

Layout of large integrated steelworks

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INTRODUCTION

WORLD STEEL production doubled between 1920 and 1940 and doubled again between 1940 and 1960, despite the dislocation caused by a major global war. Reliable estimates, such as those drawn up by the Economic Commission for Europe (ECE), indicate that world production may double once more from about 350 to 700 million tons in the next 15 to 20 years.

Much of this growth will take place outside the countries where steel production is already well established—in Latin America, Africa and Asia. In many cases, it will be a question of designing and setting up new plants to achieve an annual increase of anything from 10 to 20% in steel capacity. This lends importance to the adoption of design and layout concepts which will facilitate rapid growth, and not hinder it by failure today to take into account what may be needed a decade or two hence.

The layout concept to be adopted would of course be largely governed by the technological processes selected; it also depends on the future potential capacity visualised for the steelworks. This in turn depends on the economic growth that is planned for the country itself, and the significance the planners attach to the role of steel in accelerating growth. In this Development Decade—and the decades to follow—many emergent countries are installing new steel capacity. Clearly, it is not just a false sense of prestige that prompts this; it is the conviction that 'industrialisation without metal-working industries and economic development without industrialisation are hardly possible'.¹

This paper outlines some criteria for the general layout of large integrated iron and steelworks in developing countries, such as India, which have adequate raw material resources and also vast potential demands. This is not to say that under such conditions smaller plants of under one million tons per year capacity are ruled out. Indeed, depending on circumstances, small plants may have a significant role in meeting regional demands. Clearly, the necessity for large steel complexes would not arise in all countries or in all regions within a country; each nation must evolve its own planning strategy, based on its raw material reserves, consumption patterns, and other factors.

It need only be mentioned that even regions with limited raw material resources have chosen steel as the spearhead of economic advance. The example of Japan, which in 1961 imported over 90% of its iron ore and 40% of its coking coal requirements to produce 28 million tons of steel, would indicate that the locational pull of raw materials is often less decisive than the determination of a people to lift themselves by their boot-straps. Today, there are not many countries in the happy position of USSR and China which can sustain large steel outputs wholly on indigenous raw materials. Even these countries must incur increasing costs on raw materials beneficiation, while others such as India must begin to think not only in terms of beneficiation but also imports of one or other of the essential raw materials. It must be remembered that even the largest steel producer in the world today—the United States—has to

SYNOPSIS

The size of steelworks is on the increase all over the world because rising steel demands are most economically met by expanding the capacity of existing plants. Bearing this trend in mind, developing countries—where many new steelworks are being built—would be clearly lacking in foresight if they did not make provision in their plant layouts today for steel that will be required a decade or two hence. It is not implied, however, that small plants are necessarily uneconomic or that they should not be built. The argument is that regardless of the initial size or extent of integration at a new steelworks, its layout can be so planned as to enable large future expansion. This provision in design and space need not add much to the initial investment and has been known to pay handsome dividends at a later date. The paper illustrates how some steelworks have grown and why there is no plant in the world today which has stopped growing.

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import all of its manganese ore and over 35 million tons of iron ore per year. In addition, it has to beneficiate an equivalent tonnage of low-grade ores, mainly taconites with only about 30-35% Fe-content. It also imports practically all of its nickel and chromium.

DEVELOPED AND DEVELOPING COUNTRIES

The likely trend of steel growth in the 'developed' and the 'developing' countries of the world is brought out in Table I below, which is based on work by ECE.²

While ECE estimates for some individual countries may be questioned, the trend is clear: North America and Western Europe's percentage share of world steel production will continue to drop, while the rest of the world will contribute an increasing proportion. Quite naturally, the rate of growth in the developing countries will be many times more than elsewhere. In spite of this

TABLE I Steel production trends in developed and developing countries

| Regions | Share of world production | | | Annual rate of increase 1957 to 1972/75 % | Per capita prodn. 1972/75 kg |
|---------------------------|---------------------------|--------|-----------|---|------------------------------|
| | 1937 % | 1957 % | 1972/75 % | | |
| <i>Developed</i> | | | | | |
| North America | 38.2 | 36.8 | 25.3 | 2.7 | 742 |
| Western Europe | 38.8 | 31.1 | 25.5 | 3.9 | 437 |
| Eastern Europe | 3.4 | 5.6 | 6.1 | 5.9 | 364 |
| USSR | 12.5 | 16.4 | 18.5 | 5.7 | 482 |
| Australia and New Zealand | 0.7 | 1.0 | 1.5 | 8.1 | 488 |
| Sub-total | 93.6 | 90.9 | 76.9 | | |
| <i>Developing</i> | | | | | |
| Africa | 0.3 | 0.7 | 1.2 | 9.9 | 26 |
| Latin America | 0.3 | 1.2 | 3.0 | 12.5 | 75 |
| Far East | 5.4 | 5.3 | 10.0 | 10.5 | 66 |
| China & N. Korea | 0.4 | 1.9 | 8.2 | 16.4 | 65 |
| Middle East | — | — | 0.4 | 19.4 | 27 |
| Sub-total | 6.4 | 9.1 | 22.8 | | |
| World, % | 100.0 | 100.0 | 100.0 | 5.3 | 189 |
| m. tons | 105.9 | 230.8 | 630.7 | | |

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seemingly large increase, their per capita production in 1972/75 will have risen to only about 60 kg. Even this figure does not tell the whole story because it includes such high values as 324 kg for Venezuela and 339 kg for Japan.

An emergent country has perforce to make a much greater effort to initiate steel development than one in which machine-building, transportation, power, and various infra-structure items already exist. A new steel plant in a developing country generally imports the bulk of its equipment and often its building structurals, and also incurs considerable expense—perhaps 20 to 30% of plant cost—in organizing a township, augmenting water and transport facilities, and for the training of supervisory, operating and maintenance personnel. Against the above disadvantages, a developing country has the unique opportunity to make a fresh start by adapting the most up-to-date processes to its own needs, and by following the trail of technological progress which other countries have blazed. Indeed developing countries which are building new plants and countries, such as Japan, which are rebuilding their steel industry today have some of the most modern facilities in the world.

LAYOUT CRITERIA

Planning the general layout of an integrated steelworks is basically an exercise in making a rational arrangement of the main production units, the energy networks and the auxiliary shops, within the limitations of the selected site. A good steel plant layout must fulfil at least three major criteria :

First, it must provide for the uninterrupted receipt and stocking of bulk-materials, the rapid movement of in-process loads, and the smooth disposal of products and by-products.

Second, the production and auxiliary units together with the systems for utilities must be so arranged as to assist in achieving minimum capital and operating expenditures, not only for the initial plant but also for subsequent expansion. It often happens that a plant in which facilities have been designed 'tightly' in order to cut costs is in the long run more expensive than one which has incurred slight extra costs on ampler and sturdier equipment.

Third, it must provide opportunity for rational expansion to large future capacity in order to meet growing requirements and also to take advantage of the economies of scale. This requires not merely space for additional and larger production units, but also design provision for enlarging utilities such as water, power and tracks with minimum interference with existing operations.

The layout should not only incorporate proved technological advances in the initial design, but also give thought to techniques which show promise for the future. For example, the planning of any new steelworks today would need to take into consideration such ideas as automatic conveyor charging of materials either to the skip or to the blast furnace top, the continuous casting of large slabs for direct rolling in the same heat, and the programming of operations using computer techniques.

Construction planning

At the same time the layout must facilitate expeditious construction and commissioning of units. It is vital that the massive capital invested in a steel plant is put to work in the shortest possible time, to which end the construction schedule must be directed. For a complex project which involves hundreds of inter-related construction items and where job plans have to be revised frequently

the conventional bar-schedule is cumbersome and the new 'critical patch scheduling' systems, using computers, are indispensable.

Standardisation

A developing country like India, which has to initiate a number of new steelworks in the foreseeable future, must adopt a high degree of standardisation in layout, buildings and equipment. Commenting on the assortment of widely different facilities at the three new Indian steelworks, a leading steel plant engineer remarked : 'If our country had the opportunity to build three new one-million-ton plants concurrently, we would certainly have adopted the same building and crane spans, similar coke oven and blast furnace designs, and similar types of meltshop and mill equipment'. Apart from substantial capital cost savings and facility of manufacture at the new machine-building plants, standardised facilities would be easier to operate and maintain.

EVOLUTION OF LAYOUT

The layout inevitably undergoes a tortuous series of revisions from the time it is a gleam in the designer's eye until the last foundations have been poured. Even so, this 'final layout' is necessarily a compromise between the desire to fulfil the criteria outlined above and the limitations imposed by the selected site, available finance, construction schedules, preferences of the client, and a host of other factors. It is also certain that the plant operator and the designer himself will soon consider this layout somewhat obsolete. But, where the designer has had the conceptual vision to look beyond the present needs and immediate difficulties of his client, the resultant layout is likely to maintain its logic and flexibility. In retrospect, the plea that 'conditions have changed' is seldom remembered ; the success or failure of a steelworks layout is its capability to operate continuously at low cost in spite of changing conditions.

Significance for developing countries

Layout mistakes are usually permanent and expensive ; therefore it is essential that many man-years of engineering enter into evolving the most suitable arrangement of facilities. Careful layout planning is even more important in under-developed countries which must make the most effective use of their limited resources, specially foreign currency, and at the same time provide for much-needed growth. Here, as in the planning of a nation's economy, the choice is really one of deciding between immediate and long-term benefits to the enterprise. There is no doubt a real need to limit initial investment. However, should the plant layout be 'crammed' and the equipment sizes restricted to cut down initial costs, or should the planners adopt a bold layout which, while costing somewhat more, would ultimately enable expansion at considerably smaller additional cost in order to contribute to the country's growing needs and aspirations ?

Additional cost of provision for expansion

It may be clarified that the additional cost of providing for sizeable expansion may be in two directions. First, there is the provision to be made of space for new production units. This involves extra cost in somewhat longer tracks, roads, and utilities, and in additional site preparation. With careful engineering, this extra cost may well be only 2 to 4% of original investment. Secondly, additional cost may be incurred in providing certain

'in-built' facilities at the initial plant. For instance, conveyor galleries may be designed for a second belt, buildings constructed for heavier future cranes or with clearances for larger equipment. While for processes such as coke-making the requisite numbers of ovens can be adopted to give any desired initial output, a modern primary rolling mill has a high optimum capacity (4 to 5 million tons per year) and it is often preferable to install such a unit, rather than a smaller one which would have to be duplicated as the plant expands. The additional cost of such 'in-built' facilities could be as much as 10 to 15% of the original investment.

The final decision on whether to tie up capital as 'in-built' capacity will have to depend on the assessment of the time that it will take for demand to grow to the level where high equipment utilisation is reached. All developing countries are faced with scarcity of capital relative to their needs, and the calculation will, therefore, have to take into account the difference in investment requirements between one optimum sized unit now and several put up over the next few years. This solution must necessarily be governed by the individual circumstances of the country or region where the plant is to be sited, and the technical production problems of the categories of steel that are to be produced.

To illustrate, take a situation where a primary rolling mill with two million tons per year throughput is required at a new steelworks, but it can reasonably be foreseen that the mill would have to double its output in about five years after commissioning. For the initial output, a 44in blooming/slabbing mill costing say Rs 90 million (excluding buildings and cranes) would be adequate. But alternatively, a 46in universal slabbing mill having a capacity of 4 million tons and costing say Rs 115 million could be installed and operated for only part of the time. In this case, the idle 'in-built' capacity would incur interest charges (say 6% on the extra Rs 25 million for 5 years, that is a total of about Rs 7.5 million). However, this course would still be more economical than having to install two smaller mills later. Indeed, after five years the cost of the additional equipment itself may well have risen by 10 to 15%. Further, the larger mill would have greater technological capability and would also be more economical in operation. If the equipment is well engineered, there is little likelihood of obsolescence in a 5 or 7-year period—technological break-throughs seldom occur with such rapidity.

PRE-REQUISITE FOR GOOD LAYOUT

A good layout requires a good site. Depending on the scope of the project an area of about 5 to 10 sq. miles needs to be set apart for the steel plant proper. Under conditions such as in India, an area many times as large could be kept reserved for the controlled development of marshalling yards, townships and ancillary industries. While the acquisition of such a vast area for a steel complex may appear extravagant, it is wiser to incur this expense initially, than to allow the future growth of the plant to be stifled by artificial and avoidable obstructions such as townships, slag dumps and railway yards.

In addition to the availability of a large land area, its topography should be such as to enable the cost of site preparation to be kept low—an expense of say up to 5% of the total plant cost for land acquisition and preparation may well be considered a legitimate charge. Further, a site with a firm sub-soil at reasonable depths and a low ground water level would be desirable. Various other requirements can readily be stipulated, but all of these can rarely be found in one specific location. Nor are there limitations such as cannot be overcome by some

additional expenditure. Numerous examples can be quoted of plants which have created adequate sites from difficult terrain. We have the recent instance of the new Spencer Works at Newport in Wales, which starting with what was 'rotten land', spread about 9 million cubic yards of filling materials at the rate of 5 000 lorry-loads per day and raised the site by about 5 to 6 feet above ground level as an insurance against site flooding and also to assist drainage.³ Plants such as the Indiana Harbour Works of Inland Steel have reclaimed almost two miles of land from Lake Michigan and sited their new rolling mills on 40 feet of slag fill.

Seaboard location

Growing inter-dependence of nations regarding iron-making materials is forcing new steel plants to be sited at seaboard locations where a captive fleet of fast high-capacity carriers can often deliver raw material supplies at lower cost and of higher quality than indigenous sources. India too may soon have to join this trend to the coast as the Bengal-Bihar coalfields begin to lose some of their locational advantages due to rising mining costs, transport bottlenecks, increasing ash content in coal, and limited reserves to sustain a growing steel industry. Indeed, it is already worthwhile today to import low-priced foreign coal to a suitable coastal location, rather than transport washed Indian coal over long distances. Further, the ash content of imported coal may be only one-fourth that of washed Indian coal, resulting in substantially higher blast-furnace outputs. A seaboard location would have an important effect on the layout of the raw materials unloading and stocking facilities.

LAYOUT PATTERNS

The layout pattern to be adopted for an integrated steelworks depends on so many factors—the shape of the selected site, its contours and soil characteristics, alignment of the external railway system and the direction of incoming and outgoing traffic—that any generalisation about an 'ideal layout' pattern has little significance.

Coke and ironmaking

However, it may be said that in most of the integrated steel plants of the world, the centre lines of blast-furnaces and coke ovens are parallel. This is because a number of coke ovens and blast furnaces are required to balance the steelmaking and rolling complex, and each line of ovens or furnaces may extend for over 1 km in length. Plants of large capacities often adopt parallel rows of coke oven batteries, but laying out blast-furnaces in parallel sets—as at Salzgitter Huttenwerk—is likely to create more problems than it solves. The granulation of slag or its collection in dry pits at the blast furnaces for subsequent utilisation in slag cement, road metal or building blocks has freed the layout of the space requirement and the ugliness of vast slag dumps.

Raw materials beneficiation

Till recently, there was complacency that Indian raw materials were among the best in the world and could be fed direct from mine to blast furnace without beneficiation. However, with increased mechanised mining it has now become essential to prepare the burden for the modern blast furnace. Under Indian conditions, this means heavy media separation or washing of the iron ore to reduce its high alumina content, uniform sizing, bedding to homogenize the materials, and agglomeration of the large proportion of fines created during the mining and beneficiation operations. At the same time,

practically all coals constituting the blend have to be washed to reduce the ash content, stocked separately, and prepared selectively for coking. Even the fluxes, particularly the limestone for steelmaking, may now require beneficiation to reduce the high insolubles. The modern steelworks layout has to make provision for many of the above activities, which may well occupy a third of the site area.

Meltshops and mills

The steelmelt shops may be parallel to the coke oven/blast-furnace base line or at varying angles to it in 'herring-bone' pattern. As the length of an LD meltshop is only half that of an equivalent open-hearth shop, the layout of a plant with LD steelmaking is considerably more compact. The rolling mill complexes may then follow a sequential flow from the meltshops, or may again be parallel to the base line. Generally, at plants designed for three or four such production lines to attain large future capacities, the arrangement of both meltshops and primary mills in sequence, rather than in parallel to the base line, is preferable. This allows rational forward movements and provides adequate space for three or four production cycles. Whether soaking pits should be perpendicular to or in line with the primary mill is a question that can only be decided for each specific site and flow-pattern. An 'in line' arrangement using fast ingot buggies and heavy ingots would generally avoid the obstructions to traffic that perpendicular pits may pose.

Auxiliaries and utilities

As important as the juxtaposition of the main production units is the siting of its auxiliaries. The arrangement of mould preparation, scrap yard, stripper, ingot storage and soaking pits around a steelmelt shop is specially difficult as it involves the frequent movement of large tonnages over short distances. The production shops and their satellites are to be connected up to water and energy sources. The vast inputs of utilities required by modern processes make it desirable that production units be planned around a 'utilities corridor' which has ample space for distribution networks, their substations, water cooling and treating units, and has easy access for maintenance as well as for future expansion. The location of the power plant again depends on the load centre and the quantum of power to be generated. While the steelworks must indeed concentrate on producing steel, the availability of surplus fuels and the high peak demands of continuous strip rolling may make it desirable to generate substantial power within the plant itself.

Repair and maintenance facilities are crucial to uninterrupted plant operation and are generally larger in developing countries than in countries where repair services and supplies can readily be procured from well established sources. Maintenance shops are best located in a completely separate zone, so that their functioning does not in any way obstruct the operation or growth of the plant.

Many processes at the steel plant create fumes and smoke while others contaminate water supplies. The siting of production units and their design must therefore pay attention to the control of air and river pollution. These problems need to be tackled from the earliest stages in order that the atmosphere above an industrial community and the rivers flowing away from it remain clean for all time.

It is desirable that at new steel plants, particularly those where expansion is likely to be a continuing pro-

cess, construction yards and facilities are provided in a separate adjoining area. So-called 'temporary' facilities have a habit of continuing indefinitely and it is therefore necessary that construction yards be well-conceived and have access to expansion sites with minimum interference to plant operations.

TRANSPORT

Transport facilities are the most expensive single item in a steelworks and also constitute the most serious threat to its smooth operation; therefore, facility and economy in movement are the primary objectives of an adequate layout. In the past, railways have been the major carrier of materials inside a steelworks. This required that the positioning of facilities be subservient to the inflexibility of the rail system, its rigid track curvatures and permissible gradients, its limitations of capacity and speed. However, today increasing tonnages of steel plant loads are leaving the tracks and taking to the air on ropeways, conveyors or cranes and to roads in a variety of heavy versatile vehicles.

In a developing economy, where the pace of industrial growth tends to outstrip the capacity of transport systems, the plant design must have the flexibility to cope with the vagaries of railways. Where possible, the transport of coal at a coal-based works over distances of 5 to 50 miles may be by ropeway or pipeline. Raw materials coming by rail are best received and unloaded at the plant boundary so that there are no internal rail movements to interfere with plant operations. Combinations of tippers and ground hoppers offer fast and reliable unloading. These need to be adequately designed to handle a variety of wagons and to return empties in short prescribed times. From the tippler onwards, until the materials are deposited in the blast-furnace skip or at the top, belts offer fast economical conveyance.

For a low rate of movement over short distances, such as the disposal of blast-furnace and meltshop slag, the supply of fluxes and refractories to basic oxygen converter shops, and the movement of goods between storages, maintenance shops and production units, road transport is today a preferred method. Greater reliance on road-bound vehicles gives flexibility to plant operations and brings the main production departments closer in a compact layout. The disposal of finished steel within a radius of 100 to 200 miles may well be undertaken by modern truck-trailer combinations. Even intermediate products such as hot rolled strip are today being moved from the primary mills to the finishing plants a few hundred miles away.

In addition to materials, men have to be moved quickly to their stations. Today, provision of large car-parks at a steelworks in a developing country may appear as fanciful as it perhaps did to those who planned the Gary Works before the advent of Henry Ford. But this problem is going to be upon us, unless thought is given today to planning peak personnel movements over roads free of railway crossings by trolley-car or other vehicle.

Steelworks of the future

Even with the semi-continuous iron- and steelmaking processes available today, it is possible to contemplate a fully automated steelworks in the near future. The profusion of existing transport methods such as railways, scale cars, cranes and ingot buggies would be replaced by a unified handling system which lends itself to a high level of automation.

In such a steelworks, large blast furnaces (say 5 000 tons/day capacity each) would be continuously belt charged

with a prepared two-component burden, the slag tapped continuously and granulated away from the furnace. The tapping of iron direct into the mixer bay of the steelmelt shop or its transfer by induction would avoid cumbersome movement of ladles by rail. Pneumatic tubes will send pulverised materials such as fluxes to the meltshop, which may have oxygen converters, each capable of producing 2 to 3 million tons of steel per year. If conventional teeming is still in vogue, ingots are likely to be moved to stripper and to soaking pits by automated mechanical transport. However, widespread use of continuous casting would enable the cast bloom or slab to go direct from meltshop on roller tables to fully continuous high-capacity finishing mills.

Complete automated control of all phases of blast furnace, steelmaking and rolling operations will be introduced in steps, together with centralised production control. What results is a plant with a very compact layout, run by a small number of skilled personnel, having low production costs and a uniform high-quality product.

PLANT SIZE

In the last decade, the phenomenal improvements in performance of blast furnaces, the rapidity of steelmaking process using oxygen, and the large throughputs at modern blooming and slabbing mills, have made previous concepts of a good initial plant size obsolete. Indeed, some recent plants such as Rourkela have had to double their initial capacities while still on the drawing-boards.

One of the factors governing the starting size of any industrial plant is the existing volume of demand; other factors are production technology and optimum equipment sizes. In the steel industry, as in many others, costs decline with an increase in size of equipment, a trend which will, if anything, be strengthened as research succeeds in replacing batch production by continuous or semi-continuous operations. Past experience provides ample confirmation; for instance, the change-over from hand-sheet mills to continuous strip rolling has increased the economic size of the production unit by 10 to 50 times, and has been accompanied by a substantial reduction in costs, together with sharp improvement in product quality.

This would suggest, therefore, that planning of new works should, as far as possible, be in terms of production units of optimum capacity. From this point of view, a 4 to 5 million ingot-ton plant is today a desirable initial size, as it enables one modern primary rolling mill of optimum capacity to be effectively utilised. Such a plant would perhaps have four large blast furnaces and a steelmelt shop with three basic oxygen converters. It would of course be possible to start with a lower output in the first phase of construction; for instance, the adoption of two blast furnaces and two basic oxygen converters (one operating) would enable a production of 1½ to 2 million tons.

But this is not to suggest that plants with smaller initial capacities (say, 200 000 to 500 000 tons) could not be economic or should not be built. Limited initial demand; or paucity of funds, or inadequate raw materials may necessitate such a plant. Or, conditions may require a non-integrated operation to start with. In such cases, the significance of proper layout planning is even greater, because regardless of the initial size or extent of integration, the plant layout can be so devised as to enable expansion to a large integrated future capacity.

All over the world, wherever space and opportunity permit, steel plants are growing larger and larger. For instance, in the USA the number of plants with over 4 million tons annual capacity has risen from one in 1930

to eight in 1960—of which number at least two plants have capacities over 8 million tons. The Soviet Union has one such plant at Magnitogorsk, and their designers are now reported to be working on a single steelworks with an ultimate capacity of over 15 million tons a year. Even a small country such as Czechoslovakia, with a population only one-thirtieth of India's, is today installing a new works at Kosice in East Slovakia with a capacity of 4 million tons but laid out for expansion to 8 million tons. The trend is clear: Where raw materials and steel demands warrant, a plant with an output of over 10 million ingot tons is technically feasible and economically desirable.

Why large plants?

It may well be asked: In a developing country, with low initial levels of technical and managerial skills, what is the necessity of gigantic steel complexes? The reasons are many-fold.

First of all, regardless of the size of the steelworks, competent managers and technicians are essential. A large steel complex would have high capacity production units and high labour productivity. Its operation need not be any more difficult than that of a small plant, provided of course that responsibilities and powers have been clearly delegated, procedures well established, and personnel at all levels suitably trained.

Further, in any country, ideal locations in proximity to raw materials and water sources are limited, and it is therefore imperative that where such locations are available they should be fully exploited by making provision for large future capacities. In a developing country installing even one steelworks imposes such strains on the economy that construction of new plants needs to be phased carefully; moreover, the decisions required (and the delays in making the decisions) are practically the same regardless of the size of the new steelworks.

Creation of steelworks nuclei

As assured supplies of steel are vital to industrialisation and as planning for steel is a time-taking process, the developing countries have to take a long-term view based on projections of steel demand. For instance, a previous study⁴ of steel required by various sectors of the Indian economy to meet the planned future targets indicated that requirements would reach 19 million ingot tons by 1970 and 28 million ingot tons by 1975, figures which have since been generally accepted as bases for steel planning. Now, clearly, India cannot attain a steel output of 28 million tons by 1975 or 100 million tons by the end of this century unless enough steel plant nuclei are created and have the potential to grow continuously, as indicated in the hypothetical pattern of future growth⁵ and summarized in Table II.

TABLE II Hypothetical pattern of steel expansion^{4, 5}

| | Per capita consumption, kg | Ingot steel demand, m. ton | Possible pattern: number of steelworks | | | | |
|----------------|----------------------------|----------------------------|--|------------|------------|--------------|-------------------|
| | | | Over 8 m. ton | 3-8 m. ton | 1-3 m. ton | 0.5-1 m. ton | Under* 0.5 m. ton |
| End of | | | | | | | |
| 1st Plan(1955) | 8 | 3 (actual) | — | — | 1 | 1 | 1 |
| 2nd Plan(1960) | 14 | 6 (") | — | — | 5 | — | 1 |
| 3rd Plan(1965) | 25 | 12 (est.) | — | — | 5 | — | 1 |
| 4th Plan(1970) | 36 | 19 (") | — | 4 | 2 | 3 | 4 |
| 5th Plan(1975) | 50 | 28 (") | 1 | 3 | 3 | 4 | 8 |
| 20th century | 130 | 110 (probable) | 2 | 5 | 14 | 22 | 100 |

* Including non-integrated plants

While undoubtedly a large number of small steel plants will be necessary, their contribution to the country's output will be comparatively minor. The bulk of production will have to come from complexes of over one-million-ton capacity.

Experience of foreign countries

In this connection, one may note the experience of the Soviet Union where the steel industry has expanded at a rate of about 7 to 8% per year, a rate comparable to that projected for developing countries. In the early years of the Soviet regime, new steelworks played a big part because plans called for substantial production which could not have come from existing enterprises, and because steelmaking was being dispersed widely for both strategic and economic reasons. In the thirties, some 15 new works were, therefore, started. But in each case, the design would seem to have been made with the future in mind. Consequently it was possible to rely upon re-developing old steelworks for the greater part of the 60-million-ton increase in capacity between 1945 and 1961, requiring the construction of only three completely new plants at Cherepovets, Orsk-Khalilovo and Karaganda. New steelworks have contributed only about 15% of the iron-making, ingot steel or rolling capacity that was added in the 20-year period starting in 1941.⁶

Today, modernisation and expansion of existing plants are the main forms of Soviet steel development because these offer the most effective use of capital investment. Table III below indicates that during the Soviet Union's current Seven Year Plan (1959-65) additional production from entirely new plants or plants under construction will be only about one-fourth; the greatest part of the increase (about 60%) will come from the expansion of existing facilities.

Steel growth in USA

It is not only a centrally planned economy where modernization and expansion have been the principal instruments of growth. In the United States, the industry's capacity has risen in the last 30 years from 65 to 140 million tons but only a few integrated new works have been built in this period—such as the two in the west at Fontana and Geneva and one on the east coast at Morrisville, Pa. Although steel capacity in the USA is generally ahead of actual consumption, additions are constantly under way. It is difficult to say whether demand creates the new mills, or vice versa, but it is clear that as soon as the new mills come into operation, the availability of a cheaper, versatile and high quality product stimulates further demand. Also this 'excess capacity' has always been very useful in the face of national emergencies. For instance, the

TABLE III Method of increasing Soviet production in Seven Year Plan (1958-65)⁷

| | Pig iron | | Ingot steel | | Rolled steel | |
|--|----------|------|-------------|------|--------------|------|
| | m. ton | % | m. ton | % | m. ton | % |
| Total increase in production of which | 30.5 | 100 | 36.1 | 100 | 26.7 | 100 |
| 1 by better utilisation of equipment existing as on 1.1.1958 | 10.9 | 35.7 | 8.6 | 23.8 | 7.0 | 26.4 |
| 2 by expansion of existing plants | 15.0 | 49.2 | 21.3 | 59.0 | 15.3 | 57.1 |
| 3 by establishment of entirely new steel plants | 7.4 | 24.3 | 8.3 | 23.0 | 6.7 | 25.1 |
| Less reduction in capacity due to obsolete plants | -2.8 | -9.2 | -2.1 | -5.8 | -2.3 | -8.6 |

operating rate rose from 59.2% in 1914 to 93.4% in 1916, again from 64.5% in 1939 to 98.1 in 1943, and reached an all time high of 100.9% in 1951 during the Korean war.⁸

Bearing in mind this world-wide trend of continuous expansion of steelworks, developing countries will be clearly lacking in foresight if the needs of the future are not fully kept in view while planning the layouts of new plants today.

ECONOMY OF SIZE

Another compelling reason for large plant size is economy in costs. These economies come from many directions. Capital costs per ton of installed capacity decrease as the size of the production unit increases and as techniques for speeding up throughputs are adopted, the proportionate cost of tracks, utilities, maintenance shops and other auxiliaries goes down and 'off-site' facilities such as township, marshalling yards and mines are better utilised.

At the same time operating costs favour a large plant. Costs of centralised maintenance and utility systems are lowered, transportation is better utilised and there is a significant improvement in labour productivity. Also, overheads and fixed charges (interest plus depreciation) are significantly reduced.

This characteristic lowering of costs with size is illustrated by the recent report of the Indian Tariff Commission⁹ on fair ex-works steel prices. This indicates that as the new plants of Hindustan Steel Limited expand, a reduction of up to 30% may be expected in the 'gross block' or the cost per ton of annual capacity (Table IV).

The 4-million-ton steelworks

In order to evaluate the effect of plant size on economics, we made a study of a hypothetical steelworks designed for 4 million ingot tons/year. It was assumed that the plant would produce a range of flat products, and that it is to be installed in a developing country which has a sound raw materials base and rapidly rising steel demand. It was taken for granted that an appropriate location and a site meeting the requirements indicated earlier would be available.

The factors involved in deciding on the most suitable processes, equipment sizes and layout are so numerous and varied, that the solution adopted is by no means the only economic one. The plant chosen envisages the requisite coke oven capacity, four blast furnaces (about 2 500 t/day) and three 250-ton LD converters. Conventional teeming, a universal slabbing mill, plate mill, strip mill and finishing lines including continuous galvanizing and tinning were adopted. Extensive repair and maintenance shops together with all auxiliary facilities and utilities were provided.

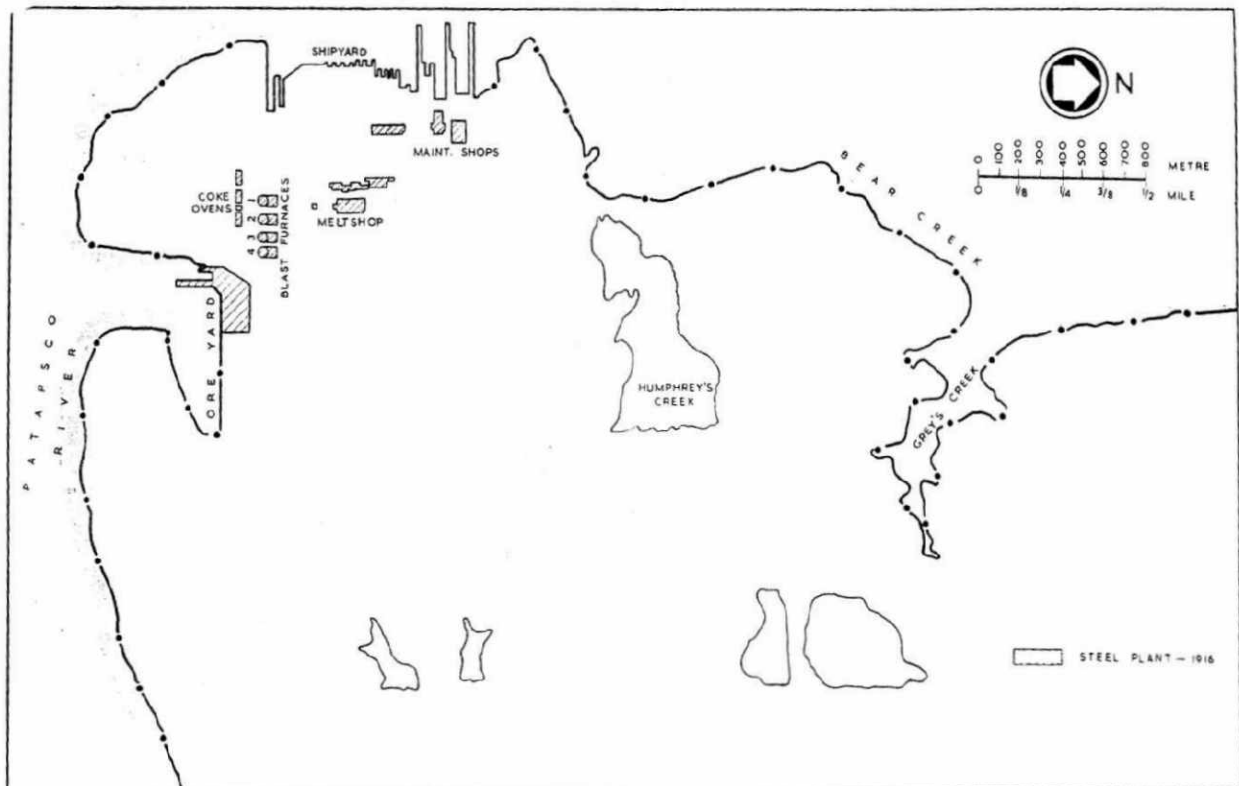
TABLE IV Capital costs for initial and expanded steelworks

| | Durgapur | Rourkela | Bhilai |
|--|--------------|------------|------------|
| Initial (1962) | | | |
| Capacity | 1 m. t | 1 m. t | 1 m. t |
| Gross Block*, per annual t | Rs 1 728 | Rs 2 349 | Rs 1 734 |
| Expanded (1966) | | | |
| Capacity | 1.625 mill t | 1.8 mill t | 2.5 mill t |
| Gross Block*, per annual t | Rs 1 436 | Rs 1 834 | Rs 1 229 |
| Reduction in Gross Block after expansion | 17% | 22% | 29% |

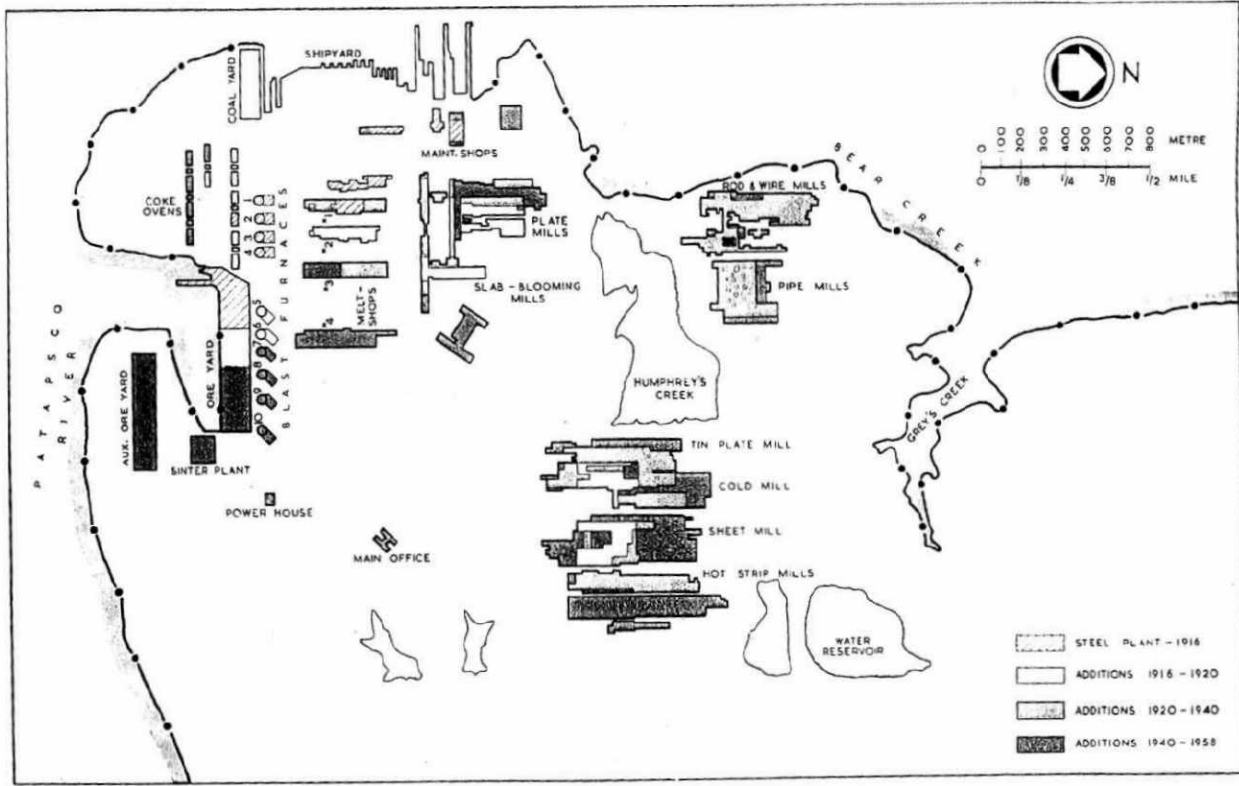
* Gross Block includes off-site facilities such as township, and in the case of Rourkela and Bhilai also includes iron ore mines and limestone quarries.

914 to 934" in 1916, and reached 11 during the Korean trend of continuous 19 countries will be ceds of the future are g the layout of new

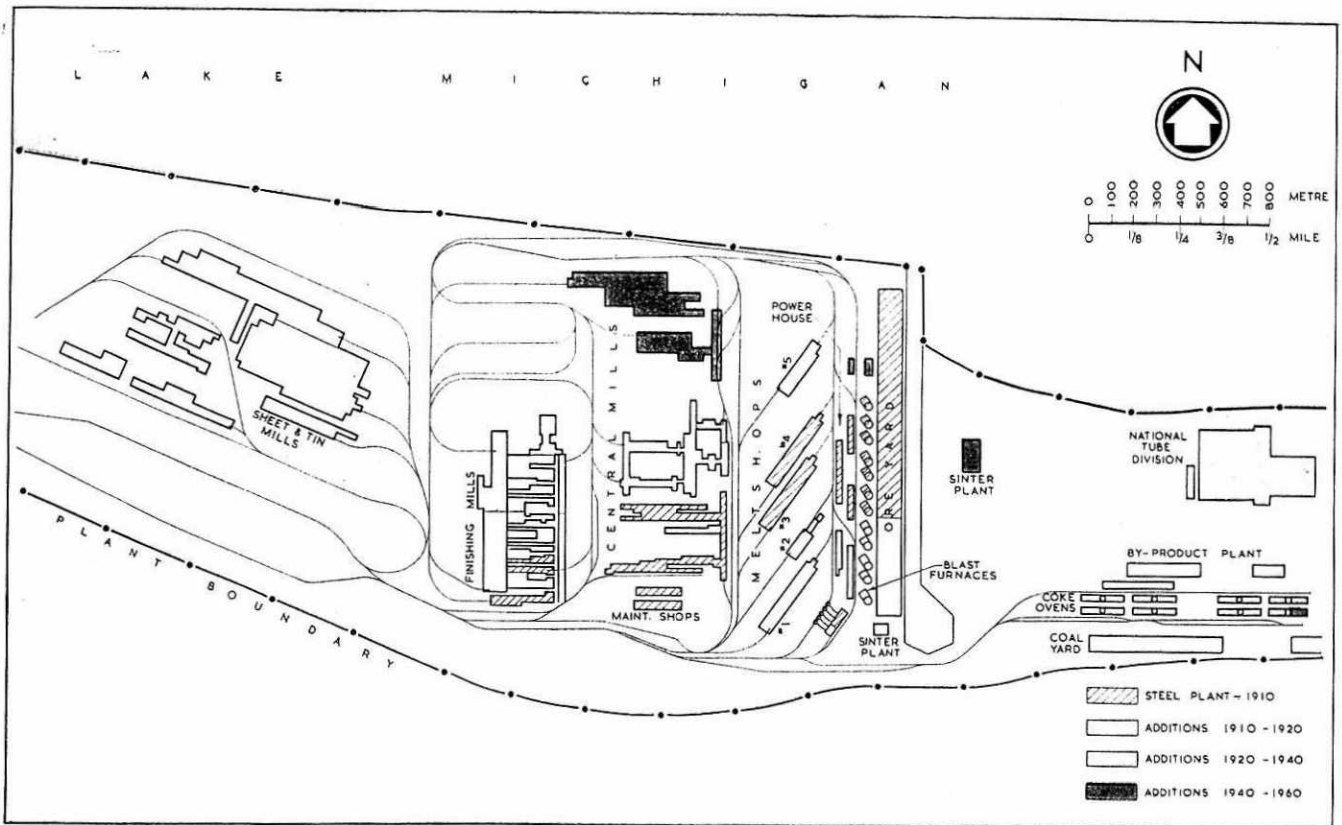
ge plant size is eco- me, from many direc- led capacity decrease reases and as techn- re adopted, the pro- maintenance shops and facilities such as better utilised. a large plant. ly systems are ad there is a tivity. Also, (precipitation) ze is illus- r Commis- s that as ppend, a e Gross hie IV).



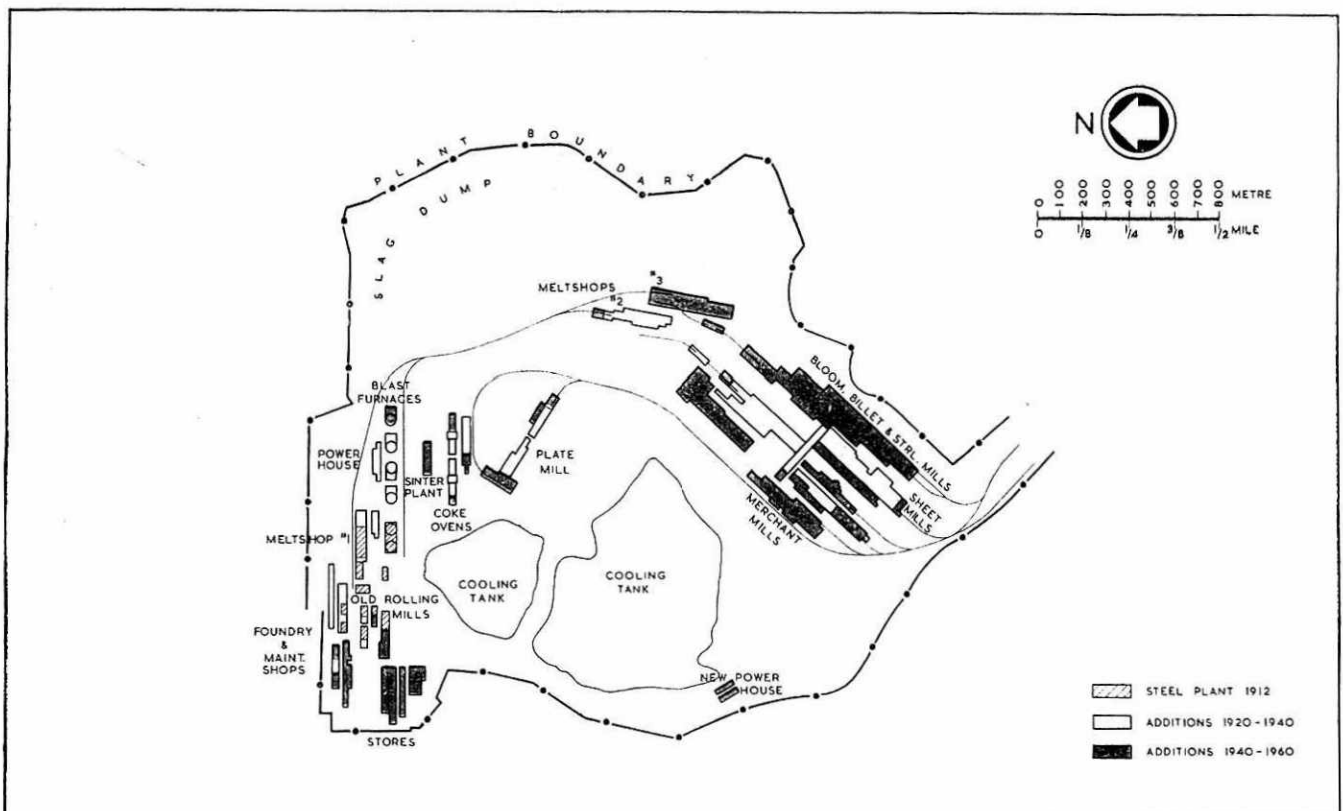
2. Schematic layout of Sparrows Point Plant (Bethlehem Steel Co., USA) 1961



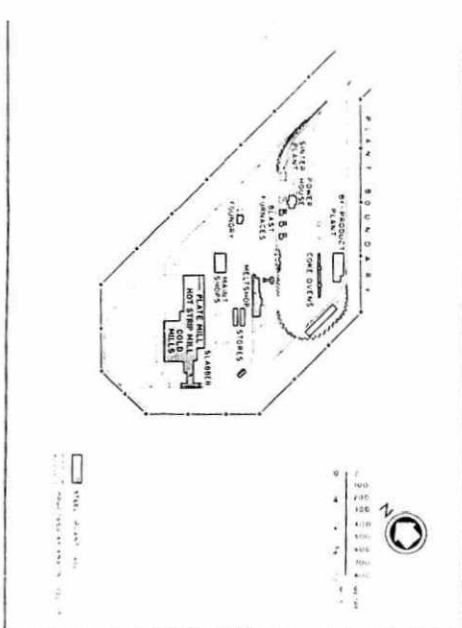
3. Schematic layout of Sparrows Point Plant (Bethlehem Steel Co., USA) : present capacity 8.2 m. ingot tons/year



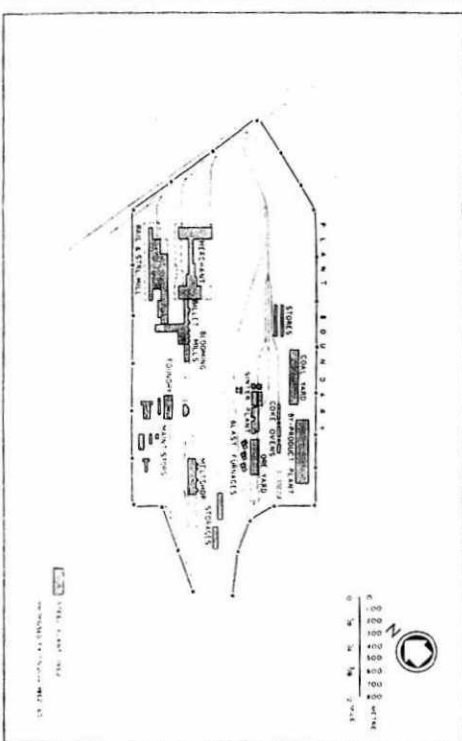
4 Schematic layout of Gary Steel Works (US Steel Corp., USA) ; present capacity 7.2 m. ingot tons/year



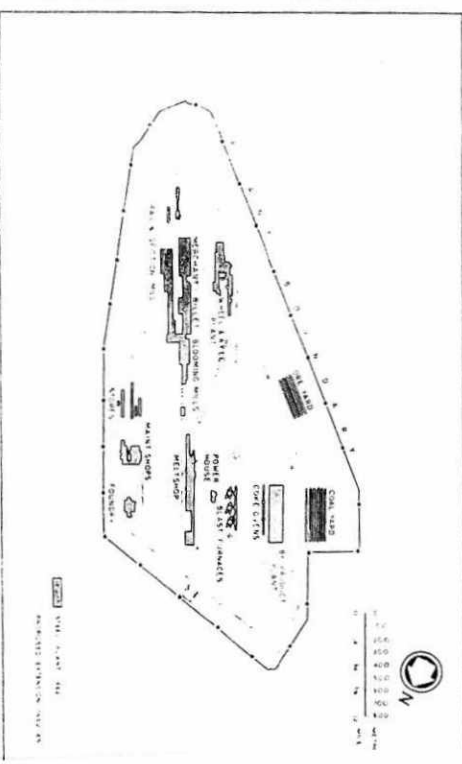
5 Schematic layout of Tata Iron and Steel Works, Jamshedpur ; present capacity 2 m. ingot tons/year



of Runkala Steelworks (Hindalun Steel Ltd.): present capacity 1 m. ingot tons/year

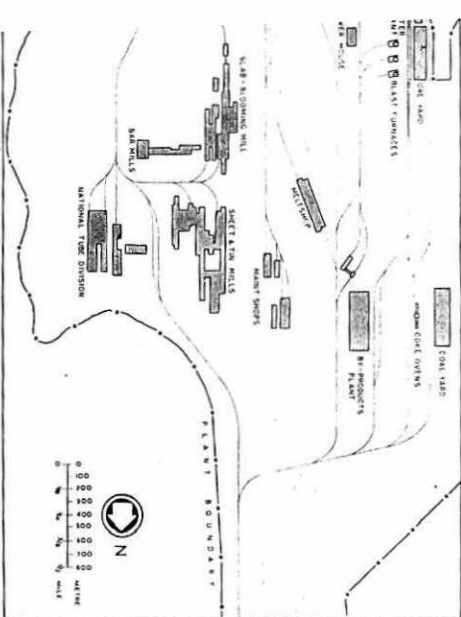


7 Schematic layout of Bilhar Steelworks (Hindalun Steel Ltd.): present capacity 1 m. ingot tons/year

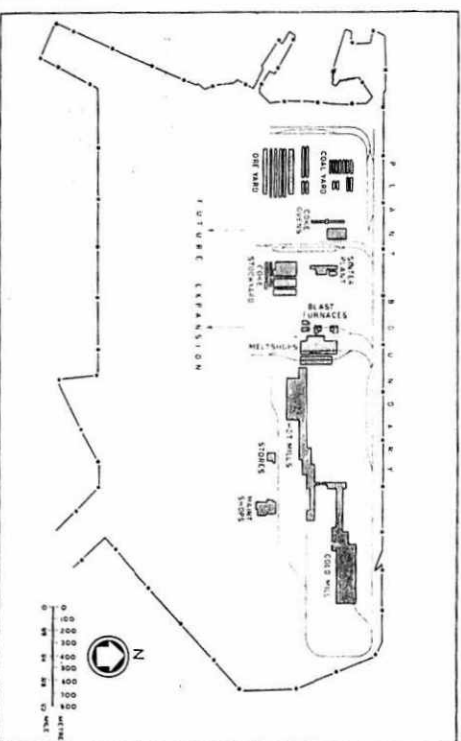


8 Schematic layout of Durazque Steelworks (Hindalun Steel Ltd.): present capacity 1 m. ingot tons/year

8 pages are shown in the same scale: each rectangle encloses an area of 81 square miles. Clearly, the plants have been laid out with much less precision in space and design for expansion than the layouts of unless works, or even the six-year-old Sparrows Point Plant



unless Works (U.S. Steel Corp., USA): present capacity 3.2 m. ingot tons/year



10 Schematic layout of Spencer Works, Newport (Richard, Thomas and Baldwin, UK): present capacity 1.4 m. ingot tons/year



11 Schematic layout of Sparrows Point Plant (Bethlehem Steel Co., USA): present capacity 8.2 m. ingot tons/year

'Cheap labour'

A modern plant was visualised incorporating a fair level of mechanization and automation. Indeed, up-to-date equipment is considered necessary if such a plant is to produce a high-quality product at competitive costs. Moreover, there is in our opinion a fallacy that developing countries have abundant 'cheap labour' and therefore extra employment is preferable to mechanization. In such countries, where labour costs tend to go up rapidly with advance in living standards, the fight against inflation must depend for its success upon the achievement of higher productivity. This underscores the need for maximum economy in the production costs of steel, a commodity which enters into the costs of all manufactured goods. It therefore implies taking the fullest advantage of technological advances such as automation in the basic industries, even at some sacrifice to labour employment. India's Third Plan, while giving the greatest importance to maximizing employment, recognizes that 'in certain branches of industry, it is essential to adopt the scales and methods of production which will yield the largest economies'.¹⁰

For the hypothetical plant, cost of equipment was estimated on recent European prices including 15% freight and an average 5% import duty. A contingency figure was added for unforeseen expenses, and necessary spares provided with the initial plant—a practice considered essential for a developing country. To make the figures comparable with those in Table IV, provision was made for a township, an ore mine and a limestone quarry. On the above basis the capital cost of the plant is estimated at approximately Rs 5 000 million, that is, Rs 1 250 per ton of annual capacity. As this plant is for flat products, which require larger investment, it may be compared to the gross block of Rs 2 349 for the million-ton Rourkela plant and Rs 1 834 for its 1.8-million-ton expansion.

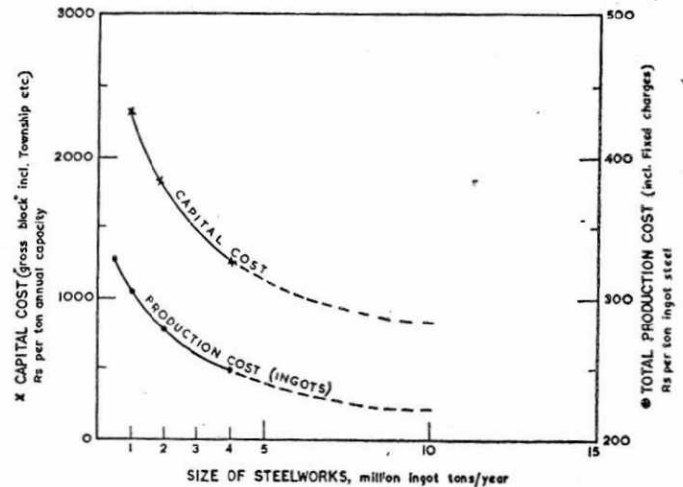
Our estimates indicate that the total production costs (including fixed charges) of steel ingots for the 4-million-ton plant would be about Rs 30 per ton less than for a 2-million-ton plant and about Rs 50 per ton less than for a one-million-ton plant. In addition, the limited resources of technical man-power in a developing country are likely to be better utilised.

Figure 1 indicates the effect of size on gross capital as well as on production costs. It will be noted that investment is reduced by one-third as plant capacity doubles from 2 to 4 million tons. This downward trend would continue, though to a less extent, as the steelworks expands further.

OLD PLANTS WITH MODERN LAYOUTS

As discussed, the market for steel as well as economies of scale inevitably forces a steel plant to expand provided of course, the original planners have shown '...the courage to look far enough ahead and provide a basic layout which can increase in size beyond anything which may be contemplated at the time or during the life of the people immediately concerned'.¹¹ There are several excellent examples of steel plants which have, over the course of decades, expanded tenfold and more, for instance, Bethlehem Steel Company's Sparrows Point Plant, United States Steel Corporation's Gary Works, Inland's Indiana Harbour Works, the Magnitogorsk Metallurgical Combine, and the Anshan Works in China.

An important case in point is the Sparrows Point Plant, which made its first pig iron in 1889 and two years later poured its first heat of Bessemer steel. Figure 2 shows the plant in 1916 with four blast-furnaces, a single meltshop and rolling mills. These old facilities have



1 Relation of plant size to capital and production costs

gradually evolved into an up-to-date layout, shown in Fig. 3, with 10 blast furnaces, 4 meltshops, a number of primary mills and various finishing facilities. In this period of half-a-century it has expanded 12 times and sprawls over 4 000 acres. To do this, a large area has had to be gradually reclaimed from the sea, and a part of the old township had to be demolished to make way for the fourth steelmelt shop. Today it is the world's largest steelworks with a capacity of over 9 million net tons, employing a force of 30 000 people. But, it has still not stopped growing!

The same vision is evident in the growth of Gary Works of the United States Steel Corporation. An old drawing dated 1906 is known to exist showing the location of twelve proposed blast furnaces. This original layout concept has permitted the installation of a dozen blast furnaces, five meltshops, and a host of rolling and finishing facilities. Fig. 4 shows the original 1908 facilities and the plant as it stands now. It is foresight such as this which has enabled the plant to become one of the largest in the world today.

Also of interest is the growth of the TISCO Works (Fig. 5), which started at almost the same time as Gary, and with an initial capacity of about 100 000 tons. The plant today has a capacity of two million tons and could attain still higher capacities, thanks largely to the vision of the original planners who, under very adverse conditions, installed a steelworks 50 years ago which has already expanded twentyfold!

LAYOUT OF RECENT STEELWORKS

In contrast to the layout of the three half-century old plants, it is interesting to see three steelworks of recent vintage—the new one-million-ton plants at Rourkela, Bhilai and Durgapur which are coming into full production (Figs 6, 7, and 8). It needs to be clarified that the layout sketches in this paper are purposely to the same scale; each figure encloses a rectangle of about 8½ square miles. This has been done in order to give a visual impression of the comparative areas occupied and layout concepts.

It is at once clear that the new Indian plants encompass an area (about two square miles each) which is only a fraction of the extent of the old plants. Also, production units and traffic are laid out for limited expansion only. If the perspective of our future steel demands had crystallised a decade earlier and had been brought forcefully before the plant suppliers, the layouts would undoubtedly have been different.

The Fairless Works of US Steel, shown in Fig. 9, has been called the 'steelmakers' dream plant' because of its spacious and carefully planned layout. In the initial plant the coke traverses a distance of a mile to the blast furnaces, but as the plant expands the flow of materials, which has been dictated by the incoming indigenous coal and imported ore, will assume a rational course. Here again, the arrangement of initial facilities over an area of about 4 000 acres may appear extravagant. But the plant has already doubled its initial 1½ million tons capacity; at the time of installation it was said to have a potential of 10 million tons but today due to recent technological advances it could be expanded to 15 million tons.

Even in a country where only a decade ago steelworks were not known for spacious or planned layouts the sheer logic of competition has produced a steel plant—the new Spencer Works of Richard Thomas and Baldwins Limited (Fig 10)—which in concept and facilities is ahead of its times. The extensive raw materials blending facilities, conveyerisation of bulk supplies and adoption of a high level of initial automation may be said to have fulfilled the original objective that this should be the most modern steel plant in the world.

To emphasize again the manner in which the site of a steel plant begins to fill up in course of time, the layout of Sparrows Point is reproduced in Fig 11. As it is on the same scale as the five 'modern layouts' one is able to compare the arrangement and use of space.

CONCLUSION

The layout of a steelworks has an important effect on cost as also on its potential to grow. There is no steel plant in the world which has stopped expanding or which considers itself too large even though its capacity may be in excess of 7–8 million tons.

Rapid growth of steel demand is a characteristic of developing countries, making it worthwhile therefore to take advantage of the economies of scale and plan in terms of production units of optimum size; even if their

full utilisation is not immediately feasible, steel demand would overtake this excess capacity in a very short period.

The decision in each case must of course depend on the combination of circumstances obtaining in a specific situation—the perspective of demand, the cost and availability of capital, and the raw materials position. More often than not physical resources will be less of a limitation than the lack of courage to look ahead. Technological advances today permit the exploitation of very lean ores and inferior coals for ironmaking; alternatively, there is the possibility of importing one or the other of the main ironmaking materials and siting a new works on the sea-board to augment indigenous production.

Sound business judgement would undoubtedly dictate that a new steelworks should enter the field with an economic product at competitive costs. But regardless of the size of the initial plant, it can be laid out at only small extra cost, to expand substantially in order to meet spiralling steel demands. The need, therefore, emerges for balanced decisions fully taking into account technical and economic factors, or in other words, for plant layout design to be informed by a sense of social purpose and a faith in the future.

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