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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

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ECONOMIC AND TECHNICAL COMPARISON BETWEEN CONVENTIONAL CASTING (SMALL AND LARGE INGOTS) AND CONTINUOUS CASTING[1/]

by

Seiichi Kojima
Kobe Steel Limited
Japan

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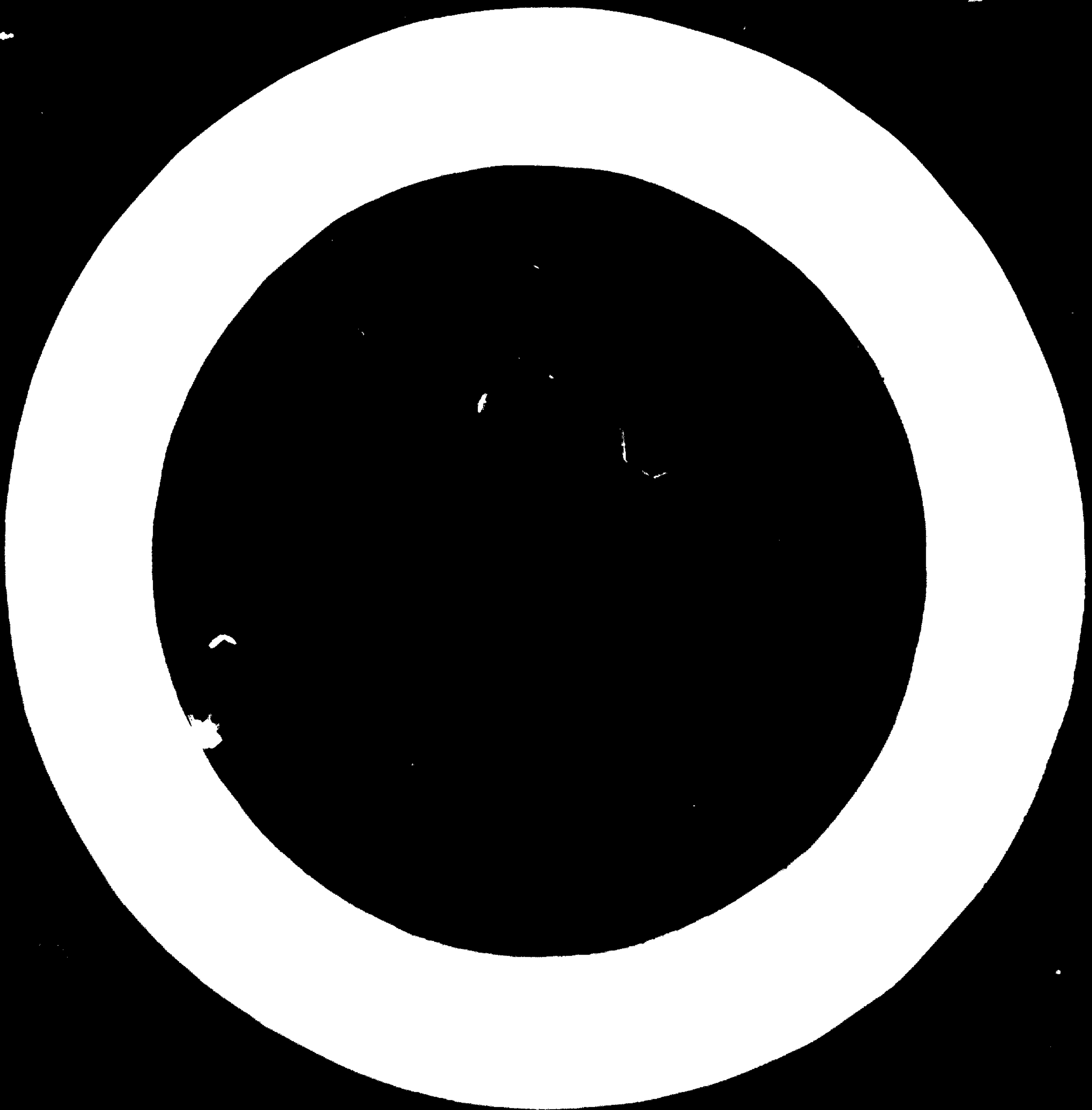

S U M M A R Y

In the study and comparison of the three processes (conventional casting - small ingot, conventional casting - large ingot, continuous casting), there are a number of technical and economic factors which influence decisions. Based on the experience of Kobe Steel Ltd, the three processes are compared in the paper on the basis of eight fundamental parameters : production scale, type and quality of product, materials yield and balance, investment and energy requirements, operating costs, manning, technical requirements in supporting sectors, and amanagement and control requirements.

These factors are not independent but closely inter-related. The following are the main criteria governing the choice of process :

A. On the basis of the type and quality of product in relation to market conditions and the investment and engineering required, the processes can be recommended in the following ranking order :

1. Small ingot process; 2. continuous casting plus small ingot practice; 3. large ingot process; 4. large ingot process plus continuous casting.

B. The processes should be selected on the basis of available data relating to materials, manning, geographical considerations, energy sources, and the degree of development of product consumer industries.

C. After due consideration of the two conditions above, the choice should be further conditioned by whether it is proposed to build a new works or to expand an existing works.

D. It is necessary for a new iron and steel making enterprise to pass through a number of successive development stages before it can be considered fully prepared to enter into competition with long-established large-scale iron and steel enterprises.

E. Even if there is some imbalance between the various factors enumerated above, it is conceivable that the national economic interest may override purely technical considerations. It is therefore essential to take into account when selecting a process the national growth pattern and demands.

Introduction

In this paper, three methods of steel casting - conventional small ingot practice, conventional large ingot practice, and continuous casting - are compared and their economic and technical advantages and disadvantages are explained and discussed.

There are a number of divergent viewpoints on the relative merits of these three methods of casting, because any comparison of them must necessarily involve the evaluation of many inter-related factors.

In this paper, the following factors are reviewed in the light of our experience :

- Production scale
- Type and quality of product
- Materials yield and balance
- Investment and energy requirements
- Operating costs
- Manning problems
- Technical requirements in supporting sectors
- Management and control requirements.

All these factors are closely connected. There are also other factors which influence the problems under review, such as market conditions, transportation, inventory and maintenance of equipment, etc.

Production Scale

Each of the three methods is technically and economically feasible within a certain production range, taking into account ingot weight, dimensions of cast billets, steel furnace capacities, number of furnaces and strands, etc.

Figure 1 shows the relationships between the capacities and the heat tonnages under various conditions.

The small ingot process is subject to a restriction caused by the relationship between ingot weight, number of ingots per heat, and operating cycle (teeming, stripping, mould preparation). Although ingot weight is fixed by the specification of the rolling mill to which the ingots are supplied, the maximum number of ingots may be estimated as follows :

Up to 300 kg ingots	About 200 ingots/heat maximum
300-600 kg ingots	" 100 " / " "
Over 600 kg ingots	50-60 ingots/heat.

If these limits are measured in terms of furnace capacity (tons/heat) 50-60 tons/heat is a suitable limit for the application of this process. Furthermore, taking into account the tap-to-tap cycle of the furnaces (or number of heats per day) and the series of operations at the casting pit, the maximum feasible operating cycle is 3-4 heats/day. If higher capacities are needed, the number of pits must be increased or track-teeming must be used.

The use of large ingots involves increase of capacities and the adoption of mass production. In this method the number of ingots per heat is not higher than 30. However, the use of track-teeming and

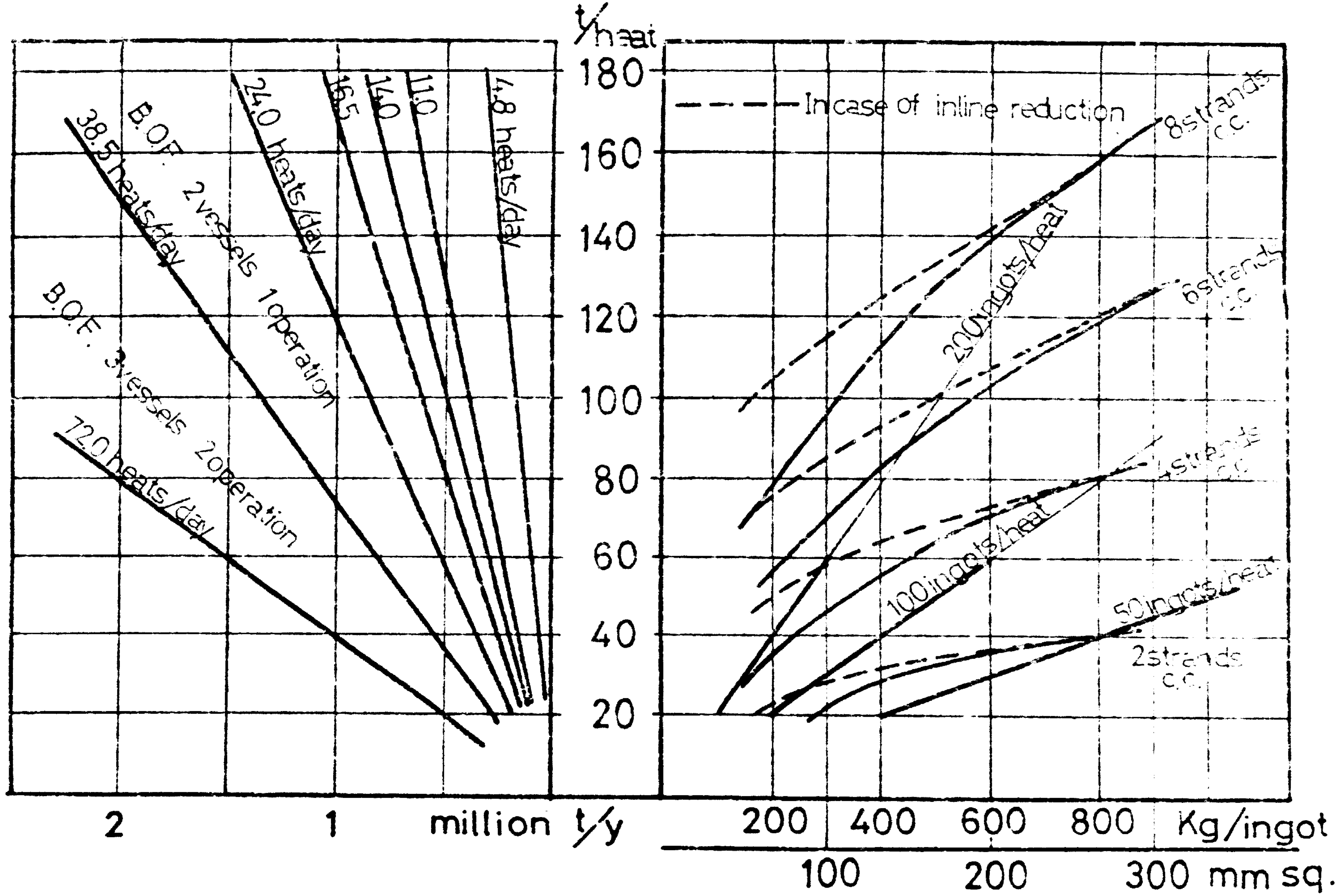

Fig. 1 - Relationship between production scale and conditions for each casting process

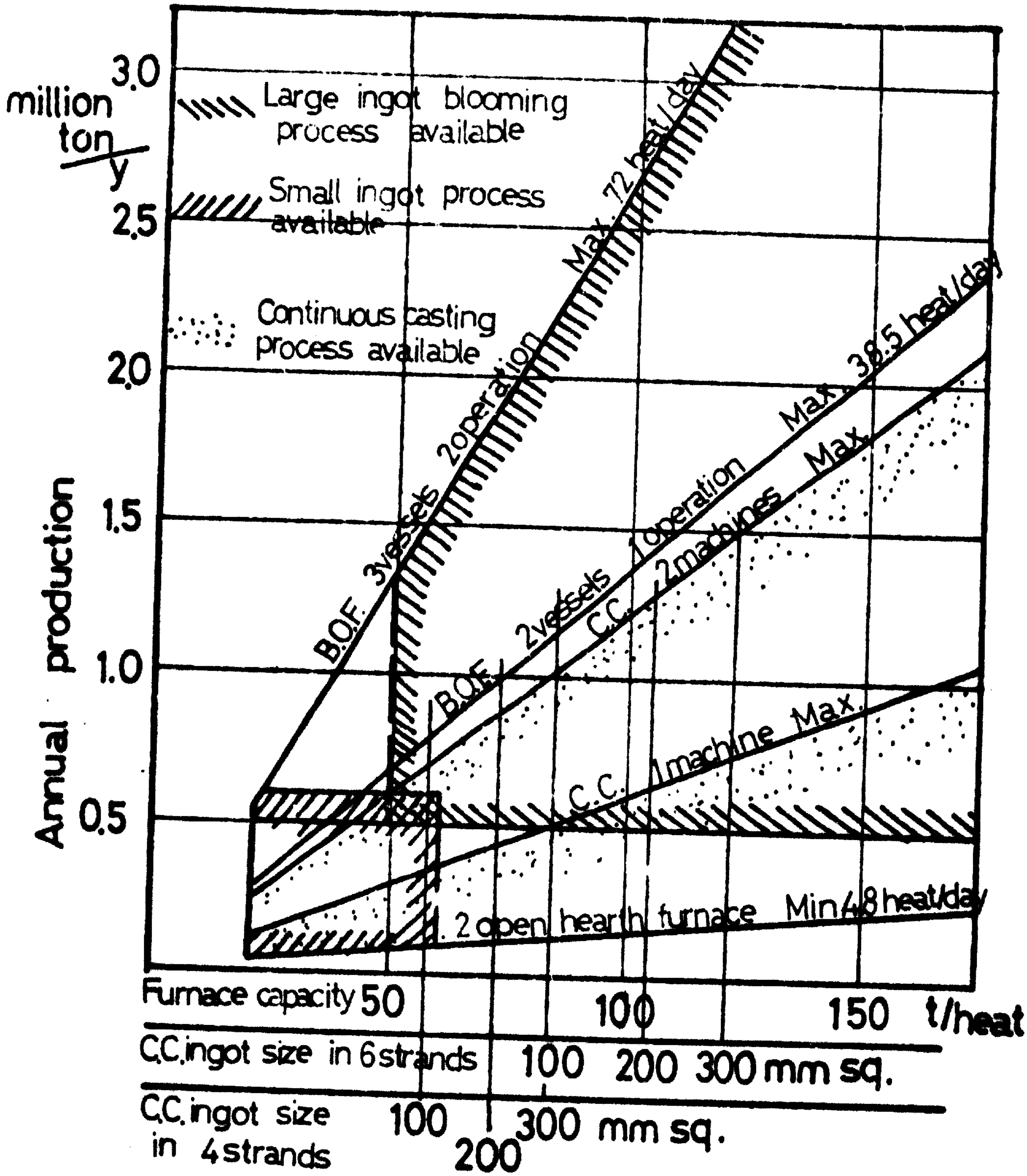

Fig. 2 - Limits of production capacity for the three processes

mould preparation can provide favourable conditions for a greater number of heats to be cast per day.

Large ingot casting facilities are usually followed by blooming mills with capacities of over 1 million tons/year. Full utilization of the blooming mill capacity is an important factor in the overall economies of scale.

It is considered essential that the minimum capacity of a blooming mill should be not less than 0.5 million tons/year with a utilization rate of over 60%.

The number of strands in a continuous casting machine is calculated in such a way as to permit casting of one ladle of molten steel within 50-60 min. Nowadays, the maximum number of strands on bloom and billet casting machines has reached eight. Depending on specific local conditions, this number may be four or six.

The consumption of molten steel (t/min per strand) is determined by the average withdrawal speed and by the size of the cast section. As shown in Fig. 1, when 100 mm^2 billets are cast, a six-strand casting machine is used and the furnace capacity is 70 t/heat. Furthermore, with the application of so-called in-line reduction, which has been adopted recently, the production rate is expected to increase, especially with small-section billet continuous casting. As shown by the dotted line in Fig. 1, it is now possible to produce 80 tons/heat of billets of about 80 mm^2 cross-section on a six-strand continuous caster with in-line reduction.

On the other hand, the number of heats per machine can be raised to 400-500 heats/month by means of sequence (continuous-continuous) casting and by matching control of the caster with the furnace tapping cycle. The equipment capacity can be increased still further, as required, by installing multiple machines, to suit the production cycle.

With these considerations in mind, the limits of production capacity for these three processes is shown in Fig. 2.

Type and Quality of Product

In the steel production line, the first technological process which influences the quality of the product is the solidification stage of molten steel and the second is the reduction ratio from cast ingot to final product.

For each of the three methods under consideration, the solidification mechanism is different.

Table 1 shows the suitability of these methods for the production of bars, sections, and wire rod. This classification is related to the high level of control and technology required in markets where the maximum quality level is demanded by customers. It may not be applicable in other countries of the world.

In the case of small ingot casting, the number of ingot moulds per heat is large. The process of solidification of molten steel is short and the appearance of shrinkage cavity is unavoidable. The application of hot-tops for all ingots is difficult, especially when larger tonnages of steel are to be produced by this technique. Small ingots of killed and semi-killed steel are normally supplied to reinforcing or general structural bar mills. Such ingots are not usually rolled to wire rod in industrialized countries. Even for production of reinforcing bars, the press-joint method has recently become more popular. Customers are nowadays reluctant to accept rolled products manufactured from small ingots, in view of the quality of these products, which tends to be lower.

Table 1 Applicability of the three processes to different types of steel product

	Small ingot, direct rolling	Large ingot, blooming	Continuous casting and breakdown
Reinforcing bar	Yes (1)	Yes (1)	Yes (1)
General structural bar and section	Yes (1)	Yes (1)	Yes (1)
Low-carbon wire rod	Yes (2)	Yes (1)	Yes (1)
High-carbon wire rod	Yes (2)	Yes (1)	Yes (1)
Cold-drawing quality	Doubtful	Yes (3)	Yes (4)
Cold-heading quality	Impossible	Yes (5)	Yes (4,5)
Mechanical structural carbon steel	Difficult	Yes (5)	Yes (4,5)
Low-alloy steel	Impossible	Yes (5)	Doubtful
High-alloy and stainless steel	Impossible	Yes (3)	Doubtful

Notes : (1) Easily applicable
(2) Only applicable for low quality level
(3) Surface conditioning required
(4) Over 150 mm square bloom recommended; surface conditioning required
(5) Surface conditioning and guaranteed internal quality required.

Steel products manufactured from large ingots are preferable. The amount of steel cast in large ingots is far greater than that cast using other methods. The techniques of large ingot casting and their further treatment are so well developed that almost all the required qualities of steel product can be produced. Various technologies are in commercial operation : open rimmed ingots, capped rimmed ingots, semi- and fully killed hot-topped ingots, top or bottom pouring, hot scarfing, etc.

In accordance with the requirements of customers for higher steel quality, the manufacturers apply surface conditioning of billets and final products as well as more strict technical and management control.

It has been found to be difficult and uneconomic to detect defects in cast billets and treat them further to eliminate these defects. In the case of continuously cast billets smaller than 120 mm^2 in section, the intermittent occurrence of shrinkage cavities and segregation in the axial zone is unavoidable. However, this quality problem at the press-joined part of reinforcing bar, resulting from use of the small ingot method, can be avoided by using continuous casting.

On the other hand, continuously cast blooms with cross-sections larger than 150 mm^2 are suitable for cold-rolled and structural steels, subject to proper control of the technological factors. The maximum size of continuously cast blooms is 300-350 mm^2. Since the reduction ratio for manufacturing high-grade steel is of the order of 15-20 : 1, the maximum product size would be 40-60 mm dia.

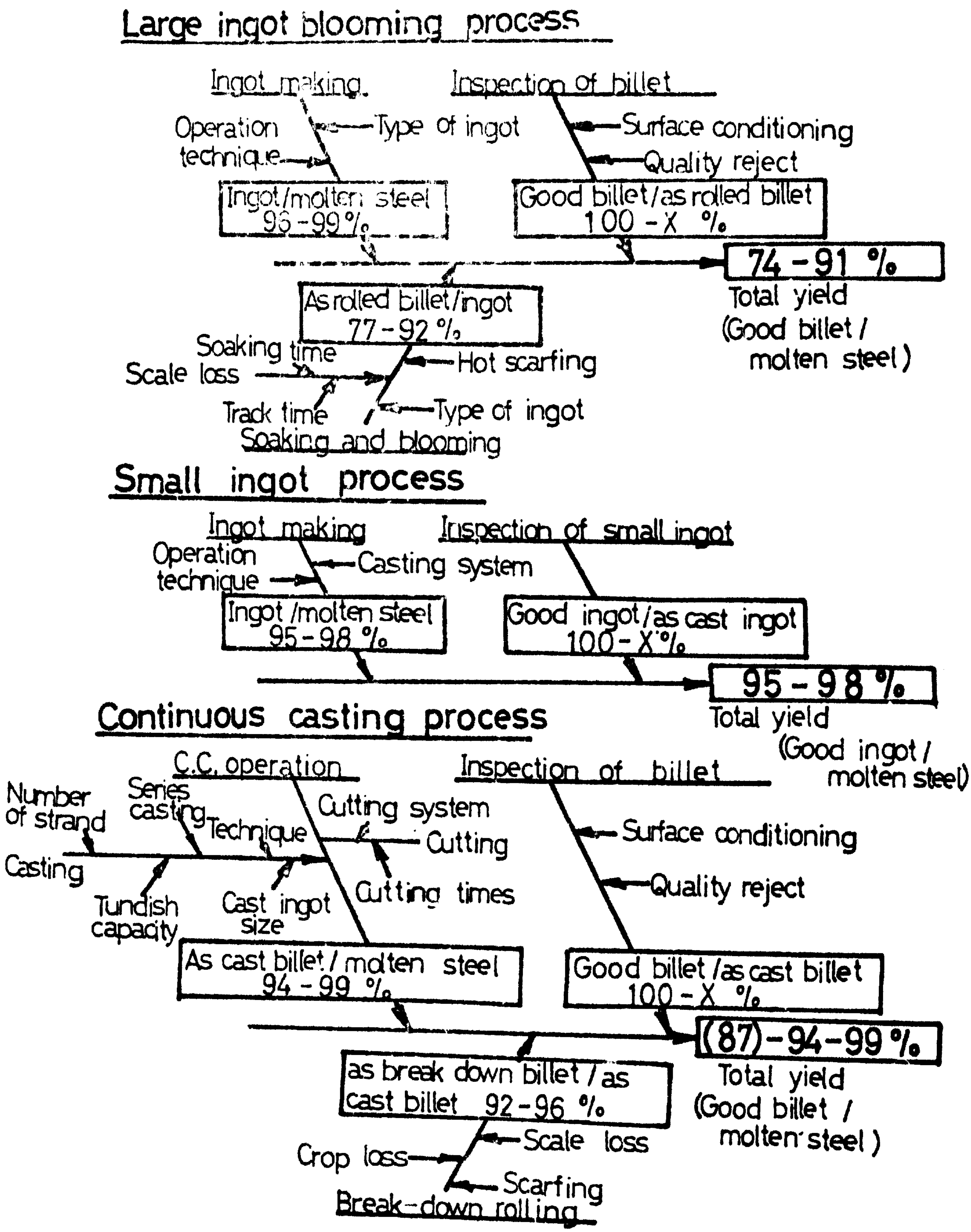

Fig. 3 - Factors affecting yield of the three processes

Ma[illegible]

[illegible] raw materials [illegible] the works.

Each of the three methods [illegible] total yield, which is largely dependent on the [illegible] performance of personnel and equipment, required product quality, etc.

Figure 3 shows total yields (good billet/molten steel) in relation to the three different casting processes.

In small ingot casting, the [illegible] of [illegible] technique are virtually fixed. The factor which influences the yield is the knowledge and skill of the personnel. The yield of this process can generally be expected to be of the order of [illegible]-98%.

In the case of the large ingot process, there is a [illegible] difference in yield (ingot/molten steel) between top-poured rimmed or semi-killed ingots and bottom-poured hot-topped killed ingots.

In continuous casting, the yield value (cast billet/molten steel) varies between 4% and 5%, according to the number of sequence-cast heats and cutting conditions. The relationship between the number of sequence-cast heats and the yield is shown in Fig. 4.

The method of cutting cast billets has recently changed from gas-torch cutting to shearing or other types of mechanical cutting, and the cutting loss of 5-13 mm per cut length that was inevitable with gas cutting is gradually disappearing. If these optimum conditions are satisfied, the yield (cast billet/molten steel) can be expected to be 99%. If the continuously cast bloom is passed through a breakdown rolling process, as suggested above, the yield (rolled billet/cast bloom) will be 92-97%.

Investment and Energy Requirements

The relationship between the investments required by the three processes under consideration and the production capacity is shown qualitatively in Fig. 5. From the viewpoint of scale of production, the small ingot process has limitations, but the investment is far smaller than for the other two processes, in general less than 30%. For a higher capacity the increase in investment is lower than with the other two processes.

Comparison between the large ingot blooming process and continuous casting is more difficult. The capacity of the continuous casting machine is influenced by the method of estimating the actual operating ratio. There are wide fluctuations in investment, resulting from the different degree of subsidiary equipment included in the plant. Moreover, in some actual cases, parts of the existing equipment are put to use for the new process, which makes comparison of these two processes on the same terms even more difficult.

According to rough estimates, when the annual capacity is less than 700-800,000 tons, the capital costs of the blooming process will be higher than those for continuous casting. On the other hand, the blooming process with a larger capacity offers considerable advantages in terms of scale and will be more economical than continuous casting. However, according to recent developments in value analysis, continuous casting equipment will progressively cost less and less, and so the relative advantages of continuous casting will improve.

If a continuous caster is combined with BOF steelmaking, which has

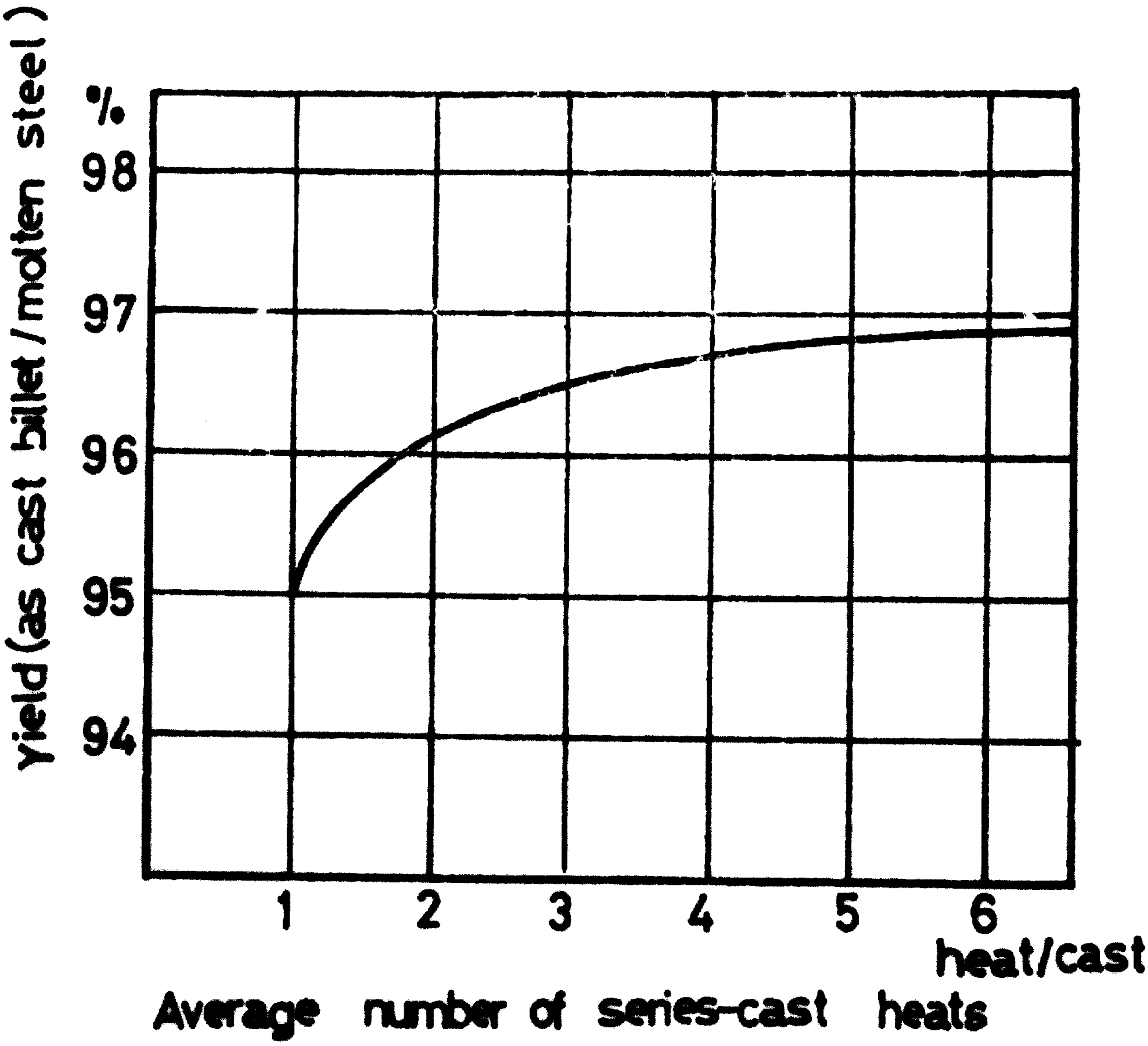

Fig. 4 - Relationship between average number of sequence-cast (series-cast) heats and yield in continuous casting

advantages in its tap-to-tap cycle, and if its layout is efficiently designed, 400-500 heats/month may be anticipated. For a larger production than this, the number of machines must be increased.

In the blooming process, greater rolling mill capacity can be installed by having two blooming stands combined with the billet mill. The capacity of equipment for over 2 million tons/year is usually decided by the heating or soaking capacity installed. It is therefore useful to design the initial installation with adequate rolling capacity, which can be balanced by adding more soaking pits at a later date.

It is rather difficult to estimate investment costs without specifying geographical conditions, layout, product range, etc. In addition, tariffs, economic policies, local materials costs, the heavy industry market, freight and labour costs, etc. vary from country to country.

These three processes have specific consumptions of energy (electric power, fuel, water, etc.). When a plant is being built in a new region or when major expansion is being carried out to an existing installation, the amount of energy required is an important factor in deciding which process is to be adopted. Table 2 shows the energy requirements for each process.

Table 2 Energy requirements for blooming mill and continuous casting

	Blooming mill	Continuous casting
Electric power		
Max. capacity required	0.094 kWh/t per month	0.048 kWh/t per month
Mean capacity required	0.054 kWh/t per month	0.010-0.025 kWh/t per month
Consumption	35-55 kWh/t	10-30 kWh/t
Water		
Capacity required	4-7 m^3/t per h	12-18 m^3/t per h

Operating Costs

The comparison of operating costs for these processes poses the following problems :

a. Consumption of material varies according to ladle capacity, ingot size, ingot type, billet size, etc.

b. There are some operating costs which vary according to the product cycle and conditions.

c. The price of materials consumed varies according to their specification and the market conditions.

d. There some items, such as labour, transportation, and maintenance costs, which can be considered as either fixed or variable costs.

The rough value of running costs per ingot ton using each process in Japan and the main consumption figures are shown in Table 3. The running costs of continuous casting are the lowest, the small ingot process comes next, and the large ingot blooming process is the most expensive.

However, since, for example, local prices prevailing for copper moulds for continuous casting and for blooming mill rolls vary considerably from place to place, a strict comparison of estimated running costr is very difficult if actual costs are not known.

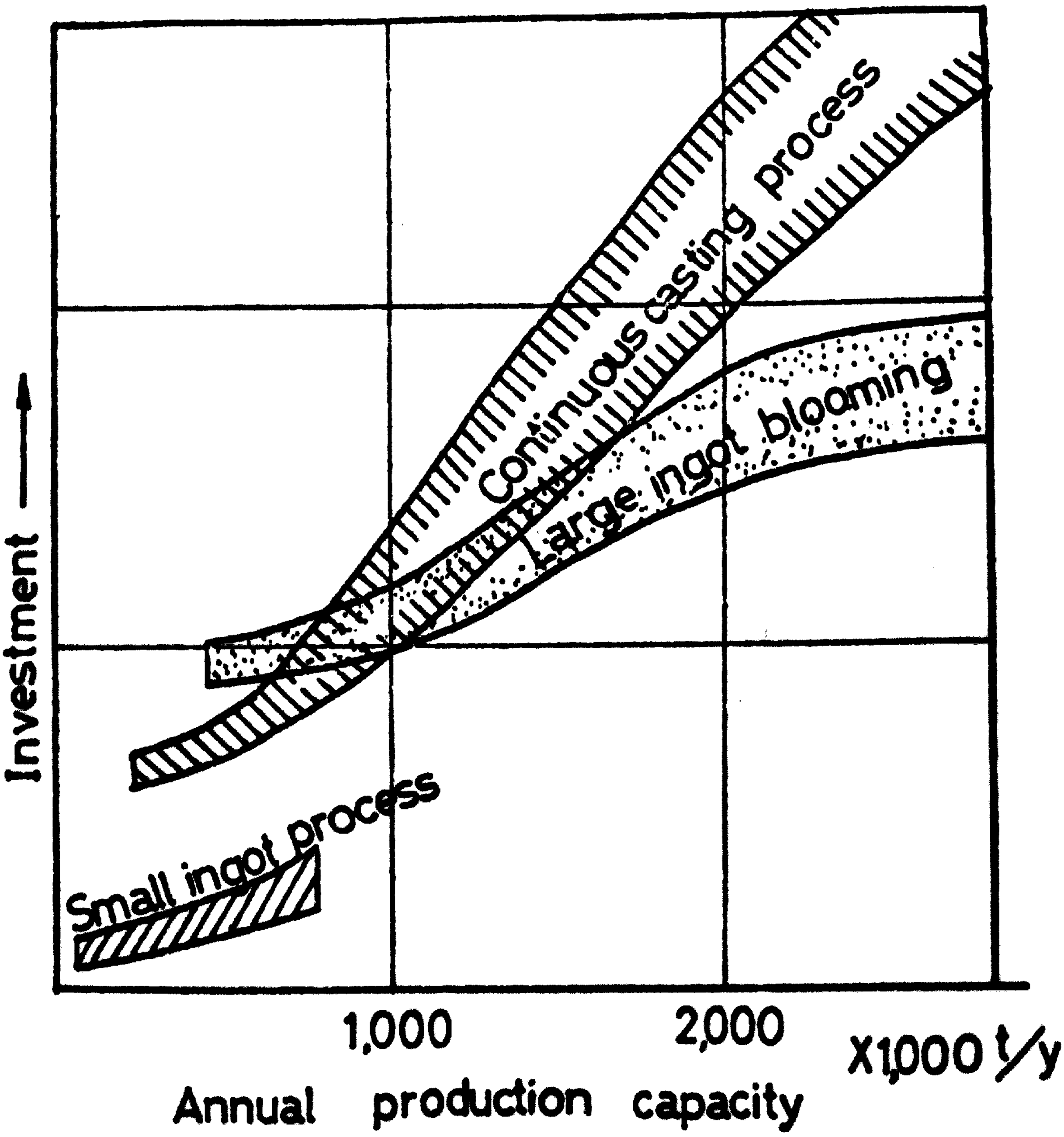

Fig. 5 - Relationship between investment costs and production capacity for the three processes

Table 3 Comparison of operating costs for the three processes

Small ingot process		
	Bricks and refractories	$4-2-5.8 per ton
		7.0-10.1 kg/t
	Moulds and plates	8.9-15.3 kg/t
Large ingot blooming process		
	Ingot manufacture	$6.6-10.4 per ton
	Bricks and refractories	$4.7-6.8 per ton
		7.2-15.0 kg/t
	Moulds and plates	8.4-16.6 kg/t
	Blooming process	$2.1-3.7 per ingot ton
	Heavy fuel oil	20-40 l/t
	Rolls	0.4-0.7 kg/t
	Electric power	35-55 kWh/t
Continuous casting process		
	Bricks and refractories	$3.0-4.8 per ton
		5.0-18.0 kg/t
	Moulds	70-500 heats/mould

Manning Problems

Manning requirements should be calculated taking into account the fatigue factor and adequate ratings on the basis of standard work time. The comparison of manning for the processes presents the following problems :

a. What are the furnace capacity, ingot weight, and billet size in the large ingot blooming process ?

b. What is the degree of automation ?

c. What is the layout of the installation ?

d. How many shifts and crews are to be working ?

e. What degree of indirect labour is required for the process (i.e. maintenance, lining, transportation, surface conditioning, etc.) ?

The estimated manning requirements for each of the processes (with some appropriate assumptions) are shown in Fig. 6. It will be seen that the small ingot process is labour-intensive, requiring more employees per ton of production and increasing markedly as the output rises.

The continuous casting of square-section products has a production limit per machine of 500-600,000 tons. Even under the best conditions of capacity utilization, with multiple-strand operation, when this limit is exceeded the number of operators increases in proportion to the number of machines.

The large ingot blooming process is a large-scale one, and so an increase in capacity utilization can effectively increase the productivity per employee.

Technical Requirements in Supporting Sectors

Basically, the iron and steel industry is a large-scale one. However, the scale of production is subject to restrictions imposed by product demand, technical level of personnel, and other factors.

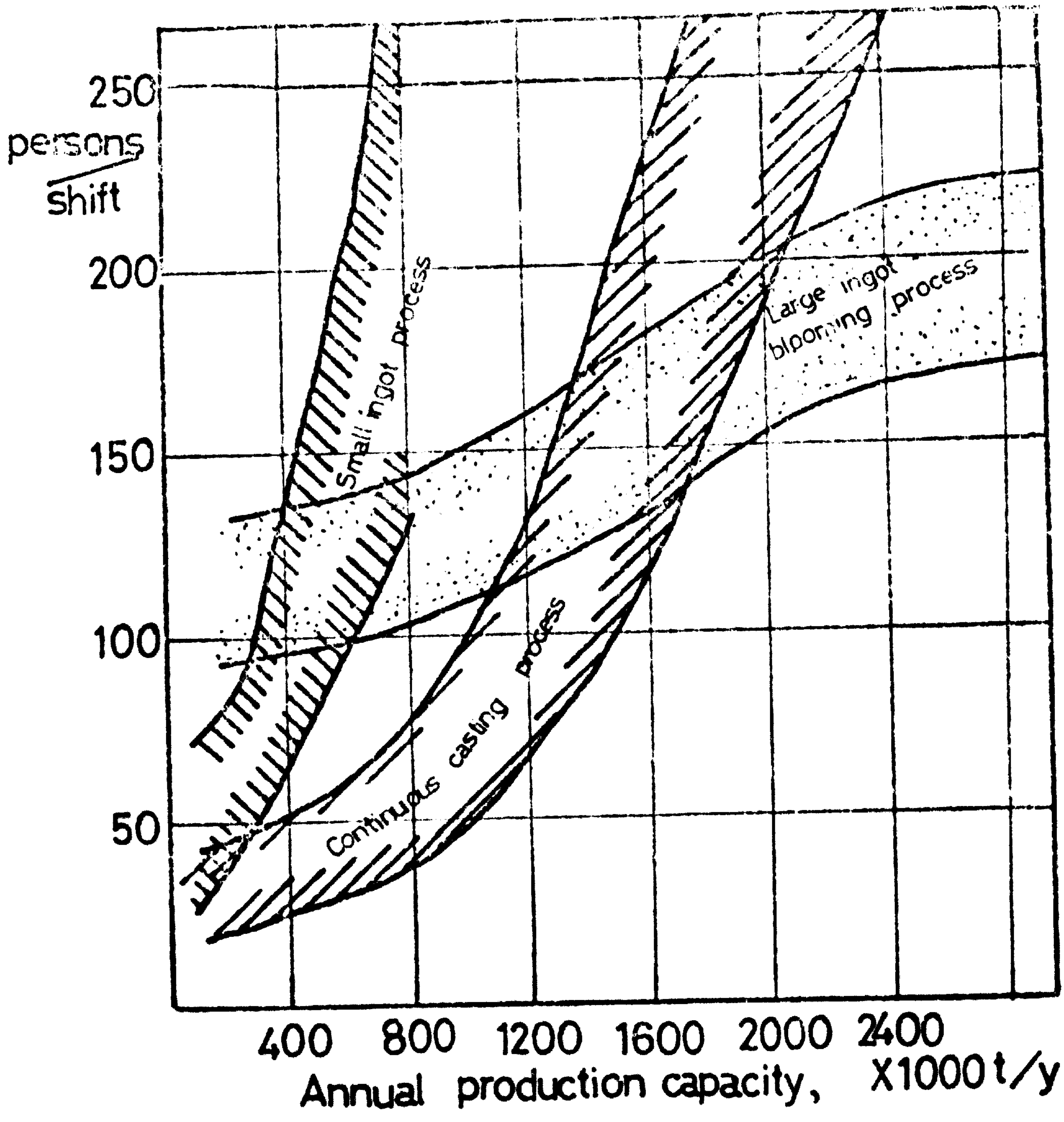

Fig. 6 – Estimated manning requirements for the three processes (excluding steelmaking)

Good economic results cannot be obtained solely through the theoretical knowledge of a handful of engineers. It is essential that all the personnel should reach a high technical level of competence.

The comparison of the three processes in terms of the technical level required by the personnel is shown in Table 4. Both large ingot blooming and continuous casting require workers with a higher level of knowledge than the small ingot process, and they also need more supporting trades with a high level of engineering expertise. The continuous casting process demands judgment and decision-making on the part of its operators and thereby a higher degree of training and basic knowledge than the small ingot process.

Table 4 Comparison of knowledge and technical skills required

	Small ingot process	Large ingot blooming process	Continuous casting
Basic process requirements			
Metallurgy	C	A	A
Machinery	C	A	A
Electricity	C	A	B
Integrated decision-making	C	B	A
Supporting industries			
Refractories	C	A	A
Heavy cast or forged rolls	-	A	C
Cast-iron moulds	C	A	-
Copper moulds	-	-	A
Hydraulics	-	C	B
Heavy electrics	-	B	C
Machinery	C	A	B
Fuel and gas	C	B	A
Measurement and instrumentation	C	B	A

Notes : A = High level required
B = Moderate level required
C = Low level adequate

Management and Control Requirements

The level of management and control personnel required in the iron and steel industry does not depend upon the tonnage output but on the degree of sophistication in the products manufactured. The simpler the process, the easier is the task of management and control personnel.

In the case of continuous casting, in order to produce several types of steel using sequence casting and to maintain a good production ratio, a comprehensive management and control is required throughout the process cycle and at at all levels. The same applies to large ingot casting, especially for special steel production.

Small ingot casting is usually restricted to lower grades of steel and to a limited product range, and so the requirements for management and control personnel are less high.

Summary

It is difficult to summarize all the considerations that come into play in the three processes. An attempt has, nevertheless, been made to do so graphically in Fig. 7. This diagram is explained below.

(1) The small ingot process

This process is suited to small-scale production : furnace capacities of 50-60 tons/heat and an annual output of 500,000 tons are appropriate limits for the application of this process. The investment required is far lower than in the other processes and the yield is high, irrespective of the quality level; the running costs are not high. This process has economic advantages in certain conditions.

On the other hand, the product range is mainly restricted to low-grade steel reinforcing bars and the productivity per employee is the lowest of all the three processes. It is labour-intensive and the knowledge and skill required are usually not high.

There is little potential for future increase in output, automation, quality improvement, or product expansion. This process can only be used for the production of low-grade reinforcing bar for the local market, and will be most useful when used as a transitional process during expansion, either used jointly with continuous casting or as a standby.

(2) The continuous casting process

The maximum production capacity is of the order of 400-500 heats/month per machine, using sequence casting; as many machines can be installed as are needed for the scale of production required. However, for production capacities exceeding 1 million tons, the investment costs are relatively higher than those for the large ingot blooming process.

The range of products is wider than that of the small ingot process; when high-grade steel is to be produced by this process, surface conditioning by means of breakdown rolling is advisable.

The yield and running costs influenced by the degree of sequence casting used and the maintenance of a high operating ratio by close matching with the tapping cycles of the steelmaking furnaces. This process is more economical than the large ingot blooming process.

(3) The large ingot blooming process

This process, as might be expected, can offer favourable economies of scale with capacities in excess of 500,000 tons/year. It can also be used for the production of all types of steel product.

However, since the yield and running costs are less favourable than in either of the other processes, it is desirable to include in the product range high-grade steels and steels with higher added values. In addition, it is important to have adequate transportation facilities, inventory control, and supporting industries (roll supply, maintenance, etc.), a stable electricity power supply, and a highly industrialized social base.

This summary is based on technical and economic considerations alone. However, the selection of the process should also be based on the following background and social factors :

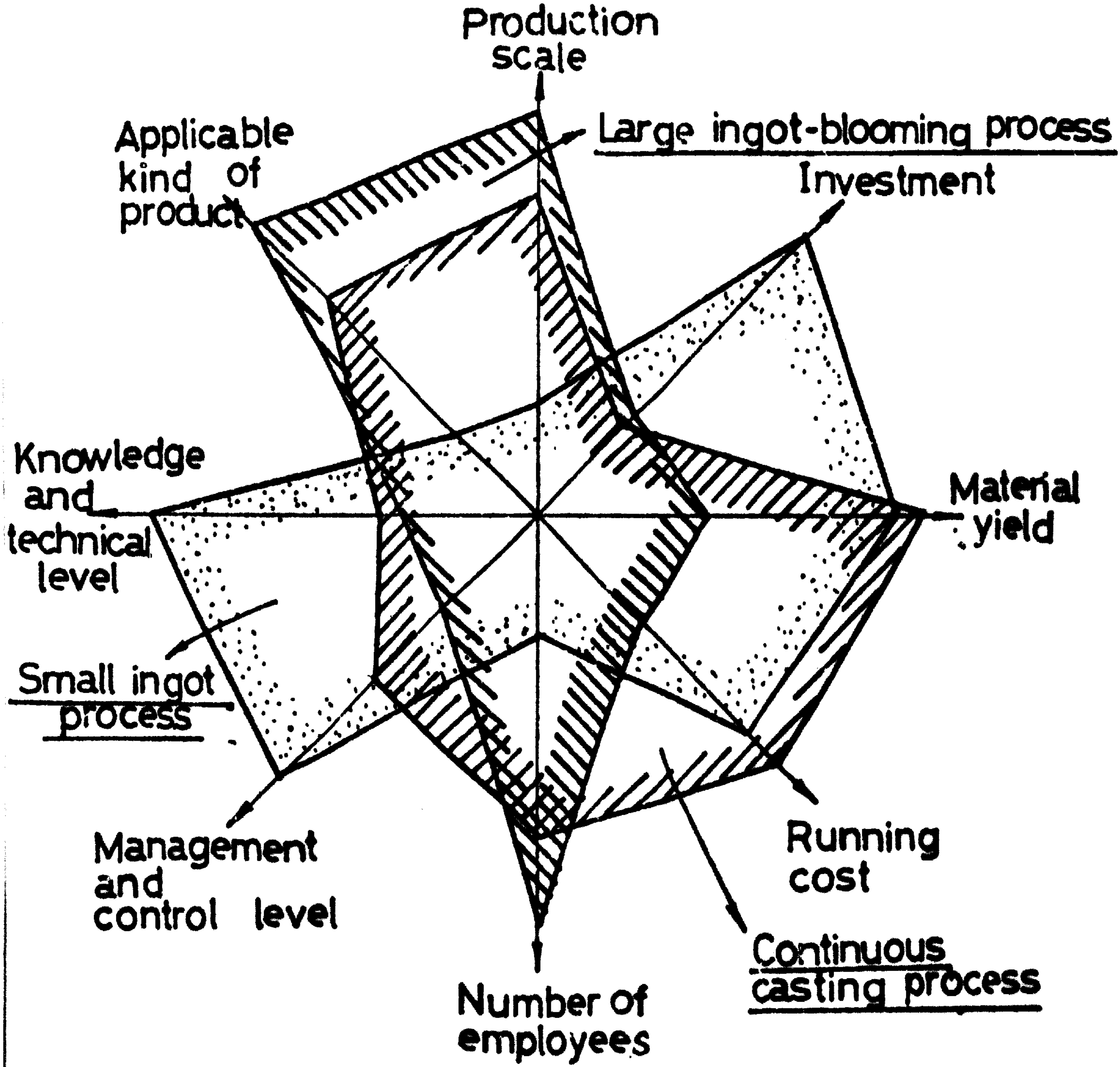

Fig. 7 - Characteristics of the three processes

A. In accordance with the degree of precision required in terms of type and quality of product (based on assured market demand) and also the degree of engineering and the investment likely to be incurred in developing future new markets, the processes are recommended in the following order :

i. Small ingot process

ii. Continuous casting with small ingot process

iii. Large ingot blooming process

iv. Large ingot blooming with continuous casting.

B. However, in the selection process, the following factors must be taken into account : the materials supply balance, labour factors, geographical circumstances, energy sources, the development of allied steel-consuming industries, etc.

C. The basis for selecting one of these processes also depends on whether a new works is to be built or whether an existing works is being extended, due consideration being at the same time paid to conditions A. and B. above.

D. Whatever casting process is selected, stage-wise construction is always preferable, since this enables experience and knowledge to be built up progressively.

E. Even if all the points enumerated above are favourable, there are other criteria that must still be taken into consideration, notably the degree of development in supporting and consumer industries and government policy regarding the development of the iron and steel industry itself.

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