CAPITAL REQUIREMENTS OF THE STEEL INDUSTRY

1958 TO 1970

by
Amnuay Viravan

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in the
University of Michigan
1958

Doctoral Committee:

Professor Donald R. G. Cowan, Chairman
Professor Olin W. Blackett
Associate Professor Thomas G. Gies
Associate Professor William B. Palmer
Professor William J. Schlatter

PREFACE

The purpose and the nature of this study have been described adequately in the introductory chapter, and this preface will thus be confined to acknowledgement.

Several people have contributed heavily to my thinking on this inquiry. Without doubt I am most indebted to Professor Donald R. G. Cowan for his incisive suggestions and criticisms at all stages of the investigation. Professor Cowan provided the writer with the opportunity of undertaking this study in conjunction with his research on the future growth of the steel industry sponsored by the Brookings Institution.

I wish to express my gratitude to Professor Olin W. Blackett for his advice and helpful suggestions with regard to the development of statistical methods used in this examination. I also wish to express my appreciation to Professors William J. Schlatter, William B. Palmer, and Thomas G. Gies for their critical reading and for their comments and suggestions. The Brookings Institution has been generous in providing access to all information developed in the aforementioned study of the steel industry.

My thanks go to Mr. D. Ross Cowan for his assistance in operating the University's IBM electronic computer and

to Miss Samonsri Bunnag for her clerical preparation of the drafts and for her constant encouragement in bringing this dissertation to its completion.

University of Michigan
Ann Arbor, Michigan
November 2, 1958

Amnuay Viravan

TABLE OF CONTENTS

		Page
PREFACE		ii
LIST OF TABLES		v
LIST OF CHARTS		viii
Chapter		
I.	INTRODUCTION	1
II.	HISTORICAL AND PROSPECTIVE GROWTH OF THE STEEL INDUSTRY	10
III.	GROWTH REQUIREMENTS OF PRINCIPAL FACILITIES	34
IV.	PROBLEMS IN THE DETERMINATION OF TOTAL CAPITAL REQUIREMENTS	85
V.	CAPITAL REQUIREMENT FOR EXPANSION	104
VI.	CAPITAL REQUIREMENT FOR REPLACEMENT	130
VII.	SUMMARY AND CONCLUSIONS	162
APPENDICES		
A.	FERROUS AND ALUMINUM PRODUCTION; U.S. POPULATION, 1810-1957	170
B.	a, b, c, SYSTEM OF LIFE CURVES	176
C.	STATISTICS FOR THE LIFE ANALYSIS OF DEPRECIABLE STEEL ASSETS	186
D.	COMPUTATIONS OF ESTIMATED PLANT BALANCES AND ANNUAL RETIREMENTS OF STEEL DEPRECIABLE ASSETS	190
BIBLIOGRAPHY		200

LIST OF TABLES

Table		Page
1.	Annual Production Statistics of the Steel Industry for Selected Years from 1828 to 1956	15
2.	Rate of Growth of Steel Ingot Production in Four Different Periods	18
3.	Annual Steel Production and Number of Years Required to Approximately Double Production, 1810 to 1955	19
4.	Annual Steel Production and Real Gross National Product, 1913-1957	22
5.	Consumption and Capacity Ratios of Coke to Pig Iron, 1943-1956	42
6.	Total Coke Capacity in the United States and Coke Capacity in the Steel Industry	46
7.	Blast Furnaces: Number of Stacks, Total Annual Capacity and Average Annual Capacity per Stack, 1925-1957	49
8.	Blast Furnaces: Numbers and Percentages in Capacity Groups, Years 1945, 1948, 1951, 1954	52
9.	Material Consumption Per Ton of Pig Iron Produced	55
10.	Blast Furnaces: Capacity and Production, 1946-1957	57
11.	Consumption and Capacity Ratios of Pig Iron to Steel Ingots and Castings	59
12.	Comparison of Estimated Costs per Net Ton of Ingot for Open-Hearth and Electric Furnace Shop and their Initial Capital Investment	73
13.	Total Production and Net Shipments to other Industries of Steel Ingots and Castings	75
14.	Steel Requirement per Net Ton of Hot-Rolled Products, 1920-1956	76
15.	Capacity Ratios of Steel Ingots to Hot-Rolled Steel Products for Five Selected Years	78

LIST OF TABLES--Continued

Table		Page
16.	Requirement Ratios and Capacity Ratios of Ingots to Hot-Rolled Steel Products for Five Selected Years	79
17.	Annual Capacities of Hot-Rolled Steel Facilities and of other Finished (Cold-Finished) Steel Facilities for Five Selected Years	82
18.	Needs for Net Expansion in Principal Capacities of the Steel Industry Between 1958 and 1970	83
19.	Capacities and Capital Coefficients of Three New and Completely Integrated Plants	108
20.	Estimated Replacement Construction Costs for the Steel Industry in 1953	112
21.	Degree of Integration in New Steel Plants	114
22.	Per Cent of Total Capacity Additions by Various Types of Expansion, 1951-1955	115
23.	Annual Capital Expenditures and Annual Gross Capacity Expansion	120
24.	Capital Coefficients of Capacity Expansion Exclusive of New Plants in Dollars of 1957 Purchasing Power	121
25.	The Degree of Integration in Past and Future Expansion	122
26.	Statistical Test of the Assumed Life Curve under the Simulated Plant Balance Method	134
27.	Determination of Average Life from Life Curve	135
28.	Hypothetical Company: Estimated Replacement Needs for the 1958-1960 Period	136
29.	Annual Additions of Depreciable Assets, 1915 to 1956, and Depreciable Plant Balances, 1949 to 1956	144
30.	Estimated Life Curves of Steel Depreciable Assets Computed by the Simulated Plant Balance Method	146

LIST OF TABLES--Continued

Table		Page
31.	Comparison Between the Estimated Plant Balances from the Life Curve and the Actual Plant Balances	150
32.	Estimated Future Retirements of Steel Assets at Original Cost Based on Annual Additions and Retirement Rates	154
33.	Estimated Capital Requirements for Replacement of Steel Facilities for the Period 1958 to 1970	158

LIST OF CHARTS

Chart		Page
1.	Annual Production of Pig Iron and Steel Ingots, 1943-1957	16
2.	Relationship between Annual Steel Ingot Production and Annual Real Gross National Product, 1913-1957	24
3.	Relationship between Annual Steel Ingot Production and Annual Real Gross National Product for Eighteen Selected Non-War Years of High Employment	30
4.	Consumption and Capacity Ratios of Coke to Pig Iron, 1943-1956	43
5.	Coke Production, Coke Consumption and Proportion of Consumption Produced within the Steel Industry, 1943-1956	45
6.	Number and Average Annual Capacity per Stack of Blast Furnaces, 1925-1957	50
7.	Material Consumption per Net Ton of Pig Iron Produced, 1924-1956	56
8.	Consumption and Capacity Ratios of Pig Iron to Steel Ingots and Castings, 1946-1956	61
9.	Production and Capacity Ratios of Pig Iron to Steel Ingots and Castings, 1920-1956	63
10.	Material Consumption per Net Ton of Steel Ingots by Type of Steel-Making Furnaces in 1955	67
11.	Per cent Distribution of Steel-Making Capacity by Type of Furnaces, 1914-1957	71
12.	Relationship between Steel Ingot and Hot-Rolled Production, 1921-1940 and 1946-1956	77
13.	Capital Coefficients of New and Completely Integrated Plants Built since 1943	110

LIST OF CHARTS--Continued

Chart		Page
14.	Rate of Survivorship and Average Useful Life of Depreciable Steel Assets	148
15.	Comparison between Plant Balances Estimated from Life Curve and Actual Plant Balances, 1949-1956	151

CHAPTER I

INTRODUCTION

The role of capital investment is relatively more important to the steel industry than to most other industries. In the thirteen years between 1945 and 1957, all industries in the United States expended 314 billion dollars for new plant and equipment.[1] Of this, manufacturing industries accounted for approximately 42 per cent. The remainder was shared by mining, transportation, communication, public utilities, and others. The steel industry alone invested more than 11 billion dollars for its plant and equipment. The amount represented 3.5 per cent of all industries, 8.5 per cent of manufacturing industries, and 18.5 per cent of durable goods industries. Within the durable category, the steel industry ranked first in capital investment with motor vehicles and equipment groups a close second. Only the petroleum and coal products industries, which are classified under nondurable goods, had higher capital outlays during the 1945-1957 period.

The relative importance of the steel industry in total capital expenditures is due both to its absolute size, which can be measured by total sales, and to its high ratio

---

[1] U. S. Department of Commerce, Survey of Current Business, 1950-1958.

of capital investment to annual sales. In the 1945-1957 period, total net sales of the steel industry represented 3.8 per cent of all manufacturing sales.[1] The relative importance of the steel industry to all manufacturing industries, however, was significantly greater in terms of capital expenditures than in terms of net sales over the same period (8.5 per cent). The statistics imply that the steel industry required relatively more capital outlays to produce a given volume of sales than most other industries. A quick survey indicates that the steel industry needs about one dollar of plant and equipment for one dollar of annual sales.[2]

The fact that the steel industry is highly capitalized does not mean an economic disadvantage in its productive undertaking. Capital expenditures, by their nature, are disbursed for construction of new plant and equipment which may be utilized for a long period of time. Consequently, the initial outlays represent total costs of future services to be procured from the facilities during their useful life. The capital service cost, which is applicable to a period of sales, is therefore only a portion of the initial expenditures. How large that portion is depends upon the length of the facilities' average useful life.

---

[1] American Iron and Steel Institute, Annual Statistical Reports, 1945-1957; U. S. Department of Commerce, Business Statistics, 1958.

[2] The average annual sales per net ton of steel shipped was approximately $200 in 1957 and an addition of one ton of annual steel capacity required capital outlays from $100 to $300, depending upon the nature of capacity expansion. The capital cost per ton of annual capacity is higher for expansion through new plant than for expansion through enlargement of existing facilities.

Actually, the intense degree of capitalization in the steel industry has strong economic justification. Capital is not the only factor input used in the steel or any productive activity. The other basic inputs are labor and raw materials. Theoretically, many combinations of these three inputs can be adopted in steel production, but only one or a few will minimize production costs at any given time. In the early years of steel production, labor and materials were used extensively with a small amount of capital. However, the search for increased operating efficiency and cost reductions, through technological progress and innovations, has favored greater use of the capital input.

For this reason, capital investment has become a matter of increasing importance in the steel industry. The situation necessitates careful planning and control of the industry's capital expenditures. The need is even more pronounced in view of the long life of steel fixed assets since it means a long-run financial commitment.

In general, capital planning consists of two basic parts: (1) a survey of the industry's anticipated needs for capital, and (2) a review of the sources of funds which may be available to meet the needs. The first part deals with capital demand, and since the objective of capital outlays is to make profits by providing sufficient capacity to meet demand, capital investment must be estimated in view of prospective demand. The second part is concerned with capital supply, or more specifically, how much money can be

raised internally from depreciation plus retained earnings, and how much must be obtained from outside financing. The availability of money supply is generally conditioned by the profitability of the business undertaking and the policy decisions of the management.

The purpose of this dissertation is confined to a prediction of capital investment requirements of the steel industry between 1958 and 1970. Since capital investment is defined in this study as all outlays for plant and equipment, a thorough study of future plant and equipment needs, which will be referred to as physical capacity requirements, will be undertaken. This initial study will form the basis for an estimate of capital investment that the steel industry must make in order to acquire the expected level of its capacity to produce. Such an analytical process implies a development of some system and techniques which will disclose the relationship between capacity and capital requirements. It is in this area of translating capacity to capital needs that lies the main emphasis of this dissertation. Since the main emphasis is placed upon the techniques of analysis, the projected magnitudes of capital requirements during the 1957-1970 period can be taken only as first approximations. Moreover, because of the long-run nature of this study, the analysis will deal exclusively with total capital requirements in the period without any consideration to their cyclical movements.

Problems of the Study

The problems involved in the study may be stated in relation to the hybrid nature of capital investment. It is an accepted practice to regard capital outlays as expenditures on durable and tangible assets which may last more than one year. Basically, capital expenditures can be made for two different purposes: (1) to build new facilities which will increase the current productive capacity, and (2) to build new facilities which will replace discarded plant and equipment so that current capacity will be maintained at the same level. However, the allocation of expenditure between expansion and replacement is extremely difficult in practice. The allocation problem stems mainly from the fact that, due to technological change, the new replacement facility is not a mere replica of the old facility. The replacement may represent a different capacity-capital cost relationship. Consequently, part of the investment in new facilities for replacement may be attributable to expansion as well, and the allocation is not merely a matter of the collection of statistics.

The relative importance of these two basic elements in total investment is conditioned by many factors. In a long-run analysis, capacity expansion or prospective growth of the industry depends on such variables as change in real income, shifts in taste, and technological advancement. On the other hand, requirements for replacement to maintain the existing total capacity depend on the age distribution of existing capacity and its average useful life.

Since the sets of factors which influence the needs for capacity expansion and capacity replacement are dissimilar, the relative proportion of the two components in total capital needs is not likely to be constant from year to year. Consequently, in a long-run analysis of capital demand, expansion and replacement should be studied separately. Such an approach is particularly desirable in an analysis of the steel industry which has been in existence for more than a century, because both elements of its present and future capital demand are and will be significant.

Plan of the Study

The main body of this dissertation will be divided into two basic parts. The first part, which is covered in the next two chapters, will deal with a projection of basic outputs and capacities in the steel industry in view of a prospective demand for steel by 1970. The second part will be devoted to an analysis of capital expenditures needed to finance the capacity expansion.

Following this plan, the historical and prospective growth of the steel industry will be appraised in chapter ii. Growth will be measured in terms of the most basic and homogeneous steel product: the steel ingot. The growth pattern of steel ingot production will be reviewed in connection with the level of economic activity in the United States. On the basis of the past relationship between steel ingot production and real Gross National Product, a level of steel ingot production and capacity will be projected to 1970.

An analysis will be made in chapter iii of the capacity requirements for other principal outputs associated with iron and steel production. These are coke, pig iron, and hot-rolled steel. Their requirements will, of course, be related to the anticipated level of steel ingot production and capacity. Since the output relationship of these major facilities to that of steel ingot is conditioned by the productive technology in the industry, the projection of these basic outputs and capacities to 1970 will be based on prospective technology and demand during the period under consideration. The excess of the projected levels of the principal capacities over their current levels will indicate additional capacity requirements or net capacity expansion desired for growth.

Knowledge of the net capacity expansion in the basic facilities will form a basis for determining the capital requirement for net expansion. The conversion from capacity to capital needs can be accomplished with a development of capital coefficients which indicate the relationship between capital expenditures and the capacity additions. There is, however, a serious problem of instability in the use of capital coefficients. The sources of instability will be discussed and remedial methods suggested in chapter iv.

In addition to capital requirement for net expansion, capital needs for replacement must also be estimated. While the approach to the capital demand for expansion commences with an analysis of physical capacity expansion for various

major types of steel facilities, the same pattern cannot be followed in the study of capital demand for replacement because of the lack of physical asset data. To overcome this problem and still maintain a separate analysis of replacement demand, it is proposed that the life characteristics of the steel assets be determined on an aggregate value basis. The value approach makes it possible to deal with all types of steel facilities on a homogeneous basis and to estimate capital needs for replacement without the knowledge of capacity replacement. The suggested approach will also be discussed in chapter iv.

The projection of capital coefficients and capital requirement for expansion will be presented in chapter v. The main analysis in that chapter will be devoted to a development of capital coefficients which are applicable to the future expansion. These capital coefficients or the capital outlays for a net ton of annual ingot capacity and other related facilities will be determined on the basis of past data with necessary adjustments for future conditions. The derived capital coefficients will be estimated in dollars of 1957 purchasing power. The coefficients will make possible an estimate of the capital needs for expansion from the projection of net capacity additions.

The capital requirement for replacement will be estimated separately in chapter vi. The life characteristics of the steel plant and equipment, which are necessary for the estimate of capital demand for replacement, will be ascertained from value data of steel assets by the so-called

simulated plant balance method. This technique is designed to estimate a life curve from a series of annual additions and plant balances of the fixed assets account. An elaboration of this technique will be found in the chapter. The estimated life curve and the known series of annual additions will be used to estimate the average useful life and the age distribution of steel assets. From this information, an estimate will be made of asset retirements at original cost by years of acquisition for the period under study. The retirements at original cost will then be adjusted for capital demand for replacement in dollars of 1957 purchasing power in view of the changes in prices and technology.

The sum of capital requirements for expansion and replacement will constitute total capital needs for financing the expected growth in capacity of the steel industry. Again it must be kept in mind that, on the whole, the methods of analysis advocated in the study of capital requirements will provide the nucleus of this dissertation. It is believed that these methods will lead to useful results and will have further applications to the study of capital demand in other industries. The findings from this study will be summarized and concluded in chapter vii.

CHAPTER II

HISTORICAL AND PROSPECTIVE GROWTH OF THE STEEL INDUSTRY

This chapter is concerned with (1) the measurement of growth and a review of the growth pattern of the steel industry since its inception in the American economy, and (2) the historical relationship between the growth of the steel industry and the levels of economic activity in the United States and a projection of steel production and capacity requirements at a projected level of economic activity in 1970.

An industrial growth is normally measured by the volume of output. In the highly-integrated steel industry, the growth measurement presents a problem because the industry produces at various stages of its productive process many kinds of outputs such as pig iron, steel ingots and rolled steel products. The problem lies in selecting the output which is the best measure of the industrial growth. The subsequent analysis of growth measurement will suggest that the production of steel ingot, which is the most basic and homogeneous output of the industry, best represents the industrial progress.

To understand more fully the growth movements of the steel industry, it will be desirable to review the past trend

of steel ingot production. The growth of the steel industry will then be compared with the economic growth of the national economy as represented by real Gross National Product. On the basis of a historical relationship between steel ingot production and real G.N.P. the growth pattern of the steel industry will be projected to 1970.

The level of steel ingot production projected according to its past relationship with the real G.N.P. will be used to determine required capacity by 1970. The required capacity will have to be in excess of the projected production to the extent that it will insure sufficient steel supply in a period of abnormally high economic activity. How much steel ingot capacity needs to be added to the 1957 capacity level will form a basis for an estimate of corresponding additions to other principal capacities of the steel industry in chapter iii.

Following the above plan for the present chapter, the analysis will commence with a review of the productive activities in the steel industry and a selection of its output which best represents the industrial growth.

Productive Activities of the Steel Industry

As is common in a highly integrated industry, the productive activities of the steel industry are multiple. Generally, the industry is referred to as a group of firms whose major activity is the production of pig iron, steel ingots, and finished steel products such as wire, rods, bars, plates, sheets, and strip. There are, however, other

productive activities of varying importance undertaken by the steel industry throughout its vertical integration. Under the present technology, the industry produces various outputs, intermediate or final, as follows:

1. Crude raw materials: by mining iron ore, coal, and limestone.
2. Coke: by processing coal into the coke necessary for the production of pig iron.
3. Pig iron: by smelting it from iron ore, limestone, and coke.
4. Ingots and castings: by refining pig iron and steel scrap into steel ingots and castings.
5. Mill products: by shaping ingots and castings into various finished and semi-finished products.
6. Fabricated steel products: by fabricating semi-finished products into final products such as tanks, ships, and railway cars.

Not all individual steel companies are engaged in the production of all of the outputs listed above. Some companies are fully integrated, some are semi-integrated, and some are specialty producers. Only the thirteen largest steel companies, which accounted for more than 81 per cent of the industry's total ingot capacity in 1957,[1] are regarded as fully integrated. For the whole industry, which consists of more

---

[1]The size of individual companies is ranked according to its annual ingot capacity, and fully-integrated operation means all activities from mining to rolling mills.

than 200 independent companies, complete vertical integration covers the range from coke to mill products. The range of complete integration means that the industry does not provide from its own sources all its needs for iron ore, coal, and limestone, and it does very little in the fabrication of steel.

Measurement of Growth

To determine quantitatively the extent of growth in the steel activities, certain measures of steel output in aggregation are imperative. The aggregate output can be measured either in terms of a value or a physical unit. A physical unit, however, is easily chosen over a value unit because data in the latter are less accessible and particularly because, due to price changes, the value unit is not constant through time. The physical unit, on the other hand, is completely free from the price effect, and physical data are much more comparable from year to year.

The selection of the type of output is another problem. It is usually more desirable to measure growth of the steel industry in terms of its final output. In the case of heterogeneous output like the mill products, however, the steel production in rolling mills also is a weak barometer of growth. When the final output is not homogeneous, the changing proportion of product-mix can easily distort the volume of production over a period of time. Consequently, better measurement of growth can be obtained by use of homogeneous output such as pig iron or steel ingot production.

A question arises whether pig iron or steel ingot production should be used in a study of the long-run growth of the steel industry. Prior to 1860, the industry was basically known as the iron industry because its final product was pig iron. But when technology developed new products, the industry began to produce increasing volume of steel with the use of pig iron as its major material input. A review of historical trends in the production of pig iron and steel ingot will prove instructive to the selection of output to measure growth.

The production data for a number of selected years are presented in Table 1, and these two series on an annual basis are shown in Chart 1 for the period from 1843 to 1956. Historical evidence indicates that pig iron production has been more than 200,000 tons annually since 1831, whereas steel ingots did not reach that mark until 1873. From 1863 until 1883, steel ingots increased 207 times from 9,044 to 1,874,359 tons, but pig iron only increased 5.4 times from 947,604 to 5,146,972 tons in the same period. The absolute volume of steel ingots finally overtook pig iron production in 1915, and has gone steadily ahead since. In 1956, steel ingot production was 115 million net tons in comparison with 77.6 million net tons of pig iron production.

It is apparent that pig iron has surrendered its marketability to steel. The production of pig iron still shows an increasing trend because pig iron has become a basic material required in the rising production of steel

TABLE 1

ANNUAL PRODUCTION STATISTICS OF THE STEEL INDUSTRY FOR SELECTED YEARS FROM 1828 TO 1956

Year	Steel Ingots[a] and Steel for Castings Production (Tons)	Pig Iron[b] Production (Tons)
1956	115,216,149	77,575,458
1929	61,741,962	47,727,661
1915	35,179,668	33,506,159
1900	11,227,229	15,443,951
1883	1,874,359	5,146,972
1863	9,044	947,604
1844	N.A.[c]	544,320
1828	N.A.	145,600

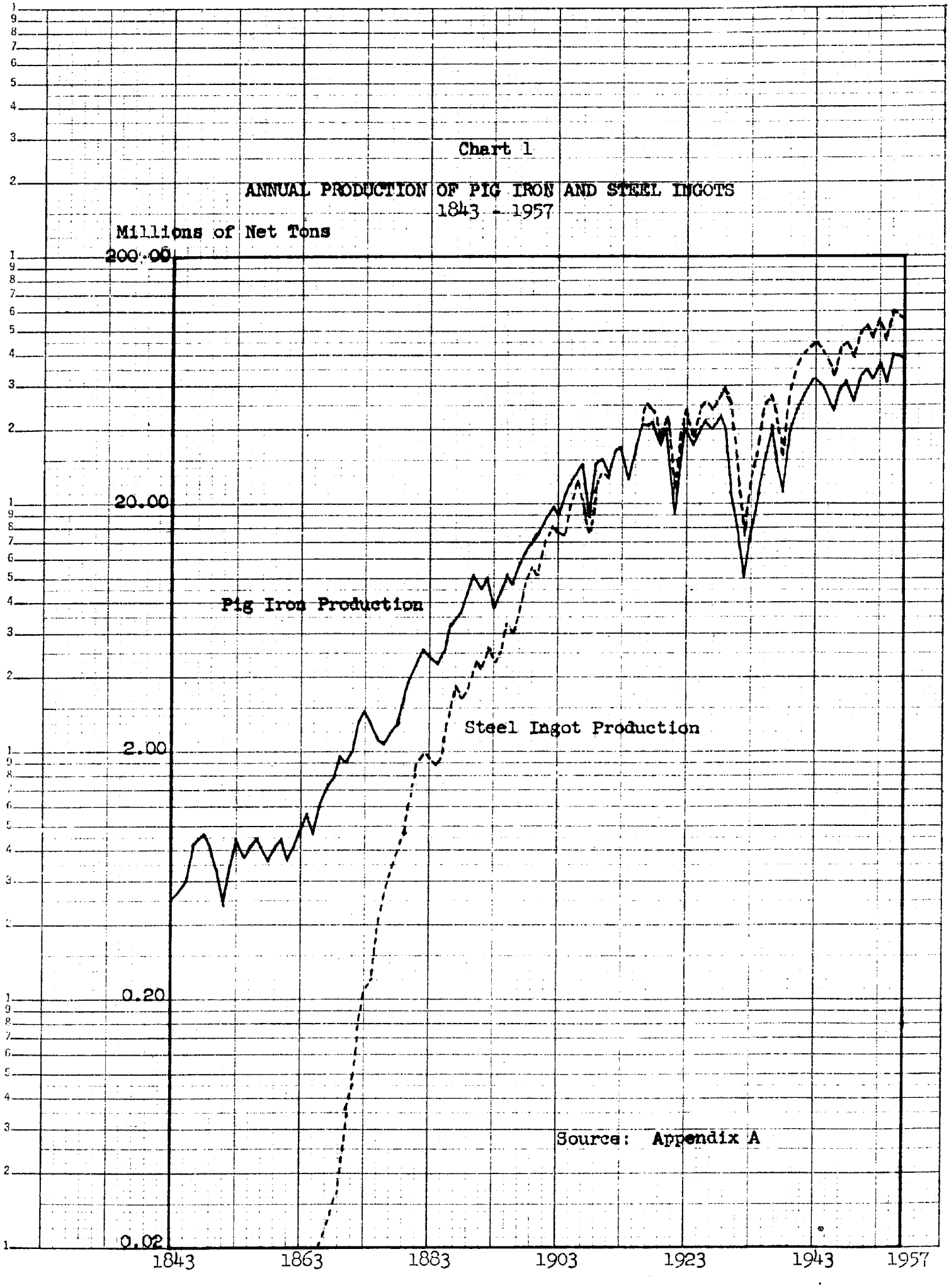
[a]Sources: 1863 - 1956, Furnished by the American Iron and Steel Institute.

[b]Sources: 1956, American Iron and Steel Institute, Statistical Annual Report, 1956, p. 10.; 1828-1929, Iron Age, June, 1955, P.M-18.

[c]N.A.: Not available.

Chart 1

ANNUAL PRODUCTION OF PIG IRON AND STEEL INGOTS
1843 - 1957



Source: Appendix A

ingots. The rate of growth in pig iron production since 1863, however, has been lower than that of steel ingot production. This tendency is due to the development of open-hearth and electric furnaces which permit greater use of steel scrap in place of pig iron on an economic basis.[1] Consequently, pig iron production does not represent adequately the growth pattern of the steel industry during the period in which pig iron ceased to be the final output of the industry.

Moreover, the primary concern of this growth study is with the steel industry as a separate economic unit, but one which depends on pig iron as one of its major material inputs. Consequently, steel ingot rather than pig iron is the most basic and homogeneous output of the steel industry. The subsequent analysis will use ingot production in disclosing the growth in the productive activity of the steel industry.

Pattern of Growth in Steel Production

The output of steel ingots has grown remarkably since their production began in this country. Steel output consisting of about one thousand tons in 1810, expanded to 13 thousand tons in 1860, 28 million tons in 1910, and 117 million tons in 1955, the all-time peak.[2]

The steel production in successive periods grew slowly, then very rapidly, less rapidly, and very slowly.

---

[1]Bureau of Mines, Mineral Facts and Problems, Bulletin 556, pp. 815-19.

[2]The Iron Age, 100 Years of Metalworking, (June, 1955), p. M-18.

These tendencies may be seen in Table 2 in which rates of growth in successive periods are computed. Four different periods are selected on the basis that steel production in each period indicated an approximately constant rate of growth.

TABLE 2

RATE OF GROWTH OF STEEL INGOT PRODUCTION IN FOUR DIFFERENT PERIODS

Period	Average Annual[a] Rate of Growth (Per cent)
1810 - 1860	5.3
1863 - 1880	34.5
1881 - 1907	10.8
1908 - 1956	4.3

[a]Computed from $Qn = Qo\ (1+g)^n$ where
Qn = Quantity at the end of the period
Qo = Quantity at the beginning of the period
n = number of years in the period
g = average annual rate of growth

Sources: Iron Age, June 1955, p. M-18
American Iron and Steel Institute, Annual Statistical Report, 1956, p. 51.

The pattern of growth in steel production can be presented in a more convincing fashion by computing for successive periods[1] the number of elapsed years required

[1]Since gaps exist in the records of steel production after 1810, it is necessary to estimate the average rate of doubling in the interval between that year and the next recorded year having larger production. In the fifty-year interval 1810-1860, steel production, on the average, doubled every 13.5 years.

approximately to double production. The computations which are shown in Table 3 disclose that early slow growth of the

TABLE 3[a]

ANNUAL STEEL PRODUCTION AND NUMBER OF YEARS REQUIRED TO APPROXIMATELY DOUBLE PRODUCTION 1810 TO 1955

Year	Steel Ingots and Steel for Castings Production (in Thousands of Net Tons)	Elapsed Years to Approximately Double Production
1810	1	-
1860	13	13.5 average
1868	30	8
1870	77	2
1872	160	2
1875	437	3
1878	820	3
1881	1,779	3
1887	3,733	6
1897	7,940	10
1902	16,402	5
1912	34,079	10
1929	61,742	17
1955	117,036	26

[a]Sources: American Iron and Steel Institute: Annual Statistical Report 1956, p. 51; The Iron Age, 100 Years of Metalworking (June, 1955), p. M-18.

steel industry ended between 1860 and 1868. Between the latter year and 1881, production doubled every two or three years, as the use of steel entered most phases of the economy. From 1881 to 1912 doubling took place more slowly in succeeding irregular intervals of 6, 10, 5 and 10 years, as steel enabled rapid expansion of the economy geographically and approached saturation of existing markets. Production doubled in the 17-year period 1912-1929. From 1929 it took the industry 26 years approximately to double its output.

Even omitting the abnormal depression periods of the 1930's, the estimated period of doubling between 1940 and 1955, the last peak output year, is 18.6 years.[1]

This pattern of growth actually is very common in other industries. This general tendency has led Raymond B. Prescott to characterize it as a law of industrial growth.[2] This law describes four different stages of growth: (1) period of experimentation during which the rate of growth is small; (2) period of growth into the social fabric during which the rate of growth is great; (3) period during which growth rate is retarded as saturation point is approached; (4) period of stability.

While no rules are given for identifying the periods, one may recognize that the steel industry is now in the mature third period, with its growth at the slowest rate in its history.

Comparative Growth Between the Steel Industry and the National Economy

Despite the declining growth pattern in the steel industry since 1870, one can hardly notice a decline in the growth rate of the industry during the past forty years. The steel industry in its present stage is matured in the sense that it has, to a considerable extent, saturated its existing

---

[1]Doubling period estimated from rate of growth for steel ingots and steel for castings between 1940 and 1955.

[2]Raymond B. Prescott, "Law of Growth in Forecasting Demand," Journal of the American Statistical Association, XVIII (December, 1922), pp. 471-79.

markets, and that its growth has now been more closely in line with the expansion in the productive activities of the national economy.[1]

The close correspondence between steel production and real G.N.P. is evident in Table 4 and in Chart 2 in which the two series are plotted on an arithmetic-scale chart from 1913 to 1957. The closeness of their relationship can be measured statistically by the coefficient of correlation which is 0.95 (where 1.00 is a perfect correlation). The close relationship has led many analysts to forecast steel growth on the basis of projected real G.N.P. Such a technique and its variants deserve some attention here. The forecasting technique implies two basic assumptions: (1) real G.N.P. represents adequately all the major forces whose movements influence change in the demand for steel, and (2) the past relationship will remain valid in the future.

There is a basis for regarding real G.N.P. as the most convenient summary of the major forces creating fluctuations and trend in the demand for steel. While other basic factors, such as real income, taste and technology may be more important to the secular demand for steel in a causal sense, a quantitative analysis embodying all the possibilities would be exceedingly complex because some of the factors are not directly measurable. It is, therefore, convenient to

---

[1]Productive activities of the national economy can be best represented by the Gross National Product in constant dollar value, since real G.N.P. series measure the physical volume of goods and services produced by the entire economy.

TABLE 4

ANNUAL STEEL PRODUCTION AND REAL GROSS NATIONAL PRODUCT 1913 - 1957

Year	Steel Ingots and Steel for Castings Production[a] (in Millions of Net Tons)	Real G.N.P.[b] (in Billions of 1957 Dollars)	Year	Steel Ingots and Steel for Castings Production (in Millions of Net Tons)	Real G.N.P. (in Billions of 1957 Dollars)
1957	112.7	434.4	1934	29.2	148.9
1956	115.2	430.3	1933	25.7	134.9
1955	117.0	417.4	1932	15.1	138.0
1954	88.3	389.7	1931	28.6	162.7
1953	111.6	397.0	1930	44.6	175.7
1952	93.2	381.1	1929	61.7	193.8
1951	105.2	367.6	1928	56.6	183.0
1950	96.8	341.6	1927	49.3	181.4
1949	78.0	313.3	1926	52.9	181.1
1948	88.6	314.0	1925	49.7	127.1
1947	84.9	300.5	1924	41.4	157.9
1946	66.6	301.1	1923	49.0	157.9
1945	79.7	340.1	1922	38.9	140.9
1944	89.6	348.0	1921	21.6	122.6

TABLE 4--Continued

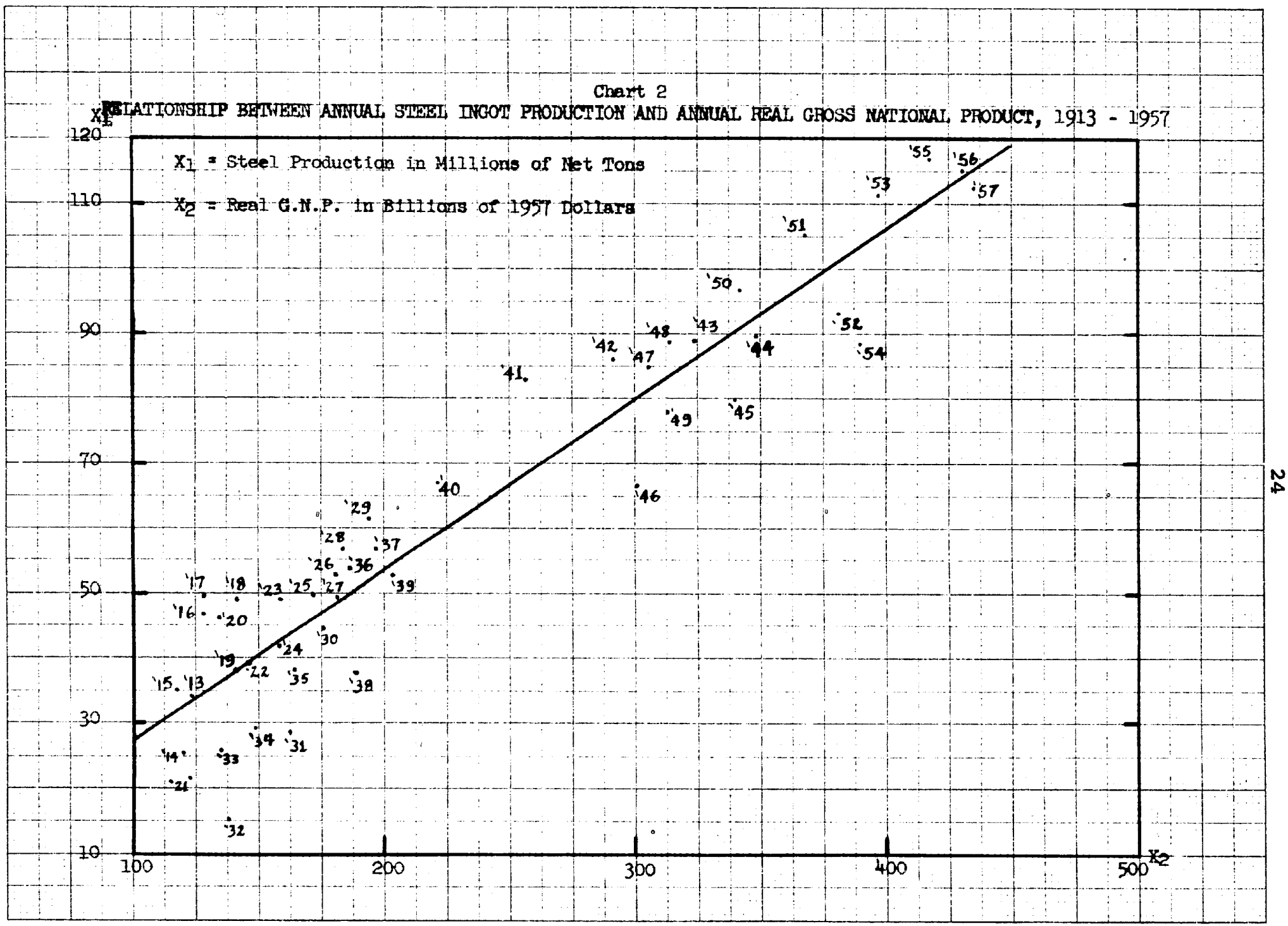
1943	88.8	323.9	1920	46.2	134.1
1942	86.0	291.4	1919	38.1	140.9
1941	82.8	256.8	1918	49.0	141.5
1940	67.0	221.6	1917	49.8	128.2
1939	52.8	203.5	1916	46.8	127.9
1938	31.8	188.5	1915	35.2	117.6
1937	56.6	197.0	1914	25.6	119.5
1936	53.5	186.3	1913	34.1	123.2
1935	38.2	164.0			

[a]Source: American Iron and Steel Institute, Annual Statistical Reports.

[b]Source: 1909-1928: Joint Economic Committee, Productivity, Prices and Income, G.N.P. Index, p. 85, changed into 1957 dollars by dividing index by 1947 index (97.2) and multiplying by G.N.P. for 1947 in 1947 dollars (232.2) and then multiplying by 1957 implicit deflator (129.6).
1929-1956: Economic Report of the President, January 1958, p. 118.
1957: Survey of Current Business, Feburary, 1958.

Chart 2

RELATIONSHIP BETWEEN ANNUAL STEEL INGOT PRODUCTION AND ANNUAL REAL GROSS NATIONAL PRODUCT, 1913 - 1957



assume that real G.N.P. is a resultant of those forces and that its movement describes the shift of demand through time.

That the above assumption was reasonably valid for the 1913-1957 period was suggested by the high correlation between steel ingot production and real G.N.P. However, the close relationship does not always mean that steel ingot production can be projected accurately on the basis of real G.N.P. Such a projection will be reliable only if the historical relationship will remain stable in the future period.[1]

For the purpose of a projection of steel ingot production to 1970, the historical relationship will be assumed to continue. The assumption implies that the past demand function, which related steel ingot production to real G.N.P., will not change under future conditions. Since real G.N.P. is used to represent mainly the effects of real income, taste and technology on the demand for steel, the assumption further implies no revolutionary changes in taste and technology of the steel industry by 1970.[2]

---

[1]The historical relationship designates the position and slope of the regression line of steel ingot production and real G.N.P.

[2]This belief is based on the fact that while movements of real G.N.P. may indicate adequately changes in the level of real income generated in the economy, its movements do not represent directly the influences of taste and technology on the demand for steel. Consequently, the effects of taste and technology on the demand function relating steel ingot production to real G.N.P. are reflected only in the quantitative relationship of the function. The historical relationship, therefore, will not change significantly if no revolutionary changes in taste and technology occur in the future period.

This assumption appears reasonable for a thirteen-year projection to 1970. Major shifts in taste from steel to other materials are unlikely because of limited availability of substitute materials. Moreover, the industries[1] which produce substitutable materials for steel are still relatively young and small. Thus their increasing importance will not be likely to disturb the historical relationship with real G.N.P. during the next thirteen years. Nor are major technological changes such as those which influenced the rapid growth of the steel industry in the early period[2] expected by informed persons in the industry. While there has been some experiment in a new process of steel production, commonly known as a direct-reduction process,[3] this process has not

---

[1]Most notable among them are aluminum and plastic industries.

[2]Major technological advancement in the steel industry took place in the last half of the nineteenth century. With the existence of unsatisfied needs for better and cheap metals in the nineteenth century, during which industrialization was being accelerated, major technological advancement in the steel industry was of paramount importance to its rapid growth. The chief technological changes were the development of steel-making processes by Bessemer, open-hearth and electric furnaces in the 1860-1890 period. These new processes enabled the steel industry to produce better steel at lower cost and wider range of steel products for different purposes. The combination of lower cost and diversity of steel products also helped influence the shifts in taste from iron and other materials to steel. This development contributed significantly to the great expansion of steel markets in the last half of the nineteenth century and to the continuation to the present of its dominance as a semi-finished material for manufacture into innumerable finished products by dependent industries.

[3]The direct reduction process will eliminate the use of blast furnaces and will enable the industry to substitute natural gas for coke in the production of steel.

been fully developed for production on a commercial scale. In fact, most metallurgical experts do not anticipate a significant adoption, by 1970, of this new technology which may lead to an appreciable reduction in steel cost and an acceleration in the rate of steel growth relative to the national economy.[1]

Without major changes in taste and technology in the steel industry, the past relationship between steel ingot production and real G.N.P. may be expected to continue. The continuation of a historical relationship does not always mean, however, that the steel industry will maintain its relative importance to the national economy. In fact, a decline in relative importance of the matured steel industry will be the case.[2] In commenting on this tendency, Simon Kuznets, an outstanding authority on industrial growth, offers the following explanation:

---

[1]For further discussion, see Donald R. G. Cowan, "Future Growth of the Steel Industry," Unpublished manuscript to be published by the Brookings Institution (Washington, D.C., 1958), chapter on Prospective Technology.

[2]The relative importance of steel production to real G.N.P. will be constant only when the relationship, expressed by a regression equation, has an abscissa value of zero. Since the "a" value of the regression line is +0.81, [from the equation steel production (in million tons) = +0.81 + 0.263 real G.N.P. (in billions of 1957 dollars)] it means that steel production will be less relative to G.N.P. as we move along the higher portion of the scales.

> As we observe the various industries within a given national system, we see that the lead in development shifts from one branch to another. The main reason for this shift seems to be that a rapidly developing industry does not continue its vigorous growth indefinitely but slackens its pace after a time, and is overtaken by industries whose period of rapid development comes later. Within any country we observe a succession of different branches of activity leading the process of development, and in each mature industry, we notice a conspicuous slackening in the rate of increase. For example, the vigorous development of copper mining during the years 1880-1900 in the United States did not continue unabated, nor did that of steel after 1870-1900, nor railroad construction after 1830-1880.[1]

Prospective Growth in the Steel Ingot Production and Capacity by 1970

In adopting the correlation technique for the projection of steel growth, an estimated real G.N.P. in 1970 is required. An estimated G.N.P. of 650 billion dollars in 1970, based on 1957 purchasing power, is furnished by a study of the Brookings Institution.[2] Since the real G.N.P. is projected on an assumption of 4 per cent unemployment in the economy, it is desirable to modify the correlation analysis somewhat and make it more consistent and uniform to the estimated real G.N.P. Less distortions can be attained by employing the past relationship between steel production and real G.N.P. for the non-war years which have 5 per cent or less unemployment. In the 1913-1957 period, there are 18 years which fall into this category.

---

[1] Simon S. Kuznets, Secular Movements in Production and Prices (New York: Houghton Mifflin Company, 1930), pp. 4-5.

[2] Cowan, op. cit., chap. iii: Real G.N.P. is estimated on the basis of 96 per cent employment, 36 hours work week, 2.0 million people in Armed Forces, and annual increase in productivity of 2.04 per cent per annum.

The two series for the selected 18 years are plotted on a logarithmic basis in Chart 3. The scale transformation is desirable since it will not only improve the coefficient of correlation, but will also contribute a special advantage which will be described later. On this basis, a very close relationship is evidenced by a coefficient of +0.98. The plus sign indicates that steel production will grow as the real G.N.P. increases. More significant is the statistical estimate that 96 per cent of the variation in annual steel production in the high employment years can be explained by real G.N.P.[1]

Since the remaining 4 per cent of variation is still left unexplained, a certain margin of error is to be expected in the estimation of steel output on the basis of real G.N.P. This error margin, expressed statistically by the standard error of estimate, is found to be within 8 per cent of the regression line. The expression of the margin of error in percentage form is the distinct advantage of the correlation analysis on a logarithmic scale.

To put it in a different manner, it can be said that estimated steel output will be subject to a range of ± 8 per cent error, 67 times out of 100; or a range of ± 16 per cent error, 95 times out of 100.[2]

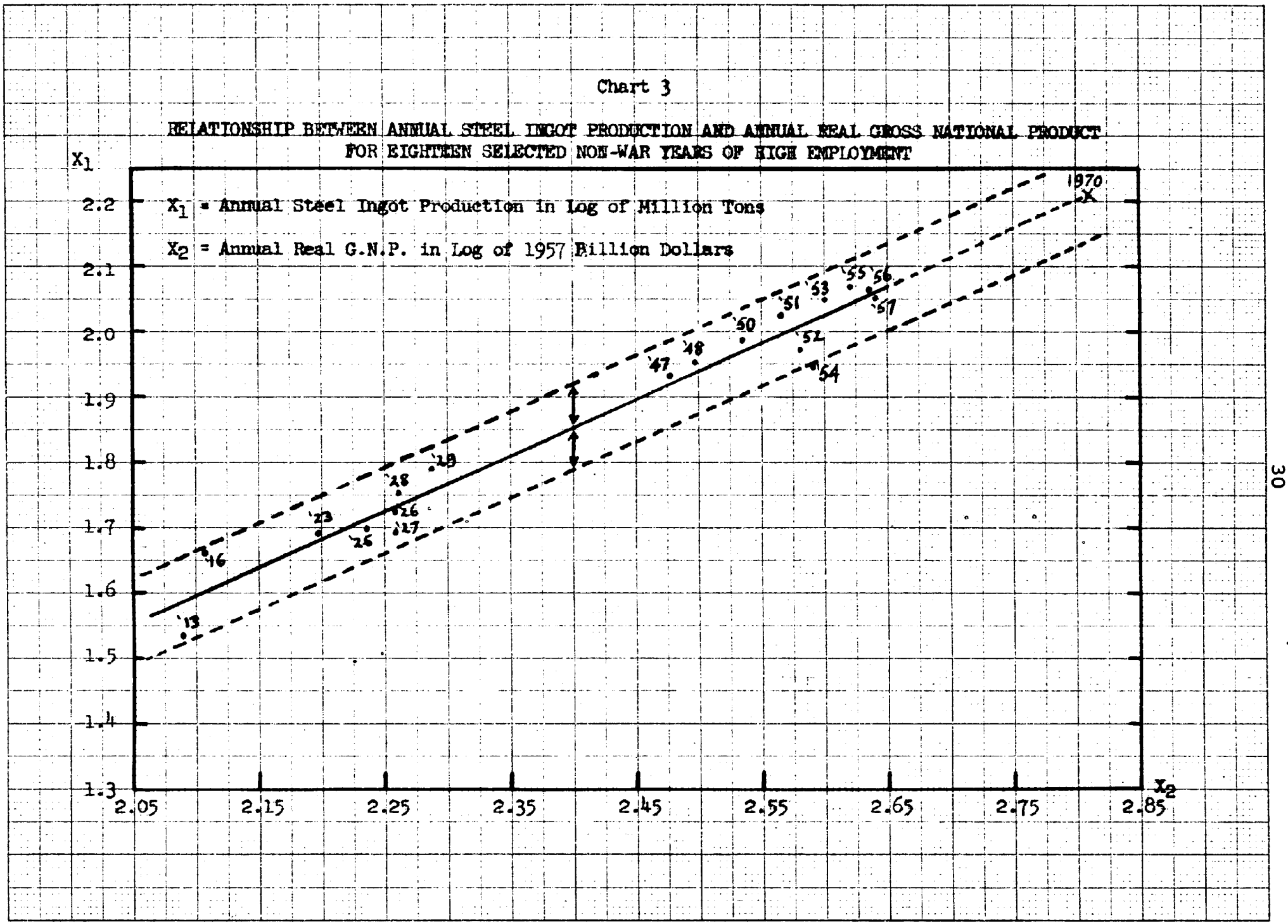
---

[1]The proportion of the variation explained is ascertained by a coefficient of determination which is a square of a coefficient of correlation

[2]Based on a normal distribution, the range of ± one standard error represents a margin of error with 67 per cent confidence limit, and the range of ± two standard errors represents a margin of error with 95 per cent confidence limit.

Chart 3

RELATIONSHIP BETWEEN ANNUAL STEEL INGOT PRODUCTION AND ANNUAL REAL GROSS NATIONAL PRODUCT FOR EIGHTEEN SELECTED NON-WAR YEARS OF HIGH EMPLOYMENT



Plotting the range of two standard errors above and below the regression line in Chart 3, one can readily see that all scattered points should fall within the upper and lower range with 2.5 per cent above the upper limit. The nature of the estimating errors indicates that a capacity expansion, geared to the upper range of two standard errors, should provide sufficient safety margin against inadequate steel supplies in time of business prosperity.

To estimate future steel output and, subsequently, steel capacity by 1970, it is necessary to resort to the quantitative relationship in Chart 3. That relationship is expressed as follows:

Steel Production (Log of Million Tons) = -.1919536 + 0.8525455 Real G.N.P. (Log of 1957 Billion Dollars).

Substituting into the equation the estimated G.N.P. at 650 billion dollars, which is 2.813 in logarithmic value, steel production is projected at the level of 160.8 million tons or 2.206 in logarithmic value.

Steel output which is expected to increase from 112.7 million tons in 1957 to 160.8 million tons in 1970, will rise at an average annual rate of 2.8 per cent. In comparison to the 4.3 per cent annual rate of increase from 1908 to 1956, the future growth rate reflects a substantial decline. In terms of the relative importance of steel output to real G.N.P., the ratio will decline from .0002775 ingot ton per one dollar of real G.N.P. for the selected 18

years of high employment to .0002474 in 1970.

Since the projected steel ingot production from the regression line is, by its nature, an average figure with a possible estimating error, the capacity expansion in the steel industry must provide a safety margin in addition to the estimate average level of production. From the previous analysis, the safety margin should be about 16 per cent. Consequently, the annual steel ingot capacity is expected to be about 186.5 million tons by 1970. The expected capacity will add approximately 45.8 million tons to the industry's rated capacity in 1958, an average of 3.8 million tons per year.

While the prospective expansion in steel ingot capacity will require a large amount of capital investment in steel fixed assets, the capital needs for steel ingot capacity as such will represent only one part of total capital requirements of the steel industry, since the industry is integrated to the extent that they perform many operations prior to and after actual steel ingot production. These other productive functions are mining, transportation, coke production, pig iron production and steel-finishing process. The types of plant and equipment used in these operations, such as mining and transportation facilities, coke ovens, blast furnaces, and rolling mills, constitute another important requirement for capital investment.

In order to estimate total capital requirements for the over-all capacity expansion of the steel industry, a projection of capacity needs in other principal steel facilities

must also be undertaken. The subsequent analysis in chapter iii will include estimates of capacity requirements in coke ovens, blast furnaces and rolling mills. These facilities plus the steel-making furnaces, at present, comprise the core of the steel plant and equipment. With the prospective expansion of steel ingot capacity, a corresponding augmentation in the capacities of the other principal facilities is needed if the industry is to maintain its degree of self-sufficiency.

CHAPTER III

GROWTH REQUIREMENTS OF PRINCIPAL FACILITIES

The capacity requirements of principal facilities in the steel industry are interrelated by nature because productive activity in one facility depends upon output of the others. In addition to 140.7 million tons of annual steel ingot capacity at the end of 1957, the steel industry maintained 72.2 million tons of annual coke capacity, 91.0 million tons of annual blast furnace capacity and 109.2 million tons of annual hot-rolled steel capacity. With the future needs for annual steel ingot capacity estimated at 186.5 million tons in 1970, the questions which must now be answered are: (1) will the interrelationship of these capacities change in the future period, and (2) to what extent will the steel industry have to expand its existing capacity in each of the other facilities?

The interrelationships of the major capacities of the steel industry are influenced mainly by the technology of steel production. Technological advancement may lead to change in the amount of coke and pig iron needed to produce a given volume of steel ingots and hot-rolled steels. Such change in the functional output relationship may lead further to change in the balance between the major capacities of the

industry. Because technological change has considerable influence on the relative capacity requirements and thus on the future capital needs, the nature of future steel technology will be appraised in this chapter prior to the projection of other principal capacities needed for a balance with the estimated steel ingot capacity in 1970.

The complex nature of the steel capacity system makes it advisable to discuss separately the characteristics of coke ovens, blast furnaces, steel-making furnaces and rolling mills. For each of these facilities, it is desirable to review its past production and capacity requirements in relation to other dependent producing functions. Such an analysis is essential to an understanding of how the industry expanded each capacity relative to the others in order to keep pace with changing production requirement. The analysis will provide a basis for projecting the future interrelationship between major steel capacities in view of functional output relationship as influenced by the prospective technology. Finally the estimated interrelationship of steel capacities will make it possible, by using the projected steel ingot capacity as a pivot upon which other capacities depend, to estimate the magnitudes of capacity needs for coke ovens, blast furnaces, and steel rolling mills.

Following this plan, this chapter will begin with an appraisal of the nature of steel technology in 1970. Information from this initial analysis will make it possible to ascertain the effects of future technology on the functional

output requirements in the subsequent analysis of major facilities of the steel industry.

Prospective Technology

In a broad sense, the technical production function indicates how much labor, raw materials, and capital are required to produce a given amount of steel. These three productive inputs can theoretically be combined in many different ways in the production of steel. However, competing uses and resources establish a cost for use of these inputs in the steel production, and only the least costly combination will be adopted in view of the desire for cost minimization or profits maximization.

Technological changes in the steel industry have continuously altered the steel production function so that now relatively greater amounts of capital are used in proportion to labor and raw materials in the production of steel. Such changes have enabled the industry to reduce its production cost or increase its productivity as measured by steel output per man hour. From the available statistics compiled by the Department of Labor, steel productivity increased approximately 123 per cent from 1929 to 1956.[1]

In the past few decades technological progress in the steel industry has been continuous, but not revolutionary. The advancement has been mainly in the improvements of the existing process. Some of the important innovations were

---

[1] U. S. Bureau of the Census, Statistical Abstract of the United States, 1958, p. 226.

continuous rolling mills, the beneficiation process, the sintering process, and the enlargement of various furnaces. The first continuous rolling mill was built by Armco Steel Corporation in the late 1920's and soon afterwards adopted by all large producers. The continuous rolling mill is powered by coordinated electric motors which operate at high speeds as the ingot is rolled into a long thin sheet. In this spectacular example of improved technology, scientific skill, electric power, and new equipment were combined to reduce unit costs by substitution for the old types of hand-rolling mills and many hours of common labor.

The general principle of the beneficiation process is to improve the quality of subgrade iron ores, coke and limestone, and make them more effective for use in the blast furnace. Beneficiation includes improvement in physical form and properties as well as enrichment. The process has contributed significantly to increased efficiency in blast furnace practice by reducing fuel consumption and shortening smelting time. The same advantages have also been accomplished by the sintering process whose primary function is to agglomerate the flue dust and filter cake produced in the operation of the blast furnace into a product more acceptable for recharging into the furnace.

Another important aspect of technological change in the past has been the enlargement of existing furnaces. All types of furnaces, when first introduced, were of very small capacity because of the handicaps of human labor in charging

and manipulating the furnaces. Mechanical aids, however, have enabled the enlargement of some furnaces and accelerated the handling of outputs from each charge. Such an evolution in steel facilities has contributed substantially to increase in steel output per man hour.

It is apparent that future change in technology will have its effects on the production function which relates steel output to all productive inputs. Consequently, the question which must be considered here is what type of technology the steel industry is expected to adopt by 1970.

Because of the increasing attention given to a new steel-producing method, commonly known as the direct-reduction process, this new technique and its advantages need to be examined here. The new process, if adopted, will eliminate the use of the blast furnace in steel production. The process, like the blast furnace, essentially reduces iron ore to metallic iron that can be fed into steel-making furnaces. However, the direct process can accomplish this task with fewer and cheaper plant facilities and without dependence on high-grade coking coal. In addition, it is claimed that the end product usually contains fewer impurities than the pig iron produced by blast furnaces and may be substituted for frequently costly scrap iron in steel-making.

Although most major steel companies in the United States are working intently in perfecting this new technique, many veteran steel producers discount the immediate commercial feasibility of the direct-reduction process, except in

special areas where metallurgical coke is not available or is prohibitively costly. Their attitudes are perhaps explainable by the fact that the current development of this new technique has been largely experimental and the process has yet to prove itself in large-scale production.

That there is a small likelihood of wide adoption of the direct-reduction process in the steel industry by 1970 is believed by Dr Charles J. Marcel; Dr. Harold K. Work and Dr. Edwin C. Wright, three outstanding authorities in steel metallurgy.[1] Consequently, it is reasonable to assume that there will be no revolutionary change in steel technology by 1970, and that most of the technological progress in the steel industry during the 1958-1970 period will occur in the greater adoption of the most recently developed techniques, such as the beneficiation process, the sintering process and the enlargement of existing facilities.

Since the main purpose of this chapter is to evaluate and ascertain the prospective increases in major capacities of the steel industry in the light of future technology, primary attention will be focused upon the effects technology will have on the production requirements of coke, pig iron, and hot-rolled steels in view of the expected ingot production in 1970.

---

[1] Cowan, op. cit., chapter on Prospective Technology.

Coke Oven Capacity

The steel industry has long been a major consumer of coke in the United States and in recent years has absorbed more than 90 per cent of the total output. The rising volume of steel output in the postwar period together with the declining use of coke in other applications has increased the relative importance of steel as a factor in the demand for coke. Concurrent with the rise in importance of steel production as a market for coke has been a tendency for coking facilities to become part of the steel industry, rather than to exist as a separate industry supplying a variety of users. Total coke capacity in the steel industry increased from 89 per cent to 94 per cent of the total coke capacity between 1949 and 1953. Presumably, this trend has continued to the present. Thus it is desirable to review the present coke capacity of the steel industry as well as the long-run changes which have occurred in coke production before forming an estimate of the needed expansion of coking facilities.

By-Products vs. Beehive Ovens

The proportion of coke capacity attributable to the newer by-product type of ovens has grown to the point where these newer ovens have displaced the older beehive ovens almost completely. As of January 1, 1957, only 1.7 million tons of coking capacity were attributable to beehive ovens. The remainder, 71.3 million tons, or almost 98 per cent were by-product ovens. Furthermore, the beehive ovens in existence

generally provide only standby facilities, to be brought into operation under emergency conditions.

The shift to by-product ovens is due to the fact that in addition to their ability to preserve valuable by-products of the coking process, which are lost in the beehive oven, they are capable of producing coke from a grade of coal which would be unsatisfactory for the beehive ovens.

Along with the trend toward the use of a by-product type of oven, the industry has gradually increased in the size of producing units. In 1945, for example, by-product ovens had an average capacity of about 5,000 tons per year, whereas by 1957, the introduction of new, larger units had raised the average oven capacity to 5,066 tons.

Secular Trend of Coke Output and Capacity

Virtually all of the new coke ovens established in the past twenty years have been built in conjunction with steel plants. Non-steel industry use of coke has actually undergone a decline as other fuels have displaced it for many domestic purposes. Whereas in 1938, consumption other than for blast furnaces totaled 16 million tons, by 1956 such use was down to 7.5 million tons.[1] Even in the steel industry, coke oven capacity has grown less than might have been anticipated during the last decade considering the extraordinary expansion of blast furnace capacity. Between 1946 and 1957, expansion of coke capacity was only 21 per cent, while blast furnace capacity rose 29 per cent.

---

[1] U. S. Bureau of Mines, Mineral Yearbooks.

In part, it appears that there has been an existing imbalance of productive facilities within the steel industry in recent years, in regard to the inadequate coke production capacity compared with blast furnaces (or coke consumption) capacity. As indicated in Table 5 and in Chart 4, the con-

TABLE 5[a]

CONSUMPTION AND CAPACITY RATIOS
OF COKE TO PIG IRON
1943-1956

Year	Consumption Ratios	Capacity Ratios
1956	.897	.836
1955	.907	.866
1954	.915	.893
1953	.934	.897
1952	.952	.909
1951	.956	.914
1950	.959	.915
1949	.983	.920
1948	.999	.927
1947	.990	.917
1946	.974	.897
1945	.959	.904
1944	.934	.882
1943	.932	.895

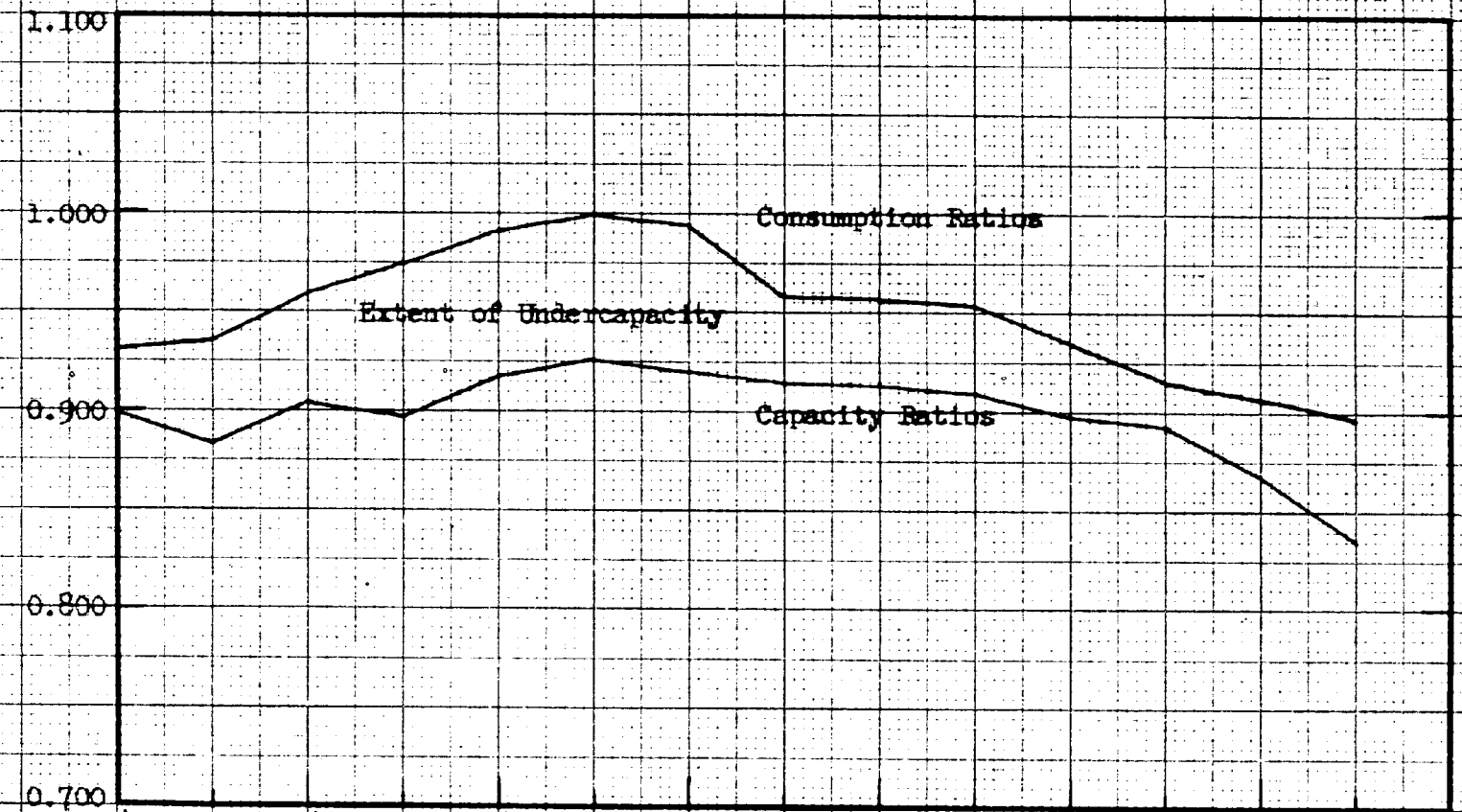
[a]Sources: American Iron and Steel Institute, Annual Statistical Reports, 1943-1956, include coke consumed in blast furnaces, foundries and other uses per ton of pig iron.

sumption ratio, expressing coke requirements per ton of pig iron, is greater than the capacity ratio of coke ovens to blast furnaces. Theoretically, the statistics imply under-capacity of coke ovens which could result in shortages in the period of full-capacity of operation in blast furnaces. However, the steel industry has experienced little actual

KEUFFEL & ESSER CO.
ULRICH'S BOOK STORE
ANN ARBOR, MICH.

Chart 4

CONSUMPTION AND CAPACITY RATIOS OF COKE TO PIG IRON, 1943 - 1956



difficulty partly because it seldom operates at full physical capacity and partly because coke supply is still available from outside sources.

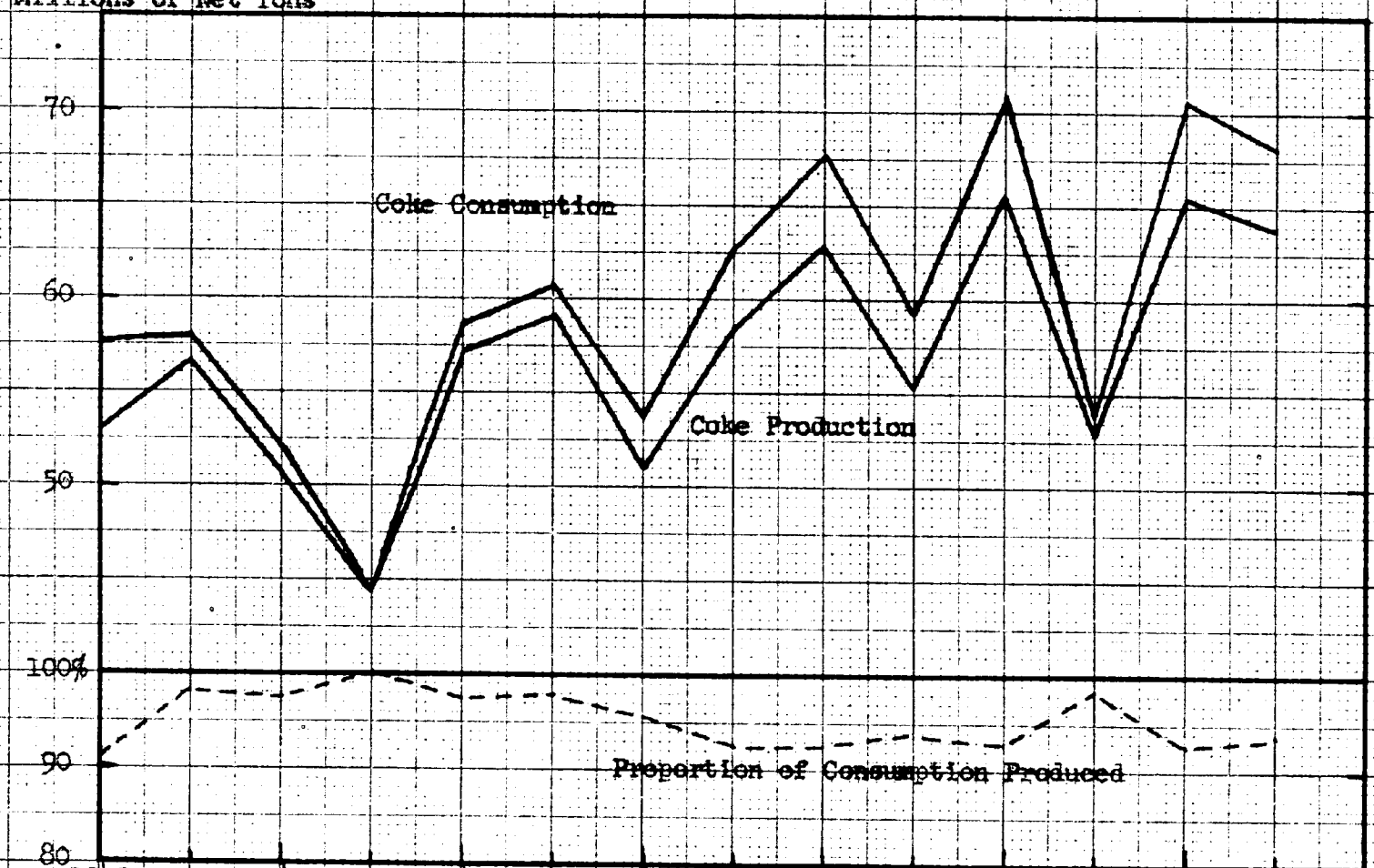
Because of the existing undercapacity, the steel industry has purchased varying proportions of its annual coke needs from independent coke producers. Since the coke capacity within the steel industry is inadequate to meet peak consumption needs, the proportion of coke purchases varies according to the rate of steel operation. As indicated in Chart 5, the steel industry supplied most or all of its coke needs in 1946 and 1954 when its operating rates were low, but purchased from independent producers more than 5 per cent of its coke needs in the boom years of 1951, 1953, and 1955.

The existing undercapacity in coking facilities is not likely to continue indefinitely because uniform coke quality is of great importance in operating blast furnaces efficiently. Control of quality, in order to provide the type of coke specified for particular furnaces, may be attained through ownership of coking facilities. The industry, therefore, has tended to provide an increasing proportion of its own needs by reducing the degree of undercapacity (see Chart 4). Another important reason for complete integration of coking capacity within the steel industry is found in the decline in coking facilities owned by independent producers. Contraction of other markets for coke and the irregularity of steel demand has made coke production by independents unprofitable, and has discouraged replacement of old facilities as

K+E 10 X 10 TO THE INCH 359-11
KEUFFEL & ESSER CO. MADE IN U.S.A.
ULRICH'S BOOK STORE
ANN ARBOR, MICH.

Chart 5

COKE PRODUCTION, COKE CONSUMPTION AND PROPORTION OF CONSUMPTION PRODUCED WITHIN THE STEEL INDUSTRY, 1943 - 1956



they depreciated or became obsolete. As shown in Table 6, coke capacity outside the steel industry has declined from 8.2 million tons in 1949 to 5 million tons in 1953, and a capacity which is presumably much lower at present.

TABLE 6[a]

TOTAL COKE CAPACITY IN THE UNITED STATES AND COKE CAPACITY IN THE STEEL INDUSTRY

Year (Dec. 31)	Total Coke Capacity in U.S. (Net Tons)	Total Coke Capacity in Steel Industry (Net Tons)	Total Coke Capacity outside Steel Industry (Net Tons)	Per Cent of Total U.S.
1953	78,258,000	73,239,540	5,018,460	93.6
1952	76,428,000	71,181,190	5,246,810	93.1
1951	74,228,400	67,060,240	7,168,160	90.3
1950	74,228,400	66,260,640	7,967,760	91.4
1949	73,710,100	65,469,240	8,240,860	88.8

[a]Sources: Total U. S. Capacity: Bureau of Mines, Mineral Yearbook, XI, 1953, Table 18, p. 230. [Total Steel Industry's capacity: American Iron and Steel Institute, Annual Statistical Report, 1956, p. 35.

The second and probably more important consideration for future growth of coking capacity is that there has been a reduction in the amount of coke needed per ton of pig iron produced. Improved technology, by the adoption of the beneficiation and sintering processes, has diminished substantially the amount of coke needed. Since 1948, there has been a substantial drop in the amount of coke comsumption per ton of pig iron output (see Chart 4).

Effects of Prospective Technology on Coke Production and Capacity Requirements

The beneficiation and sintering processes are being adopted by the steel industry on an increasing scale. Such improved practices were responsible for a reduction of coke consumption per ton of pig iron from 1908 pounds in 1948 to 1700 pounds in 1956.[1] From the current experience of the industry, it is estimated that where 100 per cent sinter burden is used in blast furnaces, the consumption of coke may be reduced to 1200 pounds per ton of pig iron produced. The use of the sintering and beneficiation processes also accelerates the output of existing blast furnaces, thereby increasing their annual capacity. Since the capital cost of constructing a corresponding amount of new blast furnace capacity is very much greater than that of constructing sintering and beneficiation facilities, the widespread adoption of these improved practices is taking place. By 1970, therefore, the consumption of coke in blast furnaces per ton of pig iron should range between 1200 and 1700 pounds, depending upon the degree to which the improved practices have been adopted. Coke in smaller quantities may continue to be used in other steel-making processes. An estimate of 1500 pounds of coke per ton of pig iron appears to be reasonable in determining the level of coke capacity required in 1970 to be in balance with blast furnace capacity.

---

[1] Coke consumed in blast furnaces only.

The economic and technological tendencies already discussed lead to the conviction that, by 1970, the steel industry will have provided sufficient coking facilities of its own to meet its coke needs. Consequently, for each ton of annual blast furnace capacity in 1970, the steel industry will maintain .75 ton of annual coke capacity.

Blast Furnace Capacity

Within the present technology of iron production, the blast furnace is indispensable. It performs the major function of forming iron ore into metal. All the preceding processes--mining and transportation of coal, iron ore, and limestone, manufacture of coke, and in some cases, refinement of ore--have been focused on preparing the ingredients used to charge the blast furnace. The furnace itself is essentially a giant stove formed by an outside shell of steel and lined with fire brick. The material to be smelted is introduced at the top of the furnace and gradually descends toward the bottom, or hearth, as it changes from a solid to a molten state.

Between 1917 and 1957, total blast furnace capacity in the United States increased from 51 million tons to 87 million tons annually, or by 70 per cent. The past expansion was characterized by a continuous change in the productive technology of existing plants and equipment. An understanding of the blast furnace facilities necessary to provide a basis for estimating future capacity needs therefore required a familiarity with the historical changes.

Blast Furnace Size

There has been a strong trend toward larger and larger furnaces, and average capacity per furnace increased 135 per cent between 1925 and 1957. As of January 1, 1957, 262 stacks of blast furnaces were available for production with an average annual capacity of 331,400 tons per stack. The growth of these facilities since 1925 is shown in Table 7 and Chart 6.

TABLE 7[a]

BLAST FURNACES: NUMBER OF STACKS, TOTAL ANNUAL CAPACITY AND AVERAGE ANNUAL CAPACITY PER STACK 1925-1957

(Thousands of Net Tons)

Year	No. of Stacks	Total Annual Capacity	Average Annual Capacity per Stack
1957	262	86,818	331
1955	261	83,971	322
1953	258	79,380	308
1951	250	72,472	290
1949	246	70,542	287
1947	233	65,709	282
1946	241	67,341	279
1945	243	67,314	277
1943	243	64,188	264
1941	231	57,775	250
1935	268	57,098	213
1930	316	57,855	183
1925	425	59,847	141

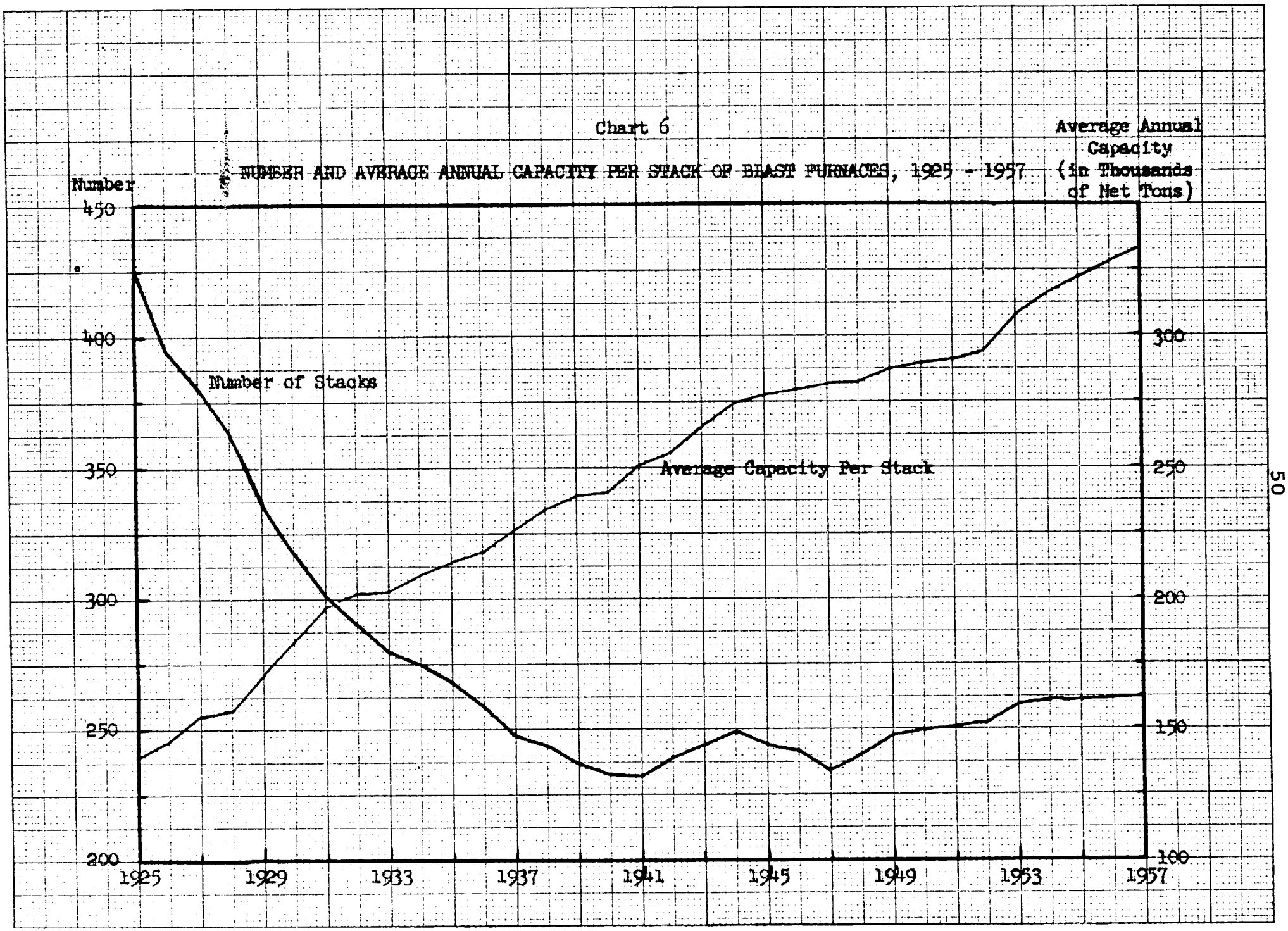
[a]Sources: American Iron and Steel Institute, Annual Statistical Reports, 1925-1957.

Although the number of stacks declined rapidly through the early 1940's, it has risen in the postwar period. However, capacity expanded in every year except 1947, because of

KEUFFEL & ESSER CO.
ANN ARBOR, MICH.

Chart 6

NUMBER AND AVERAGE ANNUAL CAPACITY PER STACK OF BLAST FURNACES, 1925 - 1957



50

the steady increase in the average capacity per stack. This development reflects the widespread tendency to enlarge existing furnaces where possible, to retire older small-size furnaces, and to meet replacement demand as well as net growth by construction of much larger furnaces. The enlargement of capacity per furnace enables the industry to reduce both its capital investment per ton of capacity, and its operating costs through much higher output per man hour. The annual capacity of the largest stack currently in operation is 600,000 tons, nearly double the average. Because of the cost advantages of the exceptionally large furnace, the average annual capacity per stack will undoubtedly continue to increase in the future.

Composition of Blast Furnace Capacity

Classification of the number of stacks according to capacity in representative recent years, contained in Table 8, indicates clearly the shifts taking place in the numerical importance of furnaces of different size. Between 1945 and 1954, furnaces having annual capacities of 300,000 tons and less decreased in number from 127 to 117 and in relative importance from 66 to 47 per cent. Exceptions to this tendency are the smallest classes of furnaces, used for producing small quantities and special grades of iron. In contrast, the growing output of pig iron of standard grade at various plants has made it possible to sustain continuous output for long periods from very large furnaces. During the same period furnaces having annual capacities of more than 300,000 tons

TABLE 8[a]

BLAST FURNACES: NUMBERS AND PERCENTAGES IN CAPACITY GROUPS
YEARS 1945, 1948, 1951, AND 1954

Capacity Groups (Net Tons)	1945		1948		1951		1954	
	No.	%	No.	%	No.	%	No.	%
0-100000	3	1.3	2	.9	6	2.5	5	2.0
100001-200000	30	13.2	34	15.3	28	11.9	30	11.9
200001-300000	94	41.4	87	39.0	87	36.9	82	32.7
Subtotal	127	65.9	123	55.2	121	51.3	117	46.6
300001-400000	66	29.1	69	26.0	69	29.2	70	27.9
400001-500000	34	15.0	38	17.9	38	16.1	43	17.1
500001-600000	0	0	8	.9	8	3.4	21	8.4
Subtotal	100	44.1	115	44.8	115	48.7	134	53.4
Total	227	100	223	100	236	100	251	100

[a]Sources: American Iron and Steel Institute, Iron and Steel Works Directories, 1945, 1948, 1951, and 1954.

increased in numbers from 100 to 134 and in relative importance from 44 to 53 per cent. By far the most important expansion has been in the group having annual capacities of 500,000 to 600,000 tons, of which there were none in 1946 and 21 in 1954. Clearly, the industry is continuing a long-period transition to larger, more economical blast furnaces.

Basic Elements in Blast Furnace Production

Iron ore is the most important element in producing pig iron, and the quality of iron ore being used affects the composition of the "charge" to the blast furnace. The furnace charge consists mainly of iron ore as well as enriching, reducing, and purifying materials such as coke and limestone. Iron ore, in nature's deposits, consists of magnetic and non-magnetic iron oxides which vary widely in purity because of admixtures of silica, sulphur, and other minerals. As in mankind's exploitation of all natural resources, the prevailing practice has been to mine and use the richer iron-ore deposits which exist in commercial quantities and are accessible, before turning to low-grade deposits, because ore of higher iron content yields relatively larger quantities of pig iron and lesser amounts of slag, and takes less time to smelt. In short, production of pig iron from high grade ores has been comparatively advantageous both technically and in cost.

Other production advantages are gained from the size and characteristics of the blast furnaces. More efficient and larger modern furnaces are capable of yielding greater

pig iron per ton of material inputs than older and smaller furnaces. Thus in order to achieve minimum production cost, in a period of low demand, only the most efficient furnaces are put in active use. This practice appeared to be responsible for the low consumption of iron ore and related materials per ton of pig iron during the 1930's. As shown in Table 9 and Chart 7, the material inputs per ton of pig iron declined significantly in the 1930's but rose and attained new peaks in 1948. The latter increase was perhaps a manifestation of both the lack of satisfactory ore quality and the necessity of utilizing less efficient furnaces to meet the rising demand in the period.

Since 1948, however, a declining tendency of the material consumption per ton of pig iron produced has taken place as a result of the gradual introduction of the beneficiation of low grade iron ore at centers near Lake Superior, and the production of sinter burden in new facilities near the furnaces. These technological improvements counteract the normal effect of declining iron-ore quality by reducing the non-ferrous content of the furnace charges and the relative amounts of the other materials required in producing each ton of pig iron. When shipments of new iron-rich Ungava ore from the northern part of the province of Quebec in Canada are brought to the furnaces in increasing quantities, furnace efficiency may be further improved. Unless blast furnaces are supplanted by a radically new innovation, such as direct-reduction now under experimentation, the iron

TABLE 9[a]

MATERIAL CONSUMPTION PER TON OF PIG IRON PRODUCED

(Tons)

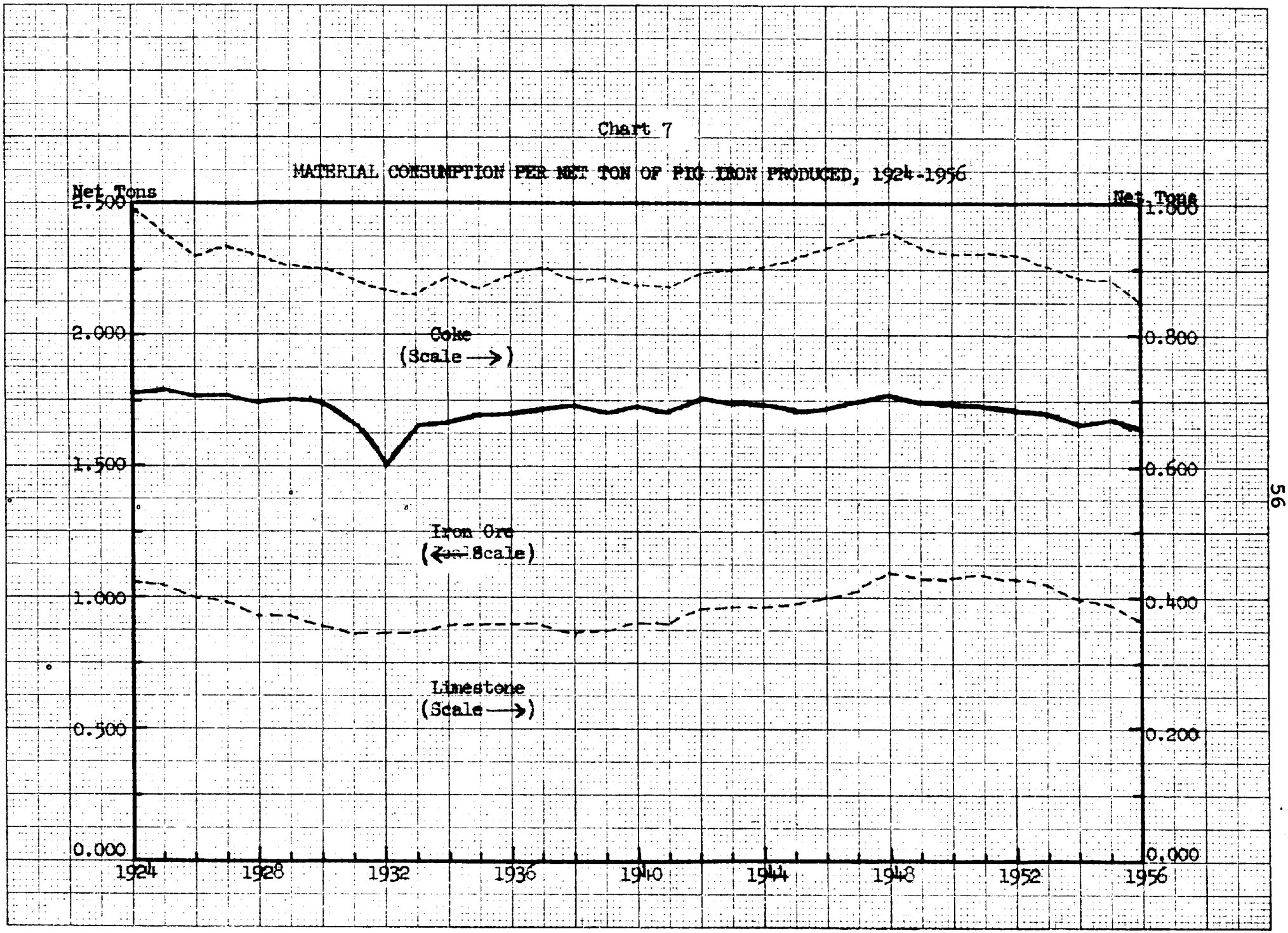
Year	Iron Ore	Limestone	Coke
1956	1.630	0.362	0.850
1955	1.662	0.387	0.873
1954	1.656	0.395	0.873
1953	1.691	0.418	0.906
1952	1.710	0.426	0.922
1951	1.725	0.432	0.924
1950	1.737	0.429	0.922
1949	1.753	0.428	0.935
1948	1.767	0.440	0.954
1947	1.478	0.412	0.950
1946	1.725	0.406	0.934
1940	1.729	0.362	0.878
1932	1.496	0.345	0.872
1924	1.781	0.425	0.872

[a]Source: American Iron and Steel Institute, Annual Statistical Reports, 1924-1956.

10 X 10 TO THE ½ INCH
KEUFFEL & ESSER CO.
359-11
MADE IN U.S.A.
ULRICH'S BOOK STORE
ANN ARBOR, MICH.

Chart 7

MATERIAL CONSUMPTION PER NET TON OF PIG IRON PRODUCED, 1924-1956



content of iron ore will continue to be the major factor affecting blast furnace efficiency and the development of supplementary processes such as beneficiation and sintering.

Capacity Utilization

The utilization of blast furnace capacity depends upon productive activity in steel-making furnaces because pig iron is used almost exclusively in the production of steel ingots and castings. As revealed in Table 10, for the

TABLE 10[a]

BLAST FURNACES: CAPACITY AND PRODUCTION, 1946-1956
(Thousands of net tons)

Year	Capacity	Production	Rate of Operation of Pig Iron Capacity (%)	Rate of Operation of Ingot Capacity (%)
1956	85,485	75,960	88.9	89.8
1955	83,971	77,790	92.6	93.0
1954	82,001	58,687	71.6	71.0
1953	79,380	75,857	95.6	94.9
1952	73,782	62,151	84.2	85.8
1951	72,472	71,228	98.3	100.9
1950	71,560	65,440	91.4	96.9
1949	70,542	54,176	76.8	81.1
1948	67,439	61.044	90.5	94.1
1947	65,709	59,314	90.3	93.0
1946	67,341	45,548	67.6	72.5

[a]Sources:American Iron and Steel Institute, Annual Statistical Reports, 1946-1956.

period between 1946 and 1956, the rates of operation ranged from 67.6 to 98.3 per cent for blast furnaces and from 71.0 to 100.9 per cent for steel-making furnaces. In the years since World War II, these operating rates have been consistently high, despite rapid expansion of the facilities.

Except in a few years after 1952, the rate of operation of pig iron capacity has usually been lower than that of ingot capacity. The comparison may indicate slight overcapacity in the blast furnaces relative to ingot capacity, especially since pig iron is exclusively supplied within the industry. Some excess capacity of blast furnaces above normal production requirements may, nevertheless, be necessary, because steel ingots may be produced with varying proportions of pig iron and steel scrap depending on the facilities and methods used and the availability of scrap at economical prices. In general, the excess of pig-iron capacity provides a margin of safety and is usually made up of old, small, and inefficient furnaces. These furnaces are usually not used except in emergencies.

Balancing Processes: Blast Furnaces and Steel-Making Furnaces

Pig iron and steel scrap not only enter as inputs into the production of steel ingots, but are also, to a major extent, substitutes for each other. Consequently, the total capacity of blast furnaces required to support steel production is somewhat flexible, and depends upon the availability of steel scrap at economical prices. In the last ten years,

scrap has constituted about 45 per cent of the total scrap and pig iron used in producing steel ingots.

A clear indication of the changes taking place in the blast furnace facilities required to support steel production may be obtained by comparing the consumption ratios and the capacity ratios for the period 1946 to 1956 inclusive. The consumption ratio shows pig iron consumption relative to steel production. The capacity ratio shows pig iron capacity relative to steel capacity. As shown in Table 11, consumption

TABLE 11[a]

CONSUMPTION AND CAPACITY RATIOS OF PIG IRON TO STEEL INGOTS AND CASTINGS 1946-1956

Year	Consumption Ratios	Capacity Ratios
1956	.600	.666
1955	.606	.667
1954	.608	.660
1953	.607	.675
1952	.592	.680
1951	.610	.695
1950	.604	.716
1949	.617	.734
1948	.612	.716
1947	.616	.720
1946	.600	.733

[a]Sources: American Iron and Steel Institute: Annual Statistical Reports, 1956, pp. 20-21; 1954, pp. 56-57. (Sources of data for computation.) Consumption includes pig iron used in other types of furnaces, namely, Cupola and air.

ratios have remained constant during the postwar decade, whereas capacity ratios have declined. The decrease in the capacity ratios has been due to the increasing supplies of scrap. Although the capacity ratios have always exceeded the consumption ratios, the decline in the former has reduced the spread between them. To a substantial degree, the spread is a measure of the margin of safety provided for producing pig iron to balance out the fluctuating supplies of scrap and more especially to offset scrap shortages.

For convenience, the spread, or safety margin, may be expressed as a percentage of the consumption ratio for each year. The safety margin[1] which was about 22 per cent in 1946 shrank to 11 per cent in 1956. Although a safety margin of 26 per cent was once regarded as desirable, this level may no longer be necessary because of the closer adjustment of pig iron facilities to steel-making needs brought about by the increasing degree of vertical integration in the industry. At any rate, the margin is not likely to dip below 11 per cent in the future because of the instability of scrap prices and some existing demand for pig iron from outside concerns.

The consumption ratios shown in Chart 8, which measure pig iron consumption relative to steel production, exhibit a remarkable stability through the period, only varying between extremes of 1,184 and 1,234 pounds per ton of ingots

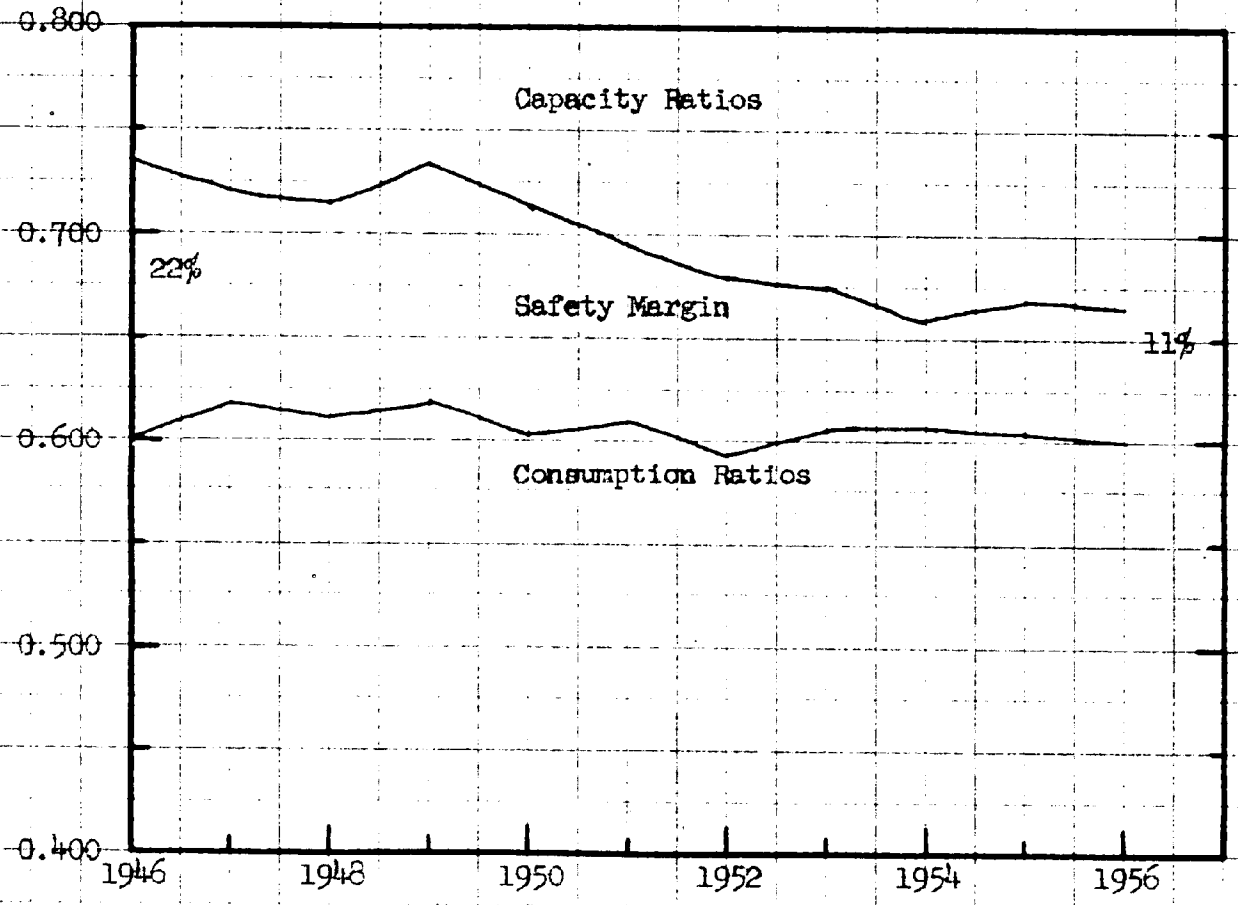
---

[a]Safety margin is estimated by the formula

$$\frac{\text{Capacity Ratio}}{\text{Consumption Ratio}} - 1 \quad 100$$

Chart 8

CONSUMPTION AND CAPACITY RATIOS OF PIG IRON TO STEEL INGOTS AND CASTINGS
1946 - 1956



and castings. These short-run variations are mainly related to the variations of scrap prices. A rise in scrap prices tends to encourage relatively greater use of pig iron than steel scrap in the steel production and thus causes an upward shift in the consumption ratio. In the long run, however, the consumption ratios are influenced primarily by the composition of steel-making furnaces in the industry and partly by the demand for pig iron from other concerns, amounting to 6.7 million tons or 9 per cent of the total in 1956.[1]

Since each type of steel-making furnace requires a different proportion of pig iron and steel scrap, changing proportions of steel output from different types of furnaces affect the consumption of pig iron per ton of steel ingots and castings, and thus cause changes in the capacity relationship between pig iron and steel ingot capacity. As shown in Chart 9, the capacity ratios have declined considerably since 1920, mainly because of the increasing importance of open-hearth and electric furnaces which are capable of using proportionally small amounts of pig iron. On the other hand, the Bessemer Converters which use relatively large amounts of pig iron and very little scrap have declined in importance from 22 per cent of total ingot capacity in 1920 to about 3 per cent in 1956.

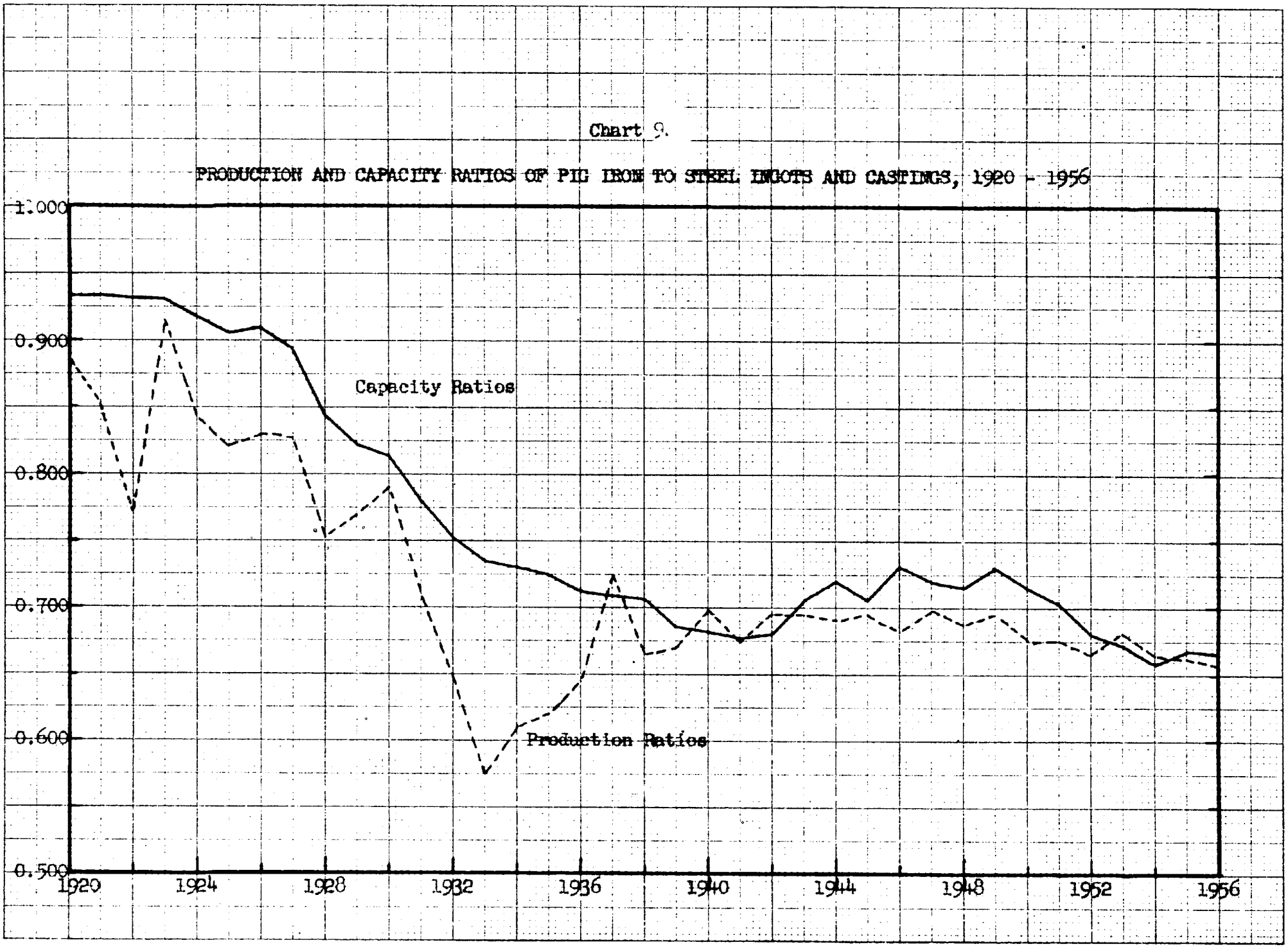
---

[1]American Iron and Steel Institute, Annual Statistical Report, 1956, p. 48. This is an estimate from the difference between total pig iron sold and pig iron purchased by steel companies; the net amount is the sales to other concerns.

KEUFFEL & ESSER CO.
ULRICH'S BOOK STORE
ANN ARBOR, MICH.

Chart 9.

PRODUCTION AND CAPACITY RATIOS OF PIG IRON TO STEEL INGOTS AND CASTINGS, 1920 - 1956



The production ratios of pig iron to steel ingots are compared with the capacity ratios in Chart 9. The production ratios are, of course, greater than the consumption ratios because part of the iron output is channeled to non-steel users. Surprisingly, the production ratios fluctuated violently prior to 1942 because of the interplay of various factors such as the growing importance of the scrap-using furnaces, scrap prices, and outside demand for pig iron.

In only five annual periods since 1920 have production ratios exceeded the capacity ratios. However, this does not necessarily indicate an insufficient safety margin in the blast furnace capacity, for in those years rates of operation in blast furnaces were substantially higher than in steel-making furnaces, and pig iron was sold to users outside the industry. For example, in 1956, when the consumption ratio indicated that 0.6 ton of pig iron was needed per ton of steel, actual pig iron production was 75 million tons, or enough for 125 million tons of steel. Actual steel production in 1956 was only 115.2 million tons; consequently, surplus pig iron amounting to 6 million tons was available to non-steel users.

Prospective Expansion in Pig Iron Capacity

The above findings suggest that expansion in blast furnace capacity relative to ingot capacity depends on the following factors:

(1) The changing composition of the steel-making furnaces.

(2) The safety margin in the capacity required to meet abnormally high needs for pig iron.

Table 11 shows that the pig iron consumption per ton of steel ingots, as influenced by the composition of the steel-making furnaces, has been relatively stable in the past ten years. In 1956, an average 1,200 pounds of pig iron was needed per ton of steel ingots. The safety margin in 1956 was 11 per cent or 132 pounds. Since no major changes are expected in the relative use of the different steel-making furnaces or in the required safety margin between 1958 and 1970, the capacity relationship sould be 1,332 pounds or .666 ton of annual pig iron capacity per ton of annual ingot capacity. This ratio may be too low or too high for individual steel companies, but it would form the average capacity ratio of the industry in 1970.

Steel-Making Capacity

The making of steel from pig iron is carried out today by a variety of methods, the principal of which are the open-hearth, Bessemer and electric processes. All of these have the common essential of producing ferrous metal in which the content of carbon and other elements, such as phosphorous, silicon, manganese, and sulphur, are carefully controlled. The relative importance of these three processes today is a function of the prices of the various raw materials used, the energy and labor cost of operation, and their differing abilities to impart various qualities to steel, the demand for which has grown at different rates.

Forecasting the relative growth of these three types of steel-making facilities requires familiarity with the rudiments of steel processing, the special merits possessed by each type of facility, and the present composition of steel capacity.

Material Consumption in the Steel-Making Furnaces

The major inputs in steel-making are pig iron and steel scrap, and their relative importance varies with the type of furnace. For the open-hearth furnaces, these inputs can be used almost interchangeably, although there is an optimum combination which yields maximum results. This optimum combination at present appears to be approximately equal amounts of pig iron and steel scrap. In the electric furnaces, scrap is the major input and pig iron is secondary. In the Bessemer converters, the opposite is true. Chart 10 graphically portrays the wide divergencies in the average amounts of the materials consumed in 1955 by each type of furnace in producing one ton of steel ingots. These amounts, however, are not fixed because each type of furnace possesses a certain degree of flexibility. The Bessemer converter, for example, can consume relatively more scrap with the use of oxygen. The open-hearth furnace can also consume varying proportions of hot metal and scrap depending on the prices and quantities of steel scrap and pig iron available.[1] Flexibility in the material consumption in the electric

---

[1]Bureau of Mines, Bulletin 556, op. cit., p. 813.

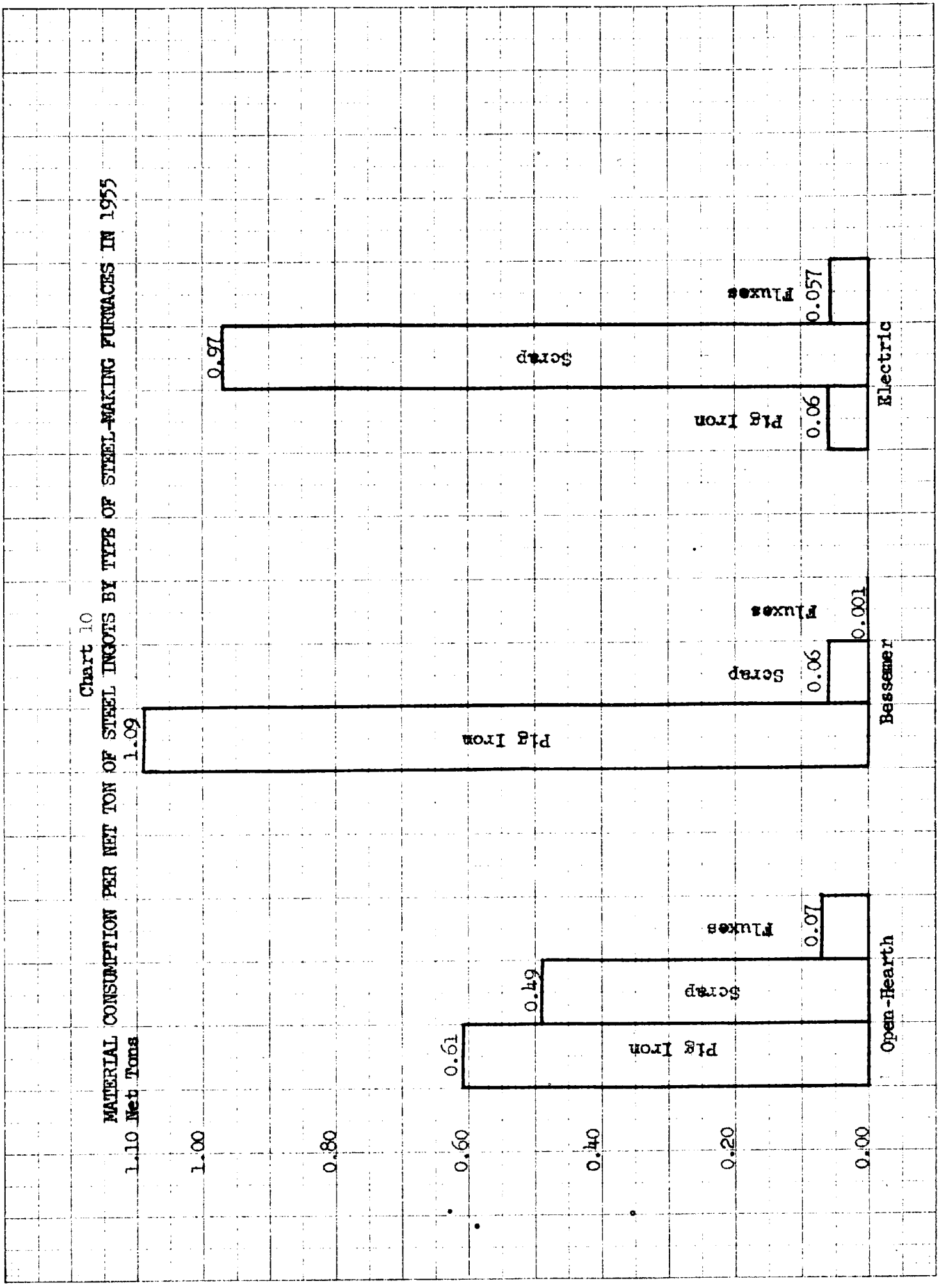


Chart 10
MATERIAL CONSUMPTION PER NET TON OF STEEL INGOTS BY TYPE OF STEEL-MAKING FURNACES IN 1955
1.10 Net Tons
1.00
0.80
0.60
0.40
0.20
0.00
Open-Hearth
Pig Iron
0.61
Scrap
0.49
Fluxes
0.07
Bessemer
Pig Iron
1.09
Scrap
0.06
Fluxes
0.001
Electric
Scrap
0.97
Pig Iron
0.06
Fluxes
0.057

furnace is also possible, although at present the furnace normally is charged with cold metal, usually scrap.

Types of Steel Made in the Furnaces

Steels produced by the steel-making furnaces are classified into general types such as carbon steel, alloy steel, stainless steel, and heat-resistant steels.[1] Each type of steel can be produced more advantageously from a certain type of furnace. At the present stage in the technology, the open-hearth furnaces are used largely to produce carbon steels, and the electric furnaces to produce high-quality alloy steels, including stainless. The Bessemer converter, on the other hand, is superior in producing steel for such purposes as free-machining steels, steels for certain types of wire, and some grades of pipe.

The economic specialization of each type of furnace may change. During World War II, large quantities of low-grade alloy steels were successfully produced by open-hearth furnaces. The electric furnaces are being adapted to the production of carbon steel; the proportion of carbon steel in the total output of electric-furnace steel has increased from 15-20 per cent during World War II to 52-60 per cent in the period 1947-1953.[2] The Bessemer converter has also been utilized more and more to blow metals for further refining in the open-hearth and electric furnaces under the "duplex" process.

---

[1] Ibid., pp. 814-815.

[2] Ibid., p. 821.

Composition of Steel-Making Capacity by Types of Furnaces

The proportions of steel capacity attributable to major types of furnaces have been changing for many years. The Bessemer converter, introduced in 1856, was the first of the three major processes to be used commercially and accounted for almost all steel produced until 1875. By 1898, it accounted for only 74 per cent and by 1907, the Bessemer converter was responsible for only 50 per cent of the total steel production. After 1907, the relative importance of steel produced by the Bessemer process was superceded by open-hearth steel, and has continued to decline to the present.[1] Changing proportions of steel output from each type of furnace has induced changes in the composition of steel-making capacity. Since 1914, when information on the capacities of steel furnaces first became available, the Bessemer's share of the total capacity has declined both relatively and absolutely, losing ground to both the open-hearth and electric furnaces. The absolute annual capacity of the Bessemer converter decreased from 15.9 in 1914 to 4.5 million tons in 1957.[2] The decline has been influenced mainly by the greater economies provided by open-hearth furnaces. The major economic reasons are the better quality of open-hearth steel and the greater availability of steel scrap from both the steel

---

[1]American Iron and Steel Institute, Annual Statistical Report, 1912, p. 94.

[2]American Iron and Steel Institute, Annual Statistical Report, 1956, p. 53.

mills and outside sources. As shown in Chart 11, open-hearth furnaces' share of the total steel capacity increased from 67 per cent in 1914 to 90 per cent in 1940, and declined slightly to 88 per cent in 1957. The recent decline in the open-hearth's share, coupled with the continuing decline in that of the Bessemer converter, is due to the more rapid expansion of electric furnace capacity. The three major forces which favor the greater use of the electric furnace are its ability to produce all known types of steel, its lower capital costs, and its advantages in consuming steel scrap.

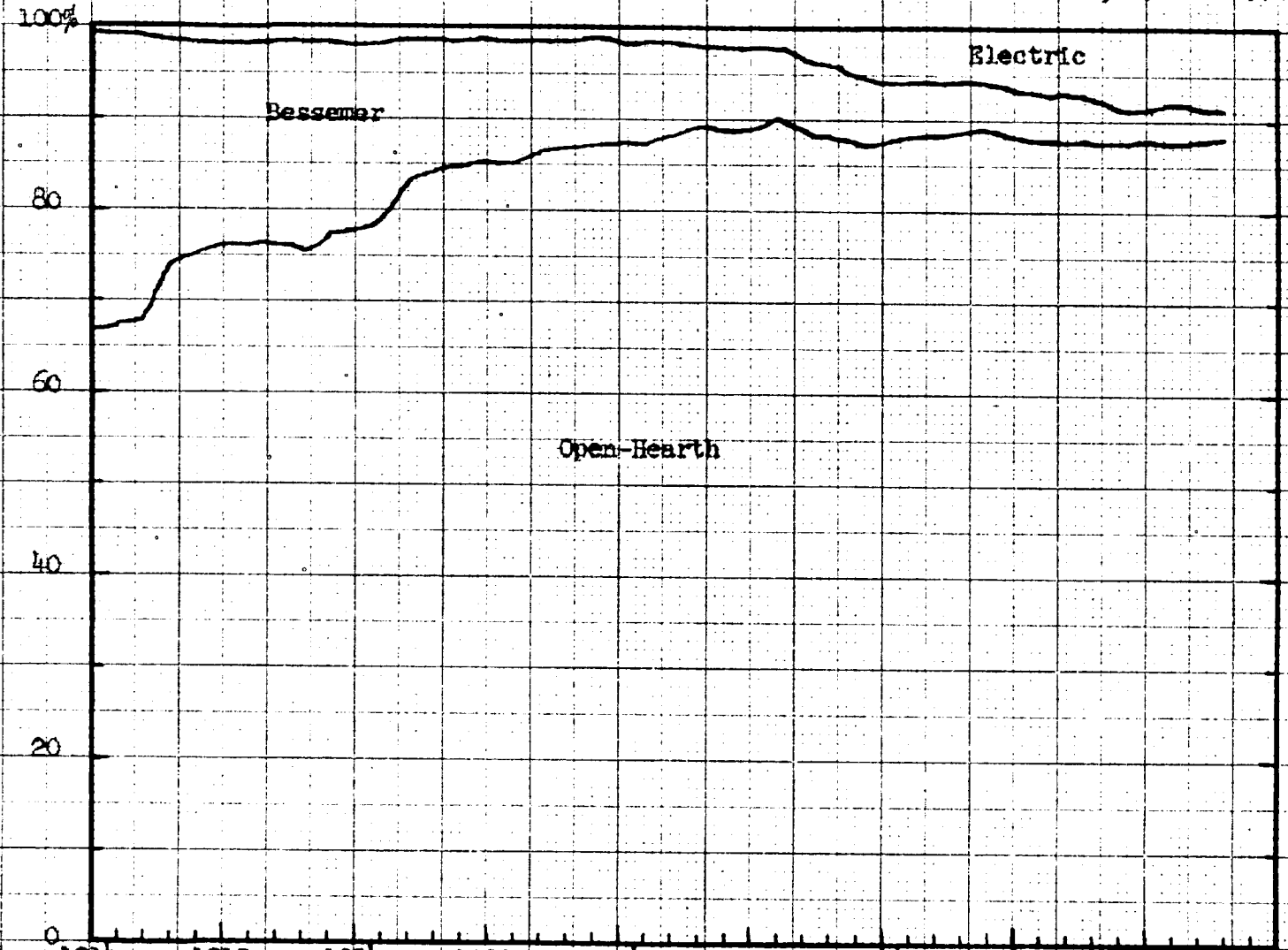
Future Trend in Steel-Making Processes

Future expansion is most likely to include only open-hearth and electric processes. The economic advantages of these two processes have made the Bessemer converter completely obsolete, and the steel industry has made no new addition to its Bessemer capacity in the past 20 years. The electric process, on the other hand, has been growing in importance and has become a potential competitor of the open-hearth process. While the electric furnace is the most efficient producer of high-quality steel, there have been developments in its design and operation which now may enable it to produce low carbon steel more cheaply than formerly. The developments have prompted many steel producers to study the comparative costs of open-hearth and of electric furnace production of low carbon steel.

K+E 5 X 10 TO THE ½ INCH 359-11 KEUFFEL & ESSER CO. MADE IN U.S.A.
ULRICH'S BOOK STORE ANN ARBOR, MICH.

Chart 11

PER CENT DISTRIBUTION OF STEEL-MAKING CAPACITY BY TYPE OF FURNACES, 1914 - 1957



The Battelle Memorial Institute made a comprehensive study of this question in 1952.[1] For open-hearth and electric furnaces of two comparable annual capacities--500,000 and 1,000,000 tons--the Institute compared their itemized and net production costs of employing hot-metal practice.[2] According to the Institute's estimates, which are summarized in Table 12, the net production cost estimated for each size of the electric furnace is somewhat higher than that of the open-hearth furnace.

There are reasons to expect that the cost disadvantage of electric furnaces in carbon steel production will in time be overcome. In the first place, the cost disadvantage per ton is estimated at only $1.10 for furnaces of 500,000 tons capacity and $1.31 for those of 1,000,000 tons capacity. Second, an examination of the itemized cost estimates shows that the heat from electricity costs about $4.07 per ton more than the oil and gas heat used by the open-hearths. This, however, is partially offset by the electric furnace's advantage in fixed charges which ranges between $1.29 and $1.55. Third, the tendencies for fuel oil prices to rise and for the rates for electricity produced from coal to fall may, in time, shift the heat-cost advantage to electric furnaces. Fourth, the Institute estimated its costs at full-

---

[1]Battelle Memorial Institute, Comparative Economics of Open-Hearth and Electric Furnaces for Production of Low-Carbon Steel, (Pittsburgh: Bituminous Coal Research, Inc., 1953).

[2]The hot metal charge is made up of half pig iron and half steel scrap.

TABLE 12[a]

COMPARISON OF ESTIMATED COSTS PER NET TON OF INGOT FOR OPEN-HEARTH AND ELECTRIC FURNACE SHOP AND THEIR INITIAL CAPITAL INVESTMENT

	Annual Plant Capacity (Tons of Ingots)			
	500,000 Tons		1,000,000 Tons	
	Open-Hearth Shop	Electric Furnace Shop	Open-Hearth Shop	Electric Furnace Shop
Cost above	$13.95	$15.95	$12.93	$15.14
Cost of Metallics (Hot Metal Charge)	42.23	41.33	42.23	41.33
Net Production Costs[b]	55.03	56.13	54.01	55.32
Initial Capital Costs	$16,900,000	$10,500,000	$26,650,000	$15,900,000

[a]Sources: Battelle Memorial Institute, op. cit., Table 5-1, p. 8.

[b]Including fixed charges and credit for recoverable scrap.

capacity operating rates. At lower operating rates, however, the total cost per ton would rise less rapidly for electric than for open-hearth furnaces, since the investment in the former is lower per ton. Fifth, the electric furnace has other advantages, including flexibility in production, shorter annual down time, greater control of sulphur, faster charging, better steel quality, better working conditions, and improved products resulting from induction stirring. These extra benefits might be enough to put the electric

furnace on an equal footing with the open-hearth furnace in the production of carbon steel.

There are important factors opposing this development. Most of the open-hearth furnaces in current operation are either comparatively new or have recently been modernized. Displacement of such a major investment could only be justified by large enough savings in the production costs to amortize the investment in both the furnaces made obsolete and the new electric furnaces taking their place. Furthermore, important technological changes in open-hearth operations may take place. The use of oxygen in the open-hearth furnace, for example, is expected to add substantially to its present annual capacity. These considerations, together with the additional cost of maintaining technical and supervisory personnel for two kinds of equipment for making carbon steel in the same plant, make it unlikely that the open-hearth furnaces will be replaced or made obsolete by the electric furnace within the next twenty to twenty-five years. Consequently, the open-hearth process is expected to still predominate the total steel-making capacity of the industry by 1970.

Ingot Requirements for Hot-Rolled Steel

Steel-making furnaces perform the function of producing steel ingots and castings, and steel ingots are further processed in rolling mills into semi-finished and finished steel products. Only a small proportion of total steel ingots and castings produced is sold directly to other

industries. As indicated in Table 13, steel ingots and castings channeled to other industrial concerns accounted for less than one per cent of the total production annually.

TABLE 13[a]

TOTAL PRODUCTION AND NET SHIPMENTS TO OTHER INDUSTRIES OF STEEL INGOTS AND CASTINGS

Year	Total Production (Thousand Tons)	Net Shipment	Per Cent of Total Production
1956	115,216	703	0.61
1955	117,036	679	0.58
1954	88,312	317	0.36
1953	111,610	919	0.82
1952	93,168	1,128	1.21
1951	105,200	1,316	1.25
1950	96,836	888	0.92

[a]Sources: American Iron and Steel Institute, Annual Statistical Reports, 1950-1956.

Excluding castings and assuming equality between total ingot production and total ingot consumption in the industry, the annual ratio of ingot production to that of hot-rolled products has been calculated for the period 1920-1956 in Table 14. These ratios, which represent the ingot requirement per ton of hot-rolled products, have varied slightly and have been somewhat lower since World War II, indicating greater hot-rolling efficiency, through less scrap steel. In Chart 12, the close correlation between the production of hot-rolled products and steel ingots is illustrated graphically. The relationship is divided into two periods, 1920 through 1940, and 1946 through 1956, with the

TABLE 14[a]

STEEL REQUIREMENT PER NET TON OF HOT-ROLLED PRODUCTS
1920 - 1956

Year	Ingots / Hot-Rolled	Year	Ingots / Hot-Rolled
1956	1.287	1939	1.347
1955	1.288	1938	1.344
1954	1.287	1937	1.369
1953	1.295	1936	1.406
1952	1.301	1935	1.416
1951	1.280	1934	1.416
1950	1.284	1933	1.368
1949	1.277	1931	1.326
1948	1.277	1930	1.342
1947	1.278	1929	1.336
1946	1.302	1928	1.336
1945	1.327	1927	1.331
1944	1.356	1926	1.322
1943	1.396	1925	1.322
1942	1.370	1924	1.311
1941	1.323	1923	1.307
1940	1.370	1922	1.307
		1921	1.301
		1920	1.264

[a]Sources; Data for computation, American Iron and Steel Institute, Annual Statistical Reports, 1940-1956.

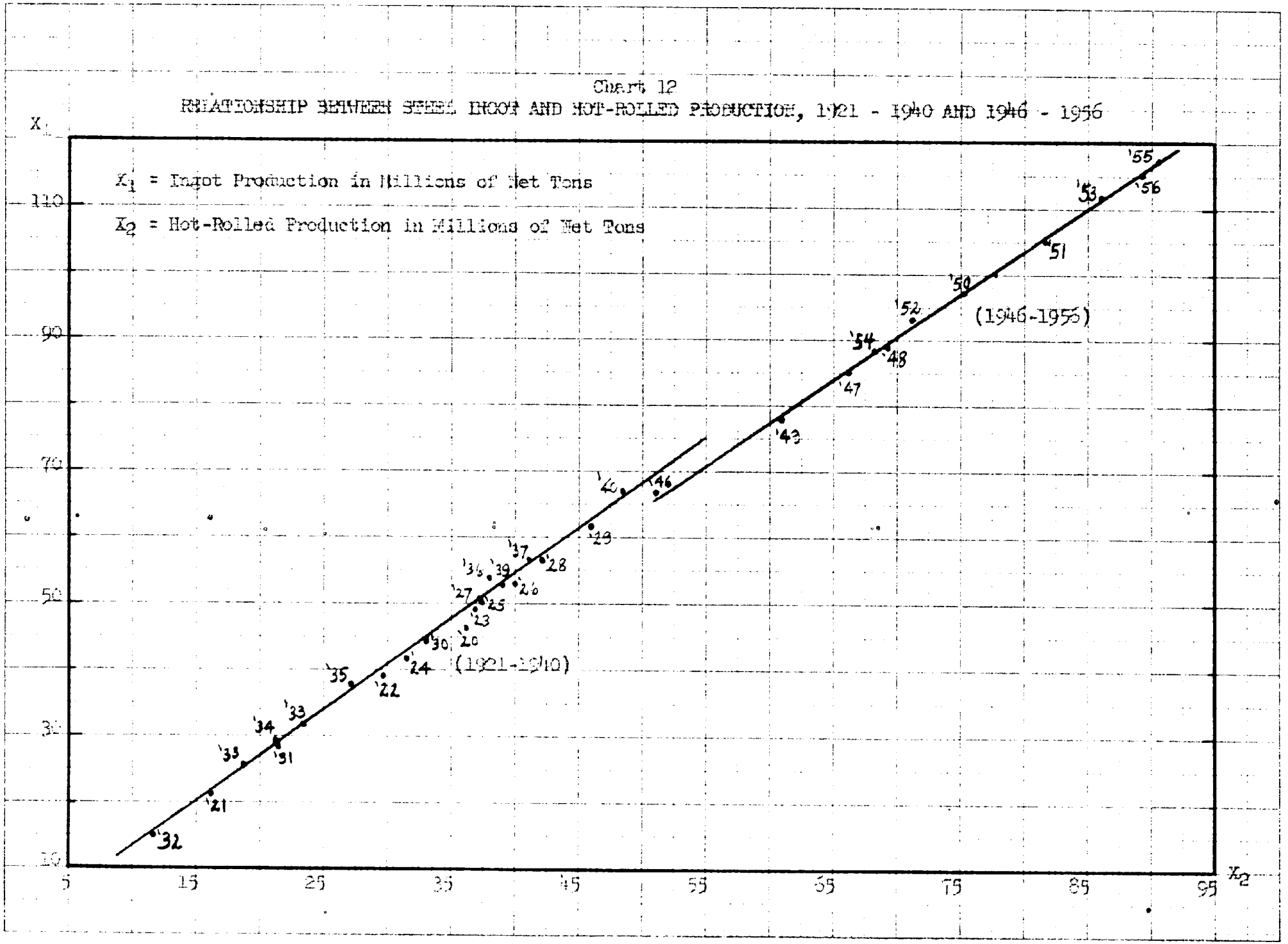
war years excluded. In the postwar period, the slope of the relationship is slightly less than in the prewar period, indicating a tendency toward lower ingot requirement per ton of hot-rolled products.

Ingot Capacity Relative to Hot-Rolling Mill Capacity

Because of the difficulty in rating the annual capacity of hot-rolling mills, available information for the industry is limited to five of the past twenty years. For

Chart 12

RELATIONSHIP BETWEEN STEEL INGOT AND HOT-ROLLED PRODUCTION, 1921 - 1940 AND 1946 - 1956



these years, Table 15 provides the ingot capacities, the hot-rolling capacities, and the ratios of the former to the latter. These ratios vary from a high of 1.310 to a low of 1.245 in 1951 and to 1.287 in 1954.

TABLE 15[a]

CAPACITY RATIOS OF STEEL INGOTS TO HOT-ROLLED STEEL PRODUCTS FOR FIVE SELECTED YEARS

Year	(I) Annual Ingot Capacity	(II) Annual Hot-Rolling Capacity	(III) Capacity Ratios (I)	(II)
1954	124,330	96,641	1.287	
1951	104,230	83,700	1.245	
1948	94,233	73,872	1.276	
1938	80,186	64,277	1.248	
1935	78,452	59,875	1.310	

[a]Sources: American Iron and Steel Institute, Directory of Iron and Steel Works, 1935, 1938, 1948, 1951, 1954.

To obtain an indication of the degree of balance in the capacities of these two functional facilities, the capacity ratios may be compared with the steel requirement ratios. To have completely adequate capacities at the time of peak operation, the capacity ratios should be at least as high as the steel requirement ratios.

The comparison presented in Table 16, however, indicates that the capacity ratios were below the requirement ratios in the years considered except in 1954, when the two ratios were equal. Clearly, there has been a shortage of

TABLE 16

REQUIREMENT RATIOS AND CAPACITY RATIOS OF INGOTS TO HOT-ROLLED STEEL PRODUCTS FOR FIVE SELECTED YEARS

Year	Capacity Ratios	Requirement Ratios	Excess of Requirement Ratios
1954	1.287	1.287	.000
1951	1.245	1.280	.035
1948	1.276	1.277	.001
1938	1.248	1.344	.096
1935	1.310	1.416	.106

ingot capacity relative to the hot-rolled capacity. This shortage, however, declined after 1935 and was finally eliminated in 1954, as the differences between the requirement ratios and the capacity ratios show. The significance of a lack of sufficient ingot capacity to balance hot-rolling capacity becomes apparent when demand for steel is high and a shortage of ingots prevents the industry from fully utilizing its hot-rolling facilities to satisfy the demand. Such a situation did not occur in the 1930's because the operating rates for all facilities were substantially below the maximum. The relative undercapacity in ingot facilities became apparent, however, in 1951. Because of the high demand for steel, steel furnaces were operated at 100.9 per cent of capacity but only succeeded in supplying sufficient ingots to operate the hot-rolling mills at 97.9 per cent of capacity.

In view of the long-time tendency for capacity to rise less rapidly than production and for the average operating rate to be well above 90 per cent in the past decade, the importance of maintaining proper balance in the capacities of these highly related facilities is very important, especially if emergencies should arise. The requirement ratio in production, therefore, should be the guide for proper balancing of capacities. It is conceivable, of course, that a further reduction in metal scrap from hot-rolling may slightly reduce the requirement ratio in the future. In this study, use will be made of the average requirement ratio for the period 1946-1956, according to which 1.291 tons of ingot capacity should be added for every additional ton of hot-rolled capacity.

Rolling Mill Capacity

All steel ingots are shaped in blooming or slab mills. Then they pass at high temperature through "hot" rolling mills. Many resulting products receive no further rolling and are known as hot-rolled products. Others, after cooling, are again passed through cold rolling and finishing mills and are known as cold-rolled or cold-finished products. Hot-rolled steel products include rails, bars, structural shapes, plates, sheets, strips, wire rods, along with other products. Cold-finished products include bars, sheets, strips, plates, wires, pipe and tubing, etc. In 1956, total shipments of steel products amounted to 83 million tons, of

which about half were hot-rolled and half cold-finished products.[1]

Since all finished steel must be hot rolled, the hot-rolling capacity may be regarded as the primary measure of rolling-mill capacity. Cold-rolling capacity is dependent not only on how much steel can be hot rolled, but also on the relative demand for cold-rolled products. On January 1, 1957, the annual capacity of hot-rolling mills was 103.6 million net tons, while that of cold-rolling mills was 66.7 million or 64 per cent as large as the former.[2] In other words, cold-finishing facilities were sufficient to utilize 64 tons out of every 100 tons of hot-rolled steel, if hot-rolling capacity were operated at maximum output. At lower hot-rolling rates, however, it is conceivable that maximum output of cold-finished products might be a higher proportion of the total hot-rolled steel.

The nature of steel demand from the various sectors of the economy influences the ratio of cold-rolling to hot-rolling capacities. Postwar expansion in the economy has featured an extraordinary growth in the demand for cold-finished products, especially by the automobile and appliance industries, and this development has led to rapid expansion in the cold-rolling capacity. As indicated in

---

[1]Estimated from the shipment data in the American Iron and Steel Institute, Annual Statistical Report, 1956, p. 94.

[2]Sources: American Iron and Steel Institute, Iron and Steel Works Directory of the U. S. and Canada, 1956, pp. 454-497. (Capacity data provided for each type of finished steel product.)

Table 17, the ratios of cold-finishing capacity to hot-rolling capacity during the postwar period were much higher than the comparable ratio in 1938.

TABLE 17[a]

ANNUAL CAPACITIES OF HOT-ROLLED STEEL FACILITIES AND OF OTHER FINISHED (COLD-FINISHED) STEEL FACILITIES FOR FIVE SELECTED YEARS

Year	Annual Capacities (Net Tons)		Ratios of Cold-Finished to Hot-Rolled Steel Capacities
	Hot-Rolled Steel Facilities	Cold-Finished Steel Facilities	
1957	103,022,230	66,743,400	.648
1954	96,641,240	63,057,755	.653
1951	83,699,890	54,294,610	.649
1948	73,872,430	47,371,100	.641
1938	57,389,800	31,036,638	.541

[a]Sources: American Iron and Steel Institute, Directory of Iron and Steel Works, 1938, 1948, 1951, 1954, and 1957.

It is apparent from this historical review of the principal steel facilities that past growth in the steel capacity system has been characterized by continuous changes in method and composition of output. These changes have affected not only the type of facilities in use but also the interrelationship among their capacities. Projection of future needs for steel facilities and estimates of concomitant investment must therefore give recognition to the influences of such changes.

Estimated Capacities of Principal Steel Facilities by 1970

From the foregoing analysis of capacity interrelationship and the estimated capacity of steel-making furnaces in 1970 (from chapter ii), estimates of coke, pig iron and hot-rolled steel capacities can be readily ascertained. The probable magnitudes of the four major capacities are shown in Table 18.

TABLE 18

NEEDS FOR NET EXPANSION IN PRINCIPAL CAPACITIES OF THE STEEL INDUSTRY BETWEEN 1958 AND 1970

(In Millions of Net Tons)

Type of Facilities	1970	1958	Net Expansion Needed
Hot-Rolled Steel Capacity	144.5[a]	109.2[e]	35.3
Steel Ingot Capacity	186.5[b]	140.7[f]	45.8
Blast-Furnace Capacity	124.2[c]	91.0[f]	33.2
Coke Capacity	93.2[d]	72.2[f]	21.0

[a]Based on the estimated ratio of 1.291 ton of steel ingot capacity to 1 ton of hot-rolled capacity.

[b]Based on the estimated capacity for steel-making furnaces (see chap. ii).

[c]Based on the estimated ratio of .666 ton of pig iron capacity to 1 ton of steel ingot capacity.

[d]Based on the estimated ratio of .75 ton of coke capacity to 1 ton of pig iron capacity.

[e]Estimated on the basis of Ingot and Hot-Rolled capacity relationship prevailing in 1957.

[f]From American Iron and Steel Institute, Steel Facts, No. 148 (Feb. 1958). Rated capacities as of January 1, 1958.

The excess of the projected capacity to meet future growth in steel demand over the present capacity represents net capacity expansion needed in the steel industry. Between 1958 and 1970, the industry must increase its annual productive power by 21 million tons of coke capacity, 33.2 million tons of blast furnace capacity, 45.8 million tons of steel-making capacity, and 35.3 million tons of hot-rolled steel capacity. The relationship between the net capacity expansions of the major facilities are as follows: .632 ton of coke per ton of pig iron, .725 ton of pig iron per ton of steel ingot, and 1.297 tons of steel ingot per ton of hot-rolled steel.

Net capacity additions necessary to meet the estimated growth in steel demand call for capital investment by the steel industry. This amount of capital needs, however, represents only one of the two components of total capital requirements. The other component, capital requirement for replacement, is needed to replace steel facilities to be retired during the accounting period for reasons of physical wear and tear or obsolescence. In the subsequent chapters, the study will be devoted to the projection of capital investment for expansion and replacement necessary to finance the estimated growth of the steel industry.

CHAPTER IV

PROBLEMS IN THE DETERMINATION OF TOTAL CAPITAL REQUIREMENTS

The analysis of capital needs for financing the estimated level of capacity in 1970 poses two different types of problems. The first type is concerned with the projection of capital requirement for net expansion. While the preceding analysis has provided estimates of net capacity additions for each segment of steel facilities, problems still remain in the conversion from physical capacity needs to financial capital requirement. The second type of problem concerns the projection of capital needs for replacement. This problem lies in the estimation of life characteristics of steel facilities necessary for the projection of retirements and replacement. Adequate understanding of the two types of difficulties will provide a basis for developing methods of analysis for forecasting each component of total capital requirements.

Problems in Estimating Capital Requirement for Expansion

Projection of capital needs for expansion requires advance knowledge of net capacity expansion and capital cost per unit of capacity expansion. The previous analysis has estimated net capacity expansion of major steel facilities,

and further development is required in predicting the relationships between capital outlays and capacity additions. These relationships, which may also be referred to as capital costs per unit of capacity additions, are called capital coefficients by economists. By multiplying capital coefficients of the steel industry by the required capacity additions, capital investment for expansion can be estimated.

The original concept of capital coefficients was a product of vast research developed in recent years under the name of input-output analysis. In that research, a capital coefficient was defined as the quantity of capital needed for the production of a unit of product.[1] However, in recent years this concept has been used widely with variations in its definition.

For use in this study capital coefficient will be defined as a ratio of capital investment to an incremental amount of capacity. This definition differs from the original capital-output concept in two respects: (1) it implies full employment of capital so that output and capacity are equal, and (2) it deals with marginal relationship rather than average relationship between capital and capacity. The marginal concept is absolutely necessary because the analysis of capital needs for expansion is concerned with the incremental amount of capital stock in relation to capacity accretion. The average capital coefficient, on the

---

[1]See Wassily W. Leontiff, et al., Studies in the Structure of the American Economy (New York: Oxford University Press, 1953), pp. 55-57, 185-89.

other hand, deals with total capital stock in relation to accumulated capacity, a concept which is not directly applicable to a study of future investment, because it represents past rather than future technology in productive capacity. Unless otherwise stated, subsequent discussion of the capital coefficient will be in terms of its marginal capital-capacity meaning.

Since both elements in the definition of capital coefficient can still be expressed in a variety of ways, further care must be taken in selecting standard quantities of capital and capacity. For the purpose of this study, capital or investment will be expressed in dollars of 1957 purchasing power and the capacity in terms of annual steel ingot output. The selection of annual steel ingot capacity to represent a unit of capacity additions in the steel industry implies that for each ton of annual ingot capacity, there will be corresponding additions of other related capacities as estimated in the previous chapter.

Problems of Instability

The most serious concern of economic analysts who make use of the capital coefficients has been the problem of variability. This problem is obviously aggravated by the marginal concept of the capital coefficient. In a study on this problem, Ann P. Carter has correctly pointed out that:

> While at any given time, [average] input coefficients are representative of a wider range of techniques than [marginal] capital coefficients, they tend to be relatively stable because of their 'moving average' property. Capital coefficients are more sensitive, describing

> technical characteristics of the incremental portion of the industry capacity picture only. Furthermore, capital coefficients in dynamic input-output models describe prospective rather than 'sunk' investment.[1]

In dealing with the capital coefficient for use in estimating capital requirement for expansion, it is important to establish stable and predictable coefficients in view of the prospective factors involved. The first step is, therefore, to identify those factors which are responsible for the variability in the individual-industry capital coefficients.

Sources of Variability in Capital Coefficients

The causes of variation in capital coefficients are numerous. The search for capital coefficients has suggested three different kinds of variability: statistical variation, interplant variation, and industry variation. In each of these groups, there are numerous factors of varying importance which cause variations. Only those factors which are significant will be brought to our attention here, however.

Statistical Variation. In a historical study, statistics in both capital and capacity are needed. Annual capital expenditures reported by an industry,however, include both expansion and replacement, whereas capacity data are normally reported in terms of net annual increase. Capital coefficients must reflect either the relationship between net

---

[1]Ann P. Carter, "Capital Coefficients as Economic Parameters: The Problem of Instability," Problems of Capital Formation, Studies in Income and Wealth, XIX, National Bureau of Economic Research (Princeton: Princeton University Press, 1957), p. 289.

investment for expansion and net capacity addition or the relationship between total investment and gross capacity addition, which includes the amount for replacement. The first alternative is impractical because of the serious difficulty involved in distinguishing on a reliable basis the expansion and replacement components in total investment. The second alternative which describes the gross relationship between capital and capacity is more easily attainable because of the availability of gross capacity addition in the steel industry.

The gross relationship does not, nevertheless, rule out the possibility of statistical variation in the estimates. Coefficient variation can come from the rather arbitrary definition of steel capacity. Capacity is rated on an annual basis, and annual capacity of any particular facility can vary according to the number of working days used in the capacity rating by individual companies. This problem in the steel industry does not seem to be serious, however, because the industry has a good reputation in the maintenance of its records on a uniform basis.

Even more important is the coefficient variation caused by the varying proportion of investment expended for facility modernization. Such outlays are made to increase operating efficiency but do not affect capacity. Since the importance of such outlays in total investment may vary significantly from year to year, it is not safe to estimate the capital coefficient from expenditure information in any one year without knowing the relative magnitude of capital for

modernization. The capital coefficient will be abnormally high for the year in which the industry expended most of its capital outlays for facility modernization, and vice versa. A way to overcome this problem is to estimate the capital coefficient on a basis of a longer period than one year, so that the proportion of modernization expenditures in total investment can be considered normal and representative.

Interplant Variation. Numerous factors can be held responsible for the interplant variation in the capital coefficients as experienced by various steel companies in the past. The following list is not exhaustive, but includes the most important factors involved.

Nature of Capacity Expansion.--There are basically three different ways of increasing capacity: the construction of a completely new plant, the addition of new facilities to the existing plant, and the improvement of the basic facilities. The first and the third alternative represent the two extremes in capital requirements. According to past experience, the capital coefficient can vary from less than $100 to more than $300 depending on the nature of the capacity expansion.

Degree of Integration.--A highly integrated plant always requires greater capital investment than a non-integrated steel plant. This variation can be very substantial. A steel plant which produces only steel ingots and mill products

will cost much less than another plant of equal steel capacity which produces coke and pig iron as well.

Size of Expansion.--The capital coefficient of steel plants and facilities of varying size will differ since there will generally be some economy of scale. The capital coefficient in a larger plant is usually relatively less than that of a smaller plant.

Provision for Future Expansion.--With good prospects for the rapid growth of the steel industry, most or all new plants are built with an eye toward further expansion in the future on the same site. Many economic reasons justify this action. Most important, perhaps, are the ability to expand rapidly to meet rising demand and the lower investment costs of expansion. It is common to find a new steel plant built with excess capacity of general plant facilities and land.

Composition of Product-Mix.--The various finished steel products satisfy different market demands. Each type of finished steel requires different steel mill facilities to process the steel ingots. Cost of mill facilities per ton of its finished steel are the lowest in the production of wheels, axles, and forgings and the highest in the production of wire rope. The cost variation is great. Two steel mills producing different mixes of product are not likely to have similar construction costs.

Other Factors.--First, characteristics of the plant site may require different foundation and piling work. For example, a plant on land and a plant on deep water may require different general facilities and thus different investment costs. Preference of plant layout and equipment is the second factor. The possibilities of technical substitution in various steel facilities give steelmen some choice for the plant layout. Thirdly, construction costs vary in different geographical areas. Finally, the type of quality of raw materials are pertinent. The use of high quality iron ore through beneficiation requires extra facilities. Different proportions of hot metal and scrap in the melting process require a different level of pig iron capacity relative to ingot capacity.

The problem of interplant variation appears much more significant in the nature of capacity expansion and the degree of integration, and less significant among other factors. In any event, the dispersion of capital coefficients does not in itself necessarily imply instability of the industry-wide coefficients over time. In a process of aggregation for the industry's capital coefficient, a substantial portion of the interplant variability will be eliminated. Further reduction in the variability can also be made by estimating capital coefficients on a longer-period basis. Consequently, the problem of interplant variation can be largely solved.

Industry Variation. The problem of variation in the industry-wide capital coefficients over time is of great concern

in our study of capital requirement for expansion. Again numerous variables can be accounted for, but only significant factors are described here.

Change in the Nature of Capacity Expansion.--This factor is similar to the nature of capacity expansion in various plants, which has been described in the interplant variation. It is also essential as a source of industry variation in the capital coefficients, because the proportion of new plants in total capacity expansion may be changing through time due to various economic and non-economic factors. Since the capital coefficient of a new steel plant is much greater than with other types of expansion, the changing proportion of new plant additions can be very influential.

Change in the Degree of Integration.--While the degree of integration among different plants may differ markedly, the degree of integration for the industry as a whole may also alter through time. In the steel industry, there is an obvious tendency towards greater self-sufficiency through a greater degree of vertical integration. If this tendency continues, one would expect the capital coefficients to increase.

Change in Prices.--Empirical evidence has shown that price stability in the American economy is a rarity. This was particularly so after the second World War, when prices or construction costs of steel facilities increased markedly. Since the capital coefficients have capital in money terms as

their numerator, change in prices will cause variation in the coefficients.

Change in Tecnnology.--Newer and more efficient productive processes have been continuously introduced for the purpose of increasing efficiency in operation or minimizing production costs. The effects of technological advancement on capital input may be either capital-using or capital-saving. Change in capital-using technology implies higher costs in capital input, but high capital costs will be more than compensated for in the cost reductions in labor and material inputs.

The effects of technological change on capital input may, therefore, increase or decrease the capital coefficients. Apparently the changes in technology and prices may have offsetting or complementary effects on each other. For example, rising prices in construction materials and capital-saving technology will have offsetting effects on the capital coefficients.

The problem of the industry variation is extremely difficult to overcome. Fortunately, the problem of price variations can be avoided by determining capital coefficients in constant dollars. The same treatment, however, is not applicable to other influential variables. Consequently, to establish a stable and predictable capital coefficient, certain techniques must be introduced for the reduction of its variability. The most promising method appears to be a process of stratification which classifies capital coefficients

by the important variables. For example, capital coefficients can be estimated separately for the following classifications: expansion through new plants, expansion through new facilities or improvements, degree of integration, and type of technology.

Estimating Future Capital Coefficients

Other difficulties will be encountered in the estimation of capital coefficients applicable to the future period under study. The quantitative magnitudes of capital coefficients depend upon the future behavior of those underlying factors. Consequently, it is necessary to predict the proportion of capacity addition through new plants, prospective degree of integration, and prospective technology, and if the predictions indicate any changes, what effects those changes will have on the capital coefficient.

The foregoing discussion indicates that the problems of estimating capital coefficients for the determination of capital requirement for expansion are not insurmountable. The primary concern of this study will be with the industry-wide coefficients, and the problem of industry variation may be solved by classification of the effects of the major factors and the predictions of their future behavior.

Problems in Estimating Capital Requirement for Replacement

In general, age distribution of existing capacity and rate of survivorship or retirement of steel facilities determine capacity retirement in each type of steel facility in the

future period. The age distribution of existing capacity represents the past capacity additions which remain to be exposed to future retirement, and the rate of retirement or average useful life reflects the rapidity of physical deterioration and technological obsolescence of the fixed assets. A projection of capacity retirements therefore necessitates a study of the average useful life, rate of survivorship, and age distribution for each type of steel equipment.

The average useful life and the rate of survivorship for each type of steel fixed asset are normally estimated by actuarial methods, which require physical asset data in sufficient detail so that the age of each unit of facility is known at all times. These methods are used to compute the percentage of assets retired at each age and thus provide necessary information for estimating the rate of survivorship and the average useful life. The steel industry, however, owns so many different types of facilities that the costs of keeping the necessary data are reported to be prohibitive. As a result, a reliable study of replacement demands in terms of annual capacities is virtually impossible.

Alternative Methods of Capital Replacement Determination

Since the lack of physical data does not permit a reliable estimate of capacity retirements which may lead to a determination of capital replacement by the capital coefficient concept, many analysts have resorted to alternative methods which would accomplish essentially the same purpose.

While these alternative methods have many limitations which are not acceptable in this study, it will be advantageous to review these techniques for better understanding of the problems involved in the analysis of capital replacement.

Depreciation Approach. Evsey D. Domar has pointed out that replacement requirements could at one time be measured by identifying them with depreciation charges, as reported in financial statements.[1] He goes on to say that this approach is no longer plausible since depreciation charges are now related more closely to tax considerations than to actual obsolescence or deterioration of capital.

The depreciation approach, however, never was acceptable for the estimate of capital retirements and replacement. Replacement investment and depreciation charges do not have the same concept. Replacement expenditures are the cost of replacing facilities which have been retired with an equivalent amount of physical capacity. It is a physical concept and not an accounting concept like depreciation allowances. Accounting for depreciation is merely an assignment of costs to the period during which assets are used. Consequently, replacement investment and depreciation allowances for an economic unit will not be equal over time, unless there are no changes in price level and productive

---

[1]Evsey D. Domar, in his comment on "Estimating Future Purchases of Capital for Replacement" by Robert N. Grosse and Edward B. Berman. See National Bureau of Economic Research, Problems of Capital Formation, Studies in Income and Wealth, Vol. 19 (Princeton: Princeton University Press, 1957), pp. 415-417.

efficiency and no growth in size. Actually, changes occur in all three conditions with the result that (1) replacement needs and depreciation charges differ markedly, and (2) one measure can be used to represent another only after adjustments of substantial proportions.

Total Investment Approach. This approach, which is more popular than the first one, makes no effort at all to separate replacement and expansion investment. In this case, capital estimates cover investment for both replacement and expansion. The total capital requirements are based on multiplying net capacity additions by net capital coefficients which relate total investment to incremental capacity additions.

This approach has its merits in simplicity. The Chase Manhattan Bank study of the world petroleum industry has employed this technique presumably to avoid the difficulties involved in distinguishing between capital replacement and expansion.[1] The aggregation of replacement-expansion under this method, however, implies that the proportion of capital replacement in total investment will remain constant through time. In a short-run study, this assumption may be justified because the relative importance of the two basic components of total investment may not change markedly in a short-time period. The same assumption, however, is not quite so valid

---

[1]The Chase Manhattan Bank, Future Growth and Financial Requirements of the World Petroleum Industry (New York, 1956).

in a long-run study during which the growth rate of the industry keeps changing, since in a rapidly growing industry the capacity expansion will account for most of the capital expenditures, while in a stagnant industry, the expenditures will be made exclusively for replacement.

The previous analysis of growth in the steel industry indicated that the prospective rate of growth is significantly lower than the growth rate of the recent period. Therefore, the relative importance of replacement in total investment will increase in the future period under study. Moreover, the steel industry has been in existence for more than a century and a considerable proportion of its assets will be ripe for retirement in the next ten or fifteen years. The importance of the replacement in total investment plus the significant change in the future rate of growth make it undesirable to estimate total capital requirements on a combined basis. In other words, the resulting errors from the rigid assumption regarding the constant proportion of replacement in total investment is beyond justification.

A Suggested Approach to the Estimate of Capital Needs for Replacement

The life characteristics of steel plant and equipment, which are necessary for an estimate of capital retirements, can be ascertained from value data of depreciable assets by the so-called simulated plant balance method.[1] This technique

---

[1]The simulated plant balance method is originally designed to estimate a life curve from physical data when data

can be used to estimate a life curve (or rate of survivorship) from a long series of annual additions and a number of plant balances of the depreciable assets account. The principle underlying this method is that each annual addition is exposed to retirements at various ages in accordance with its life curve, and the portion of additions which survive at a particular time will appear in the plant balances. Consequently, a life curve may be arbitrarily assumed and tested for its validity by a trial and error process. The assumed life curve which yields estimated plant balances corresponding most closely to the actual balances will best represent the typical life curve of steel facilities.

The derived curve can be used in the determination of capital replacement by the following outlined process. The estimated life curve and the data of annual additions will represent necessary information for estimating future retirements at original cost by years of acquisition. (An elaboration of this estimating process will be found in chapter vi.) The retirements at original cost can then be further converted to replacement investment with appropriate adjustments for price and technological changes.

The advantages of the suggested approach on a value basis are found not only in its expediency for overcoming data shortages, but also in its ability to deal with all types of steel facilities in aggregation. The physical unit of

---

on retirements, which are required under conventional actuarial methods, are unknown. The underlying principle of the plant balance method, however, is equally applicable to value data.

steel plant and equipment differs substantially among various types of steel facilities, and in many cases, within each type of facility. Estimate of capacity retirements therefore requires at least separate analysis for each type of plant and equipment. The analysis of value retirements, on the other hand, would make possible the study of life characteristics of steel facilities on a combined basis. While the life curve derived from aggregate value data may not be applicable to any type of steel plant and equipment, the information provides an adequate basis for making an overall estimate of retirement and replacement needs.

Projection of capital replacement on the basis of life curve, however, has had adverse criticisms. Most important among these are:

1. No account is taken of the effects of future technological change, either on the life characteristics--namely, average useful life and rate of survivorship--or on the amount of capital necessary to maintain capacity at a certain level. Future technological change may shorten the present average life of steel assets and thus induce considerably more retirements than otherwise. The effects of new technology may also reduce capital coefficients, and the asset retirements equal in constant dollars may be substantially greater than expenditures needed to replace the scrapped capacity.

2. No price indexes are compiled, particularly for the construction of facilities.

3. Retirements and replacements may not correspond with the average useful life, rate of survivorship, and age distribution of existing assets; since replacement may be affected by business expectations, the availability of material supplies, and the supply of funds. Frequently, the effects of these elements result in the postponement of replacements.

While these three limitations may be too severe in many circumstances, the weaknesses of the life-study approach can be tolerated in the replacement analysis of the steel industry. Prospective changes in technology in the steel industry are not expected to be revolutionary in the 1958-1970 period. Consequently, the effects of prospective technology on life characteristics and capital coefficients should be nominal. The lack of a specific price index for the construction materials of steel facilities is not a matter of serious concern in the steel industry. According to the U. S. Steel Corporation, which owns a large share of the industry's total fixed assets, the Engineering News Construction Costs Index exhibits a close agreement with the changing costs of steel facilities.[1] This index can thus be used with reasonable assurance.

The problem of replacement postponement may be very serious in a short-run study because the length of the postponing period depends largely on the financial and demand

---

[1]U. S. Steel Corporation, Steel and Inflation, Fact vs. Fiction, (1958), p. 51.

situations. In a growing industry the period of postponement is not, as a rule, longer than one period of business cycle. In the steel study which covers a thirteen-year period, the adverse effects of postponement on the accuracy of retirement and replacement estimates will be substantially reduced. Consequently, the life-study approach can be properly utilized for the estimate of capital needs for replacement in the steel industry.

It is apparent from the foregoing discussion that the problem of variability in capital coefficients is most pronounced in the projection of capital needs for expansion, while the problem of estimating the life curve is of great importance to the study of capital replacement. Projection of total capital requirements to finance the future growth will necessarily give recognition to the problems revealed in this chapter.

CHAPTER V

CAPITAL REQUIREMENT FOR EXPANSION

The preceding chapters have indicated the requirement for net capacity addition during the 1958-1970 period and the problems involved in the projection of capital needs for expansion. The purpose of this chapter is to estimate in dollars of 1957 purchasing power the capital investment needed to finance this net expansion. The emphasis of the following analysis will be on the prediction of the industry-wide capital coefficients which are applicable to the future increments in the basic capacities of the steel industry. Capital coefficients or the capital costs per ton of capacity expansion establish an important link between capacity addition and capital investment.

Because of the great variability normally existing in the capital coefficient, it will be desirable to estimate the industry-wide coefficients by two major categories of expansion: expansion through new and completely integrated plants, and expansion through other types of capacity addition. The second category includes both the additions of new equipment and the enlargement of existing facilities. Estimates of the capital coefficients of the two categories, which differ markedly in their capital costs, make it

feasible to reveal the effects of changing proportion of the expansion through new plants on the capital needs for expansion.

The capital coefficients will first be estimated from the past capacity addition of the steel industry. The historical coefficients were naturally affected by the various conditions prevailing at the time. These conditions are the level of prices, the degree of integration, and the steel technology. Consequently, the historical coefficients of each category of expansion will necessarily be adjusted for changes in these conditions before deriving the capital coefficients which are applicable to the future expansion.

In addition to the estimates of the capital coefficients of new-plant and non-new-plant expansion, the relative importance of these two types of capacity expansion in the future period must be ascertained for the projection of capital needs. The estimate of their relative importance will provide a basis necessary for determining the value of the overall capital coefficient of the required net capacity addition. The overall capital coefficient can be estimated by averaging the coefficients of new-plant and non-new-plant expansion according to their relative importance. Since the coefficient is estimated in terms of annual steel ingot capacity, the capital investment for expansion can be projected simply by multiplying the overall capital coefficient by the estimated net expansion of steel ingot capacity.

Capital Coefficients of New and Completely Integrated Plants

Expansion by building new and completely integrated steel plants is recognized as initially the most expensive. The main advantage of a new plant is, of course, high operation efficiency. Because of its high capital costs, however, this type of expansion is not predominant in the steel industry. In general, new steel plants are built primarily in anticipation of heavy future demand, and they are mainly resorted to when the existing plants cannot be expanded feasibly and economically.

At least two alternative procedures can be adopted in estimating the capital coefficient of new-plant expansion; one is by the use of the estimate based on the past experience of the steel industry and the other is by the use of the estimate by engineers. Both of these methods can be used advantageously to complement each other for comparative purposes.

Empirical Estimate

Only three new and completely integrated plants were constructed during the 1940-1957 period, and two of these were financed by the government for defense needs during the second World War. The first is the Fontana plant in California which was completed in 1943 and later became part of the Kaiser Steel Company. The second plant is the Geneva Works completed in 1944 in Utah and later transferred to the United

States Steel Corporation. The last is the Fairless Works of United States Steel Corporation which was completed in 1953.

The characteristics of the three new plants are not identical. The Fontana and the Geneva plants were built to produce mainly sheared plate, heavy structural shape and hot-rolled bars because of the great needs for these steel products during the second World War. The Fairless plant, on the other hand, was built to produce mainly sheet, electrolytic tin plate, and hot-dipped tin and terne plate. Neither were the size and the degree of integration of the three new plants similar. As revealed in Table 19, the plant size in terms of the annual steel ingot capacity varied from 720,000 tons in the Fontana plant to 1,280,000 tons in the Geneva plant and to 1,800,000 tons in the Fairless plant. The degree of integration, as indicated by the capacity ratios of coke to pig iron, pig iron to steel ingot, and steel ingot to hot-rolled steel, was also substantially different among the three plants.

Difference in the plant characteristics will normally cause variations in the capital coefficient of each plant. However, since the three new plants were constructed at different times in the 1943-1953 period, the other factors, such as changes in price and technology, appear to be much more influential to variations in the capital coefficient. During the ten year period, the price or the cost of construction materials for steel facilities, as measured by the Engineering News Record Construction Costs index increased

TABLE 19[a]

CAPACITIES AND CAPITAL COEFFICIENTS OF THREE NEW AND COMPLETELY INTEGRATED STEEL PLANTS

Type of Capacities and Capacity Ratio	Plants and Location		
	Kaiser Steel Fontana, Calif. 1943	U. S. Steel Geneva Works, Ut. 1944	U. S. Steel Fairless Works, Pa. 1953
Coke Oven Capacity	340,000 N.T.	971,100	875,000
Coke Oven/Blast Furnaces	.874	.844	.772
Blast Furnace Capacity	388,800	1,150,000	1,134,000
Blast Furnace/Steel-Making	.540	.898	.630
Steel-Making Capacity	720,000	1,280,000	1,800,000
Steel-Making/Hot-Rolled	1.043	1.347	1.278
Hot-Rolled Capacity	690,000	950,000	1,408,500
Estimated Construction Costs	$95.5-111 million	$190-196 million	$450-500 million
Estimated Capital Coefficients	$133-154	$148-153	$250-278
Average Value of the Capital Coefficients	$144	$150	$264

[a]Sources: American Iron and Steel Institute, Directory of Iron and Steel Works, 1944 and 1954.

107 per cent. The extent of price change almost always leads to a rise in the capital coefficient. The value of the capital coefficients of the three plants, which are estimated also in Table 19, did increase 83 per cent from the plant built in 1943 to the plant built in 1953. The failure of the capital coefficients to rise as much as the cost of construction may be due either to the capital-saving effect of technological change, or to the effect of different plant characteristics.

The rising trend of the capital coefficient of new plants has presumably continued to the present. In 1957, the Jones and Laughlin Steel Corporation contemplated construction of a new steel plant in Houston, Texas. Its construction cost per ton of steel ingot capacity was estimated to be somewhere between $250 and $350. According to an extrapolation of the historical trend, as shown in Chart 13, the capital coefficient in 1957 should be about $310, which is quite close to the average construction cost of the planned plant in Houston.

Engineering Estimate

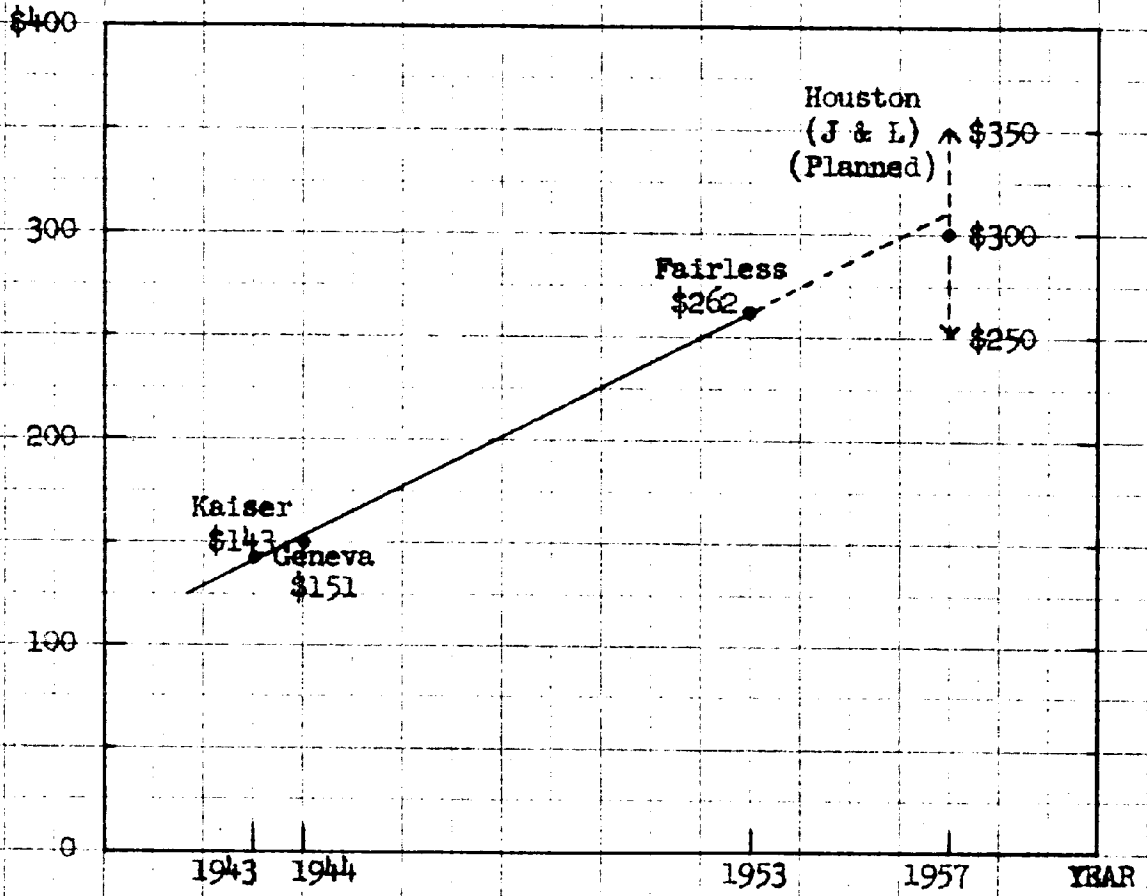
Some studies of the capital coefficient of new steel plants have been made on an engineering basis. The most comprehensive study in recent years was developed in 1953 by Steward M. Marshall for the Rand Corporation.[1] The study

---

[1]Steward M. Marshall, "A Review of the Steel Industry of the United States," The United States Air Force Research, Rand Research Memorandum, RM-1091 (California: 1953), Table XV, pp. 50-53.

Chart 13

CAPITAL COEFFICIENTS OF NEW AND COMPLETELY INTEGRATED STEEL PLANTS BUILT SINCE 1943



was conducted to estimate the replacement costs of all steel facilities plus expenses of construction on unprepared sites. The estimated replacement costs were based on the existing facilities as of mid-1952, when the steel industry had 112.2 million tons of annual ingot capacity. The replacement or construction costs were estimated on a plant basis with 66 average plants altogether required to furnish the annual ingot capacity. Thirty-three of these plants had an annual ingot capacity of 1.1 million tons each; the remainder had 2.3 million tons each.

The results of the above study are summarized in Table 20 and can be compared with the historical capital coefficients shown in Table 19. The capital coefficient estimated on the engineering method is $272 and is based upon the 1953 price level and the steel technology at that time. This figure differs slightly from the estimated coefficient of the Fairless plant in 1953, which is about $264.

Prospective Capital Coefficient

While the capital coefficients of new-plant expansion in 1953 are not directly applicable to the study of future investment, they do establish a basis for predicting a prospective capital coefficient with necessary adjustments for future conditions in terms of the price level, the degree of integration and the technology of steel production. As explained earlier, changes in these three factors will have considerable influences on the value of the capital coefficient.

TABLE 20[a]

ESTIMATED REPLACEMENT CONSTRUCTION COSTS FOR THE STEEL INDUSTRY IN 1953

Ingot Capacity - Tons per Annum

Plant A = 1,100,000; Plant B = 2,300,000
Total Ingots = 112,200,000

Steel Facilities	Estimated Cost
Plant A[b]	$ 131,400,000
Plant B[b]	232,700,000
Total 33 pairs of plants A and B	12,015,000,000
Mills for Hot-Rolled and other Finished Products[c]	6,846,000,000
Electrical Equipment[d]	5,100,000,000
Miscellaneous not included above	1,539,000,000
Total Fixed Assets, excluding under-surface construction	$25,500,000,000
Under-Surface Construction[e]--about 20%	5,100,000,000
Total Replacement Costs	$30,600,000,000
Capital Coefficient	$272

[a]Source: Stewart M. Marshall, "A Review of the Steel Industry of the United States," U. S. Air Force Research, Research Memorandum RM-1091 (California: 1953), Table XV, pp. 50-53.

[b]Includes pumping plants, coke ovens, blast furnaces and mould foundry, steel-making furnaces, skull cracker and cinder yard, ingot stripper, blooming mills, railroads, offices, shops, sanitary buildings, and laboratories, boiler plants and power houses, electric distribution and substations, steam compressed air oxygen and acetylene distribution and liquid fuel facilities, roads, fences, miscellaneous.

[c]Includes all kinds of finished steel product capacity as well as miscellaneous heating and annealing furnaces. The relative capacity of each type of mill conforms to the actual composition of product-mix in the steel industry at the time of the study.

[d]Electrical equipment excludes generators and distribution systems which are included above in Plants A and B.

[e]Under-surface construction includes sewers, water, gas and other mains, electrical conduits and miscellaneous pipe lines and other water front developments.

The historical coefficients may first be adjusted for change in the price level. Since the purpose of this study is to estimate the capital coefficient and capital investment in dollars of 1957 purchasing power, the historical costs per unit of capacity expansion require an adjustment for price change from 1953 to 1957. According to the Engineering News Record Construction Costs index, the price level increased 20.6 per cent during the four-year period. Adjusted for this price change, the capital coefficient in 1957 dollars will amount to $328 for the type of new plants included in the engineering study and $318 for the Fairless plant.

The historical coefficients in dollars of 1957 purchasing power generally require further adjustments for the steel technology and the degree of integration, which will characterize the future net expansion. However, no adjustment in the past coefficients is needed for the prospective technology, because the future technology is not expected to change materially from the technical pattern which featured the capacity expansion in 1953. The adjustment for the degree of integration, on the other hand, is necessary because of the difference in this element among the past and future plants. As revealed in Table 21, the degree of integration of these plants varies significantly, and the degree of integration which characterizes the future plant expansion appears to be in the middle. Consequently, the average value of the two historical coefficients in dollars of 1957

TABLE 21

DEGREE OF INTEGRATION IN NEW STEEL PLANTS

Degree of Integration	Fairless Steel Plant[a]	Hypothetical Steel Plant[b]	Future Steel Plant[c]
Ratio of coke to pig iron capacities	.772	.883	.632
Ratio of pig iron to steel ingot capacities	.630	.716	.725
Ratio of steel ingot to hot-rolled capacities	1.278	1.332	1.297

[a]From Table 1.

[b]Stewart M. Marshall, op. cit., Table II, p. 9.

[c]From chapter iii.

purchasing power, which is $323, can be used to represent the prospective capital coefficient of new and completely integrated plants to be built in the 1958-1970 period.

Capital Coefficient of the Non-New-Plant Expansion

In addition to the capacity expansion through new and completely integrated plants, the steel industry normally undertakes a substantially greater capacity expansion through additions of new equipment and enlargement of existing facilities. As shown in Table 22, the capacity expansion by these means for each type of steel facility accounted for 85 per cent or more of total capacity additions in the 1951-1955 period.

For the purpose of projecting the capital needs for the non-new-plant expansion in the future period, a study of

TABLE 22[a]

PER CENT OF TOTAL CAPACITY ADDITIONS BY VARIOUS TYPES OF EXPANSION, 1951-1955

Type of Facility	New Plant (Per Cent)	New Equipment in Existing Plants (Per Cent)	Enlargement of Existing Facilities (Per Cent)
Coke Ovens	14.6	66.7	18.7
Blast Furnaces	11.4	43.8	44.8
Steel-Making Furnaces	9.6	38.4	52.0

[a]Source: American Iron and Steel Institute, Unpublished Monographs to the Brookings Institution, 1957.

the capital coefficients for this phase of capacity expansion will be undertaken. The capital coefficient for the industry in 1957 dollars of purchasing power will be ascertained on the basis of the past capacity additions in the 1951-1955 period, for which the data necessary for the estimates are made available by the American Iron and Steel Institute. The capital coefficient derived from the past expansion will be further adjusted for the estimated degree of integration in the net capacity expansion. The adjustment can be accomplished by (1) making two different estimates of the capital coefficient of the whole steel industry and of the eight largest steel companies, and (2) comparing the degree of integration of the capacity additions by the steel industry with the eight largest companies and evaluating

effects of variation in the degree of integration on the capital coefficients.

The selection of the time period for the study of the past capital coefficients provides two distinct advantages. First, the capital coefficients estimated on the basis of a five-year period are more likely to resemble the normal pattern of the capacity expansion. In any one year, the industry may concentrate its capacity expansion on a particular facility in order to attain better balance with other facilities which have excess capacity. Since the capital coefficients are estimated in terms of annual steel ingot capacity, the estimated coefficients of expansion in a short period may be abnormally high or abnormally low. Secondly, the capital coefficients of a five-year expansion are more representative of the normal characteristics of capacity expansion. The capital coefficients will represent the normal effects of capacity expansion in various geographical areas and the effects of other factors which basically cause interplant variation in the capital coefficients. In any one year, a few of these factors may exert abnormally strong influence on the value of the industry-wide coefficients.

The use of a long period in the study of the historical coefficients also has some inherent weaknesses because it introduces the effects of changes in price and technology. Fortunately, the effect of technological change on the capital coefficients has been considered nominal in the previous discussion, and thus the estimated capital

coefficients will require no adjustment for technological change. The effect of price changes, however, must be adjusted for in the estimation of capital coefficients in dollars of 1957 purchasing power. Since capital expenditures in different years represent dollars of different purchasing power, each of the annual expenditures must be converted to dollars of 1957 value. The value conversion can be accomplished by using the Engineering News Record Construction Costs index as the deflator, since the index most closely represents the purchasing power of dollars for steel facilities.

An additional problem which requires attention in the study of capital coefficients is the time lag between the capital outlays and the completion of the capacity construction. This time lag usually differs from one facility to another. In an exploratory study of investment costs and capacity in iron and steel by the United States Department of Commerce,[1] it was reported that the time lag--the length of time elapsing between the delivery date of a given item and the date when the facility for which the item is purchased begins production--for various equipment and construction items is as follows:

Type of Facility	Average Time Lag in Months
Coke oven plants	15
Blast furnace plants	15
Open-hearth plants	15
Electric furnace plants	10
Rolling mills	12

[1] U. S. Department of Commerce, Unpublished Mimeograph on the Investment Costs and Capacity in Iron and Steel, September, 1953.

The average lag times of the various facilities above are applicable to specific plants. The construction of new and completely integrated plants which combines all these facilities may take from two to three years from the time of starting ground work to the time of completion. On the other hand, capacity expansion by enlargement of existing facilities or by adding new equipment to the existing plants may take only a few months. Consequently, the average time lag between the capital outlays and the capacity expansion should be approximately one year. This average time lag must be recognized in estimating the capital coefficients from the ratios of capital outlays to capacity additions.

Estimate of the Past Capital Coefficients in Dollars of 1957 Purchasing Power

The foregoing discussion has indicated the necessity of adjustment for the price change and the time lag in estimating the historical coefficients for the non-new-plant expansion. The following analysis will estimate these capital coefficients for the whole industry and for the eight largest steel companies.[1] Because of the limited availability of data on the gross ingot capacity additions, which are used as the denominator of the capital coefficients, the estimate for the industry and for the eight companies will be based on the 1951-1955 expansion and the 1952-1956 expansion

---

[1]These estimates require data on capital outlays exclusive of those for new and completely integrated plants and comparable data on gross additions of steel ingot capacity.

respectively. The capital coefficient for the industry will be estimated by the ratio of the capital outlays in constant dollars of 1957 purchasing power during the 1950-1951 period to the gross capacity expansion in steel ingot facility during the 1951-1955 period. The reason for the use of the capital outlays in constant dollars is to eliminate the effects of price change on the capital coefficients, and the reason for the use of the time periods in the ratio is to allow for the effect of the average time lag. The same process is followed in the estimation of the capital coefficient for the eight steel companies, except for the capital outlays during the 1951-1955 period which will be compared with the gross ingot capacity expansion during the 1952-1956 period.

In Table 23, the data on annual capital expenditures for the periods selected for the study, and the annual capital expenditures are adjusted to the dollar of 1957 purchasing power by the ENRCC index. These data, however, include the capital outlays and the gross capacity expansion by new and completely integrated plants, which must be deducted from their respective totals for use in estimating the capital coefficients of the non-new-plant expansion.

The needed data on capital expenditures and gross capacity additions and the estimates of capital coefficients of the capacity expansion exclusive of new plants are developed systematically in Table 24. The estimated capital coefficients of the non-new-plant expansion in dollars of 1957 purchasing power are $173 for the industry and $208 for the eight leading steel companies. The higher capital

TABLE 23[a]

ANNUAL CAPITAL EXPENDITURES AND ANNUAL GROSS CAPACITY EXPANSION

For the Whole Steel Industry from 1951 to 1955

Year	I Annual[a] Capital Expenditures ($000)	II ENCC Index (1957-100)	III Annual Capital Expenditures in 1957 Dollars ($000)	IV 5-Year Total 1950-1954 ($000)	V Annual Gross Capacity Expansion[b] (N.T.Ingot)	VI 5-Year Total 1951-1955 (N.T.Ingot)
1955					3,429,450	
1954	680,000	86.8	783,410		1,954,040	
1953	1,000,000	82.9	1,206,273		8,966,830	30,755,160
1952	1,170,000	78.8	1,484,772	5,591,767	10,520,800	
1951	1,041,000	74.8	1,391,711		5,884,040	
1950	513,000	70.7	725,601			

For the Eight Largest Steel Companies from 1952 to 1956

				(1951-1955)		(1952-1956)
1956					4,235,500[b]	
1955	592,560	91.2	649,737		2,108,000	
1954	490,329	86.8	564,895		1,423,000	21,034,400
1953	733,692	82.9	885,033	4,583,242	5,617,500	
1952	1,014,610	78.8	1,287,576		7,650,400	
1951	894,609	74.8	1,196,001			

[a]Standard and Poors Industrial Surveys, Steel, CXXIV, No. 26 (June 28, 1956), Sec.2.

[b]American Iron and Steel Institute, unpublished monographs to the Brookings Institution, 1957.

TABLE 24

CAPITAL COEFFICIENTS OF CAPACITY EXPANSION EXCLUSIVE OF NEW PLANTS IN DOLLARS OF 1957 PURCHASING POWER

		For the Industry (1951-1955)	For the Eight Companies (1952-1956)
Total Capital Expenditures	($000)	$ 5,591,767	$ 4,583,242
Estimated Outlays for New Plants[a]	($000)	572,850	572,850
Total Expenditures Exclusive of New Plants	($000)	5,018,917	4,010,392
Total Gross Ingot Capacity Expansion	(N.T.)	30,755,160	21,034,400
Estimated Additions through New Plants[a]	(N.T.)	1,800,000	1,800,000
Total Ingot Expansion Exclusive of New Plants	(N.T.)	28,955,160	19,234,400
Estimated Capital Coefficients of Non-New-Plant Expansion		$173	$209

[a]These are the data for the U. S. Steel Fairless Plant. The capital outlays of 572.8 million dollars are the 1957 value of the estimated 475 million dollars expended on this plant in 1953. These estimates are also used in the industry's column despite the fact that there are few other small companies that expanded their ingot capacities through new plants. These plants, however, are not fully integrated and do not entail especially high costs; thus they are not included in the deducting amounts for the industry.

coefficient for the eight steel companies is attributable to the fact that these leading companies are more fully integrated in the scope of productive activities than is the industry as a whole.

Estimate of the Prospective Capital Coefficient

The prospective capital coefficient of the non-new-plant expansion can be estimated from the past coefficients with proper adjustment for the degree of integration which will characterize the net capacity expansion during the 1958-1970 period. The degrees of vertical integration, as measured by the relative capacity expansion among the various types of steel facilities, in the past and prospective expansion are shown for comparison in Table 25. The capacity

TABLE 25

THE DEGREE OF INTEGRATION IN PAST AND FUTURE EXPANSION

Degree of Integration	For the Industry[a] (1958-1970)	For the Industry[b] (1951-1955)	For the 8 Largest Steel Companies[b] (1952-1956)
Ratio of Coke to Pig Iron	.632	.769	.817
Ratio of Pig Iron to Steel Ingot	.725	.462	.510
Ratio of Steel Ingot to Hot-Rolled Steel	1.297	c	c

[a]See chap. iii.

[b]American Iron and Steel Institute, Unpublished Monograph to the Brookings Institution, 1957.

[c]Not available.

relationship between coke and pig iron for the future net expansion appears to be considerably less than either of the relationships for the past expansion. The opposite is true in the relationship between pig iron and steel ingot capacity. Unfortunately, no data are available for comparison in the capacity relationships between steel ingots and hot-rolled steel. With such fragmentary evidence, it is admittedly difficult to adjust the capital coefficients of the non-new-plant expansion for use in estimating the future capital requirement.

The lack of sufficient evidence makes it necessary to adjust the estimated capital coefficients by judgment. From the past experience of the steel industry, the capital cost per annual ton of blast furnace capacity appears to be substantially higher than that of coke oven capacity.[1] Consequently, the ratio of pig iron to steel ingot capacity in the future net expansion will have considerably greater effects on the prospective capital coefficient than the ratio of coke to pig iron capacity. Another important consideration is the expectation that the degree of integration in mining, transportation, and finishing facilities of the steel industry will increase gradually through time. While the data on these facilities are not available, this expectation is justified by the relatively more rapid growth of the smaller

---

[1]Marshall, op. cit., Table XV, p. 50.

steel companies in the past few decades.[1] Increase in the size of the smaller companies frequently enables them to take advantage of the increased integration.

Because the capacity relationship between pig iron and steel ingots in the future net expansion is substantially higher than that of the past expansion, and because the degree of integration in the steel industry is expected to increase in certain types of facilities, the past capital coefficient for the industry as a whole should be adjusted upward for the prospective coefficient. It will not be as high, however, as the coefficient for the eight largest companies, since they are already fully integrated in all types of facilities. Consequently, the industry will need to spend somewhere between $173 and $208 in 1957 purchasing power per ton of annual ingot capacity in the future net expansion exclusive of new plants. The average of the upper and lower limits, which is $190, will therefore be assumed in the final analysis of the capital needs for net expansion.

Estimated Proportion of the New-Plant Expansion

The preceding analysis has provided the prospective capital coefficients of the new-plant and the non-new-plant expansion separately. Projection of the capital requirement for net expansion requires an estimate of the relative

---

[1]The eight largest companies accounted for 79.0 per cent of the industry's annual ingot capacity in 1940, but their importance declined to 76.8 per cent in 1950, and to 76.1 per cent in 1957. These statistics may be interpreted to show that the smaller companies have been growing more rapidly.

importance of the new-plant expansion in the total capacity increase of the steel industry during the 1958-1970 period. Such an estimate will form a basis for determining the value of the over-all capital coefficient applicable to the required net capacity expansion.

Only a small proportion of capacity expansion in the past decade has taken the form of new and completely integrated plants because of the high initial investment. The three main factors which are responsible for the expansion through new and completely integrated plants are: (1) need to change location due to the pull of market demand and to the new discovery of raw materials, (2) physical limitation of the existing plants, and (3) change in technology or new ways to produce steel which makes the new-plant expansion economical. Each of these factors must be reviewed in the appraisal of their effects on the proportion of new plant expansion in the future period.

The normal rate of progress and the change in structure of the United States economy have created new geographical markets for steel products and have encouraged new plant expansion in those areas. The main steel consuming and producing areas have long been in the northeastern part of the United States. However, the South and the West have been gaining in their relative importance in the total steel consumption and production. In the seven-year period from 1947 to 1954, steel consumption in the outlying states increased 37 per cent whereas consumption in the northeastern areas rose

only 13 per cent. In the same period, hot-rolled production in the South and West increased 20.6 per cent but production in the Northeastern areas declined by 0.9 per cent.[1] The outlying states also showed the most rapid growth in the number of steel-using, metal fabricating establishments with an increase of 64 per cent in comparison with an increase of 31 per cent in the main areas.[2]

These statistics should not be used to obscure the fact that the importance of the northeastern regions to the steel industry still far overshadows that of the outlying states. In 1954, steel production, consumption, and the number of steel-consuming units in the northeastern part still accounted for 76.5 per cent, 75.7 per cent and 68 per cent of their respective totals in the United States.[3]

At any rate, the more rapid growth in the outlying states is expected to continue in view of the population shift to the South and West and the rapid general economic growth of the southwestern states. This shift in geographical markets plus the increased availability of iron ore supplies, which may come from Venezuela and Liberia as well as domestic sources in the southern and western districts, will undoubtedly encourage new plant expansion in the outlying states.

The physical limitations of the existing plants will also become an increasingly important factor in the near

---

[1]American Iron and Steel Institute, Steel Facts, No. 149 (April, 1958), pp. 6-7.

[2]Ibid.

[3]Ibid.

future. In the past few decades, the industry has been avoiding capacity additions through new plants because of the high capital cost of new installations. As a result, expansion in the existing plants has been pushed to or near the physcial limits of these plants. This tendency is evident in the United States Steel Corporation which found the ratio of its land value to depreciable assets dwindled gradually from 4.2 per cent in 1940 to 1.6 per cent in 1957.[1] The extent of decline may be partly ficticious because of the inflationary effect in the depreciable assets added during the period. Nevertheless, the decline in the ratio of land to depreciable assets was sufficiently sizable to warrant the interpretation. This tendency naturally makes future expansion in the existing plants more and more difficult, and eventually the industry will be forced to expand its capacity through new plants despite the high initial investment.

Change in technology may also be a factor which will influence new plant expansion. While no revolutionary change in technology is anticipated in the 1958-1970 period, the new direct-reduction process may be economically attractive in certain areas where natural gas is cheap and plentiful. However, the expansion of new plants using this new technique is not expected to be substantial.

In summary, all three factors discussed above point to greater capacity additions through new plants. The proportion of new plant expansion, which represented less than

---

[1]United States Steel Corporation, Annual Reports.

10 per cent of total ingot capacity expansion between 1951 and 1955, will therefore increase considerably. For the purpose of projecting the capital requirement for expansion, this proportion will be assumed at 20 per cent. The remaining 80 per cent of the net capacity additions in the 1958-1970 period is attributable to the non-new-plant expansion.

Estimated Capital Requirement for Expansion

The estimated proportion of the capacity expansion through new plants and the capacity expansion through non-new-plants plus the previously estimated capital coefficients of each type of expansion make possible an estimate of total capital requirement for net expansion by the following formula:

$$C = \frac{(NX + OY)}{100\%} \cdot S$$

where C = Total capital needs for net expansion in dollars of 1957 purchasing power,

O = Per cent proportion of ingot capacity addition through other types of expansion (or = 100 - N),

N = Per cent proportion of ingot capacity addition through new and completely integrated plants,

X = Capital coefficient of the new and completely integrated plant in dollars of 1957 purchasing power,

Y = Capital Coefficient of non-new-plant expansion in dollars of 1957 purchasing power,

S = Required net expansion of ingot capacity,

$\frac{(NX + OY)}{100\%}$ = The over-all capital coefficient of the net capacity expansion in dollars of 1957 purchasing power.

From the previous analysis, the following quantities are estimated for the above algebraic symbols:

N = 20 per cent
O = 80 per cent
X = $323
Y = $190
S = 45,800,000 net tons

The substitution of these quantities in the formula shows that total capital requirement for net expansion

$$= \frac{(20\% \ (\$323) + 80\% \ (\$190)}{100\%} \ (45,800,000 \text{ net tons})$$

= $216.6 x 45,800,000 net tons

= $9,920,280,000 of 1957 purchasing power.

Consequently, the steel industry will need to spend 9.9 billion dollars of 1957 purchasing power to finance the estimated net expansion in steel plant and equipment between 1958 and 1970. Since the projected amount of the capital investment for expansion makes no allowance for future price changes, this investment in actual dollars may be higher or lower than the estimated amount to the extent of price changes. In any event, the capital requirement for net expansion represents only one of the two basic components of the total capital needs. The other is the capital requirement for replacement which will be estimated in the next chapter.

CHAPTER VI

CAPITAL REQUIREMENT FOR REPLACEMENT

The preceding chapter has indicated the volume of capital outlays required to finance the net additions between 1958 and 1970 to the existing capacity of the steel industry at the end of 1957. The purpose of this chapter is to estimate the amount of capital expenditure needed to replace the portion of the existing capacity which will be retired during the 1958-1970 period for reasons of physical wear and tear and obsolescence. The sum of the capital for expansion and the capital for replacement will constitute the total needs for the capital investment of the steel industry.

The proportion of the total capital investment attributable to the replacement of existing capacity has grown to the point where it has now assumed an important role in the capital planning of the steel industry. Between 1946 and 1955, the capital outlays for replacement accounted for approximately 41 per cent of total capital expenditures.[1] This proportion is expected to be even greater in the future period for two reasons: (1) the prospective growth in size of the industry will be relatively smaller during the 1958-1970

---

[1]Clark E. Chastain, "Depreciation in the Steel Industry," Unpublished Ph. D. dissertation, University of Michigan, 1958, p. 136.

period than in the past decade[1] and (2) the level of capacity being exposed to retirements has gradually increased through time. The relative importance plus the increasing tendency of the capital replacement, therefore, make it advisable to estimate this phase of the total capital investment separately.

Preferably, the study of capacity replacement should be made in terms of physical units for each type of steel facility. When a piece of equipment reaches the end of its useful life because of physical deterioration or technological obsolescence, it will normally be replaced with a new piece of equipment. In a long-run study of a growing industry, replacement demand of a particular type of equipment depends theoretically upon its average useful life, age distribution, and rate of survivorship. Since the availability of physical data for each type of steel facility is inadequate for estimates of replacement demand in terms of physical units, an alternative approach which deals with aggregate steel facilities in dollar value has been suggested.

Method of Analysis

The method used in the estimation of the above three factors is generally known as the simulated plant balance

---

[1]The average net increase of steel ingot capacity was approximately 4.2 millions of tons annually between 1947 and 1956, whereas the annual net increase for the 1958-1970 period is estimated to be only 3.8 million tons. Because of the time lag between capital outlays and capacity increase, the capital expenditures between 1946 and 1955 should indicate capacity expansion between 1947 and 1956.

method. The method requires, perhaps, the minimum amount of empirical data--that is, a series of annual additions and a series of total plant balances at year end, in dollar value, at original cost. It is clear that fixed assets acquired in the previous years still remain in the plant balance unless they have been retired, and that each of the annual additions in the previous years are subject to a series of retirement rates according to the age of the assets. The first task of this analysis is to estimate this pattern of retirement, or the survivorship rate. With this information known, it is relatively easy to determine average life and age distribution of the steel facilities in dollar terms.

The method can best be explained by an example. Assume a series of annual additions of depreciable assets and a series of plant balances at year end of an enterprise as follows:

Year	$Annual Additions	$ Plant Balances
1950	100	*
1951	150	*
1952	160	*
1953	240	429
1954	170	445
1955	280	530
1956	320	634
1957	340	719

*Not required.

Each of the annual additions is subject to retirement by ages, and the remaining amount should be included in the plant balance. The manual method of the simulated plant balance suggests that a survivor pattern of those assets may be assumed and tested for its validity. This survivor rate,

when applied to the annual additions, will yield a series of estimated plant balances. Complete agreement between the estimated plant balances and the actual plant balances would ascertain the survivor rate typical of those assets under study. The process, however, is one of trial and error and thus is time-consuming. The assumed survivor rate or life curve of those assets may have to be changed several times before satisfactory results are obtained in comparing estimated plant balances with actual plant balances.

Suppose the best life curve from the trial and error method is found to be as follows:

Age	Survivorship Rate
0	1.000
.5	.900
1.5	.750
2.5	.500
3.5	.200
4.5	0

This life curve can readily be verified by direct application to the series of annual additions as shown in Table 26.

It is clear that the assets acquired in 1953 will be approximately .5 year old at the end of 1953 and 1.5 years old at the end of 1954, and so forth. Since 90 and 75 per cent of assets would still survive after .5 and 1.5 years respectively, the assets acquired at $240 in 1953 would remain in the plant balances at $216 at the end of 1953 and $180 at the end of 1954. Based upon this process, the plant balances at year end can be estimated on the basis of the assumed life curve. The estimated plant balances in the table show a

TABLE 26

STATISTICAL TEST OF THE ASSUMED LIFE CURVE UNDER THE SIMULATED PLANT BALANCE METHOD

Year	Annual Additions	Remaining Plant Balances at Year End				
		1953	1954	1955	1956	1957
1950	100	20	---	---	---	---
1951	150	75	30	---	---	---
1952	160	120	80	32	---	---
1953	240	216	180	120	48	---
1954	170		153	127	85	34
1955	280			252	210	140
1956	320				288	240
1957	340					306
Estimated Plant Balances		431	443	531	631	720
Actual Plant Balances		429	445	530	634	719

striking resemblance to the actual plant balances and the similarity means a high degree of reliability of the assumed life curve.

The typical curve of the assets provides a basis for determining the average life of the assets. The method and computation of this average life are presented in Table 27.

Besides the life curve and average life, the age distribution of assets is automatically illustrated in

TABLE 27

DETERMINATION OF AVERAGE LIFE[a] FROM LIFE CURVE

Age	Survivor-ship Rate	Units Surviving at Given Age	Units Retired in Age Interval	Unit Years of Service During Age Interval
0	1.000	100	10	47.5
.5	.900	90	15	82.5
1.5	.750	75	25	62.5
2.5	.500	50	30	35.0
3.5	.200	20	20	10.0
4.5	.000	0	--	--
			100	237.5

[a]Average Life = $\frac{237.5}{100}$ = 2.375 years.

Table 26. At the end of 1957, total assets in the book are $720, of which $306 are .5 years old, $240 are 1.5 years old, $140 are 2.5 years old, and the remaining $34 are 3.5 years old. There is, according to the life pattern, no asset over 4.5 years old.

The age distribution, average life, and life curve of the assets provide sufficient information for an estimate of future replacement demand not only for those assets prevailing by 1957, but also for assets added in future years, provided future annual net additions are also known.

Assume annual net additions in the next three years to be $320, $360, and $400 respectively. This information plus the known plant balance in 1957 by years of acquisition

and the rate of survivorship or retirement make possible the estimate of replacement requirements for both the existing assets and future net asset additions. The computations for this estimate are systematically shown in Table 28.

TABLE 28

HYPOTHETICAL COMPANY: ESTIMATED REPLACEMENT NEEDS FOR THE 1958-1960 PERIOD

Years of Acquisition	1957 Plant Balance by Years of Acquisition and New Net Addition	Replacement Needs[a]			
		1958	1959	1960	Total for 3 years
1953	---	---	---	---	---
1954	$ 34	$ 34	---	---	$ 34
1955	140	84	$ 56	---	140
1956	240	80	96	$ 64	240
1957	306	51	85	102	238
	Sub Total	$249	$237	$166	$652
1958	320	32	48	80	160
1959	360	---	36	54	90
1960	400	---	---	40	40
	Grand Total	$281	$321	$340	$942

[a]Estimated by the annual rate of retirements by age of assets as follows:

Age in Years	Rate of Retirements	Rate of Survivorship
0		1.000
0.5	.100	.900
1.5	.150	.750
2.5	.250	.500
3.5	.300	.200
4.5	.200	.000

On the basis of the above computation, $942 of the assets in terms of their original costs will be retired in the 1958-1960 period. If there has been no price change since 1954, that amount will correspond to expenditures needed to replace similar assets. If price has changed annually and the extent is known, the replacement expenditures in constant dollars may be estimated by adjusting the anticipated annual retirements by years of acquisition with the known price index.

Analytical Limitations of the Simulated Plant Balance Method

The method used in the above analysis is based on a number of assumptions. First, it is assumed that none of the annual additions prior to 1950 still remain in the plant balance by 1953. The condition, however, can be fulfilled by taking the historical date of annual additions for a full or almost-full span of the life cycle, so that the remaining amounts of additions in the early years are negligible or insignificant in the plant balances under comparison. It is not necessary to compare more than a limited number of annual plant balances.

Secondly, it is assumed that all annual additions are for brand new assets, and that no acquisitions or disposals of assets are made through merger. In reality, these conditions do not usually exist, particularly in regard to acquisitions of assets. If a significant amount of annual additions is made through merger, it is theoretically necessary

to reallocate those amounts according to years of installation. Similar adjustments are theoretically desired for retirements of assets through mergers. Unfortunately, this kind of information is usually meager, and the best that can be done is to estimate it.

The third assumption is that the pattern of retirement and the average life are rigidly fixed. In actual practice, asset retirements are postponable and, as a result, the average life may shift. Other important reasons for a shift in the average life may be the changing proportion of various types of assets and the continuous addition of new assets which have different average lives. The problem of the replacement postponement, however, is not serious in a long-run study of capital replacement, because it is not customary to defer retirements longer than a period of business cycle. The composition of steel assets, on the other hand, is not likely to change much because the technology of steel production has not changed substantially since the turn of the century. Because of the slow change in the basic technology and the long-run nature of this study, the discrepancy between the assumed and the actual conditions can be tolerated.

Apparently, the method is conceptually sound, but the problem in connection with the empirical data is still a serious one. Not many industries have kept records of the data required for the analysis or made adjustments for merger movements, and the results of this type of analysis can only be as good as the data.

Inflationary Effects on the Value Approach

It should be emphasized that the analysis deals with dollar value of assets at original cost. In this respect, a question may be raised whether or not the effect of price changes may invalidate the technique. Basically, price changes alone have no effect on the outcome of this analysis because both annual additions and plant balances are recorded at original cost, and each of the annual additions represents an independent group of units to be exposed to retirement by ages. The fact that the plant balances represent an aggregation of dollars of varying purchasing powers is therefore consistent with the analytical procedure.

In a special circumstance, however, the inflationary effects can cause a bias in the estimates of the life characteristics. This tendency may materialize when recent asset additions are associated with inflated cost as well as higher or lower average useful life. Since all assets are recorded at original cost, the recent additions at inflated cost relative to the total assets are apparently greater than their physical counterparts. Consequently, if the recently added assets are characterized also by an average life different from the past average, the calculated average life of the whole assets will have a bias to the extent that the average life of the recently added assets are weighted relatively more than their physical counterparts. If the added assets have a longer average life, the computed average usefulness of the whole assets will have an upward bias.

The opposite is true if the added assets have a shorter average life. The bias will not occur, however, when there is no shift in the life of assets.

Approach to the Computation of Life Curve

The extensive time requirement associated with manual computations according to the simulated plant balance method is fortunately eliminated by the use of an electronic digital computer. A mathematical program designed to compute survivor curves by the above method in the IBM "650" electronic computer has been made available to this study by the Detroit Edison Company. Detroit Edison has employed this technique in estimating average life for various facilities with the use of physical data. However, as explained earlier, the simulated plant balance can be used with either physical data or value data.

The computation of life curves by the mathematical program requires the same type of value data as does the manual method. The computation requires eight plant balances for comparison and a long series of annual additions, preferably about one life span of the steel assets. The objective of this program is to produce the average life and the life curve of the assets under study, which, in view of the actual asset additions and retirements, will minimize the squared deviations of the estimated eight plant balances from the actual ones. The life curve derived from this program is expressed in three parameters, which can be formulated into a survivor curve at different ages. The technical

aspects of this program are presented in appendix B on "a, b, c, System of Life Curves."

Study of the Life Pattern of the Depreciable Assets of the Steel Industry

The application of the simulated plant balance method by the "650" computer to the problem in the steel industry requires familiarity with the general characteristics of the steel facilities. For the most part, the steel facilities are highly durable and very costly. The average life of steel facilities has been conceded to be about 25 years by the Internal Revenue service. From time to time, the spokesmen of the industry have expressed their belief in a longer average life.

Since the average life is about 25 years or more, the average life span of these assets can be expected to be 50 or more years. It means, therefore, that a series of annual additions for that period are preferred in the computation for complete accuracy. A quick check on the availability of data suggests that no usable data on the industry's annual capital outlays are available prior to 1915. The coverage indicates only 41 years of data, which is short of the ideal. However, in a rapidly growing industry like the steel industry, the annual additions in the earlier years are likely to be very small in relation to the more recent additions, as a result both of physical growth and of the inflated costs of assets. Consequently, the additions prior to 1915 which are still in use in the 1950's should not account for a

substantial proportion of total plant balances. The margin of error thus appears to be acceptable.

The steel industry also provides limited data in the area of merger movements. Most of the mergers, however, are intertransactions between steel companies themselves; and thus, these actions are not detrimental to the quality of the asset data, provided the analysis deals with the asset account of the entire industry. The mergers between steel and non-steel companies are few, and the lack of information necessary to adjust for such mergers makes it necessary to neglect their effect.

The analysis of asset life of steel facility, however, is not entirely feasible, since the data on capital expenditures and plant balances on an industry basis are rather sporadic, and are not definitely uniform and comparable. On the other hand, an attempt to conduct the study of the industry on a sample basis, or for the thirteen largest steel companies, will introduce the problem of acquisitions and disposals due to mergers. In this analysis, therefore, it appears desirable to study the life curve for both the industry and the thirteen steel companies. Although the result of each is subject to certain short-comings, the two life curves derived from their approach provide a better basis for ascertaining the survivor rate of all steel facilities and thus a reliable estimate of asset retirement.

Statistics of the Life Analysis of Depreciable Steel Assets

The composition of steel fixed assets can be broken down into two basic components: depreciable fixed assets and non-depreciable fixed assets. Since only the first component is subject to retirement and replacement, the following life analysis will be undertaken with the use of depreciable asset data.

The compilation of data for the thirteen steel companies and for the industry requires a certain degree of statistical adjustment in view of the existing imperfections in the available records on steel assets. The process of developing such data is explained in Appendix C. The end results for both annual additions and annual plant balances are presented in Table 29.

Estimated Life Curve for the Steel Facility

From the statistical data, life curves of depreciable steel assets are computed by the "650" computer for the thirteen companies and for the industry. The life curves indicating the survivor rate for each year of age are shown in Table 30 and Chart 14.

Both of these life curves are quite similar in their characteristics, having the same average life of 34 years, no retirements of assets under 15.5 years old, and the same life span of about 42.5 years. While these features may deviate quite significantly from the previous conception of the steel facilities, they are nevertheless dependent upon

TABLE 29

ANNUAL ADDITIONS OF DEPRECIABLE ASSETS, 1915 TO 1956

Year	13 Companies (Millions of Dollars)	Industry (Millions of Dollars)
1956	1095	1129
1955	604	687
1954	510	640
1953	838	941
1952	1076	1101
1951	913	980
1950	446	483
1949	444	480
1948	602[a]	549
1947	522[a]	422
1946	414[a]	274
1945	124[a]	139
1944	100[a]	263
1943	181[a]	677
1942	225[a]	518
1941	247	400
1940	169	161
1939	99	114
1938	129	132
1937	308	301
1936	181	203
1935	114	132
1934	39	40
1933	49	51
1932	39	40
1931	116	122
1930	289	306
1929	145	152
1928	194	203
1927	155	163
1926	222	234
1925	194	203
1924	174	183
1923	116	122
1922	97	102
1921	97	102
1920	185	194

TABLE 29--Continued

Year	13 Companies (Millions of Dollars)	Industry (Millions of Dollars)
1919	155	163
1918	232	245
1917	328	346
1916	270	285
1915	164	173
Depreciable Plant Balances, 1949 to 1956		
1956	11,170	12,640
1955	10,115	11,532
1954	9,723	10,969
1953	9,031	10,527
1952	8,057	9,763
1951	7,234	8,544
1950	6,887	7,585
1949	6,522	7,027

[a]Depreciable additions of the 13 companies in 1946, 1947, and 1948 are not consistent with the industry's additions, since their actual amounts cannot possibly exceed the industry's totals. This inconsistency is due to the government-financed plant expansion during the war, which is properly recorded in the industry's additions by year of acquisitions, but not recorded as outlays or additions in the 13 steel companies until after the war when the ownership of these plants were transferred. As a result, the additions of the 13 companies during the war are underestimated but overestimated for three years after the war. These discrepancies, however, are not believed to cause material errors in the determination of their assets' life characteristics.

TABLE 30

ESTIMATED LIFE CURVES OF STEEL DEPRECIABLE ASSETS COMPUTED BY THE SIMULATED PLANT BALANCE METHOD

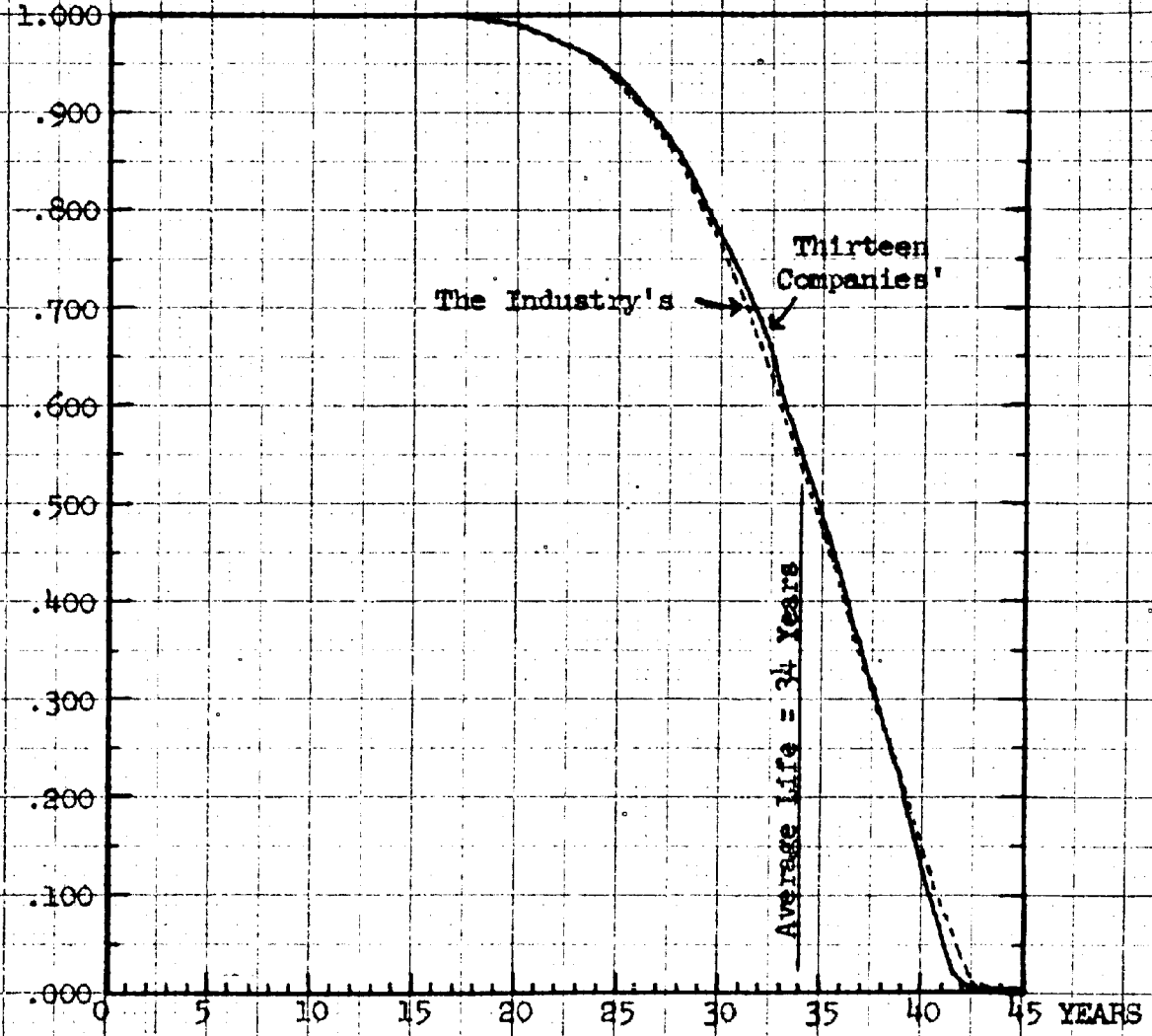
Age in Years	The Thirteen Steel Companies		The Industry	
	Survivor Rate	Retirement Rate	Survivor Rate	Retirement Rate
0	1.0000	.0000	1.0000	.0000
0.5	1.0000	.0000	1.0000	.0000
1.5	1.0000	.0000	1.0000	.0000
2.5	1.0000	.0000	1.0000	.0000
3.5	1.0000	.0000	1.0000	.0000
4.5	1.0000	.0000	1.0000	.0000
5.5	1.0000	.0000	1.0000	.0000
6.5	1.0000	.0000	1.0000	.0000
7.5	1.0000	.0000	1.0000	.0000
8.5	1.0000	.0000	1.0000	.0000
9.5	1.0000	.0000	1.0000	.0000
10.5	1.0000	.0000	1.0000	.0000
11.5	1.0000	.0000	1.0000	.0000
12.5	1.0000	.0000	1.0000	.0000
13.5	1.0000	.0000	1.0000	.0000
14.5	1.0000	.0000	1.0000	.0000
15.5	1.0000	.0009	1.0000	.0010
16.5	0.991	.0020	0.9990	.0019
17.5	0.9971	.0028	0.9971	.0027
18.5	0.9943	.0039	0.9944	.0039

TABLE 30--Continued

Age in Years	The Thirteen Steel Companies		The Industry	
	Survivor Rate	Retirement Rate	Survivor Rate	Retirement Rate
19.5	0.9904	.0053	0.9905	.0054
20.5	0.9851	.0070	0.9851	.0073
21.5	0.9781	.0094	0.9778	.0098
22.5	0.9687	.0120	0.9680	.0127
23.5	0.9567	.0153	0.9553	.0162
24.5	0.9414	.0192	0.9391	.0204
25.5	0.9222	.0235	0.9187	.0250
26.5	0.8987	.0284	0.8937	.0301
27.5	0.8703	.0337	0.8636	.0356
28.5	0.8366	.0392	0.8280	.0411
29.5	0.7974	.0450	0.7869	.0467
30.5	0.7524	.0506	0.7402	.0519
31.5	0.7018	.0561	0.6883	.0565
32.5	0.6457	.0609	0.6318	.0604
33.5	0.5848	.0652	0.5714	.0633
34.5	0.5196	.0685	0.5081	.0649
35.5	0.4511	.0707	0.4432	.0654
36.5	0.3804	.0717	0.3778	.0651
37.5	0.3087	.0718	0.3127	.0644
38.5	0.2369	.0715	0.2483	.0632
39.5	0.1654	.0708	0.1851	.0615
40.5	0.0946	.0700	0.1236	.0597
41.5	0.0246	.0246	0.0639	.0573
42.5	0.0000	.0000	0.0066	.0066
43.5	0.0000		0.0000	
		1.0000		1.0000
Ave. Life		34 yrs.		34 yrs.

Chart 14

RATE OF SURVIVORSHIP AND AVERAGE USEFUL LIFE OF DEPRECIABLE STEEL ASSETS



the period used in the analysis and the accuracy of the data. The long average life may be influenced by slow technological change and high demand, two characteristics of the period after 1940. It may also be partially affected by a shift to longer average life of the more recent asset additions at inflated cost, the element which can cause an upward bias in the estimated average useful life. Unfortunately, the extent of bias is virtually impossible to determine and adjust for in the light of present knowledge. At any rate, by its nature and the extent of inflation, the bias will not account for a great proportion of the excess of the estimated average life over the preconceived 25-year life. This is so because it takes a shift in average life in the first place, with a supplement of inflationary effects, to induce the bias. Therefore, the shift must actually have occurred, although the degree is somewhat exaggerated. As a result, retirements at original cost, estimated on this basis, will be understated to some extent.

The survivor rate and the estimated span of life suggest that, while there will certainly be some assets retired before they reach 15.5 years of age and there will be some assets still surviving after 42.5 years, the proportion of these retirements and survivorship are insignificant in terms of the total.

The accuracy of the simulated-balance technique through the "650" computer can be tested by applying the survivor rate to the annual additions and determining the

estimated plant balances according to years of acquisition from 1949 to 1956. The squared deviations between the estimated and the actual plant balances are least according to the "650" program. As revealed in Table 31 and Chart 15, the estimated plant balances show a remarkable resemblance to the actual plant balances. Consequently, the accuracy of this technique appears to be satisfactory.

TABLE 31[a]

COMPARISON BETWEEN THE ESTIMATED PLANT BALANCES FROM THE LIFE CURVE AND THE ACTUAL PLANT BALANCES

(in Millions of Dollars)

Year	For 13 Steel Companies			For the Industry		
	Estimated	Actual	Per Cent Deviation from Actual	Estimated	Actual	Per Cent Deviation from Actual
1949	6,577	6,516	0.9	7,603	7,027	8.2
1950	6,917	6,863	0.8	7,973	7,585	5.1
1951	7,711	7,686	0.3	8,827	8,544	3.3
1952	8,656	8,661	-0.1	9,793	9,763	0.3
1953	9,352	9,352	0.0	10,586	10,527	0.6
1954	9,708	9,745	-0.3	11,071	10,969	0.9
1955	10,147	10,223	-0.7	11,591	11,532	0.5
1956	10,955	11,170	-1.9	12,545	12,640	-0.8

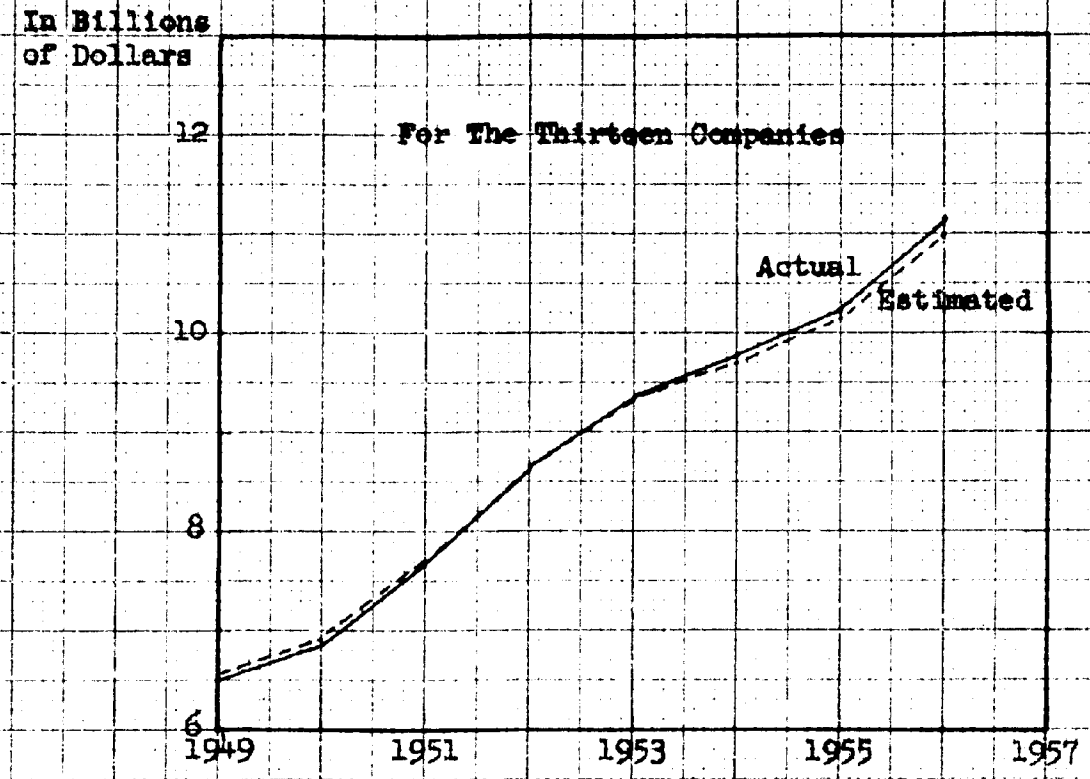
[a]Statistical Computations for this table are shown in Appendix D.

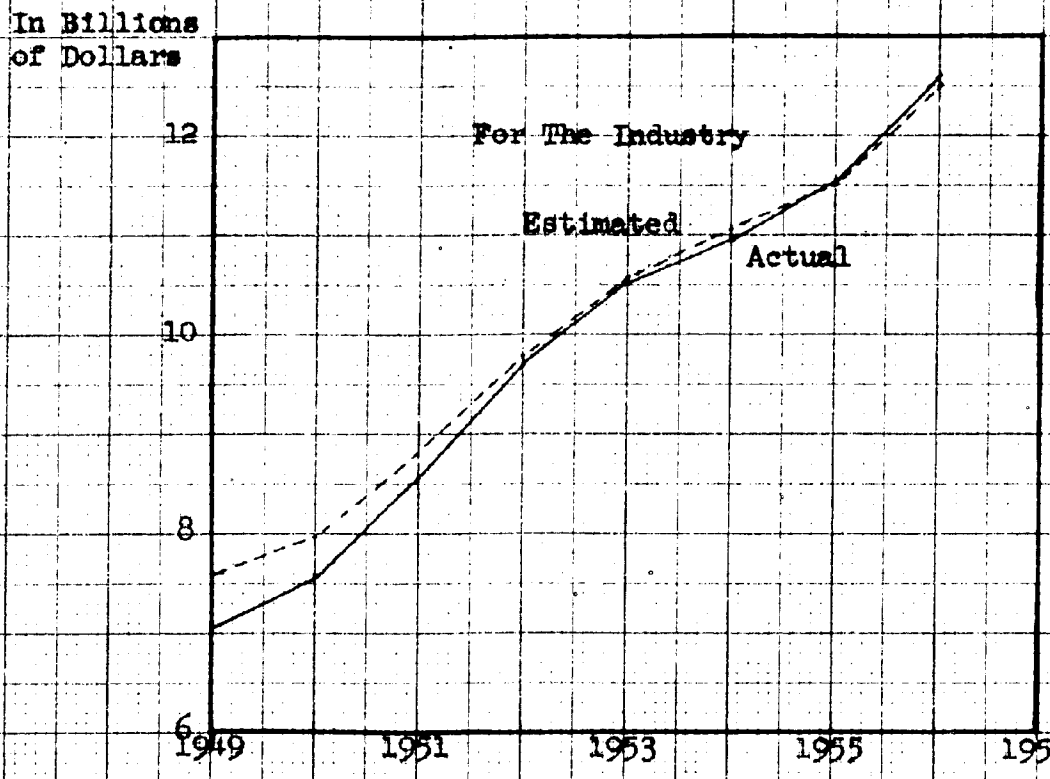
Estimated Future Retirements at Original Cost

The preceding life analysis has provided necessary information for an estimate of future retirements at original

Chart 15

COMPARISON BETWEEN PLANT BALANCES ESTIMATED FROM LIFE CURVE AND ACTUAL PLANT BALANCES, 1949 - 1956





cost. The annual rate of retirement can be easily estimated from the derived life curve. The difference between a pair of survivor rates applicable to two different ages indicates the proportion of total addition subject to retirement between those two ages. As revealed in Table 30, the estimated annual rate of retirement suggests that, for each annual addition of depreciable assets of the steel industry, none will be retired in the first 15.5 years; .10 per cent of the annual addition will be retired between 15.5 and 16.5 years of age and so forth. The annual retirements range from zero to 6.54 per cent of the annual addition according to the estimated life curve. Similar information can be obtained for the depreciable assets of the thirteen largest steel companies.

Total annual retirements between 1958 and 1970 can be estimated from the series of annual additions in the past. Since there will be no retirements of assets under 15.5 years old, the assets acquired between 1955 and 1970 will not be subject to retirements during the 1958-1970 period. The process of estimating annual retirement by years of acquisition is rather simple. The assets acquired in 1920 will be 37.5 years old at the beginning of 1958 and 38.5 years old at the end of 1958. The rate of retirement of the assets between 37.5 and 38.5 years old will determine how much of the assets acquired in 1920 will be retired in 1958 at original cost. The process is repeated for acquisitions in other years until total estimated 1958 retirement is obtained.

According to this process, the retirements at original cost can theoretically be estimated either annually or for a period of years. Since asset retirements are postponable, the estimated retirements based on a long period are usually more valid.

In Table 32 the future annual retirements of steel assets and the future total retirements between 1958 and 1970, estimated on the basis of annual additions and retirement rates (shown in Appendix D), are presented for the thirteen steel companies and for the industry. The estimated annual retirements indicate a remarkable stability, which is not likely to be the case in actual situations. The reason is that, in reality, business conditions play important roles in the decisions relating to annual retirement of assets. Therefore, only total estimated retirements for a long period are considered significant, because cyclical variation in retirements does not materially change the total amount.

Future retirements between 1957 and 1970 at original cost are estimated to be 2,260 million dollars for the thirteen leading steel companies and 2,530 million dollars for the industry. The reason for including 1957 in the future estimates is that the analysis is based on empirical data up to 1956. But the year 1957 can be easily excluded by deducting estimated retirements for 1957 from the totals, yielding 1958-1970 estimated retirements. On this basis, 2,082 million dollars are expected for retirements for the

TABLE 32[a]

ESTIMATED FUTURE RETIREMENTS OF STEEL ASSETS AT ORIGINAL COST BASED ON ANNUAL ADDITIONS AND RETIREMENT RATES

(in Millions of Dollars)

Year	The Thirteen Steel Companies	The Industry
1957	178.6	184.3
1958	173.0	184.4
1959	162.2	178.2
1960	154.3	168.5
1961	152.0	163.8
1962	150.5	164.1
1963	152.3	164.1
1964	156.7	169.3
1965	160.4	175.9
1966	161.6	182.6
1967	161.6	187.8
1968	161.5	194.1
1969	165.3	200.5
1970	170.5	212.4
Total 1957-1970	2,260.5	2,530.0
Total 1958-1970	2,081.9	2,345.7

[a]Statistical computations for this table are shown in Appendix D.

thirteen leading steel companies and 2,346 million dollars for the industry.

It is interesting to note that the estimated retirements for the thirteen companies account for about 90 per cent of the retirements for the entire industry. In terms of annual ingot capacity, however, the thirteen companies own about 85 per cent of the industry. The higher ratio in the estimated retirements indicated higher capital coefficients or greater degree of integration in the thirteen largest companies.

Capital Requirements for Replacement

The estimation of retirements at original cost is the first step in the determination of capital requirements for replacement. Since prices and costs have been rising almost continuously for many years, capital outlays required to replace retired facilities have usually exceeded their original costs. Consequently, in view of the price changes, it is necessary to estimate retirements at replacement cost.

Two sets of data are required for this purpose: (1) asset retirements according to years of acquisition, and (2) a price index which closely reflects changing costs of steel facilities. The asset retirements by years of acquisition have been made available in the preceding analysis. (See Appendix D.) The Engineering News Record Construction Costs index has heretofore been used as the cost indicator of steel facility. However, the question arises whether

this index is valid for a long-run analysis, since it has maintained a constant weight system since 1913. In view of the changing technology, it is unlikely that those construction components have remained stable.

Shown below are the fixed components of the index and their relative costs to the total in 1913 and 1956. The increased proportion of labor costs indicates that wages have been rising more rapidly than other component prices.

Index Components	1913 Relative Costs[1]	1956 Relative Costs[1]
25 cwt. of steel	38.0	17.1
.6 bbl. cement	7.0	20.5
0.6 M ft. bm. southern pine	17.0	
200 man-hours common labor	38.0	62.4
	100.0	100.0

The composition of materials and labor required in the construction of steel facilities is almost certain to have changed considerably between 1913 and 1956. Electrical equipment, which is not even recognized in this index, has been of increasing importance to the steel facilities. Consequently, if this index is compiled specifically to indicate change in the construction cost of steel facilities since 1913, the rigidity of the index components should cause a substantial degree of error in its use as the cost indicator of steel facilities.

The ENRCC index, however, is not compiled specifically for the changing costs of steel assets, and despite its constant component weight system, this index appears to be more

---

[1]United States Steel Corporation: Steel and Inflation, Fact vs. Fiction, 1958, p. 51.

appropriate than other indexes. The justifications for its use have been partly the more appropriate coverage of the index's components, and partly the close agreement, both in the short run and in the long run, between the changing costs of steel facilities and the cost index. The latter justification is supported by the United States Steel Corporation, which owns a large share of the industry's annual ingot capacity.[1] Consequently, the Engineering News Record Construction Costs index can serve as an appropriate deflator in the evaluation of asset retirements at replacement cost.[2]

When the ENRCC index is used as the cost deflator, the estimated total retirements at original cost can be translated into the capital needs for replacement in dollars of 1957 purchasing power. The translation is possible because the estimated assets for retirement can be subgrouped according to their years of acquisition. This value conversion is shown in Table 33 for both the industry and the thirteen leading steel companies.

As revealed in Table 33, the industry will have to spend $7,851 millions of 1957 purchasing power for replacement alone between 1958 and 1970. For the same period, the

---

[1] Ibid., pp. 50-51.

[2] Close agreement between change in the ENRCC index and change in the actual capital coefficients of steel facilities gives rise to an interpretation that the index can be used to adjust asset costs for not only historical price change but for past technological change as well.

TABLE 33

ESTIMATED CAPITAL REQUIREMENTS FOR REPLACEMENT OF STEEL FACILITIES FOR THE PERIOD 1958 TO 1970

Years of Acquisition	Cost Deflator ENCC Index (1957-100)	For the 13 Companies		For the Industry	
		Estimated Retirements at Original Costs	Estimated Requirements for Replacement in 1957 Dollars	Estimated Retirements at Original Costs	Estimated Requirements for Replacements in 1957 Dollars
		(Millions)		(Millions)	
1955 - 1970	---	0.00	0 00	0 00	0.00
1954	86.8	0.46	0.53	0.64	0.74
1953	82.9	2.43	2.93	2.73	3.29
1952	78.8	6.13	7.78	6.17	7.83
1951	74.8	8.77	11.72	9.31	12.45
1950	70.7	6.64	9.39	7.20	10.18
1949	65.7	9.72	14.79	10.66	16.23
1948	63.9	18.84	29.48	17.57	27.50
1947	57.5	22.60	39.30	18.86	32.80
1946	48.5	24.25	50.00	16.69	34.41
1945	42.5	9.66	22.73	11.30	26.59
1944	41.2	10.13	24.59	27.96	67.86
1943	40.0	23.48	58.70	92.34	230.85
1942	38.2	36.77	96.26	89.10	233.25
1941	35.7	49.79	139.47	84.84	237.65
1940	33.4	41.36	123.83	41.36	123.83

TABLE 33--Continued

1939	32.5	28.96	89.11	34.89	107.35
1938	32.4	44.47	137.25	47.35	146.14
1937	32.5	123.30	379.38	124.53	383.17
1936	28.6	82.99	290.17	95.35	333.39
1935	27.1	59.01	217.75	69.28	255.64
1934	27.3	22.49	82.38	23.10	84.62
1933	23.5	30.99	131.87	31.94	135.91
1932	21.7	26.74	123.23	26.82	123.59
1931	25.0	85.06	340.24	86.45	345.80
1930	28.0	224.17	800.60	226.44	808.71
1929	28.6	117.74	411.68	116.15	406.12
1928	28.6	154.70	540.91	158.40	553.85
1927	28.4	116.62	410.63	120.65	424.82
1926	28.7	155.79	542.82	161.06	561.18
1925	28.6	125.27	438.01	128.26	448.46
1924	29.7	101.75	342.59	104.57	352.09
1923	29.5	60.27	204.30	61.99	210.13
1922	24.0	43.76	182.33	45.21	188.38
1921	27.9	36.90	132.26	38.54	138.14
1920	34.7	57.11	164.58	60.66	174.81
1919	27.3	36.71	134.45	40.47	148.24
1918	26.1	38.38	147.05	45.35	173.75
1917	25.0	31.03	124.12	42.77	171.08
1916	18.0	6.64	36.89	18.21	101.17
1915	12.8	---	---	1.14	8.91
Total		2,081.88	7,036.10	2,346.30	7,850.91

thirteen largest steel companies will need $7,036 millions, or about 90 per cent of the industry's total replacement requirements. The ratio is approximately the same in terms of the original cost.

While it will cost the thirteen companies 7 billion dollars of 1957 purchasing power to replace 2.1 billion dollars of assets at original cost, the industry needs to set aside 7.9 billion dollars for assets replacement of 2.3 billion dollars at original cost. In other words, it will cost the thirteen companies 3.38 times as much, in comparison with 3.35 times for the industry, to replace their old and obsolete assets in the period 1958-1970 as it did to purchase them originally.

The two estimates--for the thirteen companies and for the industry--indicate a remarkable degree of consistency, and this fact substantiates the estimated data. The estimate for the industry is, of course, the primary concern of this study.

Total Capital Requirements in the Steel Industry

The foregoing analysis discloses that total investment needed to finance the future growth of the steel industry will amount, in 1957 purchasing power, to 17,771 million dollars, of which 7,851, or 44.2 per cent, will be expended for replacing retired assets. While the capital requirement for replacement still accounts for less than half of the total capital needs, its relative importance has suggested

an increase from 41 per cent during the 1946-1955 period to 44.2 per cent during the 1958-1970 period.

The extent of the replacement increase may actually be greater than 3.2 percentage points in view of the suspected upward bias in the estimated average life of the assets. In any event, the growing relative importance of the replacement demand is theoretically consistent with the slow growth in size of the steel industry. The relative proportion of replacement expenditures in total investment may be expected to increase gradually as long as the industry is growing at a diminishing proportion, and replacement will surpass expansion investment in time. This belief is justified by the fact that in a stationary stage, where growth rate is zero, the entire amount of investment is made solely for replacement.

It should be re-emphasized that the total capital requirements between 1958 and 1970 are estimated in dollars of 1957 purchasing power. The actual outlays for this period will be different from the estimated amount to the extent of price changes. Furthermore, the estimated total capital outlays should be regarded only as first approximations, since the main emphasis of this dissertation lies not in the accuracy of the projection, but in the development of the methods of analysis applicable to such a study.

CHAPTER VII

SUMMARY AND CONCLUSIONS

It has been the purpose of the preceding chapters to appraise the future growth and the capital requirements of the steel industry between 1958 and 1970. The conclusions which have been formed as a result of this examination can now be summarized quickly.

In chapter I, the importance of capital investment to the steel industry and the basic problems involved in the determination of the capital needs have been presented. The capital investment or capital outlays for plant and equipment are relatively more important to the steel industry than to most other industries because of the size of the industry and the capital needs per dollar of annual sales. The high ratio of capital to annual sales appears to be influenced by the type of technology and the degree of vertical integration within the steel industry.

The basic problems involved in the analysis of capital needs stem from the hybrid nature of the capital investment. The capital outlays serve two different purposes: (1) to affect net increase in existing productive capacity, and (2) to replace obsolete or deteriorated facilities. The relative proportion of these two components of capital investment are not likely to remain constant over time, because

they are largely independent of each other. On one hand, the capital requirement for expansion is influenced by the growth in demand, while on the other hand, the replacement capital needed to maintain existing capacity is conditioned by the average useful life, the rate of survivorship, and the age of existing facilities. Because of their independence, it is concluded that the two components of total capital requirements must be estimated separately.

The determination of the capital needs for net expansion between 1958 and 1970 requires a projection of the growth of steel demand and the capacity level of the steel industry to 1970. The projection, which has been undertaken in chapter ii, makes use of regression techniques to develop a long-run relationship between real Gross National Product and steel ingot production. The requirement for steel ingot production at an estimated level of real Gross National Product in 1970 is determined from this relationship. The statistical deviations from the regression line used in the production estimate for 1970 form a basis for estimating steel ingot capacity in relation to the production level. The projected level of steel ingot capacity is 186.5 million tons annually. This capacity level is 16 per cent higher than the estimated level of steel production and appears to provide sufficient safety margin to meet peak short-run demand.

Since the steel ingot capacity represents only the melting segment of the steel industry, the growth requirements of other basic facilities must also be ascertained.

These are coke ovens, blast furnaces, and rolling mills. The requirements of these basic facilities and the steel-making furnaces are interrelated, because they are used in successive stages of steel production. A historical review of capacities at each stage indicates clearly that their interrelationships are mainly governed by the overall technology of steel production, which dictates the functional production requirements for each of these facilities. With the assumption that no revolutionary change in technology will occur within the steel industry between 1958 and 1970, the production relationships between the major producing functions are projected to 1970.

The interrelationships of production among the industry stages are used to derive corresponding capacity relations. When steel ingot capacity is used as a pivot upon which other capacities depend, the corresponding capacity requirements for coke ovens, blast furnaces and rolling mills are determined from the derived capacity relationships.

The projection to 1970 of these basic capacities has been developed in chapter iii by the above process. To be in balance with the requirement of 186.5 million tons of annual steel ingot capacity, the steel industry needs to maintain 93.2 million tons of annual coke capacity, 124.2 million tons of annual blast furnace capacity, and 144.5 million tons of annual hot-rolled steel capacity. The excess of these requirements over the existing capacities at the end of

1957 indicates the needs for net expansion and the degree of integration in the net expansion between 1958 and 1970.

In chapter iv, the problem of translating the net capacity expansion into the capital requirement for expansion and the problem of estimating capital needs for replacement have been considered. The problem which exists in the determination of capital expansion appears to be the variability of the capital coefficient which indicates the relationship between capital outlays and capacity additions. The variations in the capital coefficient stem mainly from the varying proportions of new plant expansion in total capacity additions, the varying degree of integration of capacity additions, and changes in price. To cope with this problem of variability, it is suggested that two different capital coefficients--capital coefficients of new-plant expansion and capital coefficient of non-new-plant expansion--be estimated separately, and that each coefficient be adjusted further for changes in price and the degree of integration desired in the net capacity expansion.

The problem involved in the determination of the capital needs for replacement is the lack of physical data necessary for the estimates of average useful life, the rate of survivorship, and the age distribution of steel facilities. To overcome this problem and yet maintain a separate analysis of capital replacement, it is proposed that the life characteristics of steel facilities be determined on the basis of the value data of steel depreciable assets. The method which can be used for this purpose is the

simulated plant balance technique. This technique requires only a long series of annual additions and a limited number of plant balances of depreciable assets.

The analysis of capital coefficients and the capital requirements for expansion are the subject matter of chapter v. The capital costs per ton of annual ingot capacity (capital coefficient) for new-plant expansion and non-new-plant expansion are expressed in dollars of 1957 purchasing power. The new-plant coefficient adjusted for the desired degree of integration and price changes is estimated to be $323, on the basis of expansion since 1943 and an engineering estimate. The non-new-plant coefficient, estimated from expansion experience during the period 1951-1955, is only $190 after the adjustments for the degree of integration and price changes.

The wide divergence in the capital coefficients for each type of capacity additions necessitates a projection of their relative proportions. For this projection, considerations are given to such factors as geographical shifts of market demand, physical limitation of the existing plants, and change in technology. All three factors point to greater capacity expansion through new plants. Consequently, it is felt that new-plant expansion should account for approximately 20 per cent of total new capacity additions. This proportion indicates a substantial increase from less than 10 per cent during the 1951-1955 period.

The relative proportion of new plant expansion plus the estimated capital coefficients for each type of capacity

expansion are used further in the computation of the over-all capital coefficient of net capacity expansion. This overall coefficient is found to be $217. Multiplication of this coefficient by the net increase in annual ingot capacity reveals that the industry will need about 9.9 billion dollars of 1957 purchasing power to finance the net expansion in its capacity to produce.

In chapter vi, the estimate of the life characteristics of steel facilities and the capital requirement for replacement has been undertaken. A review of the simulated plant balance technique suggests that this method is reasonably sound in dealing with annual additions and plant balances in dollars of different purchasing power. The application of this method to the available data on annual additions and plant balances makes possible the estimates of the rate of survivorship, the average useful life, and the age distribution of steel facilities. While the data available for this technique could be improved substantially, the analysis indicates that this approach has sufficient validity and might be used advantageously in the life study of assets in other industries where detailed physical data are lacking.

The estimated life characteristics of the steel facilities make possible an annual estimate of asset retirements at original cost segregated by years of acquisition. The retirements by years of acquisition require further adjustment for cost changes, and the Engineering News Record Construction Costs index appears suitable for this cost

adjustment. By this procedure, the capital needs for replacement are estimated to be 7.9 billion dollars of 1957 purchasing power.

The estimated total capital required to provide the projected level of steel ingot and other related capacities in 1970 therefore amounts to 17.8 billion dollars, of which 44.2 per cent is attributable to replacement needs. This proportion of the capital requirement shows a significant rise from the 41 per cent estimated for the capital outlays in the 1946-1955 period. Two important reasons are found for this rise: (1) the smaller growth in size in the 1958-1970 period relative to the past decade, and (2) the gradual increase of existing capacity exposed to retirements.

The magnitude of the projected capital outlays emphasizes the importance of maintaining conditions in which the financial mechanism of the steel industry can function adequately. If the past experience is any indication, the industry cannot expect to supply all the capital needs from retained earnings and depreciation. The steel industry, however, can attract external funds by maintaining the interest and confidence of investors. No attempt, however, has been made in this study to cover this problem.

It is to be re-emphasized that the principal objective of this dissertation has been to present a methodology for determining the capital requirements of the steel industry. In view of this objective, it is hoped that the techniques presented in this analysis will have further applications to other studies of similar nature.

APPENDICES

APPENDIX A

TABLE 1-A

FERROUS AND ALUMINUM PRODUCTION; U. S. POPULATION 1810-1957

Year	Population As of July 1[a] (Thousands)	Steel Ingots and Castings Production[b]	Pig Iron Production[c] (Tons)	Steel Ingot and Castings Production (Tons per Capita)	Primary Aluminum Production[d] (Tons)
1957	171,229	112,714,996	79,339,671	.658	1,647,764
1956	168,091	115,216,149	77,575,458	.684	1,679,247
1955	165,271	117,036,085	79,263,865	.708	1,565,785
1954	162,417	88,311,652	59,806,242	.544	1,460,565
1953	159,636	111,609,719	77,250,168	.699	1,252,013
1952	157,028	93,168,039	63,353,955	.593	937,330
1951	154,360	105,199,848	72,448,543	.682	836,881
1950	151,683	96,836,075	66,400,311	.638	718,662
1949	149,188	77,978,176	54,916,785	.523	602,468
1948	146,631	88,640,470	61,911,559	.605	623,460
1947	144,126	84,894,071	60,117,319	.589	571,752
1946	141,389	66,602,724	46,199,826	.471	409,632
1945	139,928	79,701,648	54,919,029	.571	495,060
1944	138,397	89,641,600	62,866,198	.649	776,448
1943	136,739	88,836,512	62,769,947	.651	920,184
1942	134,860	86,031,931	60,903,304	.639	521,112
1941	133,402	82,839,259	56,686,604	.622	309,072
1940	132,122	66,982,686	47,398,529	.508	206,280

TABLE 1-A--Continued

1939	131,028	52,798,714	35,677,097	.403	163,548
1938	129,969	31,751,990	21,460,164	.245	143,436
1937	128,961	56,636,945	41,582,550	.440	146,340
1936	128,181	53,499,999	34,752,689	.417	112,464
1935	127,362	38,183,705	23,937,423	.300	59,652
1934	126,485	29,181,924	18,075,202	.231	37,088
1933	125,690	25,724,643	14,947,074	.205	42,562
1932	124,949	15,123,477	9,835,227	.121	52,444
1931	124,149	28,607,310	20,637,516	.230	88,773
1930	123,188	44,590,808	35,562,429	.362	114,514
1929	121,770	61,741,962	47,727,661	.507	113,986
1928	120,501	56,623,009	42,734,400	.470	105,272
1927	119,038	49,272,671	40,953,523	.414	81,803
1926	117,399	52,902,011	44,097,457	.451	73,693
1925	115,832	49,704,893	41,104,634	.429	70,058
1924	114,113	41,445,868	35,174,485	.363	75,282
1923	111,950	49,016,991	45,204,484	.438	64,329
1922	110,055	38,945,226	30,486,292	.354	36,816
1921	108,541	21,638,719	18,690,701	.199	27,266
1920	106,466	46,183,227	41,357,105	.434	69,021
1919	105,063	38,099,180	34,737,207	.365	64,238
1918	104,550	49,010,095	43,741,201	.475	62,362
1917	103,414	49,787,196	43,255,762	.482	64,730
1916	101,966	46,792,802	44,166,973	.459	57,553
1915	100,549	35,179,668	33,506,159	.350	45,252
1914	99,118	25,606,133	26,132,113	.258	28,986
1913	97,227	34,087,177	34,682,090	.351	23,639

TABLE 1-A--Continued

Year	Population As of July 1 (Thousands)	Steel Ingots and Castings Production[b] (Tons)	Pig Iron Production[c] (Tons)	Steel Ingot and Castings Production (Tons per Capita)	Primary Aluminum Production[d] (Tons)
1912	95,331	34,079,395	33,294,169	.357	20,903
1911	93,868	25,937,354	26,487,493	.276	19,198
1910	92,407	28,329,748	30,579,995	.307	17,701
1909	90,492	26,217,980	28,890,928	.290	14,540
1908	88,709	15,383,124	17,848,340	.173	
1907	87,000	25,375,029	28,875,124	.292	
1906	85,437	25,443,455	28,344,054	.298	
1905	83,820	21,879,593	25,751,466	.261	
1904	82,165	15,205,247	18,476,677	.185	
1903	80,632	15,865,316	20,170,362	.197	
1902	79,160	16,401,912	19,959,864	.207	
1901	77,585	14,784,142	17,783,756	.190	
1900	76,094	11,227,229	15,443,951	.148	
1899	74,799	11,738,792	15,255,187	.157	
1898	73,494	9,888,072	13,186,806	.135	
1897	72,189	7,939,616	10,811,002	.110	
1896	70,885	5,849,344	9,657,902	.083	
1895	69,580	6,784,434	10,579,865	.097	
1894	68,274	4,898,574	7,456,275	.072	
1893	66,971	4,470,668	7,979,442	.067	
1892	65,666	5,491,616	10,255,840	.084	
1891	64,361	4,348,962	9,273,454	.068	
1890	63,056	4,779,005	10,307,027	.076	

TABLE 1-A--Continued

1889	61,775	3,783,715	8,516,079	.061
1888	60,496	3,237,941	7,268,507	.054
1887	59,217	3,733,002	7,187,206	.063
1886	57,938	2,870,004	6,365,328	.050
1885	56,658	1,917,350	4,529,869	.034
1884	55,379	1,736,985	4,589,613	.031
1883	54,100	1,874,359	5,146,972	.035
1882	52,821	1,945,095	5,178,122	.037
1881	51,542	1,778,912	4,641,564	.035
1880	50,262	1,397,015	4,295,414	.028
1879	49,208	1,047,506	3,070,875	.021
1878	48,175	819,814	2,577,361	.017
1877	47,141	637,972	2,314,585	.014
1876	46,107	597,174	2,093,236	.013
1875	45,073	436,575	2,266,581	.010
1874	44,040	241,614	2,689,413	.0054
1873	43,006	222,652	2,868,278	.0051
1872	41,972	160,108	2,854,558	.0038
1871	40,938	82,000	1,912,608	.0020
1870	39,905	77,000	1,865,000	.0019
1869	39,051	35,000	1,916,641	.00090
1868	38,213	30,000	1,603,000	.00079
1867	37,276	22,000	1,461,626	.00059
1866	36,538	18,973	1,350,343	.00052
1865	35,701	15,262	931,582	.00042

TABLE 1-A--Continued

Year	Population As of July 1 (Thousands)	Steel Ingots and Castings Production[b] (Tons)	Pig Iron Production[c] (Tons)	Steel Ingot and Castings Production (Tons per Capita)	Primary Aluminum Production[d]
1864	34,863	10,369	1,135,996	.00029	
1863	34,026	9,044	947,604	.00026	
1862	33,188		787,662		
1861	32,351		731,544		
1860	31,513	13,259	919,770	.00041	
1859	30,687		840,627		
1858	29,862		705,094		
1857	29,037		798,157		
1856	28,212		883,137		
1855	27,386		784,178		
1854	26,561		736,218		
1853	25,736		901,600		
1852	24,911		605,646		
1851	24,086		462,560		
1850	23,261		631,406		
1849	22,631		728,000		
1848	22,018		896,000		
1847	21,406		896,000		
1846	20,794		856,800		
1845	20,182		562,240		

TABLE 1-A--Continued

1844	19,569		544,320
1843	18,957		
1842	18,345		240,800
1841	17,733		
1840	17,120		321,331
1810	7,224	1,027	60,337

[a]Sources: 1957, U. S. Department of Commerce, Survey of Current Business, March 1958, pp. 3-11; 1900-1956, U. S. Department of Commerce, Statistical Abstract, 1957, p. 5; 1840-1899, U. S. Bureau of the Census, Historical Statistics, 1949, p. 26; 1930-1956, total population including armed forces overseas; 1840-1929, total population residing in U. S.

[b]Sources: 1956-1957, American Iron and Steel Institute, Annual Statistical Report, 1957, p. 53; 1887-1955, furnished by American Iron and Steel Institute: 1860-1886 data are not exactly comparable to the later data which do not include production of foundries normally producing steel only for castings. Data including these foundries is available only through 1933. During 1887-1905, these latter data are larger than those exhibited as follows:

1887	.181%	1889	.219%	1891	.546%	1893	.709%	1895	.941%
1888	.291	1890	.236	1892	.496	1894	.875		

Thereafter, until 1933, the data are 1.5 to 2% larger, on the average, than the data exhibited for this period.

[c]Sources: 1953-1957, American Iron and Steel Institute, Annual Statistical Report, 1957, p. 10; 1810-1952, Iron Age, June 1955, p. M-18. This includes ferroalloys production.

[d]Sources: 1955-1957, U. S. Department of Commerce, Survey of Current Business, March, 1956, 1957 and 1958, p. S-33; 1946-1954, U. S. Department of Commerce, Business Statistics, 1955 Biennial Edition, p. 159; 1909-1954, U. S. Department of Commerce, Historical Statistics of the United States, 1789-1945, Series G-125.

APPENDIX B[a]

a, b, c System of Life Curves Based on the Probability Functions

$$\frac{2}{\sqrt{\pi}} \int_0^X e^{-X^2} dX$$

This memorandum describes a system of life curves based on the probability function $\frac{2}{\sqrt{\pi}} \int_0^X e^{-X^2} dx$ which is tabulated in many mathematical and statistical books. An excellent tabulation is given in Tables of Probability Functions, Volume I, U. S. Department of Commerce, National Bureau of Standards, Washington, D. C. This table is available in libraries.

The curves are a further extension of the h type developed by the late H. B. Benson of the New York State Commission. The h type curves are all left-moded, however, and experience with utility property showed that right-moded curves were also needed. The proposed system of a, b, c curves yield a greater variety of dispersion types than either the h or Iowa curves, and lend themselves readily to evaluation with the use of commercially available electronic stored program computers.

---

[a]This appendix is a direct quotation from the paper made available to this study by the Detroit Edison Company.

Description of Curves

In the system of life curves based on the probability curves, three parameters, a, b, and c, are used to define the type of dispersion.

The value of a is a distortion factor which may be visualized by thinking of the retirements frequency curve as being cut from a rubber sheet. If the sheet is stretched horizontally from the mode to its termination so that every point is twice as far from the mode as usual, then a = 2.0. Values of a smaller than 1.0 may be visualized graphically as a horizontal shrinking of the retirements curve to the right of the mode. Small values of a will in general give right-moded curves, and large values will give left-moded curves. For symmetrical curves a must equal 1.0, and b must equal c.

The values of b and c are a measure of the distance from the mode to the initial and terminal points, respectively, of the retirements frequency curve. The values of b and c determine the height of the retirements frequency curve at its initial and terminal points, respectively. Large values of b will yield a narrowly dispersed retirements frequency curve such as the Iowa S6, L5, or R5 curves.

The assignment of values to the parameters a, b, and c completely defines a dispersion type in the proposed probability system. Other parameters could be added, but it is believed that the added refinement cannot justify the increased complexity of computing survivor tables.

Formulas for Computation of a Survivor Table

When the parameters a, b, and c are given, a value X_L, must be determined to fix the position of average life in terms of units of X in the probability function so that values of X for the probability function may be related to values of age as a per cent of average life for which a survivor table is desired. It may be shown (see following section) that X_L is given by the formula

$$X_L = \frac{(a^2-1)\ H^1(Q) + H^1(b) - a^2H^1(C)}{2H(b) + 2aH(c)}$$

where

$$H(X) = \frac{2}{\sqrt{\pi}} \int_0^X e^{-x^2} dX \qquad \text{[Area under frequency curve]}$$

and

$$H^1(X) = \frac{2}{\sqrt{\pi}} e^{-X^2}$$

Note that the exponentials and integrals may be read directly from tables once the parameters are given.

To visualize this and other quantities in the following discussion, refer to the graph in Figure 1.

Let A_1 equal the area under the retirements frequency curve from its beginning to its modal point, A_2 the area under the curve from the modal point to its terminal point, $A_{x'}$ the area from a point X^1 to the modal point ($-b \leq x^1 \leq 0$), and $A_{x''}$ the area from the modal point to a point ax" ($0 \leq ax'' \leq ac$). Therefore,

$$A_1 = H(b)$$

$$A_2 = aH(c)$$

$$A_{x'} = H(X^1)$$

$$A_{x''} = aH(X'')$$

where X^1 and X" are the values to the left and right, respectively, of the modal point for which survivor values may be wanted.

Since $(b+X_L)$ units of X correspond to 100% of average life, the values of the two quantities X^1 and X" are given by

$$-X' = B - z(b + XL) \qquad -B \leq X' \leq 0$$

$$X'' = \frac{(b + X_L)z}{a} - \frac{b}{a} \qquad 0 \leq X'' \leq C$$

where $z = \frac{h}{L}$ or the ratio of the age, h, for which a survivor is wanted and L = average life in years.

The survivor, y, at any ratio of age to average life is the ratio of future retirements to total retirements and is given by one of the two formulae;

$$y = \frac{A_2 + A_{x'}}{A_1 + A_2} \qquad y = \frac{A_2 - A_{x''}}{A_1 + A_2}$$

The first formula is used for negative values of X and the second is for positive values. The mode of the retirements frequency curve is the dividing line between positive and negative values of X.

The formulae may be rewritten as:

$$Y = \frac{aH(c) + H(X^1)}{H(b) + aH(c)} \qquad y = a\frac{H(c) - H(X'')}{H(b)+aH(c)}$$

For values of X^1 and X" not listed in the table, values for H(X) may be obtained by applying an interpolation formula.

Derivation of the Quantity X_L

By definition the mean of the abscissas of the retirements frequency curve is equal to average service life.' Expressed mechanically, if the retirements frequency curve were cut from a uniform piece of sheet metal, its vertical center of gravity, or average life, would be as indicated by the dotted line in Figure 1. If the curve is suspended along this dotted line, the condition of equilibrium may be expressed by the calculus as:

$$\frac{2}{\sqrt{\pi}}\int_{o}^{b}(X + X_L)e^{-X^2}dX + \frac{2}{\sqrt{\pi}}\int_{o}^{X_L}(X_L - X)e^{\frac{X^2}{a^2}}dX$$

$$= \frac{2}{\sqrt{\pi}}\int_{X_L}^{ac}(X - X_L)\ e^{\frac{X^2}{a^2}}dX$$

Transposing the second term to the right side of the equation, expanding, and noting that

$$\int_{X_1}^{X_2} f(X)dX + \int_{X_L}^{X_3} f(X)dX = \int_{X_1}^{X_3} f(X)dX$$

we obtain:

$$\frac{2}{\sqrt{\pi}}\int_{o}^{b} Xe^{-X^2}dX + \frac{2X_L}{\sqrt{\pi}}\int_{o}^{b} e^{-X^2}dX$$

$$= \frac{2}{\sqrt{\pi}}\int_{o}^{ac} Xe^{\frac{X^2}{a^2}}dX - \frac{2X_L}{\sqrt{\pi}}\int_{o}^{ac} e^{-\frac{X^2}{a^2}}dX$$

To integrate the four terms above and to come out with as simple an expression for X_L, as possible, make the following substitution:

$$z = X^2 \qquad W = X^2/a^2 \qquad V = X/a$$

$$XdX = \frac{dz}{z} \qquad XdX = \frac{a^2 dw}{2} \qquad dx = adV$$

$$\frac{2}{\sqrt{\pi}} \int_0^{b^2} \frac{e^{-z}dz}{2} + \frac{2X_L}{\sqrt{\pi}} \int_0^{b} e^{-X^2}dX = \frac{2a^2}{\sqrt{\pi}} \cdot \int_0^{c^2} \frac{e^{-w}dw}{2} - \frac{2aX_L}{\sqrt{\pi}} \int_0^{c} e^{-V^2}dv$$

$$\frac{1}{\sqrt{\pi}} - \frac{e^{-b^2}}{\sqrt{\pi}} + \frac{2X_L}{\sqrt{\pi}} \int_0^{b} e^{-X^2}dX = \frac{a^2}{\sqrt{\pi}} - \frac{a^2}{\sqrt{\pi}} e^{-c^2} 1 \frac{2aX_L}{\sqrt{\pi}} \int_0^{c} e^{-V^2}dV$$

$$X_L\left[\frac{2}{\sqrt{\pi}} \int_0^{b} e^{-X^2}dX + \frac{2a}{\sqrt{\pi}} \int_0^{c} e^{-V^2}dV\right] = \frac{1}{2}\left[\frac{2}{\sqrt{\pi}}(a^2 - 1) + \frac{2}{\sqrt{\pi}} e^{-b^2} - \frac{2a^2}{\sqrt{\pi}} e^{-c^2}\right]$$

$$X_L = \frac{\frac{2}{\sqrt{\pi}}(a^2 - 1) + \frac{2e^{-b^2}}{\sqrt{\pi}} - \frac{2a^2}{\sqrt{\pi}} e^{-c^2}}{2\left[\frac{2}{\sqrt{\pi}} \int_0^{b} e^{-X^2}dX + \frac{2a}{\sqrt{\pi}} \int_0^{c} e^{-V^2}dV\right]}$$

$$X_L = \frac{(a^2 - 1)\, H^1(o) + H^1(b) - a^2 H^1(c)}{2[H(b) + aH(c)]}$$

Derivation of formula for finding parameter at which $\Sigma\Delta^2$ is a minimum for an account with fixed average life and

fixed other two parameters.

Denote parameter being varied by X. Assume that similated balances follow a second degree equation or that:

$$B = K_1 + K_2X + KX^2$$

where the three K constants may be determined after three simulations have been made by solving the simultaneous equations:

(1) $B_1 = K_1 + K_2X_1 = K_3X_1^2$

(2) $B_2 = K_1 + K_2X_2 + K_3X_2^2$

(3) $B_3 = K_1 + K_1X_3 + K_3X_3^2$

(4) $B_2 - B_1 = K_2(X_2 - X_1) + K_3(X_2^2 - X_1^2)$ (2) - (1)

(5) $B_3 - B_2 = K_2(X_3 - X_2) + K_3(X_3^2 - X_2^2)$ (3) - (2)

(6) $\frac{B_2 - B_1}{X_2 - X_1} = K_2 + K_3 (X_2 + X_1)$ from (4)

(7) $\frac{B_3 - B_2}{X_3 - X_2} = K_2 + K_3(X_3 + X_2)$ from (5)

(8) $\frac{B_3 - B_2}{X_3 - X_2} - \frac{B_2 - B_1}{X_2 - X_1} = K_3(X_3 + X_2 - X_2 - X_1)$ (7) - (6)

If $X_2 - X_1 = X_3 - X_2 = .4$, then $X_3 - X_1 = .8$

(9) $\frac{B_3 - B_2 - B_2 + B_1}{.4} = .8K_3$ from (8)

(10) $K_3 = \frac{B_3 - 2B_2 + B_1}{.32}$ from (9)

(11) $$\frac{B_2 - B_1}{.4} = K_2 + K_3(X_2 + X_1)$$ from (6)

(12) $$K_2 = \frac{B_2 - B_1}{.4} - \frac{B_3 - 2B_2 + B_1}{.32}(X_2 - X_1)$$ from (10) and (11)

(13) $$K_1 = B_1 - K_2X_1 - K_3X_1^2$$ from (1)

(14) $$K_1 = B_1 - \frac{B_2 - B_1}{.4} X_1 + \frac{B_3-2B_2+B_1}{.32}(X_1X_2+X_1^2) - \frac{B_3 - 2B_2 + B_1}{.32} X_1^2$$

(15) $$K_1 = B_1 - \frac{B_2-B_1}{.4}X_1 + \frac{B_3 - 2B_2 + B_1}{.32} X_1X_2$$

$\Delta = B - B_k$ where B_k = Book Balance

(16) $$\Delta = (B_1 - B_k) + \frac{B_2-B_1}{.4}(X-X_1) + \frac{B_3-2B_2+B_1}{.32}(X-X_1)(X-X_2)$$

(17) $$.4\Delta = .4(B_1-B_k) + (B_2-B_1)(X-X_1) + \frac{B_3-2B_2+B_1}{.8}(X-X_1)(X-X_2)$$

(18) $$.16\Delta^2 = .16(B_1 - B_k) + (B_2 - B_1)(X - X_1)^2 + \frac{B_3-2B_2+B_1}{.8}(X-X_1)^2(X-X_2)^2 + .8(B_1-B_k)(B_2-B_1)(X-X_1) + (B_3-2B_2+B_1)(B_1-B_k)(X-X_1)(X-X_2) + \frac{1}{.4}(B_2-B_1)(B_3-2B_2+B_1)(X-X_1)^2(X-X_2)$$

To find where $\Sigma\Delta^2$ is a minimum, it is sufficient to find where the derivative of $\Sigma.16\Delta^2$ changes sign. The derivative is obtained by differentiating equation (18) after suitably modifying (18) so that it is $.16\Sigma\Delta^2$.

$$(19)\quad \frac{d(.16\Sigma\Delta^2)}{dx} = 2(X-X_1)\Sigma(B_2-B_1)^2 + \frac{(X-X_1)^2(X-X_2)+(X-X_2)(X-X_1)}{.32}$$

$$\Sigma(B_3-2B_2+B_1)^2 + .8\Sigma(B_1-B_k)(B_2-B_1)$$

$$+ [(X-X_1)+(X-X_2)]\Sigma(B_3-2B_2+B_1)(B_1-B_k)$$

$$+2.5[(X-X_1)^2+2(X-X_1)(X-X_2)]\Sigma(B_3-2B_2+B_1)$$

$$(B_2-B_1)$$

$$(20)\quad \frac{d(.16\Sigma\Delta^2)}{dx} = 2(X-X_1)\Sigma(B_2-B_1)^2+3.125(X-X_1)(X-X_2)$$

$$[(X-X_1)+(X-X_2)]\Sigma(B_3-2B_2+B_1)^2+.8\Sigma(B_1-B_k)$$

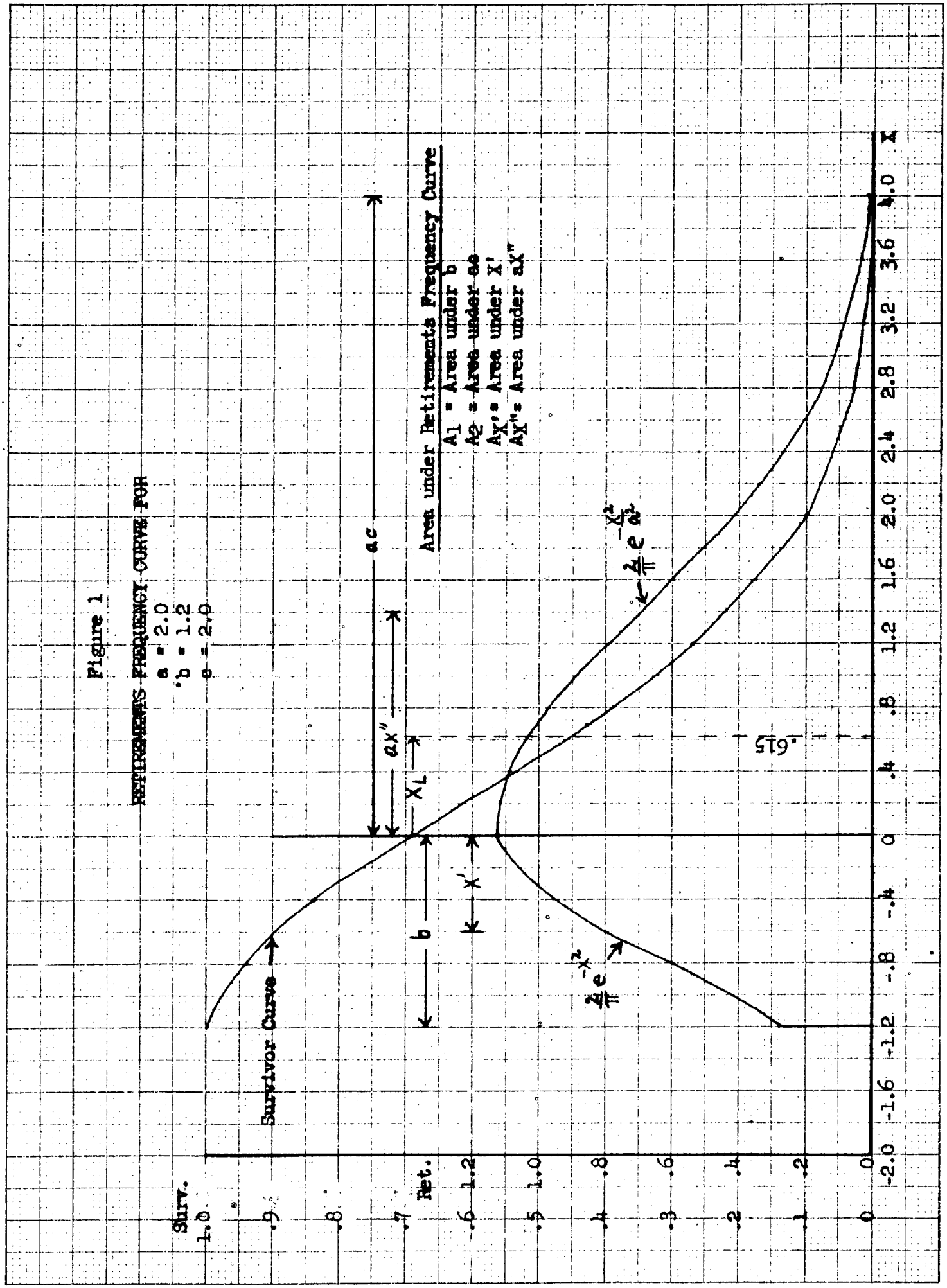
$$(B_2-B_1)+[(X-X_1)+(X-X_2)]\Sigma(B_3-2B_2+B_1)(B_1-B_k)$$

$$+2.5(X-X_1)[(X-X_1)+2(X-X_2)]\Sigma(B_2-B_1)$$

$$(B_3-2B_2+B_1)$$

When equation (20) changes sign, $\Sigma\Delta^2$ is a minimum (or maximum).

Evaluate (20) initially for X_1 and $X_1+.8$. Denote X_1 by X_{lo} and $X_1+.8$ as X_{hi}. If $(20)_{X_{lo}} < 0$ and $(20)_{X_{hi}} \geq 0$, then we have a minimum in the range $X_{lo} < X \leq X_{hi}$. If not, make a new trial for a smaller value of parameter if both values of (20) were +, and for a larger value of both values of (20) were —, but new trials are made only if difference in high and low parameters is .8; if less, continue to evaluate (20) until difference in high and low parameters is .1. Then go to new parameter or new account. Answer for a parameter is smallest absolute value of (20) for new hi or lo parameter = .1 (or the precision wanted for a given parameter).



10 X 10 TO THE ½ INCH 359-11
KEUFFEL & ESSER CO.

APPENDIX C

STATISTICS FOR THE L I F E ANALYSIS OF DEPRECIABLE STEEL ASSETS

The life curve and average life of depreciable assets of the steel industry were derived by a method of curve fitting and least squares deviation. The process was performed on an IBM "650" electronic computer and the data inputs for the computation consisted of estimates of depreciable additions from 1915-1956 and estimates of depreciable plant balances for the years 1949-1956.

Method of Obtaining Depreciable Additions for Thirteen Companies

Estimates for depreciable additions were derived by two methods, one method applicable for the period 1915-1934, the other method for the period 1935-1956. For the 1935-1956 period the information was obtained from reports submitted by the thirteen companies to the SEC. This information was in general complete; however, it was necessary to approximate the depreciable additions for individual companies for certain years.

For the period 1915-1934 the method of estimating depreciable additions was somewhat involved. For the years 1935-1956 capital expenditures for the entire industry were

plotted as the independent variable against depreciable additions for the thirteen companies as the dependent variable. The data were plotted on logarithmic scales, and a good correlation was noted. The equation for the line of regression fitting these data was derived. By assuming that the equation was applicable to the period 1915-1934 and by substituting into the equation the annual capital expenditure for the industry for the period 1915-1934, an estimate was derived for the depreciable additions for the thirteen companies.

Method of Obtaining Depreciable Plant Balances for Thirteen Companies

Estimates of plant balances for the period 1949-1956 were made by subtracting annual depreciable additions from the preceding year's depreciable plant balance and by adding back the annual depreciable retirements to this difference. The depreciable plant balance for the year 1956 was used as a starting point and a running balance was determined for each preceding year.

Method of Obtaining Capital Expenditures for the Entire Industry

The data for the capital expenditures for the industry were obtained from two sources. For 1935-1956 the annual expenditures were obtained from Standard and Poors Industry's Survey. For 1915-1934 the annual expenditures were derived from data contained in the Survey of Current Business. This data pertained only to the capital expenditures of the blast furnace, steel works, and rolling mill group; therefore, it

was necessary to adjust it upward to account for the total capital expenditures in all of the iron and steel industries. Their adjustment was made by comparing the data of a five-year period from the Survey of Current Business with capital expenditures of the entire industry for a similar period. A fairly constant ratio was noted and an average of these ratios was used to adjust the data.

Method of Obtaining Depreciable Additions for the Entire Industry

In the data obtained from the SEC reports it was possible to determine for the thirteen companies in the sample the ratio of depreciable additions to total capital expenditures. This ratio was found to remain fairly constant for each company over the period 1935-1956. An average of these ratios was derived and this average ratio was applied to the capital expenditures of the entire industry to obtain an estimate of depreciable additions for the entire industry. This ratio was also used to estimate depreciable plant balances from total plant balances.

Limitations of the Estimate of Depreciable Plant Balances for the Thirteen Companies

The particular method employed to determine the depreciable plant balances was used in order to remove, insofar as possible, the effect of additions made prior to 1915. In this method, which involves subtracting depreciable additions and adding retirements, it is believed that the plant balance

of the thirteen companies for the earlier years was overstated. This resulted from the fact that the depreciable additions represented only new assets, whereas the retirements represented assets which were originally obtained as new assets plus retirements of assets originally obtained as acquisitions. It was not possible to separate these two types of retirements..

APPENDIX D

COMPUTATIONS OF ESTIMATED PLANT BALANCES AND ANNUAL RETIREMENTS OF STEEL DEPRECIABLE ASSETS

TABLE 1-D

COMPARISON BETWEEN ESTIMATED AND ACTUAL PLANT BALANCES
(in Millions of Dollars)

Year	Annual Additions[a]	Estimated Plant Balances[b]							
		1949	1950	1951	1952	1953	1954	1955	1956
1915	173	88	77	65	54	43	32	21	11
1916	285	163	145	126	108	89	71	53	35
1917	346	219	198	176	153	131	108	86	64
1918	245	169	155	140	124	109	93	77	61
1919	163	121	112	103	93	83	72	62	51
1920	194	153	144	134	123	111	99	86	73
1921	102	84	80	76	70	64	58	52	45
1922	102	88	84	80	76	70	64	58	52
1923	122	109	105	101	96	90	84	77	70
1924	183	168	164	158	152	144	135	126	116
1925	203	191	186	181	175	168	160	150	140
1926	234	224	220	215	209	202	194	184	173
1927	163	158	156	153	150	146	141	135	128
1928	203	198	197	194	191	186	181	175	168
1929	152	150	149	147	145	143	140	136	131
1930	306	303	301	299	296	292	287	281	273
1931	122	121	121	120	119	118	117	115	112
1932	40	40	40	40	39	39	39	38	38
1933	51	51	51	51	51	50	50	49	49
1934	40	40	40	40	40	40	39	39	39
1935	132	132	132	132	132	131	131	130	129

TABLE 1-D--Continued

1936	203	203	203	203	203	202	202	201	200
1937	301	301	301	301	301	301	300	299	298
1938	132	132	132	132	132	132	132	132	131
1939	114	114	114	114	114	114	114	114	114
1940	161	161	161	161	161	161	161	161	161
1941	400	400	400	400	400	400	400	400	400
1942	518	518	518	518	518	518	518	518	518
1943	677	677	677	677	677	677	677	677	677
1944	263	263	263	263	263	263	263	263	263
1945	139	139	139	139	139	139	139	139	139
1946	274	274	274	274	274	274	274	274	274
1947	422	422	422	422	422	422	422	422	422
1948	549	549	549	549	549	549	549	549	549
1949	480	480	480	480	480	480	480	480	480
1950	483		483	483	483	483	483	483	483
1951	980			980	980	980	980	980	980
1952	1101				1101	1101	1101	1101	1101
1953	941					941	941	941	941
1954	640						640	640	640
1955	687							687	687
1956	1129								1129
Estimated Plant Balances		7603	7973	8827	9793	10,586	11,071	11,591	12,545
Actual Plant Balances[a]		7027	7585	8544	9763	10,527	10,969	11,532	12,640
Per cent Deviation from Actual		+8.2	+5.1	+3.3	+0.3	+0.6	+0.9	+0.5	+0.8

[a]Source: from Table 29.

[b]Estimated by the survivor rate obtained from the Simulated Plant Balance Method. See Table 30.

TABLE 2-D

THE THIRTEEN LEADING STEEL COMPANIES: COMPARISON BETWEEN ESTIMATED AND ACTUAL PLANT BALANCES

(in Millions of Dollars)

Year	Annual Additions[a]	Estimated Plant Balances[b]							
		1949	1950	1951	1952	1953	1954	1955	1956
1915	164	85.21	73.98	62.39	50.63	38.85	27.29	15.51	4.03
1916	270	157.90	140.29	121.80	102.71	83.35	63.96	44.66	25.54
1917	328	211.79	191.81	170.43	147.96	124.77	101.25	77.70	54.25
1918	232	162.82	149.80	135.67	120.55	104.66	88.25	71.62	54.96
1919	155	116.62	108.78	100.08	90.64	80.54	69.92	58.96	47.85
1920	185	147.52	139.19	129.83	119.45	108.19	96.13	83.45	70.37
1921	97	81.15	77.35	72.98	68.07	62.63	56.73	50.40	43.76
1922	97	84.42	81.15	77.35	72.98	68.07	62.63	56.73	50.40
1923	116	104.25	100.95	97.05	92.50	87.28	81.41	74.90	67.84
1924	174	160.46	156.37	151.43	145.57	138.75	130.92	122.11	112.35
1925	194	182.63	178.91	174.35	168.84	162.30	154.70	145.97	136.15
1926	222	212.39	208.99	204.73	199.51	193.21	185.73	177.02	167.03
1927	155	150.15	148.29	145.92	142.94	139.30	134.90	129.67	123.60
1928	194	189.75	187.93	185.60	182,63	178.91	174.35	168.84	162.30
1929	145	142.84	141.82	140.46	138.72	136.50	133.72	130.31	126.19
1930	289	286.23	284.69	282.67	279.95	276.49	272.06	266.52	259.72
1931	116	115.34	114.89	114.27	113.46	112.37	110.98	109.20	106.98
1932	39	38.89	38.78	38.63	38.42	38.15	37.78	37.31	26.71
1933	49	48.96	48.86	48.72	48.53	48.27	47.93	47.47	46.88
1934	39	39.00	38.96	38.89	38.78	38.63	38.42	38.15	37.78
1935	114	114	114	113.90	113.67	113.35	112.91	112.30	111.50
1936	181	181	181	181	180,84	180.48	179.97	179.26	178.30
1937	308	308	308	308	308.00	307.72	307.11	306.24	305.04
1938	129	129	129	129	129	129	128.88	128.63	128.26
1939	99	99	99	99	99	99	99	98.91	98.71
1940	169	169	169	169	169	169	169	169	168.85

TABLE 2-D--Continued

1941	247	247	247	247	247	247	247	247	247
1942	225	225	225	225	225	225	225	225	225
1943	181	181	181	181	181	181	181	181	181
1944	100	100	100	100	100	100	100	100	100
1945	124	124	124	124	124	124	124	124	124
1946	414	414	414	414	414	414	414	414	414
1947	522	522	522	522	522	522	522	522	522
1948	602	602	602	602	602	602	602	602	602
1949	444	444	444	444	444	444	444	444	444
1950	446		446	446	446	446	446	446	446
1951	913			913	913	913	913	913	913
1952	1076				1076	1076	1076	1076	1076
1953	838					838	838	838	838
1954	510						510	510	510
1955	604							604	604
1956	1095								1095
Estimated Plant Balances		6577.32	6916.79	7711.15	8656.35	9351.77	9707.93	10,146.84	10,955.35
Actual Plant Balances		6522	6887	7234	8057	9031	9723	10115	11, 170
Per cent Deviation from Actual		+0.8	+0.4	+6.6	+7.4	+3.6	-0.2	+0.3	-1.9

[a]Source: from Table 29.

[b]Estimated by the survivor rate shown in Table 30.

TABLE 3-D

THE STEEL INDUSTRY: ESTIMATED ANNUAL ASSET RETIREMENTS AT ORIGINAL COST BY YEARS OF ACQUISITION 1957-1970

(in Millions of Dollars)

Years of Acquisition	Plant Balance[a] 12/31/56	Estimated Annual Asset Retirements						
		1957	1958	1959	1960	1961	1962	1963
1915	11	9.9	1.1					
1916	35	16.8	16.3	1.9				
1917	64	21.2	20.7	19.8	2.3			
1918	61	15.7	15.1	14.6	14.0	1.6		
1919	51	10.5	10.3	10.0	9.7	9.3	1.1	
1920	73	12.3	12.5	12.3	11.9	11.6	11.1	1.3
1921	45	6.5	6.6	6.6	6.4	6.3	6.1	5.8
1922	52	6.8	6.7	6.6	6.6	6.4	6.3	6.1
1923	70	8.0	7.9	8.0	7.9	7.9	7.7	7.5
1924	116	11.4	11.6	11.9	12.0	11.9	11.8	11.6
1925	140	11.7	12.3	12.8	13.2	13.3	13.2	13.1
1926	173	11.9	13.2	14.1	14.8	15.2	15.3	15.2
1927	128	7.3	8.5	9.2	9.8	10.3	10.6	10.7
1928	168	8.3	9.5	10.5	11.4	12.3	12.8	13.2
1929	131	5.1	6.2	7.1	7.9	8.6	9.2	9.6
1930	273	8.7	10.9	12.6	14.3	15.9	17.3	18.5
1931	112	3.0	3.7	4.3	5.0	5.7	6.3	6.9
1932	38	1.3	1.0	1.2	1.4	1.6	1.9	2.1
1933	49	1.1	1.0	1.3	1.5	1.8	2.1	2.4
1934	39	0.8	0.6	0.8	1.0	1.2	1.4	1.6
1935	129	1.2	1.7	2.1	2.7	3.3	4.0	4.7
1936	200	1.5	2.0	2.6	3.3	4.1	5.1	6.1
1937	298	1.5	2.2	2.9	3.8	4.9	6.1	7.5
1938	131	0.3	0.7	1.0	1.3	1.7	2.1	2.7
1939	114	0.6	0.4	0.6	0.8	1.1	1.4	1.8
1940	161	0.5	0.4	0.6	0.9	1.2	1.6	2.0
1941	400	0.4	0.8	1.1	1.6	2.2	2.9	3.9
1942	518		0.5	1.0	1.4	2.0	2.8	3.8
1943	677			0.7	1.3	1.8	2.6	3.7
1944	263				0.3	0.5	0.7	1.0
1945	139					0.1	0.3	0.4
1946	274						0.3	0.5
1947	422							0.4
1948	549							
1949	480							
1950	483							
1951	980							
1952	1101							
1953	941							
1954	640							
1955	687							
1956	1129							
Total	12,545	1843	1844	1782	1685	1638	164.1	164.1

TABLE 3-D--Continued

At Original Cost by Years of Acquisition 1957-1970							Total Retirements Estimated for the 1958-1970 Period
1964	1965	1966	1967	1968	1969	1970	
							1.14
							18.21
							42.77
							45.35
							40.47
							60.66
0.7							38.54
5.8	0.7						45.21
7.3	7.0	0.8					61.99
11.3	10.9	10.5	1.2				104.57
12.8	12.5	12.1	11.6	1.3			128.26
15.1	14.8	14.4	14.0	13.4	1.5		161.06
10.6	10.5	10.3	10.0	9.7	9.3	1.1	120.65
13.3	13.2	13.1	12.8	12.5	12.1	11.6	158.40
9.9	9.9	9.9	9.8	9.6	9.3	9.1	116.15
19.4	19.9	20.0	19.9	19.7	19.3	18.8	226.44
7.4	7.7	7.9	8.0	7.9	7.9	7.7	86.45
2.3	2.4	2.5	2.6	2.6	2.6	2.6	26.82
2.6	2.9	3.1	3.2	3.3	3.3	3.3	31.94
1.9	2.1	2.3	2.4	2.5	2.6	2.6	23.10
5.4	6.2	6.9	7.5	8.0	8.4	8.6	69.28
7.2	8.3	9.5	10.5	11.5	12.3	12.8	95.35
9.1	10.7	12.4	14.1	15.6	17.0	18.2	124.53
3.3	4.0	4.7	5.4	6.2	6.9	7.5	47.35
2.3	2.8	3.4	4.1	4.7	5.3	5.9	34.89
2.6	3.3	4.0	4.8	5.7	6.6	7.5	41.36
5.1	6.5	8.2	10.0	12.0	14.2	16.4	84.84
5.1	6.6	8.4	10.6	13.0	15.6	18.4	89.10
4.9	6.6	8.6	11.0	13.8	16.9	20.4	92.34
1.4	1.9	2.6	3.3	4.3	5.4	6.6	27.96
0.5	0.8	1.0	1.4	1.8	2.3	2.8	11.30
0.7	1.1	1.5	2.0	2.7	3.5	4.4	16.69
0.8	1.1	1.6	2.3	3.1	4.1	5.4	18.86
0.5	1.0	1.5	2.1	3.0	4.0	5.4	17.57
	0.5	0.9	1.3	1.9	2.6	3.5	10.66
		0.5	0.9	1.3	1.9	2.6	7.20
			1.0	1.9	2.6	3.8	9.31
				1.1	2.1	3.0	6.17
					0.9	1.8	2.73
						0.6	0.64
							0.00
							0.00
169.3	175.9	182.6	187.8	194.1	200.5	212.4	2346.30

TABLE 3-D--Continued

Notes:

[a]Table 1-D

[b]Estimated by the retirement rate shown in Table 30.

TABLE 4-D

THE THIRTEEN LEADING STEEL COMPANIES: ESTIMATED ANNUAL ASSET RETIREMENTS AT ORIGINAL COST BY YEARS OF ACQUISITION: 1957-1970
(in Millions of Dollars)

Years of Acquisition	Plant Balance[a] 12/31/56	Estimated Annual Asset Retirements						
		1957	1958	1959	1960	1961	1962	1963
1915	4.0	4.0						
1916	25.5	18.9	6.6					
1917	54.2	23.2	22.9	8.1				
1918	54.9	16.6	16.4	16.2	5.7			
1919	47.8	11.1	11.1	10.9	10.8	3.8		
1920	70.4	13.3	13.3	13.2	13.1	13.0	4.6	
1921	43.8	6.9	6.9	7.0	6.9	6.9	6.8	2.4
1922	50.4	6.6	6.9	7.0	7.0	6.9	6.9	6.8
1923	67.8	7.6	8.0	8.2	8.3	8.3	8.3	8.2
1924	112.4	10.6	11.3	11.9	12.3	12.5	12.5	12.4
1925	136.2	10.9	11.8	12.7	13.3	13.7	13.9	13.9
1926	167.0	11.2	12.5	13.5	14.5	15.2	15.7	15.9
1927	123.6	6.9	7.8	8.7	9.4	10.1	10.6	11.0
1928	162.3	7.6	8.7	9.8	10.9	11.8	12.7	13.3
1929	126.2	4.9	5.7	6.5	7.3	8.1	8.8	9.5
1930	259.7	8.2	9.7	11.3	13.0	14.6	16.2	17.6
1931	106.9	2.7	3.3	3.9	4.6	5.2	5.9	6.5
1932	36.7	.8	.9	1.1	1.3	1.5	1.8	2.0
1933	46.9	.8	.9	1.1	1.4	1.7	1.9	2.2
1934	37.8	.5	.6	.8	.9	1.1	1.3	1.5
1935	111.5	1.1	1.4	1.7	2.2	2.7	3.2	3.8
1936	178.3	1.3	1.7	2.2	2.8	3.5	4.3	5.1
1937	305.0	1.6	2.2	2.9	3.7	4.7	5.9	7.2
1938	128.3	.5	.7	.9	1.2	1.6	2.0	2.5
1939	98.7	.3	.4	.5	.7	.9	1.2	1.5
1940	168.9	.3	.5	.7	.9	1.2	1.6	2.0
1941	247	.2	.5	.7	1.0	1.3	1.7	2.3
1942	225		.2	.5	.6	.9	1.2	1.6
1943	181			.2	.4	.5	.7	1.0
1944	100				.1	.2	.3	.4
1945	124					.1	.3	.4
1946	414						.4	.8
1947	522							.5
1948	602							
1949	444							
1950	446							
1951	913							
1952	1076							
1953	838							
19541	510							
1955	604							
1956	1095							
Total		178.6	172.9	162.2	154.3	152.0	150.5	152.3

TABLE 4-D--Continued

by Years of Acquisition[b]							Total Retirements Estimated for the 1958-1970 Period
1964	1965	1966	1967	1968	1969	1970	

							6.64
							31.03
							38.38
							36.71
							57.11
							36.90
2.4							43.76
8.1	2.9						60.27
12.3	12.2	4.3					101.75
13.9	13.7	13.6	4.8				125.27
15.9	15.8	15.7	15.5	5.5			155.79
11.1	11.1	11.1	11.0	10.9	3.8		116.62
13.7	13.9	13.9	13.9	13.7	13.6	4.8	154.70
9.9	10.3	10.4	10.4	10.4	10.3	10.2	117.74
18.8	19.8	20.4	20.7	20.8	20.7	20.5	224.17
7.0	7.6	8.0	8.2	8.3	8.3	8.3	85.06
2.2	2.4	2.5	2.7	2.8	2.8	2.8	26.74
2.5	2.8	3.0	3.2	3.4	3.5	3.5	30.99
1.8	2.0	2.2	2.4	2.5	2.7	2.8	22.49
4.5	5.1	5.8	6.4	6.9	7.3	7.8	59.01
6.1	7.1	8.2	9.2	10.2	11.0	11.8	82.99
8.8	10.4	12.1	13.9	15.6	17.3	18.8	123.30
3.0	3.7	4.4	5.0	5.8	6.5	7.2	44.47
1.9	2.3	2.8	3.3	3.9	4.5	5.0	28.96
2.6	3.2	4.0	4.8	5.7	6.6	7.6	41.36
3.0	3.8	4.7	5.8	7.0	8.3	9.7	49.79
2.1	2.7	3.4	4.3	5.3	6.4	7.6	36.77
1.3	1.7	2.2	2.8	3.5	4.3	5.1	23.48
.5	.7	.9	1.2	1.5	1.9	2.4	10.13
.5	.7	.9	1.2	1.5	1.9	2.4	9.66
1.2	1.6	2.2	2.9	3.9	5.0	6.3	24.25
1.04	1.5	2.0	2.8	3.7	4.9	6.3	22.60
.5	1.2	1.7	2.4	3.2	4.2	5.7	18.84
	.4	.9	1.2	1.7	2.4	3.1	9.72
		.4	.9	1.3	1.7	2.4	6.64
			.8	1.8	2.6	3.6	8.77
				1.0	2.2	3.0	6.13
					.8	1.7	2.43
						.5	0.46
							0.00
							0.00
156.67	160.44	161.57	161.57	161.52	165.34	170.53	2,081.88

TABLE 4-D--Continued

Notes:

[a]Based on Estimated Plant Balance 12/31/56 in Table 2-D.

[b]Estimated by the retirement rate shown in Table 30.

BIBLIOGRAPHY

Books

Alderfer, E. B., and Michl, H. E. Economics of American Industry, 3rd ed. revised. New York: McGraw Hill Book Company, Inc., 1957, pp. 1-85.

Battelle Memorial Institute. Comparative Economics of Open-Hearth and Electric Furnaces for Production of Low-Carbon Steel. Pittsburgh: Bituminous Coal Research, Inc., 1953.

Chase Manhattan Bank. Future Growth and Financial Requirements of the World Petroleum Industry. New York: 1956.

Creamer, Daniel. Capital and Output Trends in Manufacturing Industries, 1880-1948. Occasional Paper 41. Assisted by Martin Bernstein. New York: National Bureau of Economic Research, 1954.

Dean, Joel. Managerial Economics. New York: Prentice-Hall, Inc., 1951, chaps. 4 and 10.

Grant, Eugene L., and Norton, Paul T. Depreciation. New York: The Ronald Press Company, 1949, pp. 42-86.

Hogan, William T. Productivity in the Blast-Furnace and Open-Hearth Segments of the Steel Industry 1920-1946. New York: Fordham University Press, 1950.

Kuznets, Simon S. Secular Movements in Production and Prices. Boston and New York: Houghton Mifflin Company, 1930, pp. 1-58.

Leontiff, Wessily W., et al. Studies in the Structure of the American Economy. New York: Oxford University Press, 1953, chaps. 3 and 6.

Paradiso, Louis J. Capital Requirements, A Study in Methods As Applied to the Iron and Steel Industry. National Resources Planning Board. Washington: U. S. Government Printing Office, 1940.

Republic Steel Corporation. U. S. A. Tomorrow. New York: Republic Steel Corporation, 1957.

Richards, E. M. The Steel Industry--Its Growth and Problems. New York: Republic Steel Corporation, 1950.

U. S. Bureau of Mines. Mineral Facts and Problems. Bulletin 556. Washington: U. S. Government Printing Office, 1956.

U. S. Congress Joint Economic Committee. Productivity, Prices and Income. Washington: U. S. Government Printing Office, 1957.

U. S. Steel Corporation. The Making, Shaping and Treating of Steel. 7th ed. New York; U. S. Steel Corporation, 1957.

_____. Steel and Inflation, Fact vs. Fiction. New York: U. S. Steel Corporation, 1958.

Winfrey, R., and Kurtz, E. B. Life Characteristics of Physical Property. Ames, Iowa: Iowa State College, 1931.

Articles and Periodicals

American Iron and Steel Institute. Annual Statistical Report, 1912-1957.

_____. Directory of Iron and Steel Works of the U. S. and Canada, 1935, 1938, 1945, 1948, 1951, 1954, and 1957.

_____. Steel Facts, No. 148 (February, 1958); No. 149 (April, 1958).

Boschan, Paul. "Productive Capacity, Industrial Production, and Steel Requirements," Long-Range Economic Projection, Studies in Income and Wealth, XVI, National Bureau of Economic Research (1954), pp. 233-272.

Bowman, Raymond T., and Phillips, Almarin. "Conceptual and Statistical Problems in Estimating Capital Coefficients for Four Metal Fabricating Industries," Problem of Capital Formation, Studies in Income and Wealth, XIX, National Bureau of Economic Research (1957), pp. 347-374.

Carter, Anne P. "Capital Coefficients As Economic Parameters: The Problem of Instability," Problem of Capital Formation, Studies in Income and Wealth, XIX, National Bureau of Economic Research (1957), pp. 287-310.

Domar, Evsey D. "Comment," Problem of Capital Formation, Studies in Income and Wealth, XIX, National Bureau of Economic Research (1957), pp. 415-417.

Economic Report of the President Transmitted to the Congress. January 20, 1958.

Grosse, Robert N. and Berman E.B. "Estimating Future Purchases of Capital Equipment for Replacement," Problem of Capital Formation, Studies in Income and Wealth, XIX, National Bureau of Economic Research (1957), pp. 389-414.

Hodges, John E. "A Report on the Calculation of Capital Coefficients for the Petroleum Industry," Problem of Capital Formation, Studies in Income and Wealth, XIX, National Bureau of Economic Research, (1957), pp. 375-387.

Iron Age. 100 Years of Metalworking, June, 1955.

Moore, Frederick T. "Capital Coefficients in Mineral and Metal Industries," Problem of Capital Formation, Studies in Income and Wealth, XIX, National Bureau of Economic Research (1957), pp. 311-345.

Prescott, Raymond B. "Law of Growth in Forecasting Demand," Journal of the American Statistical Association, XVIII (December, 1922), pp. 471-479.

Standard and Poor's Industrial Surveys, Steel, CXXIV, No. 26, Sec. 2 (June 28, 1956), pp. 59-90.

U. S. Bureau of Census. Statistical Abstract of the United States, 1958.

U. S. Bureau of Mines. Minera` Yearbook, 1941-1956.

U. S. Department of Commerce. Business Statistics, 1958.

_____. Survey of Current Business, 1950-1958.

Unpublished Material

American Iron and Steel Institute. "Monographs to the Brookings Institution." New York, 1957.

Cowan, Donald R. G. "Future Growth of the Steel Industry." Unpublished manuscript to be published by the Brookings Institution, 1958.

Chastain, Clark E. "Depreciation in the Steel Industry." Unpublished Ph.D. dissertation, University of Michigan, 1958.

Detroit Edison Company. "a, b, c, System of Life Curves." Unpublished description of life curves based on normal distribution function.

Marshall, Stewart M. "A Review of the Steel Industry in the United States." The United States Air Force Research, Rand Research Memorandum, RM-1091, California, 1953.

U. S. Department of Commerce. "Investment Costs and Capacity in Iron and Steel" September, 1953. (Mimeographed.)