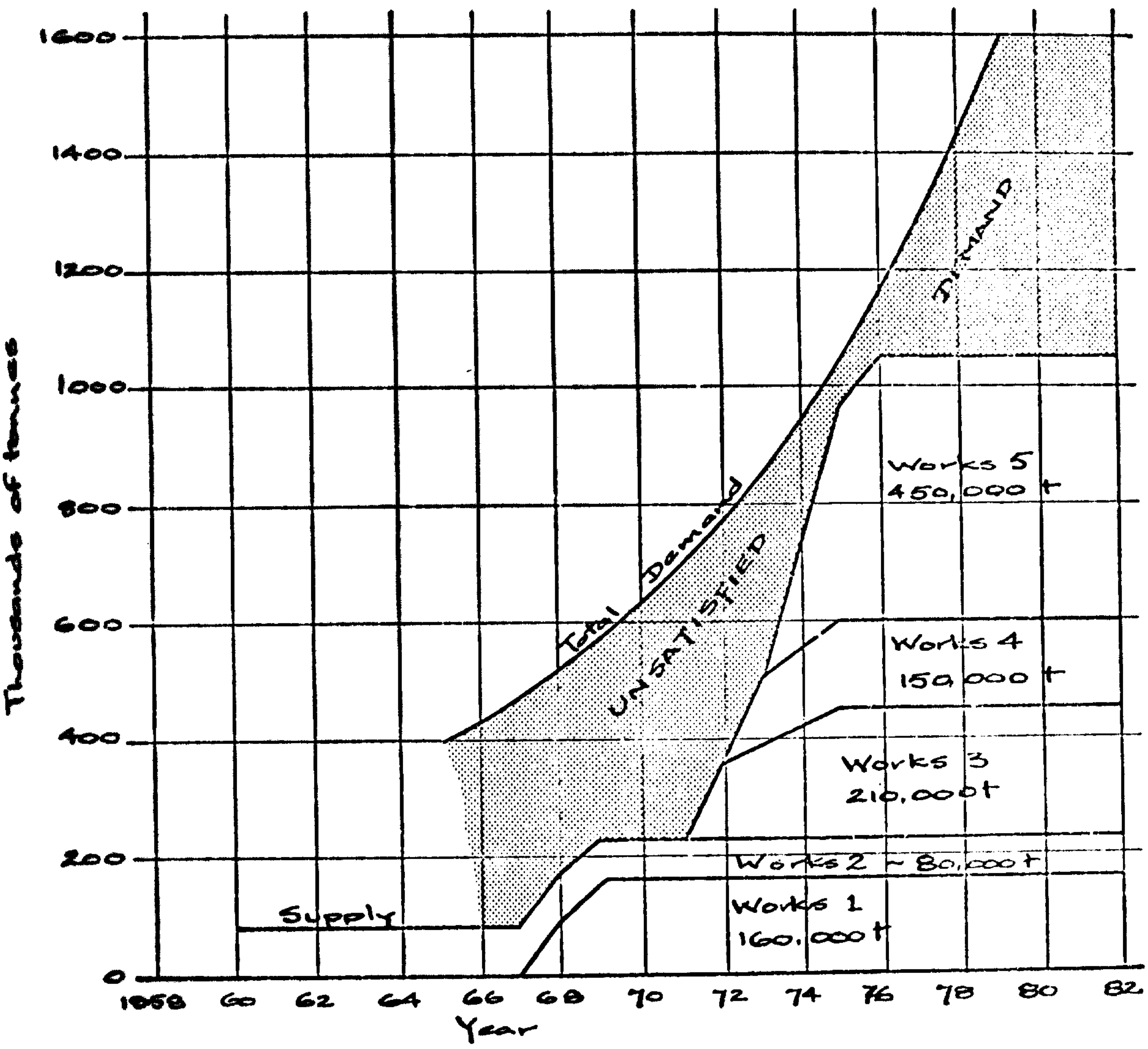
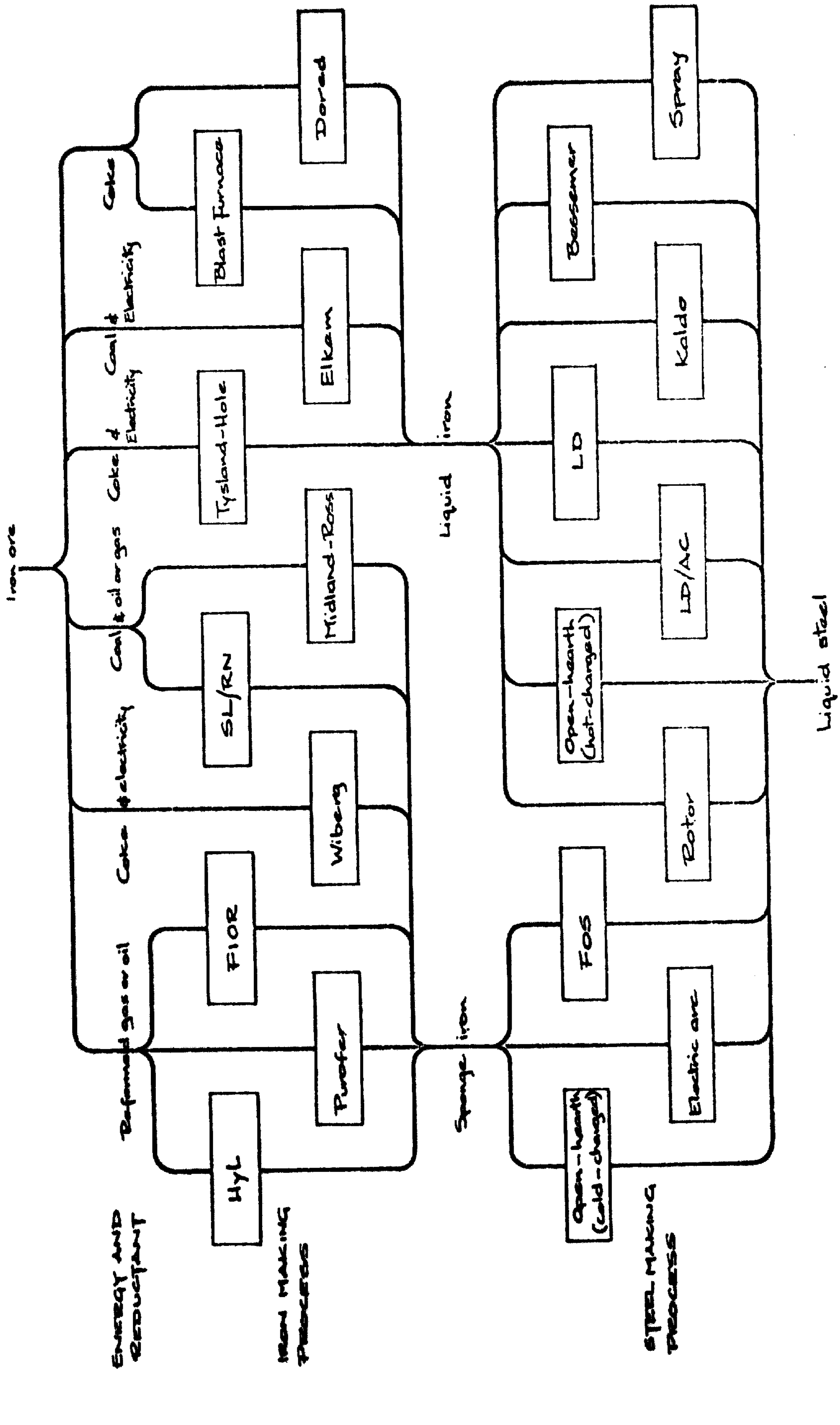


Figure 3.1

Alternative iron and steelmaking processes



Economio oriteria become relevant as soon as a process is considered for commercial exploitation. Sociological and political criteria arise at a national level and are especially important in developing countries.

This paper lists the principal criteria affecting optimum capacity, and then considers them under four headings: those which affect parts of the plant; those which affect the whole plant; those having national implications; and finally those related to the life span of the project.

In order to make valid comparisons, the effect of each criterion must be measured in the same manner. The only common ground for comparison is cost. Thus, sooiological or political factors can be judged by calculating their effect on oosts.

To take account of both capital and operating costs, capital can be regarded as a commodity which is hired for an annual charge. This charge can then be added to the annual operating cost to give a single new parameter - the comprehensive cost.

The capital cost of plant per unit of capacity falls as the size increases, but tends to an asymptotic level determined by the maximum plant size that can currently be built. A somewhat smaller plant whose cost is not greatly above this asymptotio value may be justified on the economic grounds of saving the transport costs of imported steel, but a much smaller plant will carry such high capital charges per ton that its installation must be justified on other than economic grounds.

The relationship between capital and operating costs varies from one country to another. A process of a certain capacity which is viable in an industrial country may be uneconomic ina developing country where capital costs are higher even though labour is cheaper.

The yield of a process affects the economios earlier processes in the ohain; thus a rolling process with a low yield will result in a greater demand for steel to feed it.

A oountry's demand for steel, by itself, does not determine the opportunity for sales from a new works; the important quantity is unsatisfied demand taking into acoount the capacity of other existing works. Growth of the total demand likewise does not necessarily mean growth of unsatisfied demand if new plant has already been planned to meet the needs.

The capacity of a piece of prooess plant suoh as a rolling mill depends on the product mix, and this in turn affects the required capacities of all earlier plant

Figure 3.2

Effect of capacity on choice of process

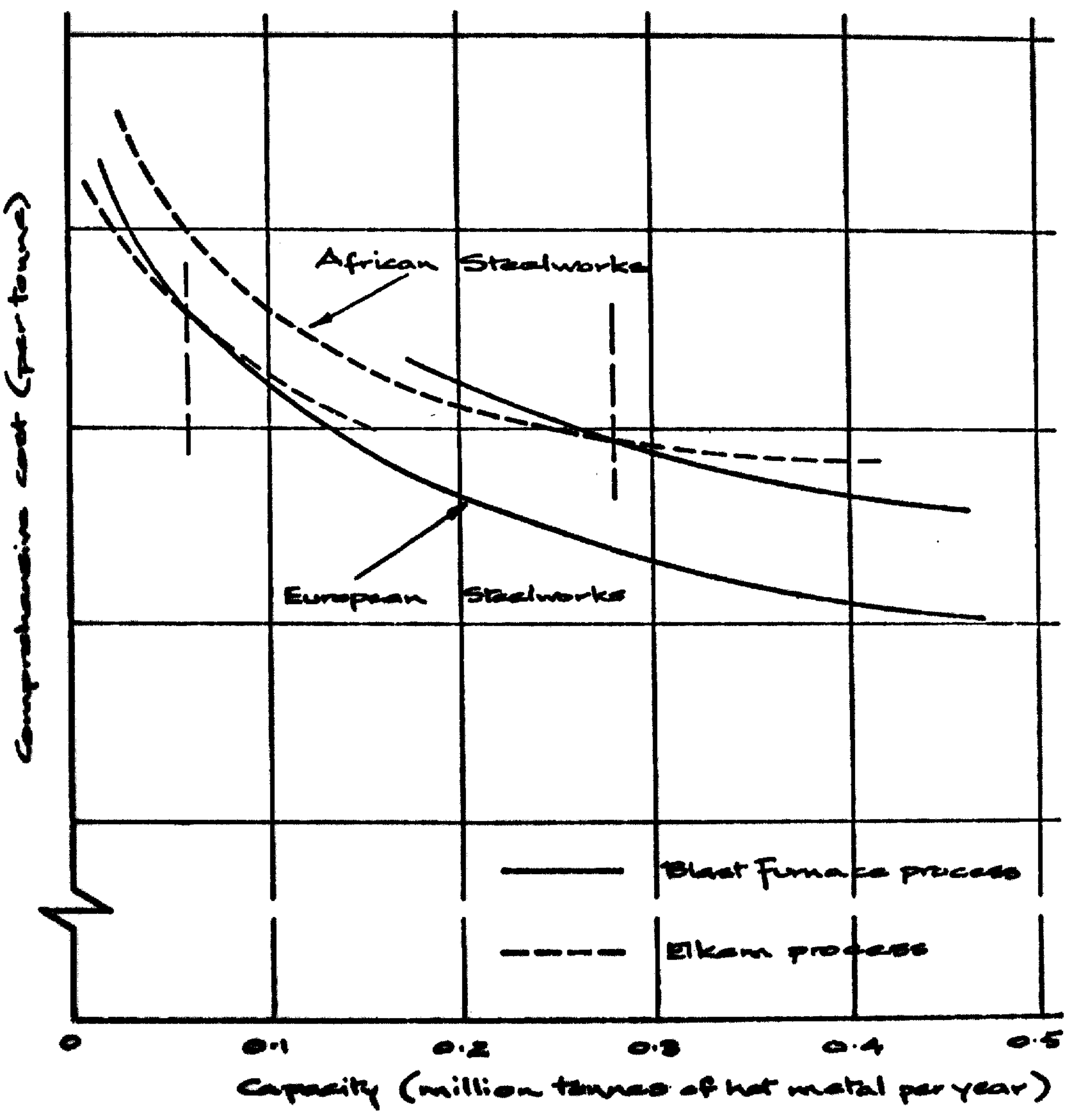


Figure 4.1

Unsatisfied demand for bloom and billet products

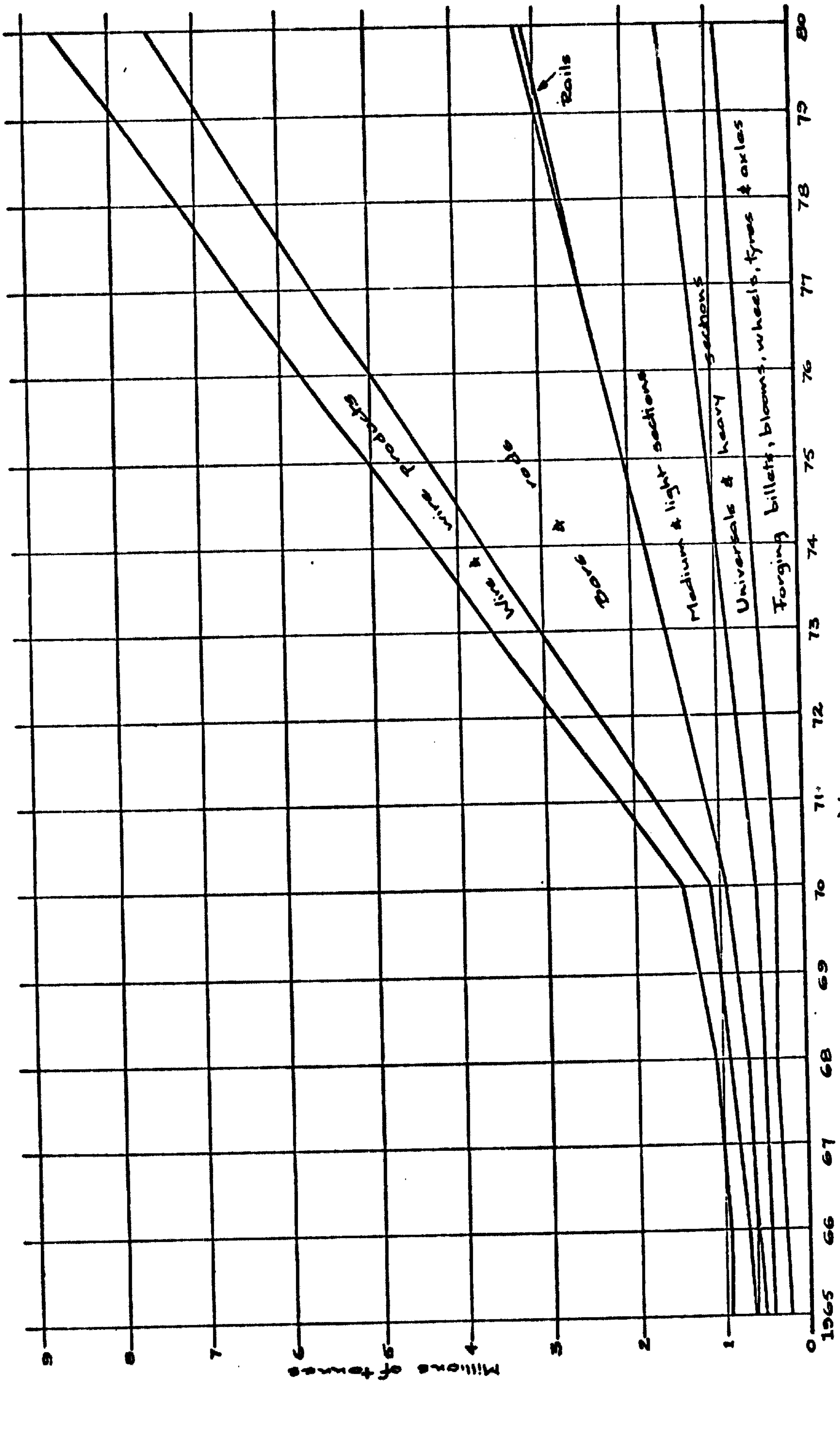


Figure 4.2

Flow diagram for secondary process

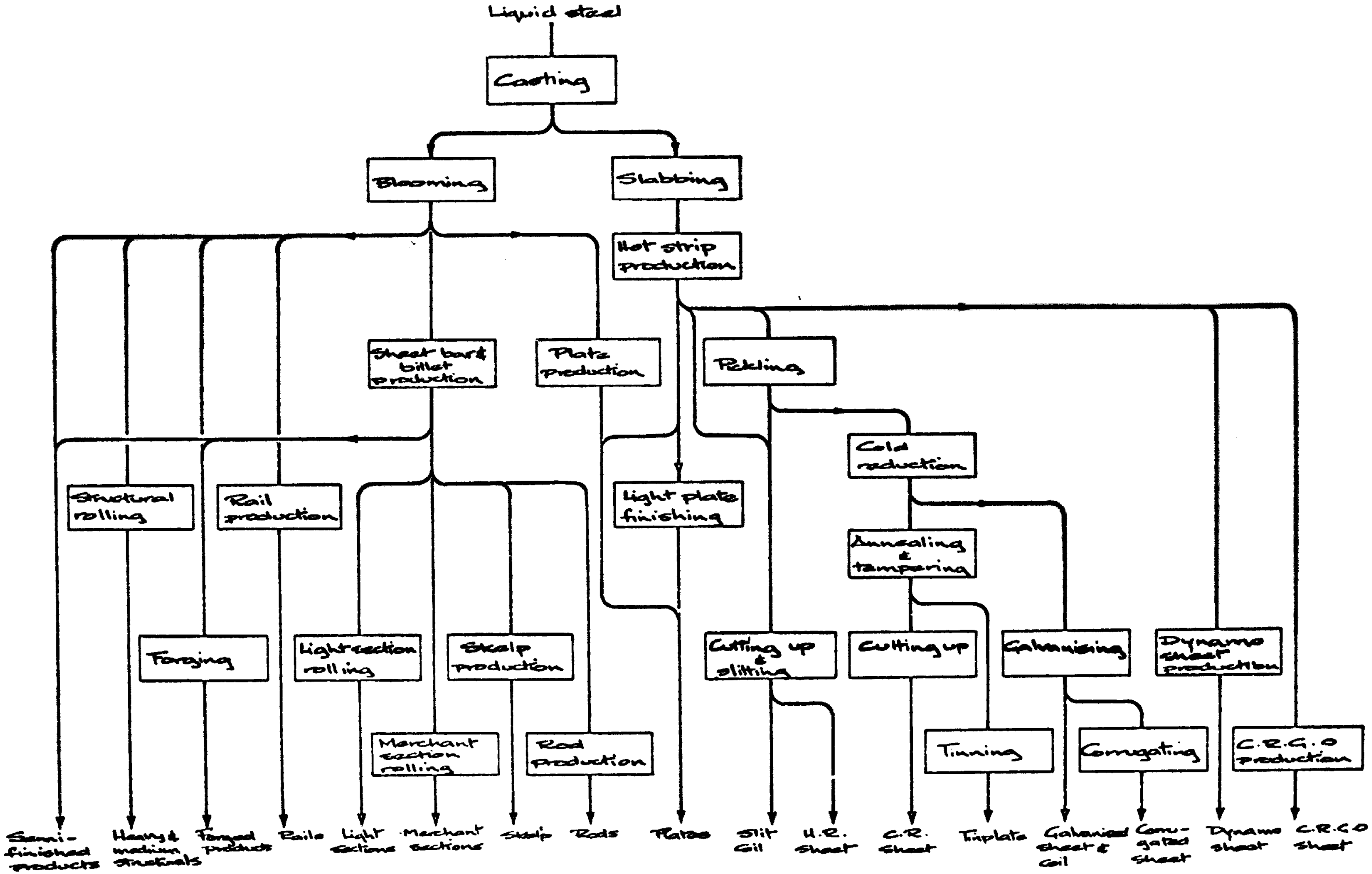


Figure 4.3

Effect of product size on capacity

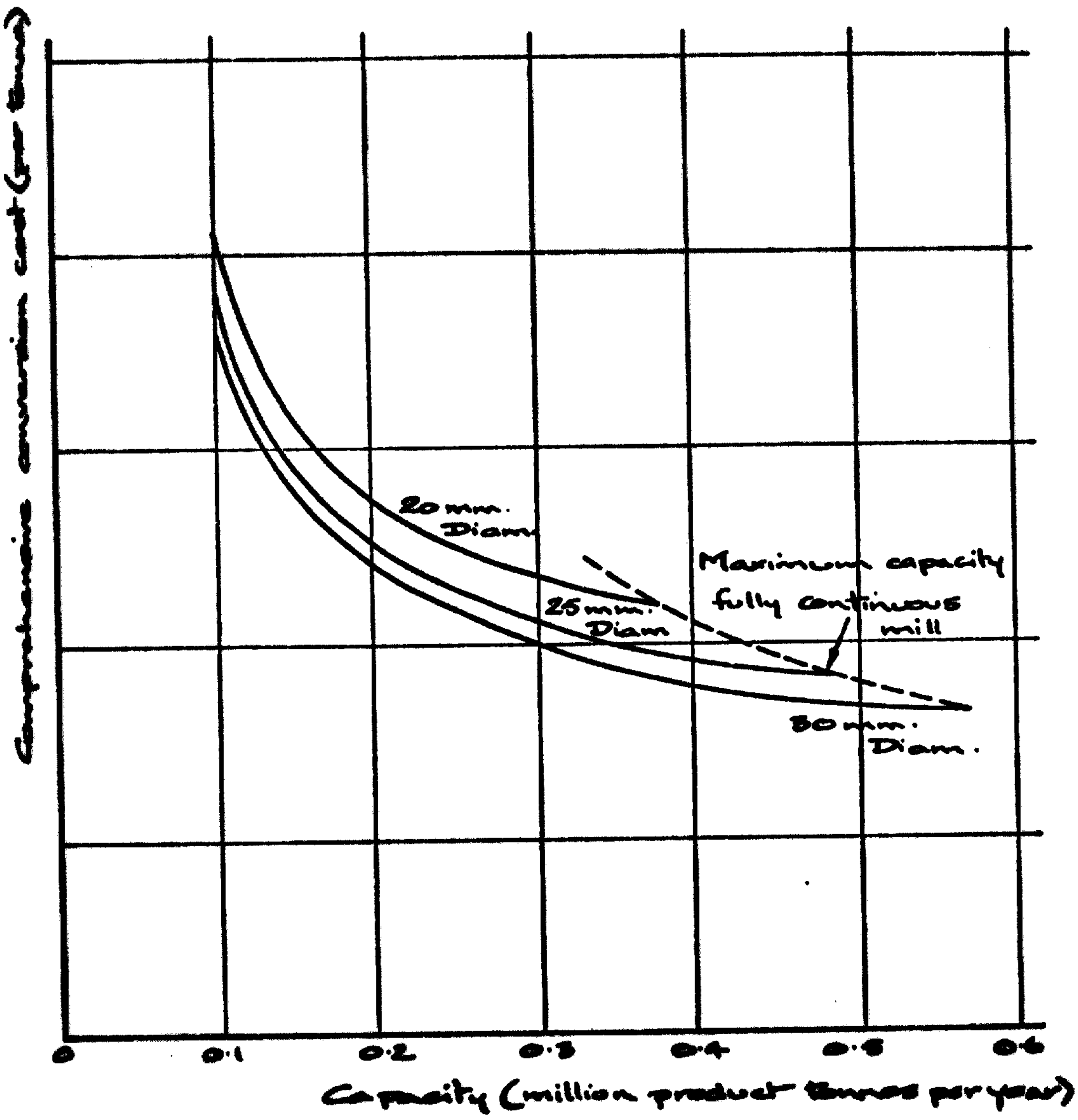


Figure 4.4

Economics of scale for hot-rolled strip production

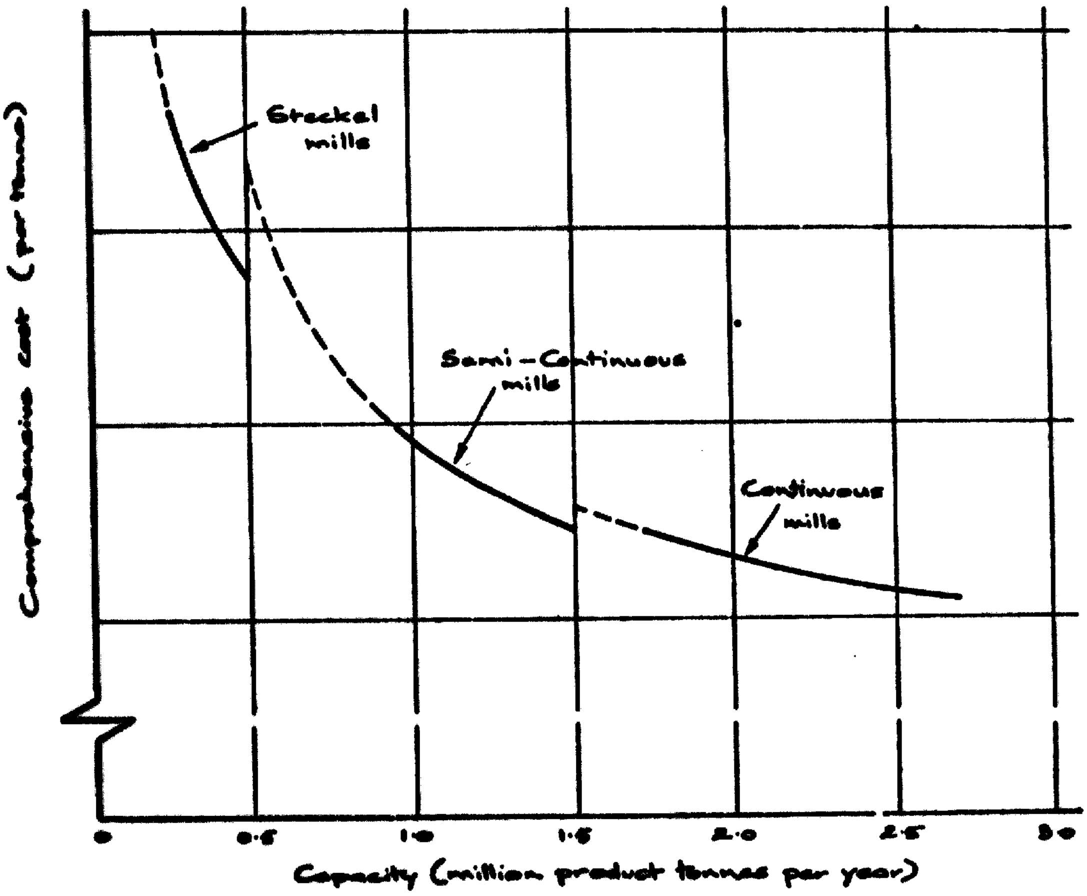


Figure 4.5

Process routes for the production of slabs, blooms and billets

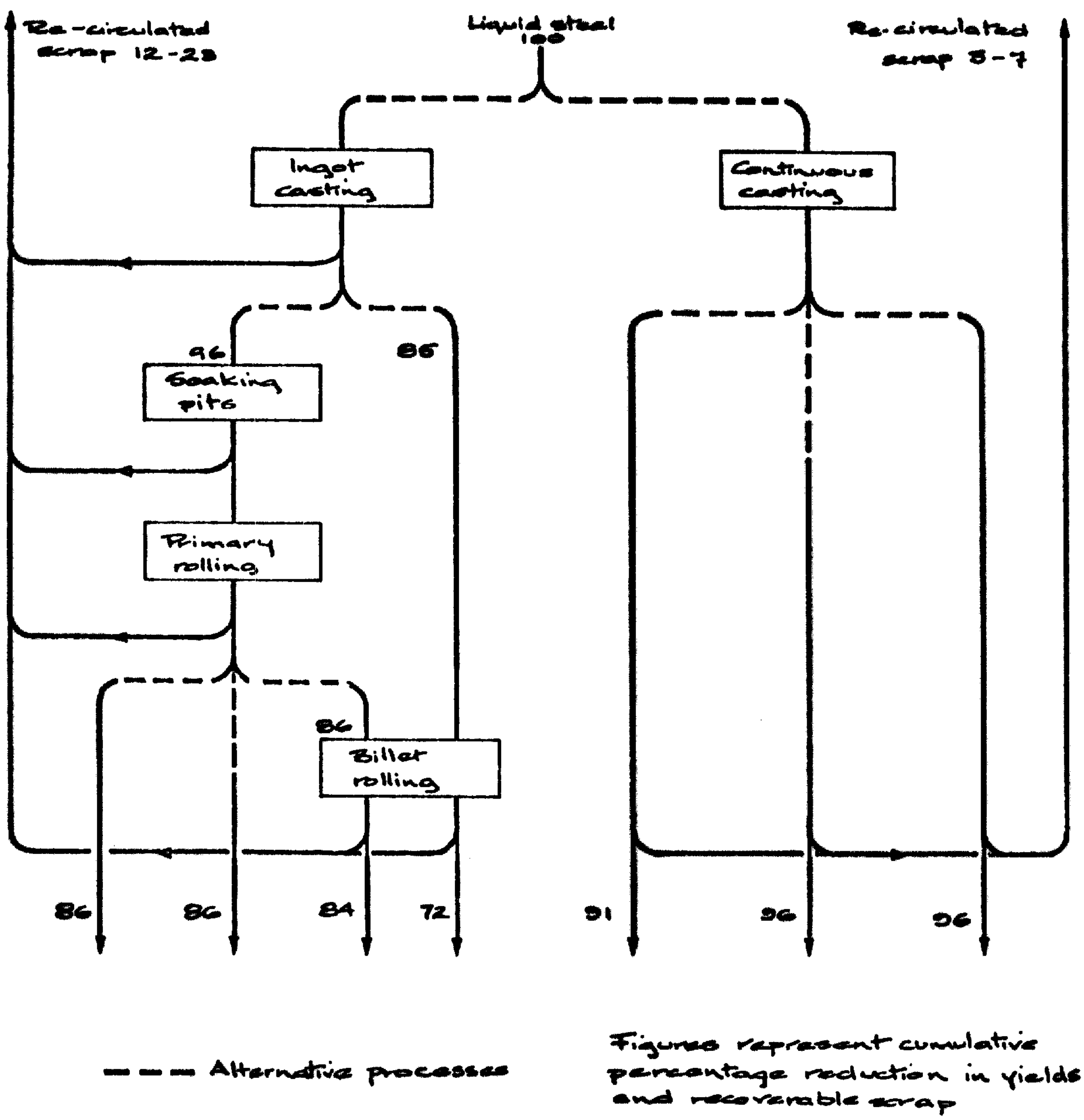
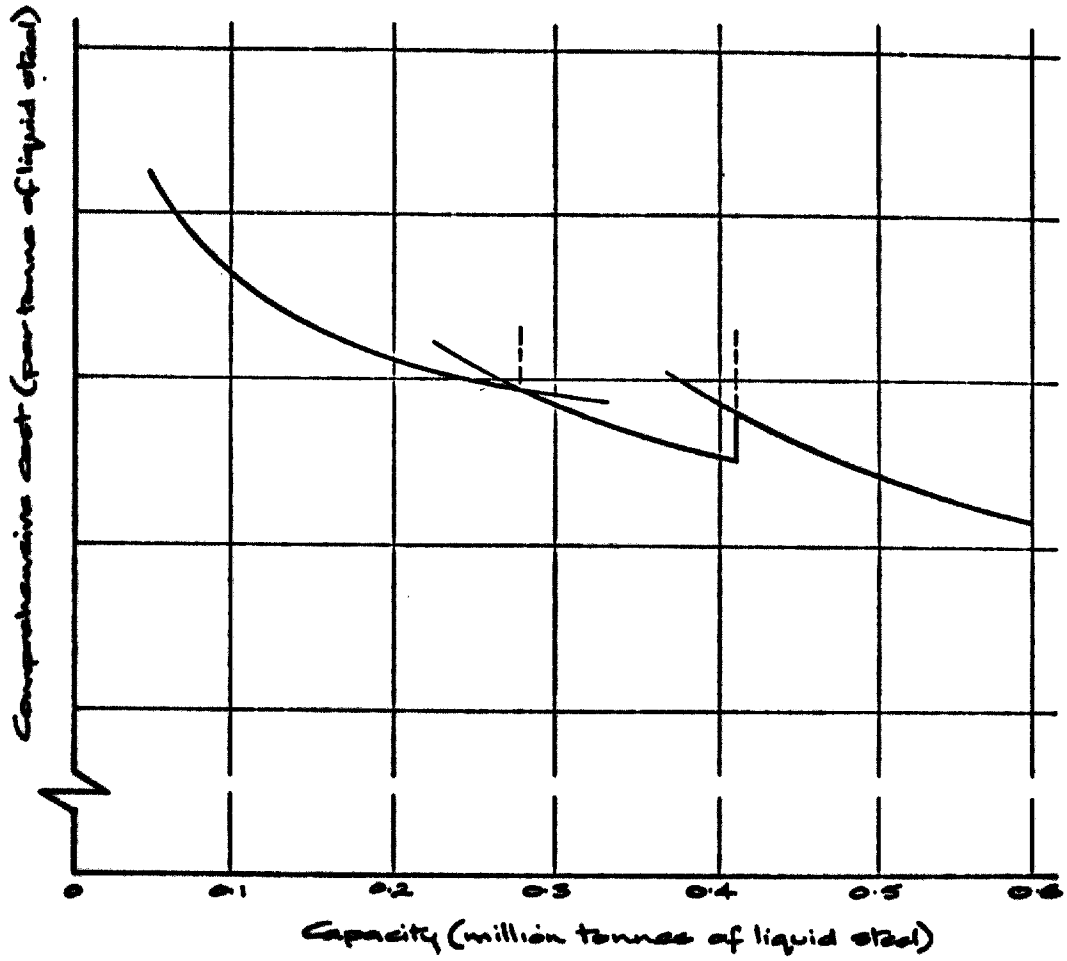


Figure 5.1

Minimum cost envelope for liquid steel production



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in the chain of processes. Disparity in the capacities of plant in a chain of processes may require the production of a wide range of finished products to justify the installation of an earlier unit of economic size, such as a primary mill.

Shortage of resources may impose a temporary or permanent limit on the capacity of a steelworks. The limit is essentially economic since all shortages, whether of material supplies, labour or finance, can be overcome at a price.

Sociological benefits may justify the establishment of a steel industry which on purely economic grounds is unacceptable, but the cost of such a decision must be calculated in order to check whether increased prosperity of the people can in the long term repay the investment.

The principal effect of political strategy is the saving of foreign exchange, but the viability of a plan may also depend on existing trade agreements or economic alliances.

Profitability is an assessment of the dynamic efficiency of a plan. As a yardstick of the effective use of money, its measurement is just as necessary for a publicly owned enterprise as for a private business. Discounted rate of return on cash flow is the generally accepted means of measurement which takes account of performance through time.

Processes in an iron and steel works are conveniently divided into primary processes, from ore to liquid steel, and secondary processes, from liquid steel to finished products. The capacity of primary processes may be governed by supply of raw materials, but possible unit plant sizes are so large that economies of scale play a large part in the decision, and it may be worth supplementing local supplies by imported raw materials to achieve these economies. One process may be cheaper than another at low capacities but the second cheaper at high capacities; moreover, the change-over point may be at a quite different capacity in a developing country from that in an industrialized country.

Care must be taken only to compare processes making the same product. Iron-making processes making liquid iron cannot be compared directly with those making sponge iron. Each requires a different subsequent steelmaking process, so that comparison must cover iron and steel making together.

The capacity of secondary processes is governed by market factors - unsatisfied demand and product mix - and design characteristics - yield and economics of scale.

When unsatisfied demands are large, it may pay to specialize in one type of rolled product but when demands are small, diversity of products is necessary to make use of economies of scale. Final products must be grouped according to the intermediate processes they render necessary; a single flat product among the list of final products needed may have to be omitted because its market does not justify installing a hot strip mill.

Product mix greatly influences the capacity of secondary processes, a higher average size of product giving a higher capacity to the rolling mill producing it. Iron and steelmaking plant can be designed for a wide range of capacities, but it is difficult to design mills to specific-capacities. There are a limited number of mill capacities suitable for a given product, each covering a range of capacity, but between them not necessarily covering the complete range. Consequently, for some outputs, plant must run below capacity.

Some plant, such as a primary mill, has an inherently large capacity and is uneconomic to install for low outputs. In such a case the production of billets or slabs directly from liquid steel by continuous casting may be more economic.

In a given set of conditions, curves for the comprehensive cost of alternative process chains over a range of capacity can be drawn and the envelope of these curves gives the most economic solution for any required capacity. For primary processes producing common steels, the indication of choice of process route and its economy is generally clear. For secondary processes, the picture is more complex; steps in the curves due to the inevitable multiplication of plant units are more frequent and occur at lower capacities than with primary processes.

When primary and secondary process costs are combined, not only differences of yield but also energy and scrap balances are introduced. A different and at first sight less economic steelmaking process may have to be adopted if there is an excess of scrap which cannot be sold and must therefore be considered as a free supply.

Shortage of resources may lead the planner to restrict the works capacity to a lower level than the market justifies. Shortages of capital may lead to the adoption of a minimum capital cost strategy which is less economic overall. An alternative is to build only part of the works initially, for example rolling mills to use imported billets.

Restricted fuel and power resources can be overcome by importing fuel, and water shortages to some extent by increased recirculation. Both solutions cost money, but this may be more economic than a reduction in capacity. Supply of sufficient skilled labour can be overcome temporarily by employing expatriates and in the long run by training. Use of automation to save labour has the drawback of requiring skilled maintenance staff.

Industrialization may be regarded as such a desirable goal that the installation of an uneconomic iron and steel plant as the first step is justified. High capital costs and adverse economies of scale may result in home-produced steel in developing countries being more costly than imported steel. The cost of overmanning to create employment may also be justified provided it is not on such a scale as actually to impair performance. These differences must be evaluated so that the government can decide whether the benefits justify the extra costs.

Steelworks to serve a whole region depend for their viability on political and economic co-operation between countries to secure the necessary large markets, and existing agreements may hamper such co-operation.

The planner must test each criterion in turn to understand the part it plays in determining optimum capacity and arrive finally at a short list of possible strategies for detailed study.

At this stage the time dimension must be considered. It is not practicable to match capacity throughout the life of the project with the changing pattern of unsatisfied demand. The lost opportunity for sales by waiting for the demand to rise to the capacity of a new unit of economic size must be balanced against the losses due to under-utilization if the plant is installed too early. Since unsatisfied demand is an incentive to action by competitors and a continued call on foreign exchange, some anticipation of demand with its disadvantages of temporary under-utilization is inevitable.

The over-all pattern of demand is the sum of the demands for individual products, which can be satisfied by installing appropriate units of productive capacity such as rolling mills. These in turn create a demand for liquid steel. The rise in demand may dictate the provision of this steel, and the iron from which it is made, in two or more stages of development. Diseconomies of scale associated with multiple smaller units must be balanced against the cost of under-utilization of larger single units.

The final test is that of profitability through the life of the project, which is evaluated by listing expenditure and revenue year by year and comparing the discounted rates of the cash flows for each of the strategies under study. The capacity of the whole works is seldom in balance until it has reached its fully developed state, and the optimum capacity at any stage is that which forms part of the most profitable over-all strategy.

This strategy forms the long term plan for the development of the works. The plan must be kept under review and re-appraised every three to five years, or whenever a new phase of the development is imminent, to take account of technical innovations, shifts in market demand and shortages of resources. Any changes in plan must take account of the heritage of plant already installed.

The concept of optimum capacity implies the discipline of following a long-term plan. There is little scope for deviation from this plan unless conditions change in an unforeseen manner, but there may be opportunities for expansion by setting up contiguous industries to use the products or by-products of the steelworks.

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Figure 5.2
Minimum cost envelope for various rolled products

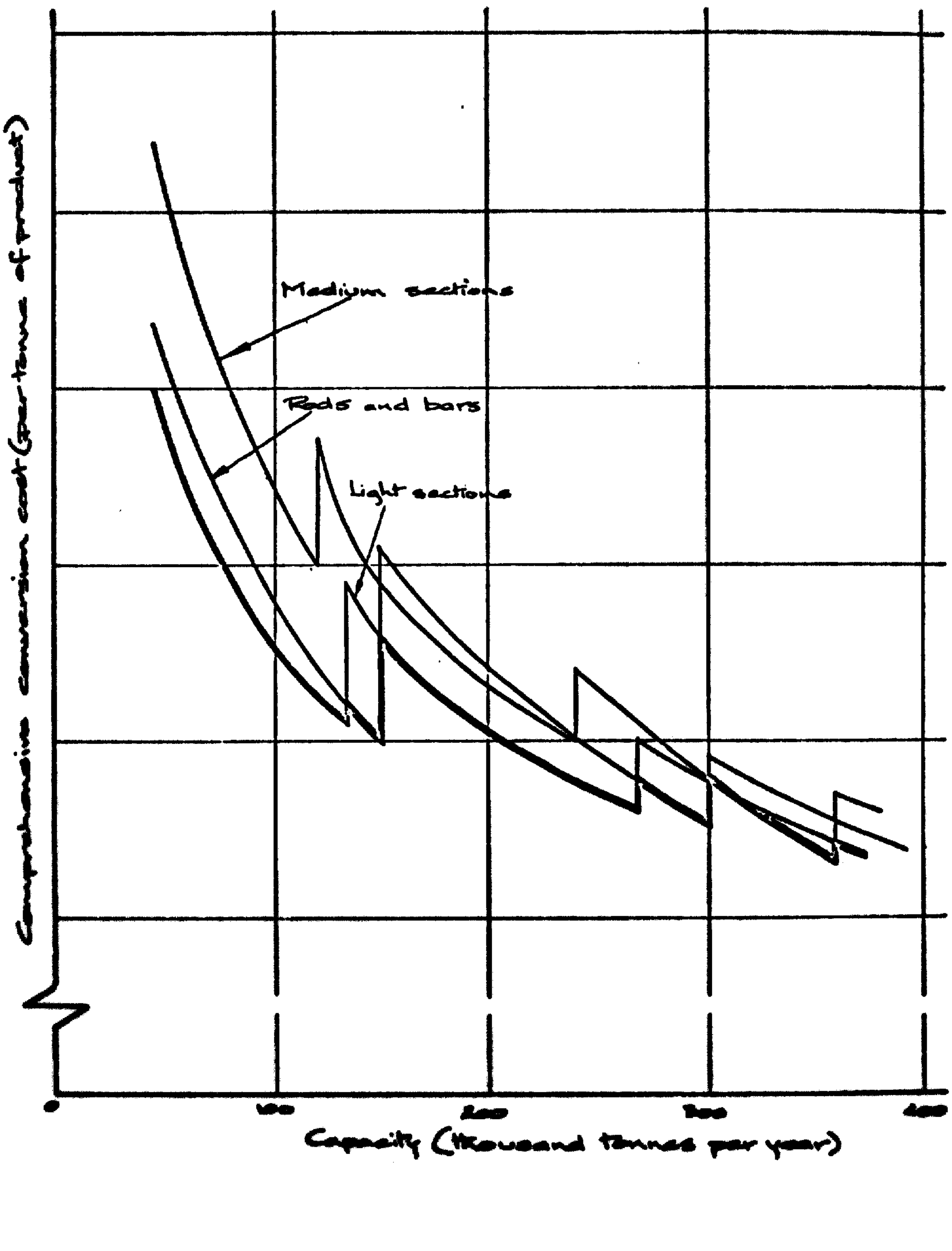


Figure 5.3

Capital cost distribution between processes

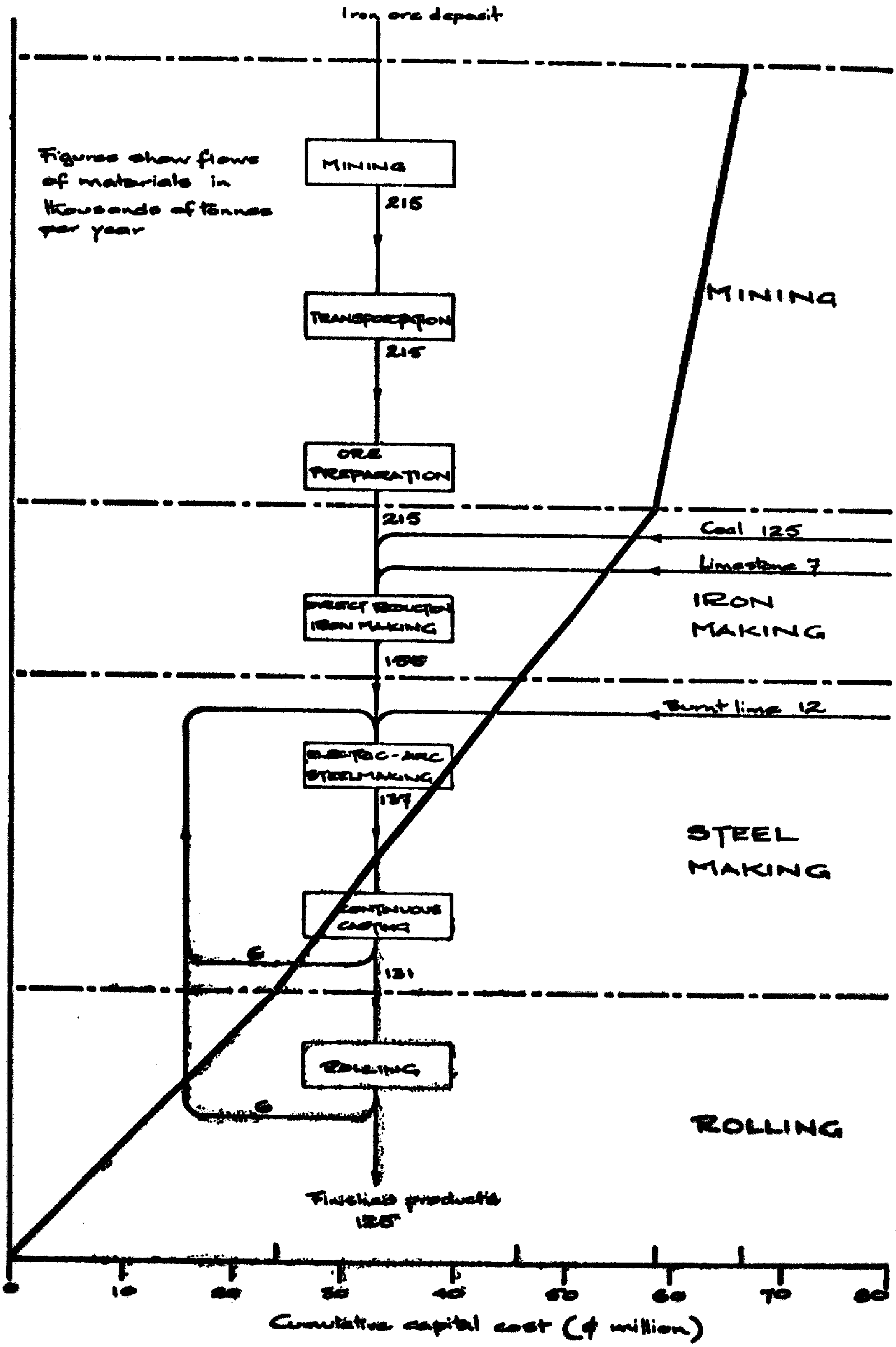


Figure 6.1

Growth of the regional demand for steel products

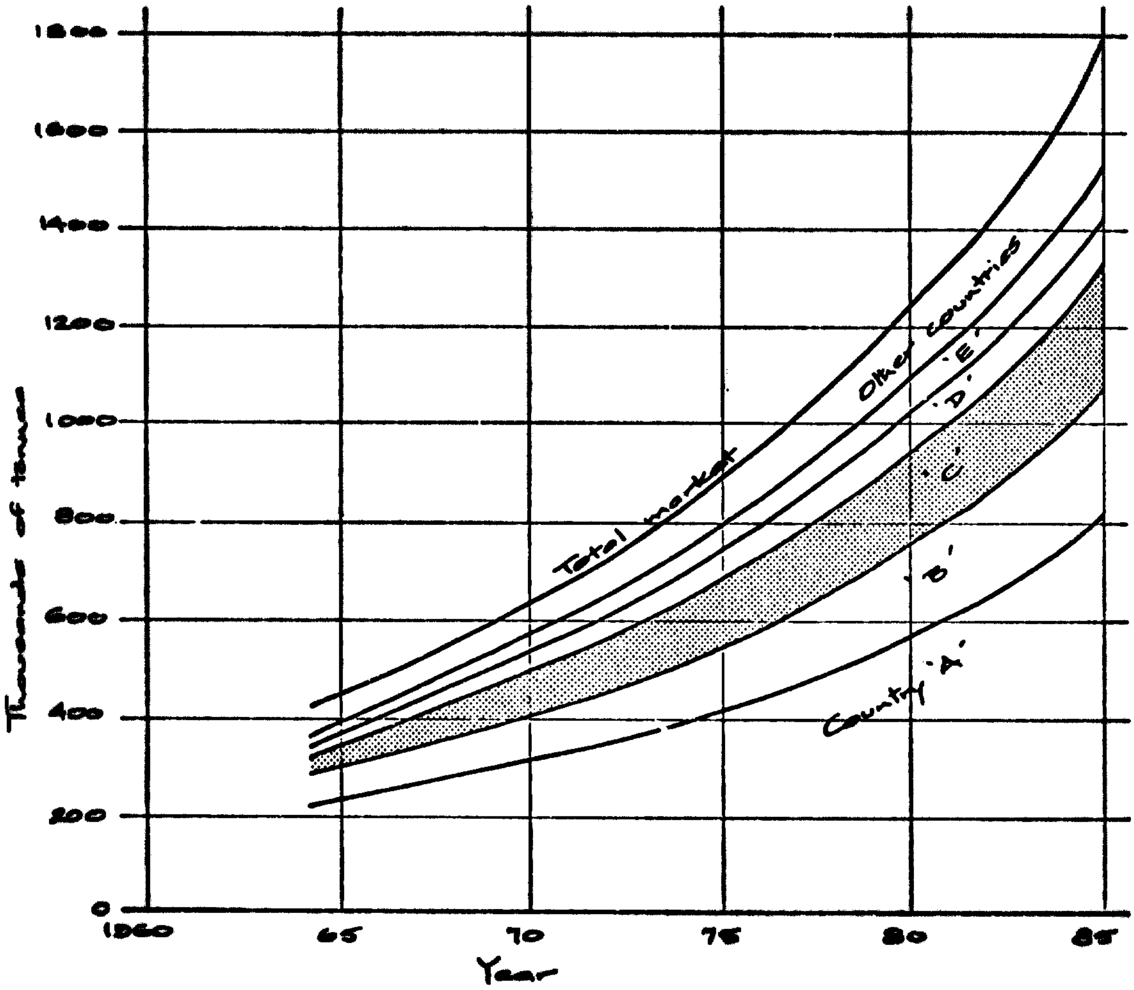


Figure 6.2

Economic ties in West Africa

	Monetary zone [1]	UMOA [2]	EEC Associate	OCAM [3]	UDEAO [4]	GATT	Commonwealth Pref.	Niger River [5]	Senegal River [6]	Entente
MAURITANIA	Fr	□	□		□	□			□	
MALI	Fr		□		□			□	□	
NIGER	Fr	□	□	□	□	□		□		□
SENEGAL	Fr	□	□	□	□	□			□	
GAMBIA	£					□	□			
GUINEA	Gfr							□	(□)	
UPPER VOLTA	Fr	□	□	□	□	□		□		□
SIERRA LEONE	£					□	□			
LIBERIA	$									
IVORY COAST	Fr	□	□	□	□	□		□		□
GHANA	£					□	□			
TOGO	Fr	□	□	□						□
DAHOMEY	Fr	□	□	□	□	□		□		□
NIGERIA	£		□			□	□	□		

1 Fr – member of franc zone
£ – member of sterling area
$ – member of U.S. dollar area
Gfr – Guinean franc

2 Union Monetaire Ouest-Africaine (West African Monetary Union)

3 Organisation Commune Africaine et Malgache (African and Malagasy Common Organisation)

4 Union Douaniere des Etats de l'Afrique de l'Ouest (West African Customs Union)

5 Niger River Development Association

6 Senegal River Development Association

Figure 7.1

Timing the introduction of new plant

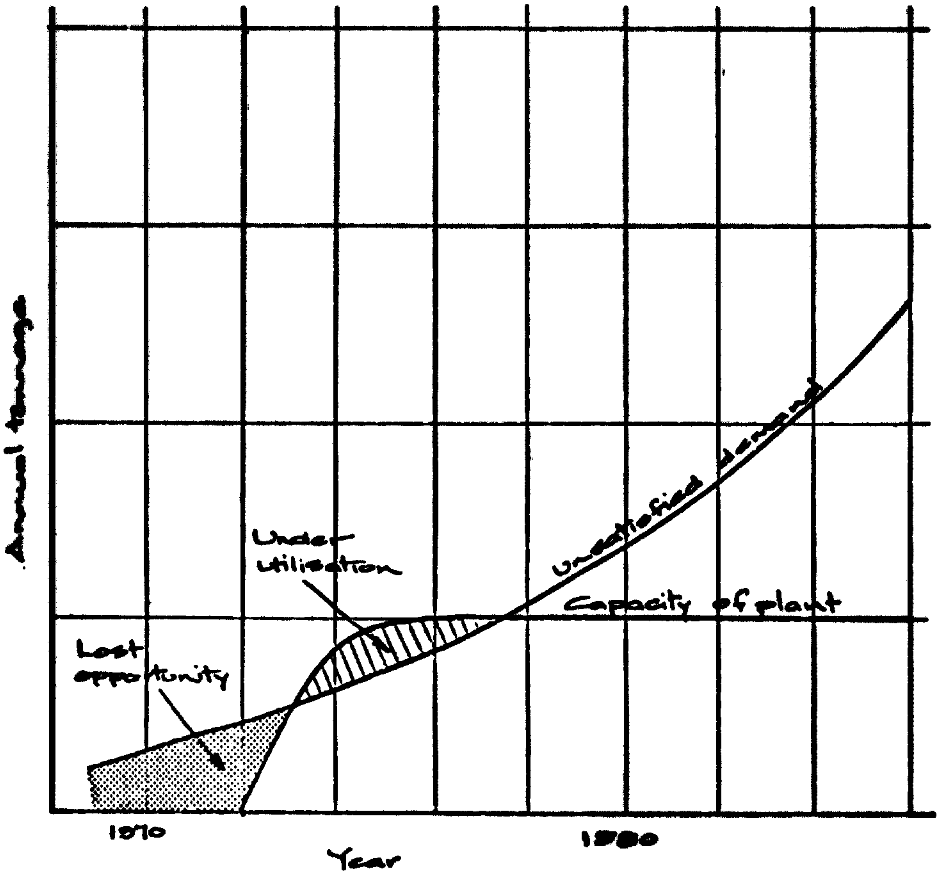


Figure 7.2

Phasing of capacity

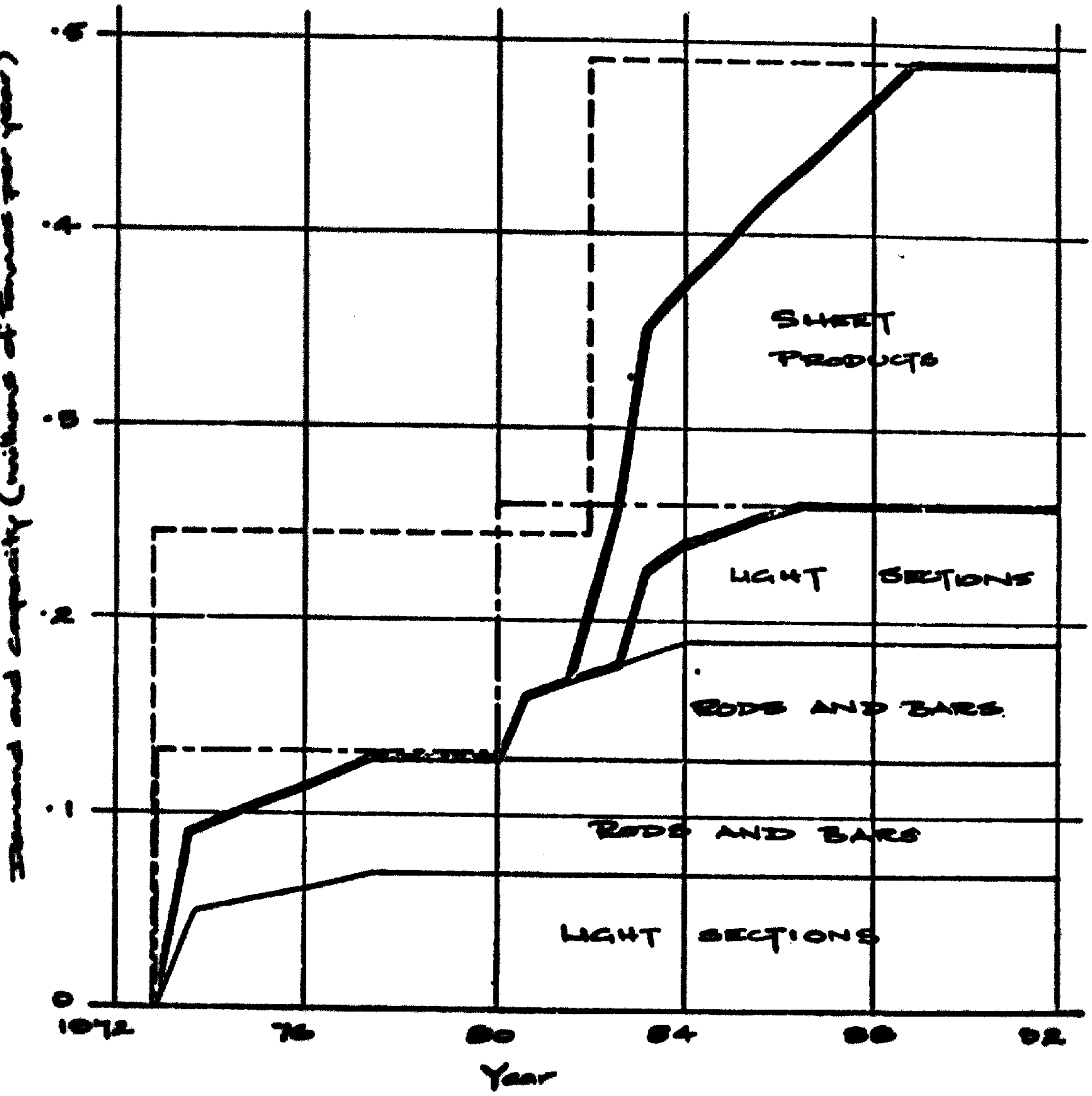
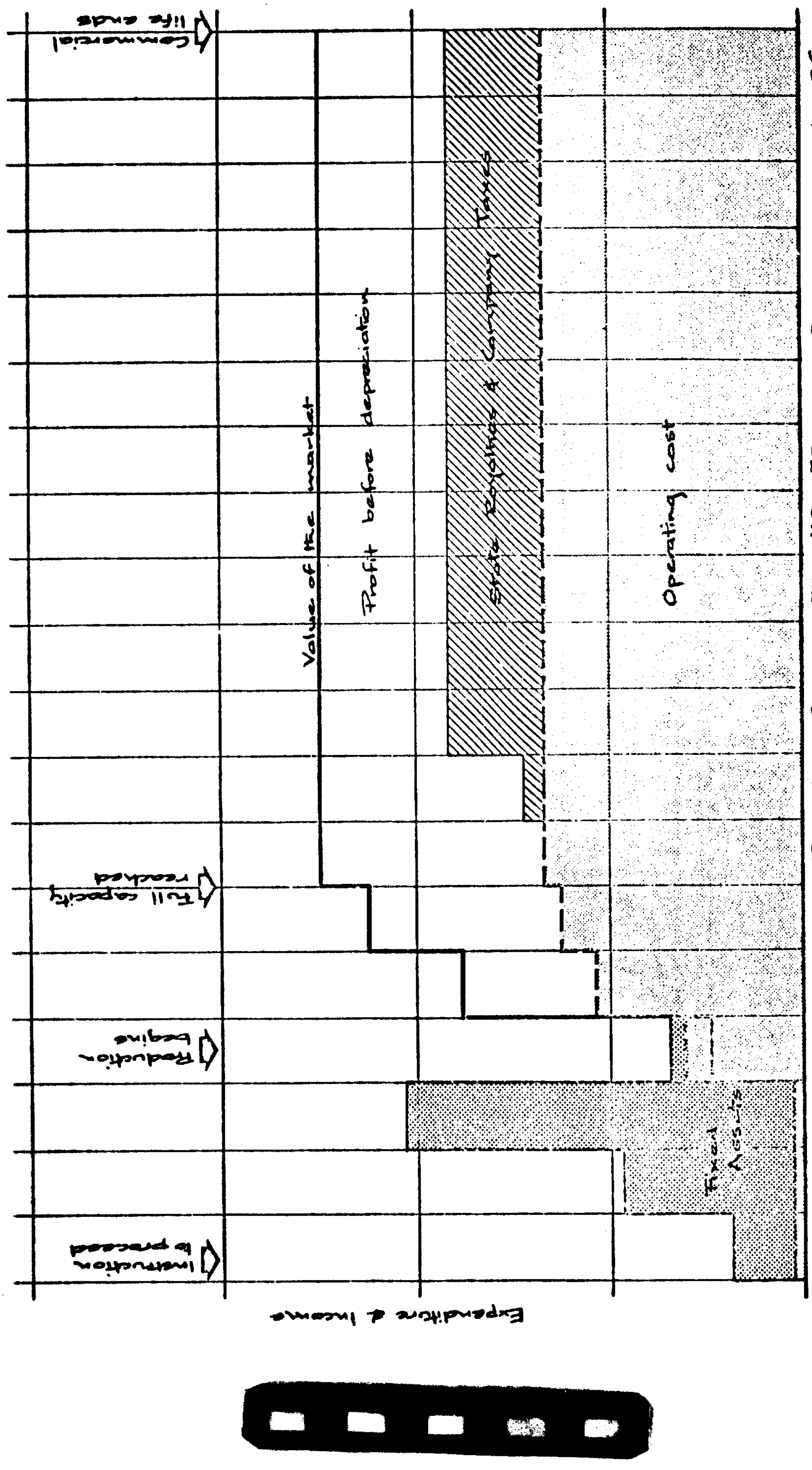


Figure 7.3

The pattern of financial development



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