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ECONOMIES OF SCALE IN THE STEEL INDUSTRY 1/

by

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Contents

I. INTRODUCTION

Owing to the importance of the availability of steel for the economic development of the developing countries, there is considerable interest in many of these countries in the construction of integrated steel plants where they do not already exist or in increasing the capacity of existing plants. Planning is required here, with regard to both small plants and factories of larger dimensions. The substantial amounts of capital needed for such projects and the importance of ensuring that steel is made available to users at the lowest possible price justify making a careful study of the processes to be used and the dimensions for factories being expanded or for new projects, whether large or small.

The choice among the possible processes which may be used in the steel industry is affected by local factors, such as the quality and type of iron ore, and the abundance and relative price of such inputs as coking coal, gas, petroleum and electric power, together with several others. In certain cases, on the other hand, the choice of process depends on the characteristics of the product desired. Section V of this document contains a detailed examination of the economic significance of the possible processes among which a selection must be made in the planning of the industry.

The rest of the work is devoted to a study of economies of scale in the steel industry, - that is to say, the relationship between annual production capacity and unit capital and production costs. As an illustration of the importance of economies of scale, the following example may be given: the production costs of a plant producing 300,000 tonnes of non-flat steel products annually would rise by 13 per cent if, instead of using local iron ore costing US$ 5 a tonne, it was necessary to import ore at US$ 14 a tonne. On the other hand, in the case of a similar plant with a capacity of only 100,000 tonnes annually, the increase in costs would be 27 per cent.

The study is not primarily aimed at determining optimum sizes for plants, though it may of course be observed that there are many factors pointing to the economic advantage of large plants. The intention is rather to analyse the technical and economic aspects of plants of different sizes by considering a series of hypothetical installations for each combination of processes. In view of the limited markets of many of the developing countries, the main object will be to throw light on the economic problems of small plants and to determine the minimum sizes at which they are economic.

One consequence of the limited markets which are often available for the industries of the developing countries is an excessive diversification of production, aimed at covering as large a part as possible of the existing domestic market. Increases in capital and other costs resulting from greater diversification of production occur mainly in the rolling operation, since if production is concentrated in a few types a much higher degree of mechanization is possible in the rolling mills. Even without this, the following example is worth noting:[2/] a rolling mill with a programme covering the production of bars and shapes and with an hourly capacity varying between 10 and 30 tonnes, taking into account the different weights per metre included in the programme and the rollings necessary to obtain them, can achieve an annual production of 120,000 tonnes, with three shifts daily and a yield of 80 per cent, if the make-up of the programme is such as to allow an average hourly weight of some 25 tonnes, and changes of rollers can be limited to Sundays. On the other hand, annual capacity will fall to 60,000 tonnes if the average weight of the product is somewhat less favourable and if it is necessary to change rollers fairly frequently, which will mean limiting the work to two shifts daily.

Steel production is a complex process and the question of economies of scale in it is also complex. If one plans a particular production process, requiring a certain type of installation, the size of the unit will have to depend on the intended scale of production. In such cases there is inevitably a maximum size beyond which similar units cannot be built at the present stage of technology. Once this size is reached, if a still higher volume of production is needed, this can be achieved by establishing several units side by side. In the same way there

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2/ Lüth/König, The planning of iron and steelworks, Springer Verlag, Berlin/Heidelberg/New York, 3rd edition, p.162.

is a minimum below which, for technical or economic reasons, it is not desirable to use the process in question and it must be replaced by another, or the minimum size which is technically feasible must be used with a low load factor.

In theory, what is interesting in a study of economies of scale is the variation in capital and production costs between these two extremes determined by technical considerations. It is highly probable that, if it were possible in the steel industry to have several plants of differing sizes in which the production process and the type of equipment remained the same, the same equation would hold good as is generally used in the chemical processing industry; according to this, the relationship between the capital costs or the variable production costs in two plants of different capacities is equal to a logarithmic relation between these capacities in which the exponent is less than unity and in most cases fluctuates around 0.6. However, uniformity in process and equipment occurs in the steel industry, taken as a whole, only for very brief stretches of the capacity spectrum, although, in the case of isolated components of the production cycle, such uniformity occurs over broader size ranges.

In practice, therefore, the situation is completely different. The process of steel production, from the mining of the iron ore to the finishing of the rolled steel, is not a single, continuous process but a series of operations which take place one after the other, transforming the principal raw material in successive, or in some cases simultaneous, steps. These operations include the following: secondary preparation of the iron ore, production of sinter, production of metallurgical coke, with or without by-product recovery, blast-furnace reduction proper, steel making with or without the use of oxygen, cogging or continuous casting, and rolling. Each installation and process used in this combination of activities has its technical limits in the form of maximum and minimum capacities for specific volumes of production, with no relationship between the limits of the different processes among themselves. Thus for a certain annual production range a certain process or type of installation is used, and once a particular dimension is reached, for the construction of a larger plant, the process or installation is replaced by another more appropriate or more economic for larger volumes of production. In this way, a curve indicating unit capital costs for a series of plants with production programmes which are similar but differ in volume is not one which can be expressed by an exponential equation, but will always rise higher at the right side than a theoretical curve, because in practice, as the annual capacity of the plant grows, increasingly complex and automated installations and processes are used. In general, this is due to the fact that it is not economic to produce automatic equipment for units below a certain size, but sometimes, too, it is physically impossible to operate certain very small units efficiently.

The technical and economic considerations developed in this document regarding the selection of the process and type of installation for the hypothetical plants serving as the basis for the calculations and the calculations themselves, are not necessarily valid for a specific plant or location. In the case of a particular plant, local factors, including the prices and quality of inputs, will influence the selection of the process and the costs. However, the information in this paper may prove applicable even to a specific project if due consideration is given to the local factors and the necessary substitutions and adjustments are made.

II. GENERAL BASIS OF THE STUDY

The information used in the present paper has been taken almost entirely from two earlier studies on economies of scale in the steel industry carried out by ECLA consultants in 1965 and 1966.[3] These two studies analyse the effect of the capacity of a series of hypothetical plants of various sizes on unit capital and production costs. For this purpose, the hypothetical plants have been regarded as situated at a given location, and capital costs have been determined for each of them, the costs have been classified under the main production departments - reduction of the ore, steel making, continuous casting or cogging, and rolling. All the cost figures for auxiliary departments and services such as administration, laboratories, power and steam plant, repair shop, works transport, etc., have been distributed among the main departments in proportion to the use made of them by each department. With regard to production costs, theoretical costs have been determined for each plant, utilizing in all cases pre-established unit cost figures for inputs which appear in annex I and are in harmony with the costs to be expected in Latin America.

Although the basic assumptions on which the two papers rest are the same, their purposes are quite different. The study by Dastur and Co. (E/CN.12/764) considers the effects of economies of scale in the smallest size-range of integrated plants, with basically a single production sequence and processes including the production of non-flat steel, and with capacities between 100,000 and 300,000 tonnes. On the other hand, the study by Mr. Martijena (E/CN.12/766) deals with plants producing between 100,000 and 2.5 million tonnes annually of flat and non-flat products, and plants with varying production sequences are considered.

3/ "Economies of scale at small integrated steelworks", by M.N. Dastur and Co. (E/CN.12/764), and "Las economías de escala en plantas siderúrgicas de tamaño medio y grande y la influencia de los adeltanos tecnológicos en las inversiones y costos de producción", by Armando P. Martijena (E/CN.12/766).

In spite of the fact that, as has been said above, the costs of inputs and a number of general assumptions were kept uniform, the authors were left free to imagine the different plants in the way they chose; that is to say, there was no specification of the type or scale of auxiliary services which, taken together, usually account for between 30 and 40 per cent of plant capital costs - laboratories, repair shops, clinics, cafeterias and canteens, etc. These were devised by each author separately, a fact which limits the direct comparability of the two studies somewhat. Similarly, the total annual working hours, the product-mix patterns and the utilization factor of the rolling mills have not been fixed, and, taking into account what is said in the example cited above, one can imagine the possible disparity which this has introduced when data from one study are compared with those from the other, although each one is quite homogeneous individually.

The effect of plant size on capital and operating costs involves many factors and these have to be analysed project by project. For the purpose of this study, a number of basic simplifying assumptions necessarily had to be made. The object of the study is limited to obtaining a broad perspective on size-cost relationships in the steel industry. While the Dastur study (E/CN.12/764) examines in depth what happens in the case of a given production sequence at the lower end of the capacity spectrum, Mr. Martijena's paper (E/CN.766) studies relationships over a wide variety of sizes, production programmes and sequences of processes. While the trends indicated by the figures and the relative costs have a validity for the purposes of each of the studies, the specific figures may vary from one study to the other and with reference to plants existing in practice.

In order to make the data for plants of different sizes more comparable, the plant design and equipment considered makes only very limited provision for future expansion, except as far as space is concerned. In practice, this approach would not be the most desirable, owing to the rapid rise in consumption in the developing countries, as a result of which, in most cases, it would be advantageous to make greater provision for future expansion, especially with regard to the more expensive installations, such as rolling mills.

The calculations of costs and investments required are based on hypothetical plants using modern technology for iron and steel making. In fact, in the two studies taken as a whole, account is taken of practically all the technological advances which, after being satisfactorily tried out at plants somewhere in the world on an industrial scale, seem of possible application in Latin American. Each production sequence is therefore an alternative of possible practical use, but this does not mean that there are not other possibilitites whose consideration has been dispensed with in order not to complicate the work excessively with all the many combinations which would then have to be analysed. In order to isolate and highlight the effects of varying size on steel plant economy the effects of sectors not directly related to plant size have been minimized as far as practicable by keeping them constant. Thus, to allow meaningful comparison of the data within the series of plants with the same basic production structure, the same production processes have been assumed for all of them, although actually, in some cases, more economical processes could have been considered for certain plant sizes.

In integrated plants with large capacities, it is possible for the mix of rolled products to be diversified somewhat and for the installation of mill units of economic size still to be feasible. But product diversification in a small plant will largely result in elimination of economies of scale as far as the rolling operation is concerned. In fact, over-diversification of output in order to cover the largest possible portion of the home market is one of the reasons for high cost of steel in the developing countries, particularly in Latin America.

It must be admitted that some of the assumptions made in the study for purposes of simplicity impose restrictive conditions and cause factors which may have some significance in economies of scale to be left out of account. This is the case, for example, when we regard the cost of iron ore as the same for all plants, whereas it is quite possible that a factory with a capacity above 1 million tons could organize the transport of the ore at a lower cost than a plant with smaller capacity. Nevertheless, it is thought that the studies provide an adequate basis for the necessary adjustments to be made in each particular case.

III. ECONOMIES OF SCALE IN SMALL PLANTS PRODUCING NON-FLAT STEEL[4/]

In this paper, the influence of the size of the operation on technical and economic relationships in very small steel plants is analysed. The study considers five cases, namely:

Case I	25,000 tonnes
Case II	50,000 tonnes
Case III	100,000 tonnes
Case IV	200,000 tonnes
Case V	300,000 tonnes

In order to have a uniform basis of study, the plant capacities are given in terms of "liquid steel" and not of finished products. The processes and principal equipment selected for this study are indicated in table 1.

Some alternatives are also considered in the paper, such as electric reduction in plants of 25,000 and 50,000 tonnes annual capacity and electric arc furnace steel making instead of LD converters in 50,000 tonne plants, in order to make a preliminary evaluation of the merits of these processes in very small plants. Since the basic object here is a study of economics of scale, no reference is made to these variants.

Account is taken in the paper of all the general assumptions enumerated in the preceding section, where those adopted in the two papers are summarized. Many other assumptions which are peculiar to document E/CN.12/764 are indicated in table 1. The following additional observations should probably be made: it has been estimated that mining and sizing of ores will yield about 30 per cent fines below 10 mm size. These are agglomerated in sintering plants in cases IV and V, and are charged immediately in the mixture in the plants of smaller size.

4/ Summary of the paper "Economies of scale at small integrated steelworks", by M.N. Dastur and Co., prepared for ECLA. (Document E/CN.12/764)

Table 1

SUMMARY OF MAJOR FACILITIES

Installation	Case I – 25,000T/yr	Case II – 50,000 T/yr	Case III – 100,000 T/yr	Case IV – 200,000 T/yr	Case V – 300,000 T/yr
Coke making	–	–	One – battery of 48 pusher type non-recovery ovens	One – battery of 20 by-product ovens	One – battery of 30 by-product ovens
Sintering	–	–	–	One – GHH pan type sintering machine. 4 pans of 4.62 sq m area each	One – GHH pan type sintering machine. 4 pans of 7 sq m area each
Ironmaking	One – 2 m hearth dia blast furnace	One – 2.75 m hearth dia blast furnace	One – 3.5 m hearth dia blast furnace	One – 4.3 m hearth dia blast furnace	One – 5.0 m hearth dia blast furnace
Steelmaking	One – 3-ton LD converter installation; one spare vessel	One – 6-ton LD converter installation; one spare vessel	One – 12-ton LD converter installation; one spare vessel	One – 25-ton LD converter installation; one spare vessel	One – 35-ton LD converter installation; one spare vessel
Continuous casting	Two – single strand continuous casting machines (curved mould type)	Two – single strand continuous casting machines (curved mould type)	Two – twin strand continuous casting machines (curved mould type)	Three – triple strand continuous casting machines (curved mould type)	Three – four strand continuous casting machines (curved mould type)
Rolling mills Reheating furnace	8-ton per hour continuous pusher type	12-ton per hour continuous pusher type	25-ton per hour continuous pusher type	50-ton per hour continuous pusher type	70-ton per hour continuous pusher type
Roughing mill	Two – 3-hi, 400 mm stands; 500 KW AC Drive	Two – 3-hi, 400 mm stands; 500 KW AC Drive	One – 550 mm vertical stand; 200 KW DC Drive Four – 2-hi 400 mm stands; two – 500 KW DC Drives	Four – 2-hi 450 mm stands; two – 500 KW DC Drives four – 400 mm stands (second stand-vertical; four 500 KW DC Drives Four – 380 mm alternate vertical & horizontal stands; four 500 KW DC Drives	Four – 2-hi 450 mm stands; two 500 KW DC Drives Four – 2-hi 420 mm stands; four 500 KW DC Drives Seven – 380 mm stand (fifth stand-vertical) Seven 600 KW DC Drive
Finishing mill	Seven – 3-hi, 300 mm stands; two – 500 KW AC Drives	Seven – 3-hi, 300 mm stands; two – 500 KW AC Drives Four – 2-hi, 250 mm cont. wire rod finishing stands; 500 KW AC Drive	One – 550 mm vertical stand; 200 KW DC Drive Two – 300 mm & Three – 300 mm stands – zig-zag two 600 KW DC Drives One 550 vertical stand; 200 KW DC Drive Six – 2-hi 250 mm wire rod finishing stands; three – 220 KW DC Drives	Five – 300 mm stands – zig-zag; Two – 400 KW DC Drives Six – 2-hi, 250 mm wire rod finishing stands; three – 220 KW DC Drives	Five – 340 mm stands (alt. horizontal & vertical); five 600 KW DC Drives Wire rod finishing – two trains each consisting of: six – 280 mm (alternate vertical and horizontal) stands; six – 220 KW DC Drives for each train

The blast temperature, the injection of hydrocarbons and other elements of the operation are fixed so as to give a coke rate of 500 kg per tonne of molten iron in the 300,000 tonne plant. In the smaller plants the same system is used, but the specific consumption of coke will necessarily be somewhat greater.

For steel making, the LD top-blown oxygen converter has been selected. The proportion of scrap used in the converter will be between 20 and 25 per cent, but not all of this quantity will be produced as plant return scrap and some of the scrap will have to be purchased. Originally, 30 per cent scrap charge was considered for all the cases, but on checking the heat balance it was found that such a high percentage of cold metal could not be used in converters as small as those envisaged in the paper.

The steel produced in the five cases is killed and is converted into billets by means of continuous casting machines. The number of machines and of strands per machine is that required to supply the quantities and types of billets given in table 2, which are those considered necessary for the production of the product-mix envisaged in each of the cases. The selection of the rolling equipment is similarly determined. However, the range of sizes and the proportions used have been kept more or less constant in all the cases considered.

Table 2

CONTINUOUS CAST BILLETS

Billet size	Case I T/yr	Case II T/yr	Case III T/yr	Case IV T/yr	Case V T/yr
75 mm square	19,200	38,400	76,800	96,000	144,000
100 mm square	4,800	9,600	19,200	57,600	86,400
125 mm square	-	-	-	38,400	57,600
Total	24.000	48.000	96.000	192.000	288.000

A summary of capital costs for the five hypothetical plants appears in table 3, which gives separately the figures for each of the production departments and for the auxiliary departments. The table brings out the relative importance of the capital costs for the auxiliary departments; taken as a whole, these vary from 32 per cent for the 25,000 tonne plant to 23 per cent for the 300,000 tonne plant.

Table 3

SUMMARY OF CAPITAL COST

	Case I 25,000 T/yr '000 $	Case II 50,000 T/yr '000 $	Case III 100,000 T/yr '000 $	Case IV 200,000 T/yr '000 $	Case V 300,000 T/yr '000 $
Production departments					
Coke ovens	-	-	1,070	3,180	4,152
Sinter plant	-	-	-	1,329	1,717
Blast furnaces	2,652	4,255	6,659	10,442	13,789
Steelmelt shop	1,910	2,861	4,879	7,226	8,901
Concast plant	761	1,033	1,860	3,519	4,724
Rolling mills	2,262	3,338	7,172	11,921	16,553
Sub-total	7,575	11,487	21,640	37,617	49,836
Auxiliary departments					
Plant laboratory	123	133	142	274	308
Power system	575	990	1,410	1,779	1,957
Water system	676	1,148	1,936	3,088	4,011
Utilities	612	906	1,330	1,746	2,391
Works transport	457	658	1,010	1,488	2,002
Repair and maint. shops	735	1,201	1,652	2,345	2,810
Miscellaneous buildings, facilities and storages	374	509	762	1,021	1,278
Sub-total	3,552	5,545	8,242	11,741	14,757
Total	11,127	17,032	29,882	49,358	64,593

The figures in table 3 reappear in table 4, after the capital costs for the auxiliary departments have been allocated to the various production departments on the basis of relative utilization of the facilities concerned. As may be deduced from the figures in the table, plant capital cost per tonne of liquid metal is US$ 299 per tonne annual capacity in the 100,000 tonne plant, rises to US$ 445 - i.e., by 50 per cent - in the smallest plant, that of 25,000 tonne capacity, and goes down to US$ 215 in the plant capable of producing 300,000 tonnes of rolled products annually.

Table 4

PLANT CAPITAL COST FOR SELECTED CAPACITIES[a]

	Case I 25,000 T/yr		Case II 50,000 T/yr		Case III 100,000 T/yr		Case IV 200,000 T/yr		Case V 300,000 T/yr	
	Total cost '000 $	Cost per tonne $	Total cost '000 $	Cost per tonne $	Total cost '000 $	Cost per tonne $	Total cost '000 $	Cost per tonne $	Total cost '000 $	Cost per tonne $
Coke ovens	-	-	-	-	1,812	35.85	4,354	47.12	5,628	40.43
Sinter plant	-	-	-	-	-	-	2,033	27.85	2,602	23.65
Blast furnace	3,291	144.34	5,253	115.20	7,895	89.21	12,086	72.16	15,855	62.92
Steelmelt shop (LD)	2,763	110.52	4,192	83.84	6,692	66.92	9,574	47.87	11,852	39.51
Continuous casting	1,248	52.00	1,809	37.69	2,767	28.82	4,693	24.44	6,200	21.53
Rolling mills	3,825	174.02	5,778	131.44	10,716	120.00	16,618	92.08	22,456	82.95
Total	11,127		17,032		29,882		49,358		64,593	
Total plant cost per tonne annual capacity:										
In terms of liquid steel		445.08		340.64		298.82		246.79		215.31
In terms of rolled product		506.30		387.47		334.64		273.49		238.59

a/ The capital costs of production departments include the allocations for capital costs of auxiliary facilities on the basis of relative utilisation of these supply and service facilities.

Using the guiding criteria referred to earlier, works production costs for each production department have been calculated and the corresponding fixed charges on capital invested have been added. The figures are summarized in table 5.

Table 5

PRODUCTION COST ESTIMATES FOR PLANTS OF SELECTED CAPACITIES

(All costs in dollars per tonne)

	Case I 25,000 T/yr	Case II 50,000 T/yr	Case III 100,000 T/yr	Case IV 200,000 T/yr	Case V 300,000 T/yr
1. Coke					
Cost of materials	-	-	27.59	26.60	26.60
Cost above materials[a/]	-	-	2.24	1.65	-0.04
Works production cost	-	-	29.83	28.25	26.56
Fixed charges	-	-	3.43	4.63	4.01
Total cost			33.26	32.88	30.57
2. Sinter					
Cost of materials	-	-	-	10.63	10.63
Cost above materials	-	-	-	2.81	2.19
Works production cost	-	-	-	13.44	12.82
Fixed charges	-	-	-	2.51	2.13
Total cost				15.95	14.95
3. Iron					
Cost of materials	33.26	32.80	32.40	32.36	31.10
Cost above materials[b/]	25.26	15.34	10.37	7.03	5.40
Works production cost	58.52	48.14	42.77	39.39	36.50
Fixed charges	12.99	10.37	9.87	9.93	8.58
Total cost	71.51	58.51	52.64	49.32	45.08
4. Liquid steel (LD)					
Cost of materials[c/]	64.44	54.39	49.29	45.59	43.18
Cost above materials	43.88	31.37	22.32	16.31	13.68
Works production cost	108.32	85.76	71.61	61.90	56.86
Fixed charges	22.19	17.00	14.76	12.62	10.78
Total cost	130.51	102.76	86.37	74.52	67.64

Table 5 (Cont'd)

PRODUCTION COST ESTIMATE FOR PLANTS OF SELECTED CAPACITIES

(All costs in dollars per tonne)

	Case I 25,000 T/yr	Case II 50,000 T/yr	Case III 100,000 T/yr	Case IV 200,000 T/yr	Case V 300,000 T/yr
5. Concast billet					
Cost of materials c/	111.90	88.44	73.72	63.63	58.38
Cost above materials	16.45	9.89	7.74	5.73	4.67
Works production cost	128.35	98.33	81.46	69.36	63.05
Fixed charges	27.38	21.10	17.97	15.35	13.17
Total cost	155.73	119.43	99.43	84.71	76.22
6. Rolling					
Cost of materials c/	138.06	105.28	85.95	72.51	65.80
Cost above materials	34.88	22.45	13.97	11.22	9.64
Works production cost	172.94	127.73	99.92	83.73	75.44
Fixed charges	45.72	34.86	30.12	24.61	21.48
Total cost	218.66	162.59	130.04	108.34	96.92

a/ Net after allowing credit for gas, tar and breeze.

b/ Net after allowing credit for B.F. gas.

c/ Net after allowing credit for recoverable scrap.

With the help of the figures in tables 4 and 5, the effect of economies of scale on capital and operating costs can be expressed in the form of an index. This has been done in table 6, in which 100,000 tonne annual capacity is taken as base 100.

Table 6

EFFECT OF ECONOMIES OF SCALE ON CAPITAL AND PRODUCTION COSTS

(Indices with 100,000 tonne plant taken as 100)

	Case I 25,000 T/yr	Case II 50,000 T/yr	Case III 100,000 T/yr	Case IV 200,000 T/yr	Case V 300,000 T/yr
Capital cost per tonne nominal capacity	149	114	100	83	72.5
Production cost per tonne rolled product	168	125.4	100	83.2	74.5

The figures in this table indicate a rapid increase in the investment necessary and above all in production costs as the size of the capacity descends below 100,000 tonnes. With an increase in the size of operation above that point, within the limits considered in this document, both capital and production costs fall, though the slope is less steep than in the first part of the curve.

Also interesting are the figures in table 7, which gives the structure of production costs in terms of percentages, based on table 5. One notices that the raw materials item accounts for a larger proportion of costs as the size of the operation increases, and the importance of labour costs decreases as a result of increased productivity due to size and the use of more highly automated equipment.

Table 7

COST STRUCTURE FOR STEEL PRODUCTION

(Percentage of total)

	Case I	Case II	Case III	Case IV	Case V
Raw materials	20	26	31	37	41
Power and fuel	4	4	5	5	6
Wages and salaries	41	33	27	22	19
All other costs	35	37	37	36	34
Total	100	100	100	100	100

The production costs given in tables 5 and 6 represent the costs of manufacture within the plant. The price at which the steel can be placed on the market is necessarily higher owing to marketing costs, the cost of credits, taxes and other items of expenditure which have not so far been considered. These naturally vary from country to country and even from plant to plant. In order to explore the results of the data obtained a little further, we shall assume that these costs amount to 30 per cent of the costs in the plant. This assumption was used in the construction of table 8.

Table 8

ESTIMATED SELLING PRICES FOR ROLLED PRODUCTS

Plant capacity T/yr	Average works production costs $/tonne	Average selling price $/tonne
25,000	219	285
50,000	163	212
100,000	130	169
200,000	108	140
300,000	97	126

The export prices for some rolled steel products in the main exporting countries were, in May 1966, as set out in table 9.

Table 9

OFFICIAL EXPORT PRICES FOR SOME STEEL PRODUCTS FROM SELECTED COUNTRIES f/

(Dollars per tonne)

Product	European Coal and Steel Community a/	United Kingdom b/	United States c/	Japan d/
Merchant bars e/	85.00	114.70	139.75	88.00
Heavy sections	76.00	113.00	133.80	117.00
Heavy hot-rolled plate	87.00	119.20	124.10	98.00
Cold-reduced sheet	108.00	132.25	145.70	107.00

a/ Export prices quoted by Usine Belge, Brussels.

b/ Metal Bulletin, London. Official nominal prices.

c/ Metal Bulletin, London. The prices are indicative, including freight to port of shipment.

d/ Metal Bulletin, London. Prices f.o.b. Japanese port.

e/ Merchant Bars

f/ May, 1966.

If the products are to reach the markets of the developing countries, it is necessary to add to those prices the costs of freight, insurance, unloading and passage through customs, costs which naturally vary greatly from country to country. Supposing that, in a given country, they amount to US$ 30 per tonne, the price of the merchant bars imported, after customs, would fluctuate between US$ 115 and US$ 169 a tonne, depending on its origin, and always supposing that the actual prices applied in the transactions correspond to those officially quoted, a subject which we will not enter into here. In these circumstances, and in the light of the figures in table 8, it appears very difficult to justify economically a plant producing non-flat rolled steel products having an annual capacity below 100,000 tonnes.

IV. INTEGRATED PLANTS PRODUCING FLAT STEEL PRODUCTS[5/]

The paper on which this section is based analyses capital and production costs in groups of hypothetical plants producing flat steel in varying annual volumes, and using different production processes in the departments of reduction, steel making and rolling, as well as different combinations of these various processes. For the sake of simplicity, we shall here consider economies of scale in a single production sequence, namely: blast furnace, LD steel making, cogging and the rolling of sheets and plates. The type of plant considered here is one using cogging mills, because, in the judgement of many experts, the problems raised by the continuous casting of rimming steel have not been fully resolved, even when it is employed in combination with degasification of the steel in a vacuum. Moreover, preference is given to the LD converter over open-hearth steel making because it undoubtedly produces steel with lower capital and operating costs and has ample capacity to permit the utilization of the scrap which is normally available in the developing countries. It is thought that the quality of the steel produced in top-blown oxygen converters is as good as that of steel obtained in open-hearth furnaces. Reference will be made in the next section to the comparative merits of some other combinations of technological processes.

In the calculations given in document E/CN.12/766, all the general observations set out in the introduction to this study apply. For the sake of greater clarity, the following comments should also be added, together with those to be found in annex III.

As the size of the plants producing flat steel products increases, there is also a higher degree of mechanization and automation, designed to raise output per man-hour. In markets all over the world one finds that an increasing part is played by flat products, particularly cold-rolled sheets and plates; this has

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5/ In the preparation of this section, use has been made of part of the paper "Las economías de escala en plantas siderúrgicas de tamaño medio y grande y la influencia de los adelantos tecnológicos en las inversiones y costos de producción", prepared for ECLA by Armando P. Martijena, consultant (E/CN.12/766).

made it possible in many places to install plants of greater capacity, equipped with semi-continuous and continuous mills. Such mills allow a higher yield of the material (ingots), a better quality of product and higher productivity, with resulting savings in production costs.

For the purposes of the study, and to simplify the calculations, it has been assumed that the make-up of the rolling mills is as indicated in annex III.

It has been assumed that the production is so arranged that the average yield of the whole plant in terms of semi-products is 83 per cent.

Taking into account the general characteristics indicated, the various types of equipment have been combined together for the calculation of capital costs and theoretical production costs.

As indicated in the above-mentioned annex, while there have been slight adjustments in the proportions of the various types of flat products included in the product-mix for the calculation of plant costs, the breakdown is, on the average, 30 per cent hot-rolled sheets and plates and 70 per cent cold-rolled sheets.

Bearing in mind the characteristics indicated, the various types of equipment have been combined together for the calculation of theoretical capital and production costs, by production department. Capital costs for capacities between 100,000 and 2.5 million tonnes are given in table 10. It may be noted that total capital cost, per tonne, falls from $US 692 to $US 252, or by 30 per cent, as annual capacity rises between those two figures. The very high capital costs per tonne in the smallest plants in the series make it improbable that an integrated plant of such a size would be economic.

Table 10

CAPITAL COSTS BY PRODUCTIVE DEPARTMENTS IN PLANTS OF VARYING ANNUAL CAPACITIES PRODUCING FLAT PRODUCTS[a]

(Dollars per tonne annual production of flat products)

Annual capacity in tonnes	Blast furnace	Steel making (LD)	Cogging and rolling	Total
100,000	124.40	83.73	484.00	691.77
200,000	113.07	75.62	428.88	617.57
400,000	89.65	57.71	330.00	477.36
500,000	82.49	52.34	287.00	421.83
800,000	66.01	41.56	220.00	327.57
1,000,000	57.80	34.90	199.10	291.80
1,500,000	52.94	30.89	193.00	276.83
2,000,000	48.68	29.96	187.00	265.64
2,500,000	45.03	29.03	178.00	252.06

a/ Production sequence: blast furnace, LD steel making, cogging and rolling of sheets and plates.

Production costs, including fixed charges on capital invested, have also been calculated and are summarized in table 11. Those corresponding per tonne to the various production processes have been divided up under raw materials, wages and salaries, other conversion costs and charges on capital. In the cost of the iron, the preponderant role played by raw materials costs is striking; they vary between 58 per cent of the total for a plant of 100,000 tonnes and 80 per cent for a 2.5 million tonne plant. Within the production costs of the final rolled product, the share of raw materials is 19 per cent in the one case and 32 per cent in the other. This brings out the need to make every effort to reduce these costs to the minimum and select the processes in order to make use of whatever local raw materials will make such reduction possible.

Table 11

PRODUCTION COSTS OF FLAT PRODUCTS IN PLANTS OF DIFFERENT CAPACITIES[a]

(Dollars per tonne)

Annual capacity in tonnes	Raw materials	Wages and salaries	Other conversion costs	Charges on capital invested	Total
Iron making					
100,000	28.30	5.18	7.35	8.56	49.33
200,000	28.30	2.83	5.48	7.78	44.39
400,000	28.30	1.53	4.30	6.78	40.91
500,000	28.30	1.13	4.05	6.24	39.72
800,000	28.30	0.99	3.91	5.20	38.40
1,000,000	28.30	0.95	3.69	4.75	37.69
1,500,000	28.30	0.77	3.23	4.35	36.65
2,000,000	28.30	0.64	2.91	4.00	35.85
2,500,000	28.30	0.53	2.69	3.70	35.22
Steel making: 0.788 tonnes of crude iron and 0.340 tonnes of scrap per tonne steel					
100,000	57.18	5.38	8.53	4.52	75.61
200,000	51.39	4.62	8.30	4.10	68.41
400,000	47.00	2.84	7.46	3.44	61.64
500,000	46.94	2.54	7.14	3.12	59.74
800,000	46.15	2.20	6.77	2.58	56.70
1,000,000	45.38	2.07	6.61	2.26	56.34
1,500,000	43.25	1.75	6.36	2.00	53.36
2,000,000	43.37	1.37	6.16	1.94	52.84
2,500,000	41.68	1.14	6.03	1.83	50.73
Cogging and rolling: consumption of ingot per tonne of rolled product as in footnotes					
100,000	105.29[b]	15.52	12.30	43.56	176.67
200,000	95.60[b]	12.60	11.25	38.60	158.05
400,000	80.46[c]	6.22	10.67	29.70	127.05
500,000	78.00[c]	5.62	10.60	25.85	120.70
800,000	72.21[d]	4.51	8.60	19.80	115.12
1,000,000	68.49[e]	3.92	7.75	17.92	98.08
1,500,000	66.05[e]	3.30	7.30	17.37	94.02
2,000,000	64.14[e]	3.11	7.15	16.83	91.23
2,500,000	62.76[e]	2.80	7.00	16.03	88.59

a/ Production sequence: blast furnace, LD steel making, cogging, and rolling of flat products.
b/ 1,660 kg of ingot per tonne of rolled product.
c/ 1,510 kg of ingot per tonne of rolled product.
d/ 1,450 kg of ingot per tonne of rolled product.
e/ 1,390 kg of ingot per tonne of rolled product.

We can assume, as we did in considering the theoretical production costs of non-flat rolled products, that in order to arrive at the possible selling prices of the steel a supplement of approximately 30 per cent must be added to the theoretical in-plant prices in order to cover the costs of credits, taxes and various other sales costs. The figures are to be found in table 12.

The flat steel products comprised in the product-mix considered in this study had, in April-May 1966, as was seen in table 9, a price f.o.b. port of origin which varied on the average between US$ 102 and US$ 139 per tonne, which might give a price c.i.f. at a port in a developing country of between US$ 132 and US$ 169 per tonne. This indicates that, unless there are exceptional circumstances in which import prices are considerably higher or there are some very cheap resources available for the production of steel, plants producing flat products with an annual capacity of less than 300,000 to 400,000 tonnes could hardly be economic.

Table 12

THEORETICAL IN-PLANT COSTS AND POSSIBLE SELLING PRICES FOR FLAT PRODUCTS

(Dollars per tonne)

Annual capacity of the plant in tonnes	Theoretical in-plant costs	Possible selling price a/
100,000	197	229
200,000	176	205
400,000	140	165
500,000	132	157
800,000	115	137
1,000,000	108	128
1,500,000	102	122
2,000,000	99	119
2,500,000	96	115

a/ Estimated by adding 30 per cent to the theoretical in-plant costs.

V. ALTERNATIVE PROCESSES APPLICABLE IN THE DIFFERENT PRODUCTION DEPARTMENTS

This section gives some of the conclusions which are reached in document E/CN.12/766 regarding the comparative merits of various alternative processes which may be used in the different major departments of steel plants. In order to avoid undue length, consideration will be confined to the most general questions, leaving out of account some important matters such as the use of ores of differing iron and phosphorus content.

(a) Reduction department: blast furnaces, electric reduction furnaces and one of the so-called direct reduction processes;

(b) Steel making department: open-hearth furnaces using oxygen for heating; low-shaft electric furnace, and top-blown oxygen converter;

(c) Rolling department: conventional cogging and rolling, continuous casting and rolling with vacuum degasification of steel for the production of flat products.

For the sake of brevity also, the rolling of non-flat products is not considered.

The same general comments as have been made in earlier chapters are valid for the study of capital and operating costs for the various processes. Certain particular comments applicable to some of the processes which are to be discussed appear in annex IV.

Bearing in mind all these points, a calculation was made of the capital costs in the reduction departments of steel plants of different sizes and using different processes. The figures appear in table 13.

Table 13

CAPITAL COSTS FOR THE REDUCTION DEPARTMENT OF STEEL PLANTS OF DIFFERENT ANNUAL CAPACITIES

(dollars per tonne)

Annual capacity for production of molten iron or sponge iron	Blast furnace	Electric reduction furnace	Direct reduction
100,000	95.11	66.00	46.22
200,000	86.44	61.11	37.89
300,000	-	-	35.11
500,000	69.33	52.78	-
1,000,000	52.78	45.67	-
1,500,000	48.33	39.56	-
2,000,000	44.40	-	-
2,500,000	41.20	-	-

The following comments may be made on the basis of the table: the highest capital cost per tonne of installed capacity is to be found in the case of reduction in a blast furnace, and the lowest in the case of direct reduction, within the limits to which this process is considered applicable. It can be seen that the difference between the capital costs for blast-furnace reduction and electric smelting decreases as annual installed capacity increases, a result which is logical in view of the maximum unit capacity of the latter. The large number of units needed and the space required mean that capital costs for electric furnaces proper are higher than those for blast furnaces even in the case of small capacities, such as 150,000 or 200,000 tonnes.

The investments required in the steel making department have been calculated and set out in table 14.

Table 14

CAPITAL COSTS FOR THE STEEL MAKING DEPARTMENT OF STEEL PLANTS OF DIFFERENT SIZES

(dollars per tonne annual production)

Annual capacity in tonnes of ingot	Low-phosphorus iron Open hearth	electric arc furnace	LD	Sponge iron from direct reduction
100,000	74.88	64.22	50.22	96.11
200,000	69.33	59.33	45.55	39.00
300,000	-	-	-	87.22
500,000	53.33	47.33	34.66	-
1,000,000	37.44	35.66	25.11	-
1,500,000	30.55	30.11	22.20	-
2,000,000	29.66	29.22	21.55	-
2,500,000	28.77	28.33	20.88	-

Confining oneself to the consideration of capital costs, and bearing in mind the high elasticity of the top-blown converter processes for the treatment of iron of differing qualities with varying percentages of scrap, these processes are found to be clearly more suitable for the majority of developing countries.

Capital costs are highest in the case of the open hearth (Siemens Martin) process, but the difference between this and the electric arc furnace decreases markedly as the capacity of the plant increases, a fact which is largely explained by the maximum production capacities of each furnace.

The investments required for the rolling mills of steel plants of varying sizes producing flat steel products appear in table 15.

Table 15

CAPITAL COSTS FOR MILLS FOR ROLLING FLAT PRODUCTS, FOR DIFFERENT ANNUAL CAPACITIES

(dollars per tonne annual capacity for rolled products)

Capacity	Cogging and rolling	Continuous casting and rolling a/
100,000	484	418
200,000	428	371
500,000	287	256
1,000,000	199	176
1,500,000	193	170
2,000,000	187	-
2,500,000	178	-

a/ Includes installations for vacuum degasification.

It is found that the production sequence comprising continuous casting and the rolling of sheets and plates requires less investment than the sequence beginning with cogging. The difference in capital costs is approximately 12 per cent in a plant of 100,000 tonnes and falls to 7 per cent when capacity increases to 1.5 million tonnes.

Table 16 gives theoretical calculations of production costs in the plant for the various production cycles, processes and sequences. The figures are expressed as indices, base 100 being in each case the figure for a plant using a blast furnace, LD steel making and cogging and rolling; the values for each type of production sequence have been entered in the table. The figures appearing in each of the production departments represents the cost per tonne of the final product produced in the department concerned, thus: crude iron in the reduction department, ingots of steel in the steel making department and flat rolled products in the rolling department. To some extent, the figures appear to be independent of one another, but in the later processes account has been taken of the earlier results where the cost of the raw material is concerned. Thus open-hearth steel produced from iron from a blast-furnace has a lower cost than that produced from iron from an electric reduction furnace, etc.

Table 16

COMPARISON OF PRODUCTION COSTS IN PLANTS ROLLING FLAT PRODUCTS, WITH DIFFERENT CAPACITIES AND PRODUCTION SEQUENCES

(Dollars per tonne, and indices; the sequence blast furnace LD steel making, cogging, rolling = 100)

Annual capacity in tonnes	Blast furnace			Electric reduction furnace			Direct reduction
Reduction							
100,000			(49.39)a/		109		76
200,000			(44.39)a/		111		78
500,000			(39.72)a/		115		-
1,000,000			(37.69)a/		118		-
1,500,000			(36.65)a/		119		-
2,500,000			(35.22)a/		-		-
Steel making	Open hearth	Electric arc furnace	LD	Open hearth	Electric arc furnace	LD	Electric arc furnace
100,000	112	103	(75.61)b/	118	109	106	103
200,000	114	104	(68.41)b/	121	111	108	105
500,000	113	103	(59.74)b/	123	113	110	-
1,000,000	111	102	(56.34)b/	124	115	111	-
1,500,000	113	104	(53.36)b/	127	118	114	-
2,500,000	108	101	(52.84)b/	-	-	-	-
Rolling	Cogging and rolling		Cogging and rolling	Continuous casting and rolling		Cogging and rolling	Cogging and rolling
100,000	109		(176.67)c/	93		105	103
200,000	110		(158.05)c/	94		107	105
500,000	109		(120.70)c/	97		108	105
1,000,000	110		(98.08)c/	96		111	108
1,500,000	110		(94.02)c/	96		112	109
2,500,000	110		(88.59)c/	-		-	-

a/ Cost in dollars per tonne of liquid iron.
b/ Cost in dollars per tonne of steel ingot.
c/ Average cost in dollars per tonne of rolled product.

With regard to the costs of the inputs considered here, the figures in the table show that the cost of inputs in electric furnace reduction are higher than those for blast furnaces, by 9 per cent in the case of an annual capacity of 100,000 tonnes, and that the disadvantage increases with the size of the plant, rising to 19 per cent in 1.5 million tonne plants. On the other hand, the production of sponge iron by the HyL process costs more than 20 per cent less than the production of molten iron by a blast furnace. As to production costs, steel making in top-blown oxygen converters is more economic than electric arc or open-hearth steel making, where the raw material is iron of a constant price. If iron smelted in an electric furnace is used, the steel is always more expensive owing to the higher price of the raw material, but once again LD steel making has cost advantages over the other processes. Lastly, steel produced in an electric arc furnace from sponge iron produced by direct reduction in small plants is almost the same price as steel from a converter. As the size of the plant increases, this advantage tends to disappear owing to the small size of the direct reduction units. With regard to rolling, production costs are shown for four types of plant using cogging and rolling and one using continuous casting. The four former types are affected only by the price of the raw material - i.e., the ingot steel - which is used. Consequently, the most economic type is that using LD steel produced from blast-furnace iron. In the case of continuous casting, the advantage decreases somewhat, without disappearing, as the size of the operation grows, but, as has been said, caution is needed in the use of this process for the rolling of sheets and plates owing to the difficulty of producing continuous cast slabs with rimming steel. On the other hand, for the production of bars and shapes, in which the same economic advantage is found, there are no technical difficulties affecting the use of the process in question.

In practice, selection between one process and another must depend on the availability of the various production factors and the characteristics of the main raw materials. Comparing, for example, blast-furnace reduction with reduction using electric power, at a cost of 5 thousandths of a dollar per kWh, the capital cost is less but the operating cost is higher in the latter than in the former. If it is possible to obtain ore of very good grade and petroleum gas at a low price (the equivalent of US$ 12 per tonne of fuel oil, or where possible even less), direct reduction by the HyL process can be considered. Lastly, continuous casting can be combined with electric-arc and LD steel making, but it would be very difficult to combine it with open-hearth furnaces.

VI. CONSIDERATION OF THE SIZES OF LATIN AMERICAN STEEL PLANTS AND GENERAL CONCLUSIONS 6/

The series of examples which have been given in the earlier sections indicate that, theoretically at least, the larger the plant, the closer it is to the optimum size. In fact, however, it is impossible to fix a definite optimum size for a steel plant, applicable in a general way, since the determination of the most favourable conditions for each specific situation depends on a series of quite complex factors. The larger plants naturally offer substantial advantages in terms of the level of capital and production costs, but even so, once a certain size is reached, the additional reductions in costs resulting in still greater size are very small, particularly when the limit of capacity for which it is possible to construct certain plant units is reached. Very often, even before this point, the disadvantages relating to human concentration, raw materials and the organization of distribution more than cancel out the technical and economic advantages of greater expansion.

Among the factors making a steel plant economic or otherwise, we may mention some which are technical, others resulting from market conditions and finally some of a political nature.

One of the most significant technical factors in determining the minimum economic scale of production is the blast furnace. Blast furnaces become increasingly efficient and economic up to quite high levels of production - some 1.3 million tonnes a year for each blast furnace - according to the figures used in the studies on which this analysis is based. Moreover, in any steel plant, dependence on a single blast furnace is a factor of instability which should be avoided as far as possible. Consequently, unless countervailing factors exist, there should be a tendency to construct plants capable of producing some 2.5 million tonnes of crude iron annually. It is to be noted, however, that the economic advantage resulting from provision for two blast furnaces which together produce 2.5 million tonnes instead of a pair producing only 1.5 million, according to the figures used in the above-mentioned study, is confined to a lower cost of iron of US$ 0.80 per tonne produced and a lower capital cost of US$ 1.78 per tonne annual capacity.

6/ In connexion with this analysis, see the article "Size of steel plants in U.K.", Steel Review, No.40, October 1965.

Another technical factor which often determines the desirable capacity for a plant is the optimum size of the rolling equipment, whereas the capacity of the steel-making installations is more easily adjustable and there is a lower specific capital cost. In the case of a continuous mill rolling flat products, the optimum situation is for total production slightly to exceed 3 million tonnes a year of ingot steel. It is clear that a plant of this size can benefit from economies of scale in all production departments. A plant rolling 3.5 million tonnes of flat products would have no place in Latin America, even if it was working for a common market, because transport distances and costs of distribution would more than cancel out any advantage derived from economies of scale. In the study, therefore, the maximum size of plants equipped with continuous mills has been limited to 2.5 million tonnes and that of those equipped with semi-continuous mills to 800,000 or 1 million tonnes, in keeping with usual practice. In mills rolling non-flat products, optimum capacity is around 500,000 tonnes for the production of bars and light or medium shapes, rails, etc. Economies of scale in blast furnaces have some importance when one is working within this order of sizes, for example: there is a reduction in the capital cost for blast furnaces of US$ 21 per tonne annual capacity and a reduction in operating costs (at the accepted prices of inputs) of US$ 3.05 per tonne produced, when output rises from 500,000 tonnes of iron annually to 1.5 million tonnes. It is therefore usual to roll different products together in a single plant, sharing the reduction and steel-making facilities. It is also advantageous to utilize sales facilities for the distribution of products of varying types.

It is quite possible that there will be an increasing tendency in future to combine several different groups of mills in one establishment, owing to the fact that some technological innovations which are now either in use or in the experimental stage will tend to reduce the optimum level of the various iron and steel making processes. This is the case, for example, with continuous casting, in which the maximum size at which individual machines can be constructed is far below the optimum size of the cogging mills which it replaces. Much more revolutionary in the sense of lowering optimum capacity in the industry will be the perfecting of the continuous hot-rolling of flat products in a planetary mill, which may reduce the thickness of a slab to one thirtieth, or even less, each time it passes through the mill. There are various designs for these mills and there are some machines, of differing widths which have been in operation for some years in various countries. If the advantages and characteristics claimed for them by their promoters are verified in practice we might see a reduction in the optimum for continuous flat rolling from the present 3 million tonnes and more to a figure as low as 500,000 tonnes.

Considerations based on the possible market for the plant are also decisive in fixing its size. Rolled steel is not a homogeneous product and the market, expressed crudely in annual tonnes of non-flat products, for example, is made up of aggregates of varying tonnages of a host of products which are included under the same generic name. The need for diversification in order to supply the usually limited market of a developing country with the largest possible quantity of products must be balanced against the advantages and disadvantages of economies of scale. The price paid for excessive diversification of production is considerable. Both factors are, naturally, in any region of the world, arguments for co-operation among several developing countries with a view to creating a more favourable market for the production of a steel plant.

The possibility has also been mentioned of the existence of political factors affecting the sizes of steel plants in the developing countries. Such factors may be a fear of possible monopolies, repercussions of the competition between the public and private sectors, or the need to economize foreign exchange.

From the point of view of economies of scale, according to the conclusions of these studies, the integrated steel industry in Latin America is not very well situated, as may be seen from table 17, in which the situation in 1961 is compared with that prevailing in 1966. It is possible to observe a moderate tendency towards growth in the size of plants. Thus, whereas in 1961 77 per cent of the plants and 42 per cent of production was constituted by plants with a total capacity below 400,000 tonnes of ingots annually, by 1966 plants of this size represented 41 per cent of the total number of plants and accounted for 11 per cent of production. This result was obtained by expanding the output of almost all the small and medium-sized plants, keeping pace with the growth of the market, and the construction of three new plants with outputs (in 1966) above 400,000 tonnes - namely, Cosipa y Usiminas in Brazil and Orinoco in Venezuela - while only one new plant has been constructed with a capacity below 100,000 tonnes, as a result of the integration of the Zapla plant in Argentina.

Table 17

BREAKDOWN OF INTEGRATED STEEL PLANTS IN LATIN AMERICA BY SIZE

(Plants, production and percentages of total production)

Annual capacity in terms of ingot steel	1961			1966		
	No. of plants	Production	% of total capacity	No. of plants	Production	% of total capacity
Over 1,000,000	1	1,130	29.8	2	2,417	33.1
800,000 to 1,000,000	-	-	-	..	-	-
600,000 to 800,000	1	674	17.6	1	722	9.9
400,000 to 600,000	1	407	10.6	7	3,355	46.0
200,000 to 400,000	3	866	22.6	-	-	-
100,000 to 200,000	3	450	11.7	3	474	6.5
Below 100,000	4	296	7.7	4	329	4.5
Total	13	3,823	100	17	7,297	100

The studies which have served as the basis for this paper do not refer to the tonnage of ingot steel but to that of finished steel products, which is considerably lower. In order to review the situation in Latin America in the light of these studies and determine the percentage of flat and non-flat products produced by the industries referred to in table 17, table 18 has been drawn up; unfortunately, owing to lack of information on 1966, the data is from 1965. It lists the plants in order of output of flat products in the case of mixed plants and of total output in the case of those engaged exclusively in making non-flat products. As may be deduced from the figures in the table, only four plants in Latin America produce flat products in quantities exceeding the minimum level which appears to be economic according to this study and it must be pointed out that one of them, San Nicolás, is equipped with a very powerful rolling mill.7/ On the other side of the table, there were five plants in 1965 with an output of non-flat products of 100,000 tonnes annually or less. Of these, the three Brazilian plants produce special steel of higher value, enabling them to make a profit; the Chimbote plant is expanding to 300,000 tonnes and only the Zapla plant in Argentina is poorly planned with regard to size and location. It was envisaged with an

7/ It improved its yield by importing, in 1965, 93,000 tonnes of slabs for rolling into sheets.

annual capacity of 120,000 tonnes of non-flat products, in a regional market protected with respect to the rest of the country by high transport costs. The market has not grown in the way that was hoped and, consequently, the plant can use only part of its capacity.

The material in table 18 indicates that, in general, economies of scale have been taken into account very little in the planning of steel plants, since the dominant trend is towards plants operating on a very small scale. Only two plants, Volta Redonda in Brazil and Altos Hornos de Mexico, have theoretically acceptable annual volumes of production, and the levels are still far from the optimum. To make possible an analysis in greater depth of the situation with regard to plants rolling flat products, table 19 gives an indication of the market available to the local steel industry in 1965 together with total capacity for the rolling of flat products, by country.

Table 18

PRODUCTION OF FINISHED ROLLED PRODUCTS IN THE LATIN AMERICAN STEEL PLANTS IN 1965

(Thousands of tonnes)

Plant	Flat products	Non flat products	Total rolled products
Volta Redonda	679	178	857
Altos Hornos de México	605	222	827
San Nicolás	468	8	476
Hojalata y Lámina	314	-	314
Huachipato	209	170	379
Monterrey	205	111	315
Belgo Mineira	94[a]	248[a]	343[a]
Acesita	20	27	47
Pas del Rio	18	175	193
Orinoco	-	200	200
Mannesmann	-	103	103
Chimbote	-	74	74
Aliperti	-	71	71
Barra Mansa	-	53	53
Zapla	-	44	44

a/ In order to give the Belgo Mineira plant in Brazil its proper place in Latin American steel production as a whole, the table gives the output of flat and non-flat products for the previous year, 1964, since in 1965 there was a drop to 55,000 tonnes of flat products and 112,000 tonnes of non-flat products, the reason for which is unknown to the writer.

Table 19

SOME DATA REGARDING THE MARKET FOR FLAT PRODUCTS IN 1965 IN THE COUNTRIES OF LATIN AMERICA WITH INTEGRATED PLANTS

(Thousands of tonnes and percentages)

Country	Market for flat products			Rolling capacity	
	Production	Imports	Total[a]	Thousands of tonnes	Percentage of excess over the market
Mexico	1,123	53	1,176	2,150	45
Brazil	1,015	124	1,139	3,070	63
Argentina	537[b]	285	822	1,000	18
Chile	239[c]	39	278	350	20
Colombia	18	101	119	40	negative
Peru	-	115	115	16	negative

a/ This figure differs from the apparent consumption of some countries, since the small quantities exported have not been subtracted, so that the total market available to the industry can be shown.

b/ This includes some 70,000 tonnes of rolled products at San Nicolás produced from imported slabs with the aim of improving the utilization of the rolling mill.

c/ In the case of Chile the 1966 production figure has been given, since the 1965 figure was abnormally low due to a strike lasting 83 days.

The figures in the table allow some conclusions to be drawn. For example, in Mexico and Brazil, with 3 and 4 plants rolling flat products respectively, and a market of about 1.2 million tonnes, it would seem that an excessive number of such plants have been built and that it will be many years before they reach optimum production levels. Moreover, the construction of rolling plants of around 300,000 tonnes capacity under way in Colombia and Peru, would seem premature. With regard to Argentina, its policy of building a single plant of high efficiency and capacity for rolling flat products is most laudable and the only drawback is the delay in the development of the first cycles of steel production - blast furnaces and steel making - preventing it from taking full advantage of the possibilities offered by its market. Apparently also there is a shortage of some auxiliary installations such as cold-rolling mills, etc.

Table 20

MARKET FOR, PRODUCTION OF AND CAPACITY FOR PRODUCTION OF NON-FLAT ROLLED PRODUCTS IN INTEGRATED PLANTS IN LATIN AMERICA

(Thousands of tonnes and percentages)

Country	Market for non-flat products			Rolling capacity in integrated plants	
	Production a/	Imports	Total a/ b/	Thousands of tonnes	Percentage of excess capacity over the market
Brasil	561	137	698	1,260	45
Mexico	334	181	515	750	31
Venezuela	200	223	423	615	31
Colombia	175	37	212	180	-
Chile	170	40	210	170	-
Perú	74	76	150	75	-
Argentina c/	52	200	252	-?- c/	-?- c/

a/ In order to eliminate the influence of the large number of semi-integrated and non-integrated plants, regarding which insufficient information is available, their output has been eliminated both in the column concerned and in the total. The result of this is that there may be excess capacity in this sector not represented in the last column.

b/ As in the case of table 19, exports have not be subtracted, so that the total market available can be seen.

c/ The semi-integrated and non-integrated plants in Argentina, in 1965, produced 920,000 tonnes of non-flat rolled products as against 52,000 tonnes produced at San Nicolás. Owing to this, it is felt that any conclusion reached without taking into account the major part of production would have no validity.

With regard to non-flat steel, the position of existing production in relation to the available market is very different, as can be seen from the figures in table 20. Except in the case of Brazil, which, like that of Argentina, is unclear owing to the high production capacity for non-flat products installed in semi-integrated and non-integrated plants, the table shows the basic general tendency towards backwardness in the installation or expansion of integrated plants for non-flat products. Colombia, Chile and Peru are shown to be working at 100 per cent of capacity, while in Mexico and Venezuela reserve rolling capacity is not significant if it is borne in mind that the demand can be expected to grow at a cumulative rate of more than 6 per cent annually.

We cannot attempt here to analyse the reason why, in the production of flat products, there seems to be excessive interest in the establishment of plants even when the size of the plant and its utilization for several years are clearly inadequate to meet the conditions imposed by economies of scale for ensuring profitability, and even though, on the other hand, there is an evident lag in the construction of integrated plants for the manufacture of non-flat products. It is quite possible that one of the reasons for this contradiction is the structure of the selling prices of finished steel fixed by the countries which are major exporters. Whatever the reply to this question, there is no doubt that there exists in Latin America a tendency, manifested in the production of flat and non-flat products, to construct very small steel plants which are extremely hard to justify in the view of the lessons of the present study of economies of scale; and here there is no room for doubt - it is essential to economize foreign exchange or, in other words, to obtain steel with the minimum expenditure of foreign exchange. The attempt is being made to remedy the disadvantage of the excessively small size of the plant, as is logical, by building mixed plants for the rolling of flat and non-flat products, making use of the same blast furnaces and steel-making facilities. In 1965, 80 per cent of production in integrated steel plants in Latin America was accounted for by such mixed plants.

ANNEX I

COSTS OF INPUTS

	US$/Tonne
Iron ore	9.50
Coking coal	10.00
Blast-furnace coke, purchased	30.00
Manganese ore	30.00
Quartzite	2.00
Blast-furnace limestone	7.00
Steel scrap	30.00 a/
SMS grade limestone	7.00
Lime	30.00
Dolomite, refractory grade	10.00
Bauxite	9.00
Fluospar (imported)	150.00
Fuel Oil	20.00
Mill scale	6.00
Oxygen (varies with size of plant)	
Average labour (plant), man-hours	1.50
Power, kWh	0.016
Gas credit, evaluated at equivalent fuel oil price	
Water (m^3)	0.005
Natural gas for HyL process at a cost equivalent to fuel oil at	12.00

a/ A flat rate of US$ 30 per tonne of scrap has been adopted for document E/CN.12/764. In document E/CN.12/766, on the other hand, a price has been used for scrap in all cases equivalent to 90 per cent of the production cost of hot metal. In the case of the very small plants considered in document E/CN.12/764, these values would clearly be unrealistic and would exaggerate the disadvantages of these plants.

ANNEX II

HYPOTHESES AND GUIDING CRITERIA USED AS A BASIS IN BOTH PAPERS E/CN.12/764 and E/CN.12/766

The study relates to hypothetical plants at a typical location in a developing country, well served with road and rail communications. By the very nature of the studies, the cost estimates and the conclusion drawn therefrom are likely to be only approximate and indicative.

The steel industry is particularly sensitive to economies of scale. The extent of economies would depend on how expansion is effected, in moving from one size range to the next size. In the papers used as a basis it was assumed that the expansion was brought about by the installation of a single larger unit and not by increasing the number of units. This procedure has been followed wherever feasible, as for instance in the case of blast furnaces, the various types of steel-making furnace, and rolling mills.

The capital investment estimates for the plants envisaged have not been arrived at by analogy with existing steel plants, but have been calculated on the basis of estimates for buildings, equipment, erection, etc., for selected processes and typical plant layouts. This approach permits a more accurate comparison of investments for the different plant capacities. The cost estimates for equipment are based on quotations on the competitive United States market, and the United States prices have been raised by 20 per cent in order to cover the costs of transport to the developing countries.

Capital costs for the auxiliary departments are quite high and may account for 35 per cent or more of total capital costs in small plants, decreasing somewhat in plants of larger size. In the studies, these costs have been estimated separately and then allocated to the production departments on the basis of relative utilization of the facilities provided, for the purpose, *inter alia*, of calculating the fixed charges component for each of the production departments in the determination of operating costs.

The estimates of labour productivity, primarily intended for the purpose of evaluating production costs, are optimum levels to be aimed at and are based on a general study of the various operations involved. No provision has been made for additional man power to cover leave and absenteeism, as these factors have been taken into account in the wage rates.

Works production costs for the steel produced by these hypothetical plants have been estimated for each process and plant size considered, on the basis of specific consumption of raw materials computed from their chemical analysis, and other inputs on the basis of efficient operation of the plants. In estimating costs it is assumed that the plants are utilized fully. Annex I indicates the prices and qualities of the inputs considered in all cases, the most important being the following:

(a) Iron ore of 65 per cent Fe content, at US$ 9.50 per tonne.

(b) Imported coking coal at US$ 18 per tonne.

(c) Steel scrap at US$ 30 per tonne in document E/CN.12/764, and at a cost of 90 per cent of the cost of the hot metal produced by the blast furnaces of the plant concerned, in document E/CN.12/766.

(d) Labour at US$ 1.50 per man-hour, a figure which is higher than prevailing wage rates in Latin America. It includes provision for social welfare legislation, leave and absenteeism.

(e) Fixed charges on capital invested have been estimated as equivalent to 9 per cent of investments annually. This figure is obtained on the basis of the following hypothesis:

(i) An estimated plant-life of twenty years;

(ii) An annual interest rate of 8 per cent, independent of the source of capital, to be paid annually on the unpaid balance, giving an average interest of 8 per cent;

(iii) An annual 5 per cent flat-rate amortisation of the capital;

(iv) The interest on reserves is compounded annually at the same rate as the interest on the capital throughout the useful life of the machinery concerned.

ANNEX III

OBSERVATIONS AND GUIDING CRITERIA RELATING TO THE CALCULATIONS REGARDING THE PRODUCTION OF FLAT STEEL PRODUCTS, SECTION IV.

For all annual production capacities, it has been assumed that the plant purchases coking coal and produces its own coke. For all capacities a uniform price of coke has been assumed; although this conceals the effects of economies of scale in coke making, it greatly simplifies the problem with very little distortion. The by-products (gas, tar, ammonium sulphate, benzene and toluene) have been valued at prices which take into account the thermic values of the fuels, the limitations of local markets and the competition of petrochemical products. With this system of calculation, one obtains the following cost per tonne of coke, without including fixed charges, which are included in the capital costs estimated for the reduction department:

	US$
Cost of coal	25.20
Cost above materials	5.30
Total:	30.50
Less credit for by-products	4.32
Total cost:	26.18

The works production cost of a tonne of self-fluxing sinter has been computed, for ore containing 65 per cent Fe, at US$12.52, of which US$0.80 is the cost above materials. Its average Fe content is 63.5 per cent.

For the preparation of the data on steel making, full use has been made of the information in the careful study produced in 1962 by the Economic Commission for Europe of the United Nations, entitled "Comparison of steel-making processes".

As a result of the manner of calculation adopted in document E/CN.12/766, the influence of plant size on capital costs for the reduction department in general will be considered under the cost of crude-iron. It is true that some variations from these figures will be unavoidable, but these will not have sufficient significance to invalidate the conclusions.

The return scrap from the rolling mills will not be sufficient to reach the 30 per cent percentage which is assumed in the cost of calculations. If we take the most favourable alternative, 300 kg will be available per tonne of ingot to be produced. In the estimates regarding the availability of return scrap, it has been assumed that some 25 per cent of what results from the application of theoretical coefficients is not utilized in the steel making installations owing to losses and the fact that it is used in the production of self-fluxing sinter (rolling-mill scale). Consequently, the quantity of scrap estimated as the specific consumption is a mixture of return scrap and purchased scrap. In any case, the total percentage of purchased scrap will not, in general, exceed 10 per cent.

With regard to the rolling operation, it can be said that this part of the production cycle has very special characteristics in the integrated Latin American plants, a situation which probably exists in other developing countries also. Owing to the small capacity of the markets of each country, small or medium-sized plants produce an over-diversified range of different types of rolled products, with a small annual volume for each product. For this reason, capital costs and also conversion osts are high, precisely at the stage of the cycle which should offer enterprises the best prospects for satisfactory returns. The hypothetical plants which have been used for this study, are assumed to include rolling mills with a capacity compatible with the markets of the country served, diversification in the rolled products of each plant being reduced as far as possible.

(a) Cogging mills

Case I Up to 300,000 tonnes of ingot annually. 3-high mill, with 3 rollers one above the other, and tilting tables in front of and behind the stand. Yield 88 per cent (rimming steel).

Case II From 300,000 to 500,000 tonnes of ingot annually. Modern 2-high reversing mill, with one motor. Can produce slabs with a yield of 81 per cent (rimming steel).

Case III For capacities above 500,000 tonnes of ingot annually. Modern 2-high reversing mills with two reversing motors. Can produce slabs with a yield of 86 per cent (rimming steel).

(b) Rolling equipment for flat products

The assumed characteristics of the equipment vary with production capacity, as follows:

Case I Capacities for sheet, plate and tinplate between 100,000 and 200,000 tonnes annually.
"Steckel" mill for hot-rolled plate and reversible cold-rolling stands. The installation consists of a hot-rolling mill with a reversing roughing mill and finishing stands; pickling and cleaning; reversible cold-rolling stands; temper stands; hot-dip tinning installations; cutting and finishing of sheet and tinplate, plus necessary heating furnaces. It has been assumed that the production of hot-rolled and cold-rolled sheet and plate and that of tinplate is distributed in such a way that the average yield of the installations in terms of semi-products is 70 per cent. The proportion of cold-rolled sheet and of tinplate varies between 67 per cent and 73 per cent of the total.

Case II Capacities for sheet, plate and tinplate varying in each case between 300,000 and 500,000 tonnes. Semi-continuous hot-rolling mill for plate and reversing stands for cold-rolling. The equipment is made up of a hot-rolling mill with a reversing roughing stand and finishing stands; reversing stands for cold-rolling; temper stands; pickling and cleaning; hot-dip tinning installations; cutting and finishing of sheet and tinplate, and heating furnaces. It is assumed that the production of hot-rolled and cold-rolled sheet and plate and of tinplate is so distributed as to give an annual yield of 74 per cent in terms of semi-products.

Case III Capacities for sheet, plate and tinplate between 600,000 and 800,000 tonnes annually. Semi-continuous hot-rolling plate mill and tandem stands for cold-rolling. The installation consists of a hot-rolling mill with reversing roughing stand, a non-reversing preparatory stand and finishing stands; a tandem cold-rolling mill; temper stands; pickling, cutting, cleaning and finishing, and heating furnaces. It is assumed that the product-mix is so such as to give an average yield of 81 per cent in terms of semi-products.

<u>Case IV</u> Capacities for sheet, plate and tinplate varying between 1 million and 2.5 million tonnes annually. Continuous hot-rolling plate mills, tandem stands for cold-rolling, hot-dip tinning installations, electrolytic tinning; pickling, cleaning, cutting of sheet and tinplate, heating furnaces, etc. For annual capacities varying between 1.5 million and 2.5 million tonnes, an independent mill for thick plate is installed.

ANNEX IV

OBSERVATIONS AND GUIDING CRITERIA RELATING TO THE CONSIDERATION OF ALTERNATIVE STEEL PRODUCTION PROCESSES

(a) Observations concerning the processes for reduction of ores

The electric reduction furnace selected for technical and economic analysis is the low-shaft furnace with a submerged arc. In the calculations of operating costs, it has been assumed that the cost of the power is US$ 0.005 per kWh and the coke consumption 450 kg, with 2,000 kWh of power. The coke is taken to be composed of a mixture, half "pea coke" and half imported coal, at an average price of US$ 15 per tonne, free at works. To arrive at these specific consumption figures, 100 per cent self-fluxing sinter must be used in the charge. The series of hypothetical plants equipped with electric reduction furnaces ranges from 100,000 to 1.5 million tonnes, and it is thought that, in practice, plants of higher capacity than this, based on the process in question, are very unlikely.

There are many processes on which experiments are being carried out in different parts of the world for directly obtaining solid iron (sponge iron), and several are being applied on an industrial scale. An analysis of the data provided by the firms which have patented the various processes shows that there are no great differences among them with regard to capital and production costs for equal contents of metal Fe in the sponge iron. As a basis for comparative study the HyL process, which is already being used on an industrial scale in Mexico, has therefore been used. Briefly, this process reduces the iron ore by catalysis, using reformed natural gas as a raw material. For the calculation of operating costs, it has been assumed that the calories contained in the natural gas have a cost which is equivalent to US$ 12 for a tonne of fuel oil. The product obtained is a good-quality scrap which may be described as having the nature of steel without being steel. It requires further processing in steel-making furnaces, and the process selected here is the electric arc furnace, since it can take a charge which is 100 per cent sponge iron. The maximum size of plant to which this analysis has been extended is 300,000 tonnes annual capacity.

(b) Observations concerning the steel-making processes

Apart from the process using a top-blown oxygen converter, which was considered earlier, the widely used open-hearth process is examined here, not on the grounds that it has advantages over the LD process but because the majority of existing plants in Latin America use it. It is assumed for the purpose of calculation that 30 cubic metres of oxygen are used per tonne of steel, to assist the heating of the charge. In any case, it does not seem likely, given the scarcity of capital in Latin America, that the open hearth furnaces now in use will be replaced by converters in the near future. Consideration is also given to the electric-arc steel-making furnace, the share of which in world output of steel advanced rapidly after the Second World War, a period when the size of the furnaces was increased considerably, up to 200 tonnes. The use of oxygen in electric arc furnaces makes it possible to increase productivity and reduce the consumption of electric power, but, to simplify comparison, only the direct refinement of the metal charge, without the use of oxygen, is considered.

The sponge iron obtained by direct reduction is assumed to be treated solely in electric arc furnaces and it is assumed that there are no technical obstacles to prevent the proportion of the total raw materials accounted for by this material from being approximately 70 per cent.

(c) Observations regarding the rolling processes

In all the hypothetical plants envisaged for the purpose of these studies of comparative costs, the same rolling facilities have been kept as are considered in section IV of this paper. The only variation considered here consists in the fact that in one case rolling is preceded by ingot casting and the cogging of the ingots, with subsequent rolling of the slabs, and, in the other, by vacuum degasification of the liquid metal, continuous casting and the rolling of the continuous cast billets in conventional mills. This last variant has been continued only up to a capacity of 1.5 million tonnes, owing to the doubts which are still entertained regarding the possibility of producing, with vacuum degasifiers, plate surfaces as good as those obtained with the use of rimming steels, which, in the present state of technology, cannot be processed in continuous casting machines. Nevertheless, according to available information, there are already plants of such dimensions in operation in some parts of the world.

The cost of vacuum de-oxydation breaks down as follows in the case of small plants:

Manpower employed directly	0.335
Manpower indirectly employed and wages	0.24
Various consumption costs	0.952
Fuel and services	0.109
Total works production cost	1.636

As to the yield of the steel used in continuous casting, it has been estimated at 94 per cent, in line with the figure given by many authorities.

As to the maximum and minimum capacities which have been assumed for the various units and processes, they are noted in table 1.

Table 1

MAXIMUM AND MINIMUM CAPACITIES OF THE DIFFERENT PRODUCTIVE UNITS USED IN THE PROCESSES CONSIDERED

(Tonnes and tonnes/year)

Unit	Capacity		Annual production per tonne capacity	Maximum annual production
	Minimum	Maximum		
Blast furnace	300	4,000	-	1,320,000
Electric reduction furnace	-	250	-	82,500
Open-hearth furnaces, with oxygen	25	500	1,200	600,000
Converter with enriched air blown in at the bottom	10	75	8,000	600,000
LD converter	10	150	8,000	1,200,000
LD-AC converter	10	150	7,000	1,050,000
Electric-arc steel-making furnaces with 70 per cent crude iron	15	150	3,000	450,000

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