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**Capital and Labor Requirements
for Iron Ore Mining and Beneficiating**

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Capital and Labor Requirements for Iron Ore Mining and Beneficiating

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CAPITAL AND LABOR REQUIREMENTS FOR IRON ORE MINING AND BENEFICIATING

by

Richard J. Leary¹ and David J. Kusler²

ABSTRACT

The inputs of capital and labor to support future iron ore production were developed by the Bureau of Mines from projections of iron demand and estimates of capital and labor requirements. Trends in technologic change and the organization of production were analyzed. Labor requirement schedules for iron ore mining and beneficiating were constructed from aggregate inter-temporal trends and 1970 cross-sectional analysis of mines and mills. A supply schedule of the capital requirement for mine-mill-pellet plants was developed from U.S. and Canadian experience. The structure of demand for iron to the year 2000 was examined as well as the availability of resources.

Projections of capital and labor requirements to 2000 were constructed under two international patterns of iron ore supply to the United States. The most likely model is for a continuation of the 70 percent United States-30 percent foreign shares, expanding at an average 2.0 percent growth rate to 2000, and supported by a cumulative gross capital investment of \$3.8 billion constant 1967 dollars and a labor force in the United States of 29,800 by 2000. The information content of projections is discussed, and the possible effects of international forces on supply are considered. A generalized methodology for estimating capital and labor requirements in other mineral industries also is included.

INTRODUCTION

Just about everyone has a large stake in a dependable and abundant flow of minerals into the U.S. economy. For nearly a century, this statement has remained largely a truism: Dependability and abundance and their consequence, low prices, have been prominent characteristics of the mineral supply system of the Nation, as fashioned by the firms in the mineral industry with the support of government policy. Recently, however, the Nation has been exposed to a succession of bothersome shortfalls in mineral supply, notably in petroleum and natural gas. These episodes have demonstrated how deeply the United States rely on dependable streams of supply and how quickly and pervasively our lifestyles are disturbed by interruptions in the mineral supply.

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²Chemist (now retired).

Obvious questions have been raised concerning the prospective adequacy of the Nation's mechanism of mineral supply: (1) What demands for minerals are expected? (2) Are there mineral resources available to meet these demands? These questions have been addressed respectively by complementary studies of the U.S. Department of the Interior: Mineral Facts and Problems, BuMines Bull. 650 (54),³ and United States Mineral Resources, Geological Survey Professional Paper 820 (8). Both studies provide projections to 2000, based upon an assumed continuity of technologic and economic developments. It seems safe enough to project the emergence of a sufficient technology to transform raw mineral occurrences into useful mineral products in view of the successive development of fission, computers, xerography, moonshots, and like achievements in our time. Much less widely understood, however, is the correlative need for sufficient flows of economic factors, first, to develop and, then, to implement the technology of mineral supply.

The absolute necessity for flows of economic factors to support the mineral supply also is largely a truism. To the public, funds have been readily obtainable for consumption goods in an easy-pay economy, and labor has become more productive through technologic development. The needs for sufficient flows of both capital and labor into mineral extraction and transformation ventures have not been public issues. These needs have been sensed primarily by mining entrepreneurs who have had to assemble the capital and the work forces to develop mineral resources in out-of-the-way locations. Yet, an investment flow of money is required to provide the stock of physical capital represented in a mine, mill, or smelter; to provide working capital during production; and to replace capital goods that wear out during operations and become obsolete over the passage of time. In like manner, one can perceive intuitively the need for providing in some sense a stock of human labor and a flow of human effort to build, operate, and maintain a physical plant for the efficient production of mineral products.

Statistics concerning investment flows of capital and labor into the mineral industries are very sparse. The mining industry generates only 1 percent of the gross national product (GNP), too small to matter much in the national accounts. Too, money and manpower both have been readily available. Thus, there has been no issue of important public concern to justify an army of statistics. No accepted method of analysis exists for the study of the influences of these factors upon mineral production and mineral supply. Yet, the need is acute. By 1975, the capital investment requirements for new and expanded mining ventures in the free world may reach \$11 billion per year. In the 5-year period 1972-76, these expenditures can be expected to aggregate \$45 billion, all of this exclusive of developments in mineral fuels (63).

The analysis reported herein had two objectives. The principal objective was to analyze and project the factor requirements for iron ore mining. A secondary objective was to construct the iron ore study so that it could be used as a model of methodology for the study of other, less documented, mineral commodities. Iron ore mining and beneficiation was selected because

³Underlined numbers in parentheses refer to items in the bibliography that precedes the appendix.

(1) it is a large and important mineral industry; (2) it is an important component of the international trade in minerals; (3) it has the most complete statistical coverage and literature; (4) it has undergone great changes both in sources and in technology; and (5) the agents and currents of change seem to be identifiable.

The method of analysis is reminiscent of that employed by Resources for the Future, Inc., in its study *Resources in America's Future* (29), but the bases for conclusions are stated more explicitly to illustrate items of methodology. The first section is a critical description of the dynamic currents faced by iron ore mining during the era of displacement since 1950. It is followed by detailed analyses of labor and capital requirements using methods suitable for experimental research in economic analysis. The sections that follow are concerned with empirical analysis of markets as a foundation for projecting future demands for iron ore. A set of projections to the year 2000 is constructed and discussed. Finally, a pattern for analysis is presented for other mineral commodities based on the experience with iron ore.

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THE BACKGROUND OF CHANGE IN IRON ORE MINING

This description must be regarded as stroboscopic--merely a stop-motion sketch of a dynamic component in our Nation's mineral supply. For 25 years now, the technology of iron mining has been in the throes of change, and the boundaries of the industry itself have been changing as well. Although the pattern is complex and is highly differentiated between firms as well as mines, the matrix of change can be usefully categorized in terms of geographic, geologic, technologic, and organizational factors. Inherent to all is the requirement of economic viability. The glimpse given in this section is intentionally historical, to impart to the reader a sense of background for his own projections into the future.

Geographic Factors

The principal vector of change has been geographic. By the end of World War II, a critical void in the iron ore reserves of steel firms in the United States had become evident. The vast Minnesota Ranges of natural ore, rich enough to ship directly to the blast furnaces and amenable to low-cost, mass-mining methods, were approaching exhaustion. Together, the Mesabi, Cuyuna, and Vermilion ranges had supplied 70 to 80 percent of the steel industry's consumption for nearly half a century. The Mesabi, alone, had contributed two-thirds of all the ore ever produced in the United States. At the war's end, the reserves of direct shipping ores remaining in the Lake Superior district were projected to become exhausted in 12 to 20 years depending on the rate of consumption. The Mesabi, especially, between 1940 and 1946 had yielded 40 percent of the total previously extracted between 1892, the year it was opened, and 1939 (22, p. 15). Its depletion is depicted by the relation between cumulative shipments and the annual reserve estimates (34, p. 6) as shown in figure 1.

Maintaining the customary grade of iron in natural ore was becoming more costly as the grade of crude declined. More crude had to be mined (fig. 2) and more capital had to be employed just to maintain a relatively constant output of merchantable ore per man-hour compared with the era before World War II.⁴

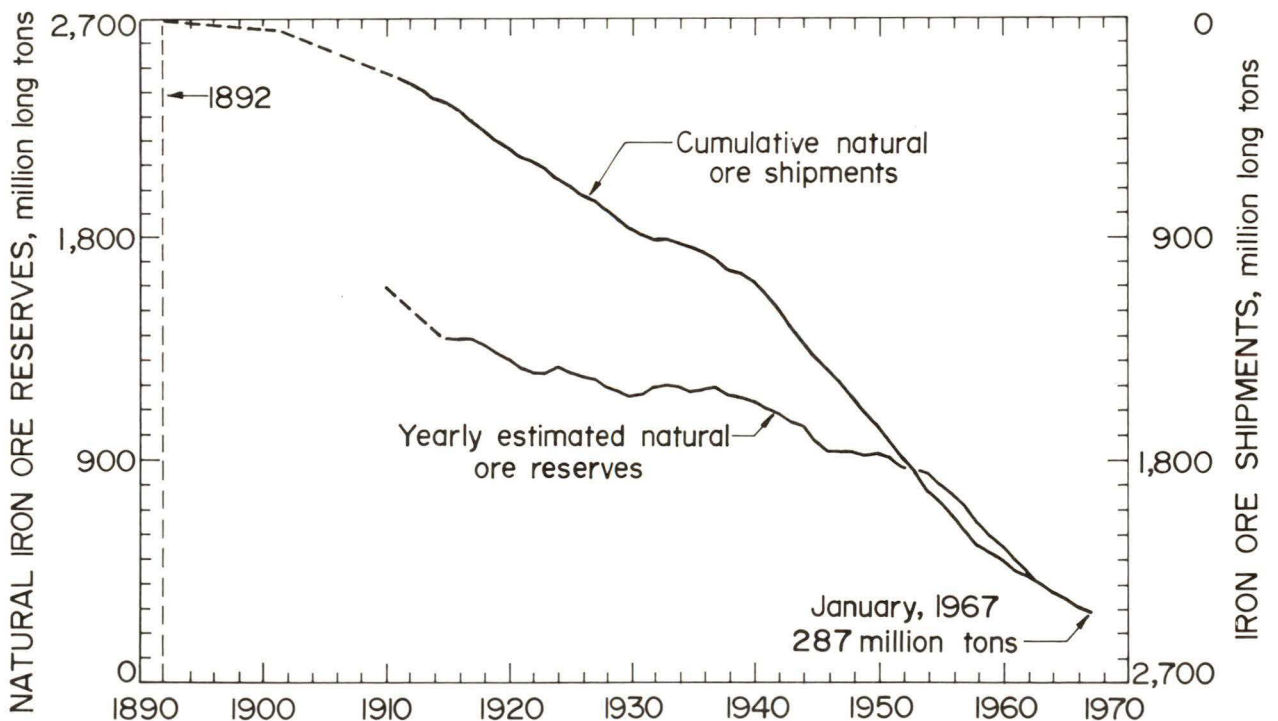


FIGURE 1. - Annual reserve estimates and cumulative shipments of natural ores from the Mesabi Range, 1892-1967 (34).

⁴Newcomb (37). A condensed presentation is more accessible (39). In retrospect, the decline in grade can be traced back to the twenties; the rise in capital employed per unit of usable ore, to the thirties.

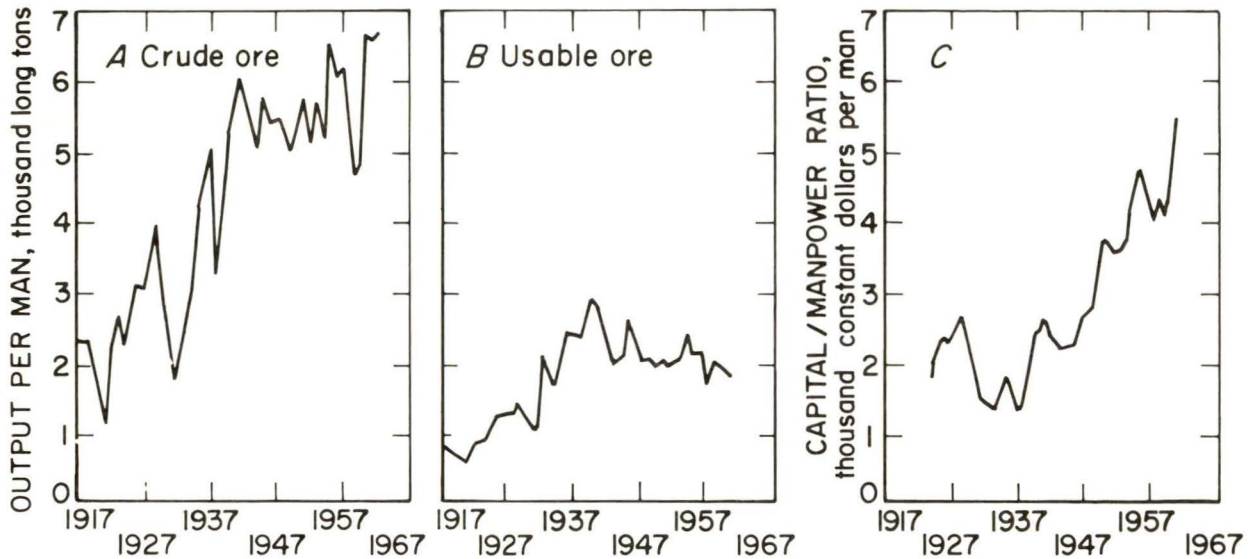


FIGURE 2. - Trends in output and capital stock per man in mining Minnesota natural ores. A, Crude ore, 1917-63; B, usable ore, 1917-63; and C, capital stock, 1924-63 (39).

Rising costs and the impending depletion were doubly alarming to the major domestic steel firms, which were accustomed to vertically integrated control of their raw materials supplies.

Two courses of response were pursued: geologic and technologic. By either means, the resource inventory might be enlarged. Both would involve discovery and development. Geologic discovery would extend contemporary reserves by identifying new deposits that were essentially similar to existing reserves and thus amenable to exploitation with the then-existing mining and metallurgical technology. Technologic discovery would transform indigenous submarginal resources into reserves by identifying gaps in the technology of mining and mineral beneficiation, developing the appropriate physical and chemical knowledge, and conceiving an economic process technology.

Geologic Factors

Postwar exploration by U.S. iron mining firms was unparalleled in magnitude and sophistication. In short order, extensive deposits suitable for direct shipment were identified in Venezuela, Labrador, and elsewhere. From 1951 onward, a succession of new foreign developments came into production. Actually, a slight trend to foreign supplies already had become evident. By 1949, net imports had risen to 5 percent, but these had come mainly from established sources in Chile, Canada, and Sweden.

These movements stood in sharp contrast to the traditional pattern of self-sufficiency of the United States in iron supply. From the inception of

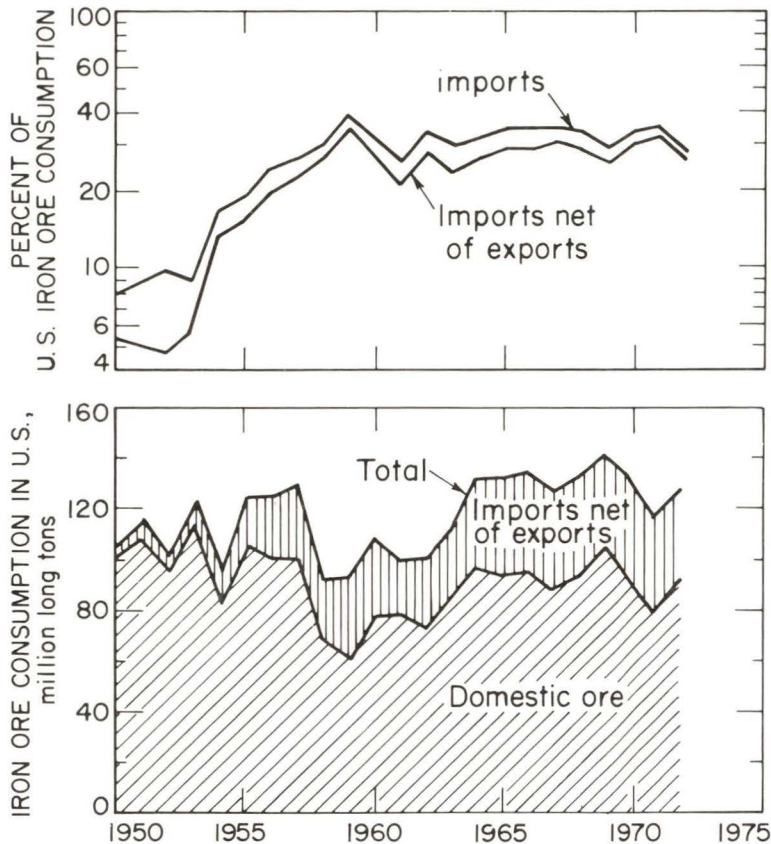


FIGURE 3. - Participation of foreign ores in U.S. iron ore consumption, 1950-72.

to an international source of iron ore supply began with the identification and development of natural ores suitable for direct shipping, especially at Cerro Bolivar, Venezuela, by United States Steel, and at Shefferville, Labrador, by the Iron Ore Company of Canada.

Technologic Factors

Intensification of research and development was the obvious response by other institutions and firms, especially those which had been pursuing the concentration and agglomeration of Minnesota magnetic taconite, some since

iron mining in the early colonial period⁵ to the end of World War II, imports of iron ore (net of exports) seldom had exceeded 2 percent of U.S. consumption. Now, the security of 3 centuries was being depleted. New outlooks and new habits were about to be formed.

The success of geologic exploration is in the statistics. From 1953 to 1959, the net share of imported ore in U.S. consumption jumped from 6 percent to 35 percent (fig. 3) and then leveled off at 28 percent.⁶ Furnace charges have averaged one-third imported ores since 1959. The stability in shares since 1959 states the aggregate judgment of domestic ironmakers and steelmakers that imported ores have become a continuing and substantial stream in the mineral supply to this industry. This shift

⁵In 1619, 12 years after the foundation of Virginia, and 1645, 25 years after the Pilgrims came to Massachusetts, according to McGannon (33, p. 8).

⁶The net share is equal to the difference between the quantity imported and the quantity exported, divided by the total consumption. It is a physical measure of trade balance. In actual practice, the exports of U.S. iron ore have moved to certain steelmakers, mainly Canadian and Japanese, from specific mines, while substantially all imported iron ores have been consumed in domestic steelmaking. The actual share of imported ore in domestic furnace charges in recent years has averaged about 5 percent higher; that is, 33 percent. The 1950-72 statistics are listed in table A-1.

before World War I (11). In the years immediately after World War II, several other firms established laboratories for this purpose or for parallel efforts upon nonmagnetic Michigan jaspilite.

An immensely detailed effort was entailed. The traditional dig-and-sell natural ore industry in Minnesota had remained relatively untouched by geo-physical or metallurgical sophistication, although significant concentration technology had been developed in other districts. To fill the gaps, a chapter in science had to be created in great detail, exemplified in processes through applied research, scaled up in pilot plants to develop workable units of equipment and operating procedures, and finally, embodied in commercial plants.⁷

The magnitude of the technologic effort is reflected by the pilot plant programs undertaken by the leading firms. From 1949 to 1955, several pilot plants were constructed to operate at rates exceeding 100,000 tons per year (fig. 4). By late 1955, when the first commercial pellet plant began operation in the United States, more than 3 million tons of agglomerates produced in pilot plants had been shipped to the blast furnaces for testing.

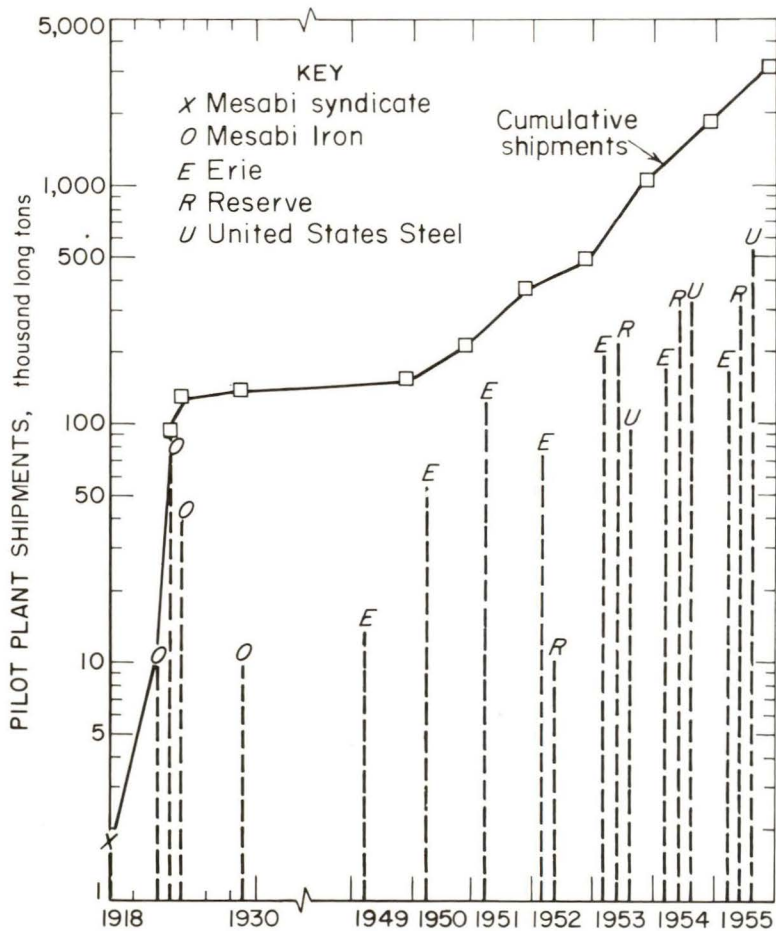


FIGURE 4. - Shipments of agglomerated concentrates from Minnesota pilot plants, 1918-55 (11).

The justification for so detailed a test program lay in the enormous capital outlay required for taconite processing. Reserve Mining Co., the first of the taconite projects, was constructed for \$185 million to provide 3.8 million tons of pellet capacity (11, pp. 146-150). By comparison, in 1953, while that construction was underway, the established iron ore industry in Minnesota produced more usable ore than any year before or since--80 million tons--on a capital base of \$70 million in equipment,⁸ equivalent to a capital-output ratio of \$1.75 per annual ton of iron-in-ore. By that measure, Reserve

⁷The story is recounted by Davis (11).

⁸Production and grade from BuMines Minerals Yearbook. Depreciated capital stock in the nearest year (1954), from Newcomb (37), p. 109.

Mining Co. in effect was committing \$4 million for capacity (on an iron-in-ore basis) and \$181 million for the new technology to produce concentrated taconite pellets.

The success of taconite pellet production was confirmed when the original plants were enlarged: Reserve Mining Co., in 1960, and Erie Mining Co., in 1965. By 1968, more than half of the production from the Mesabi was originating from taconite concentrates, and the aggregate grade of iron in shipments had risen to 59 percent, an average far beyond the reach of natural ores in the Lake Superior district.

Organization of Production

Iron ore production also has undergone major reorganization. Rich foreign ore deposits and new technologies for mining, concentrating, and agglomerating crude ores have challenged and transformed the traditional business of iron ore production. The predominantly dig-and-sell operation of 1950 has given way to highly sophisticated and organized processes for producing pellets or sinter feeds. In 1953, the largest mine (Sherman) produced 9 million long tons of usable ore at a yield of 99 percent from crude ore (57). In 1972, Reserve Mining Co. and Erie Mining Co. each produced pellets in excess of that figure, but to do so each had mined and concentrated more than 30 million tons of crude ore (46).

These currents of change are reflected in the production statistics of the industry. Table 1 lists important measures of iron ore mining in critical years: 1950, the first postwar year of ample supply and the final peacetime year before the influx of foreign ores; 1953, the year of greatest domestic iron ore production; 1970, the recent year least subjected to upsets; and 1972, the latest available statistics. Mining methods largely have shifted from selective mining underground to mass mining in open pits: 21 percent underground in 1953 to 6 percent in 1970. Average concentration ratio for the entire U.S. production had risen from 1.33 in 1953 to 2.50 in 1972. Moreover, the average grade of usable ore had risen from 50 percent iron in 1953 to 61 percent in 1972,⁹ principally because beneficiation had been extended from 31 percent of shipments in 1953 to 93 percent in 1972. Agglomerates--the most highly manufactured form--had risen from 5 to 73 percent. Conversely, direct shipping ores--the "dig-and-sell" grades--had fallen from 70 percent to a mere 8 percent of shipments. Mining also had turned from hematites and brown ores to the more easily concentrated magnetites: The nonmagnetic varieties had fallen from 89 percent to 32 percent of usable ore production. This is the background for the paradox of mining 20 percent more crude ore in 1972 to produce 36 percent less usable ore containing 28 percent less iron-in-ore.

⁹Comparisons of iron content must be used carefully. Much of the apparent upgrading has resulted from lower moisture content in processed ores. In 1953, Lake Superior district shipments averaged 50.37 percent Fe (natural) and 10.90 percent moisture; in 1970, the corresponding figures were 59.36 and 4.62 percent. The 1953 ores would have averaged 53.92 percent Fe (natural) merely by drying to the average 1972 moisture content. Of the total gain in Fe content, 40 percent was attributable to the lower moisture content. The difference between 53.92 and 59.36 percent Fe measured the improvement in gangue content of ore over the 17-year timespan.

TABLE 1. - Salient production statistics of iron mining in the United States and the Lake Superior district, selected years

| | 1950 | 1953 | 1970 | 1972 |
|---|-------|-------|-------|-------|
| U.S. production: | | | | |
| Crude.....million long tons.. | 125.7 | 156.6 | 212.5 | 187.6 |
| Usable.....do..... | 97.5 | 117.4 | 88.9 | 75.1 |
| Byproduct.....do..... | 0.6 | 0.6 | 0.8 | 0.3 |
| Total usable.....do..... | 98.0 | 118.0 | 89.8 | 75.4 |
| Concentration ratio, crude: usable..... | 1.29 | 1.33 | 2.39 | 2.50 |
| Iron in usable ore.....wt-pct.. | 49 | 50 | 59 | 61 |
| Characteristics of usable ore: | | | | |
| Percent of shipments beneficiated..... | 28 | 31 | 92 | 93 |
| Form of product, pct: | | | | |
| Direct shipping..... | 72 | 70 | 8 | 8 |
| Concentrates..... | 23 | 25 | 28 | 20 |
| Agglomerates..... | 5 | 5 | 64 | 72 |
| Mining methods, pct of crude: | | | | |
| Open pit..... | 77 | 79 | 94 | 94 |
| Underground..... | 23 | 21 | 6 | 6 |
| Varieties of ore: | | | | |
| Crude, pct: | | | | |
| Hematite..... | 83 | 81 | 27 | 19 |
| Brown..... | 7 | 6 | 3 | 2 |
| Magnetite..... | 10 | 13 | 70 | 79 |
| Usable, pct: | | | | |
| Hematite..... | 89 | 87 | 38 | 29 |
| Brown..... | 3 | 2 | 2 | 1 |
| Magnetite..... | 8 | 11 | 60 | 70 |
| Lake Superior district ¹ : | | | | |
| Pct of U.S. production: | | | | |
| Crude ore..... | 77 | 77 | 80 | 83 |
| Usable ore..... | 82 | 81 | 78 | 82 |
| Iron-in-ore..... | 82 | 82 | 78 | 82 |
| Companies active ² | 26 | 30 | 13 | 13 |
| Ore grades ² | 159 | 188 | 51 | 36 |
| Mines operated ² | 169 | 226 | 36 | 24 |
| Production, million long tons: | | | | |
| Crude..... | 96.6 | 120.4 | 169.5 | 155.5 |
| Usable..... | 79.6 | 95.7 | 69.6 | 61.6 |
| Iron-in-ore..... | 39.5 | 48.3 | 41.4 | 37.4 |
| Average mine production, million long tons: | | | | |
| Crude..... | .571 | .533 | 4.709 | 6.479 |
| Usable..... | .471 | .423 | 1.934 | 2.565 |
| Iron-in-ore..... | .234 | .214 | 1.150 | 1.559 |
| Iron content (natural).....wt-pct.. | 49.6 | 50.5 | 59.5 | 60.8 |

¹States in the Lake Superior district are listed in table A-18.

²1950 and 1953: Lake Superior Iron Ore Association; 1970 and 1972: American Iron Ore Association.

Source: Other statistics from BuMines Minerals Yearbooks 1950, 1953, 1970, and 1972. Series are listed in appendix tables A-2 through A-11.

The impact on the organization of mining is depicted by mine statistics from the Lake Superior district (Michigan, Minnesota, and Wisconsin); other States in which iron ore production has been reported since 1950 are shown in the appendix, figure A-1, and the classifications of States in regional aggregations are listed in table A-18. Although Lake Superior district mines continued to maintain an 80 percent share of U.S. production, the number of companies active in mining dropped by more than half between 1953 and 1972, from 30 to 13; the number of mines operated shrunk from 226 to 24; and the number of grades produced declined from 188 to 36.

The average scale of operations in the Lake Superior district meanwhile has increased beyond any earlier experience. Average mine production of crude ore rose elevenfold from 1953 to 1972 (0.53 and 6.48 million tons); usable ore, fivefold (0.42 and 2.57); and iron-in-ore, more than sixfold (0.21 and 1.56). The iron-in-ore is especially significant because iron ore is sold by the iron unit (1/100 of a long ton of iron-in-ore); it connotes that, on the average, the revenue per mine in 1972 was over seven times that of 1953 without allowing for price changes and quality adjustments. Based on the average value of shipments in 1972 (\$20.44 per long ton iron-in-ore) the average Lake Superior district mine produced \$31.9 million of iron ore, 12 times the average revenue of \$2.8 million in 1953.¹⁰

These organizational changes in mine operation apparently were mirrored in the remaining districts of the United States. The shares of crude ore, usable ore, and iron-in-ore originating in the Lake Superior district changed very little between 1953 and 1970, contributing about 80 percent of the Nation's total in each category. These statistics imply that the ore mining operations in other districts, in the aggregate, operate close to the Lake Superior district average.

These physical measures of changes in the production of iron ore are reflected also in the business statistics of the iron ore industry. Table 2 displays the principal statistics taken from the Census of Mineral Industries (MIC). This is the most accurate canvass because it is conducted on an establishment basis (mine, beneficiating plant, or central office) without distortion by other industrial activities of companies.

¹⁰The difference, \$29.1 million, can be decomposed roughly as \$0.5 million--higher price levels; \$11.3 million--quality extra for pellets; and \$17.4 million--scale of production. In 1953, the average value of shipments was \$12.92 per long ton iron-in-ore.

TABLE 2. - Economic statistics of iron ore production in the United States,
selected years

| | 1954 | 1958 | 1963 | 1967 | 1972 ¹ |
|---|-------|-------|-------|-------|-------------------|
| Number of establishments..... | 225 | 243 | 208 | 146 | 114 |
| Number of employees (N).....thousand.. | 34.2 | 30.1 | 23.1 | 22.6 | 19.8 |
| Usable ore produced (Q)...million long tons.. | 78.2 | 66.9 | 73.8 | 85.9 | 76.4 |
| Revenue and costs, million dollars: | | | | | |
| Value of shipments and receipts..... | 547.2 | 664.5 | 762.2 | 953.4 | 1,066.2 |
| Capital expenditures..... | 85.0 | 42.6 | 96.6 | 108.8 | 60.1 |
| Cost of supplies, etc., and purchased machinery installed..... | 196.5 | 219.4 | 309.6 | 400.3 | 424.1 |
| Value added in mining (VA)..... | 435.7 | 487.7 | 549.3 | 661.9 | 702.2 |
| Less, payroll (L)..... | 156.9 | 169.0 | 161.6 | 185.9 | 220.2 |
| Difference, gross payments to proprietors (P)..... | 278.8 | 318.7 | 387.7 | 476.0 | 482.0 |
| Unit statistics: | | | | | |
| Earnings per employee (L/N) thousand dollars.. | 4.59 | 5.61 | 7.00 | 8.23 | 11.12 |
| Output per employee (Q/N) thousand long tons.. | 2.29 | 2.22 | 3.19 | 3.80 | 3.86 |
| Value added in mining: | | | | | |
| Per long ton usable ore: | | | | | |
| To payroll (L/Q).....dollars.. | 2.01 | 2.53 | 2.19 | 2.16 | 2.88 |
| Gross to proprietors (P/Q).....do..... | 3.56 | 4.76 | 5.25 | 5.55 | 6.31 |
| Total (VA/Q).....do..... | 5.57 | 7.29 | 7.44 | 7.71 | 9.19 |
| Percent gross to proprietors (100P/VA) | 64.0 | 65.3 | 70.6 | 71.9 | 68.6 |
| Per long ton iron-in-ore: | | | | | |
| Iron-in-ore ²percent.. | 51 | 53 | 56 | 58 | 61 |
| To payroll (L/Q').....dollars.. | 3.94 | 4.77 | 3.91 | 3.72 | 4.73 |
| Gross to proprietors (P/Q').....do..... | 6.98 | 8.98 | 9.38 | 9.57 | 10.34 |
| Total (VA/Q').....do..... | 10.92 | 13.75 | 13.29 | 13.29 | 15.07 |

¹Preliminary.

²Table A-2.

Source: Census of Mineral Industries (52). Details are listed in table A-12.

Shipments of usable ore were nearly the same in 1954 and 1972 (78 and 76 million tons, respectively) while employment diminished 42 percent (34 to 20 thousand). Although earnings per employee increased by 133 percent (4.59 to 11.12 thousand current dollars), the output also increased 69 percent in tonnage (2.29 to 3.86 thousand long tons) and 20 percent in grade (51 to 61 percent iron) to aggregate an 102 percent improvement in the output per employee of iron-in-ore, the principal measure of value.

These impressive gains in quality of product and output per worker between 1954 and 1972 had been obtained by unparalleled investments in new technologies and facilities. In 1954, the depreciated value of the industry's

plant and equipment was in the neighborhood of \$113 million.¹¹ By contrast, in 1954 the industry invested \$85 million in domestic facilities (table 2), an amount equivalent to three-fourths of the worth of the entire industry's plant and equipment. Moreover, this level of investment was continued in the face of, at best, a static market for iron ore (table 1). Capital expenditures totaled \$97 million in 1963, \$109 million in 1967, and \$60 million in 1972. By 1972, the cumulative stream of investment had provided the facilities for producing nearly three-fourths of the usable ore in the form of agglomerates, mainly pellets (appendix table A-4). The traditional industry was receding toward the margin.

In summary, iron ore mining in the United States has been transformed fundamentally from simple extraction and beneficiation of natural ore to a complex manufacturing operation that gives a highly uniform product from a diversity of crude mineral compositions. An unparalleled intensity of capital investment has drawn hitherto submarginal resources into the mainstream of production to provide a continuity of secure mineral supply to the Nation. The succeeding sections of this report are addressed to separate analyses of the economic factors--labor and capital--that provide economic vitality to this system.

LABOR REQUIREMENTS

The objective of this study was to describe, analyze, and forecast the need for labor in iron ore mining. Within this general objective, the course of the analysis was shaped by the availability of information from studies by others and from periodic statistical measurements of performance.

The analysis was framed to provide useful information at both the micro-level and macrolevel. The results of an analysis at the mine level would be useful to firms for locating themselves within the context of the industry. At the industry level, the mine-level results could be aggregated to provide industrywide measures. Too, the "best practice" mines could be identified; the experience of these frontrunners in implementing technical change would provide a foretaste of the future performance of the industry.¹²

The basic needs for this analysis were twofold: (1) To understand the labor requirement for production, and (2) to view the labor input as an abstract economic factor measured in real (not monetary) terms. A sufficient labor force was assumed as well as no other issues concerning manpower, employment, and jobs. These assumptions concerning labor economics seemed valid in the context of this study so the analysis of labor requirements was directed toward analyzing the mechanism of production.

¹¹Estimated by the authors from Newcomb's detailed study of Minnesota mines (37, p. 32). Depreciated value of plant and equipment in Minnesota was \$70.9 million in 1954 exclusive of taconite developments; extending that figure by Minnesota's 63 percent share in U.S. production resulted in a total of \$113 million for the United States.

¹²Developed by Salter (45). For an example in iron and steel, see reference 30.

Prior Studies

Prior studies of employment and labor requirements provided a rich background of understanding but not much detail. The foundation study on employment in mining is that of Barger and Schurr (4). Their chapters on iron ore provided a masterful description and analysis of growth (for the years 1889-1939). However, their data were too aggregated to be directly useful; besides, the "taconite revolution" has displaced that industry, anyway. Their findings were incorporated into Kuznets' (26) monograph on capital in the American economy and later into Kendrick's (23) study of productivity trends. Both of these works were addressed to macroscale descriptions of the U.S. economy, and the information was highly aggregated. Newcomb (37) analyzed the natural ore industry in Minnesota in a richly interwoven study of technologic change and resource depletion, but he, too, dealt in aggregates of mines. Hammes (17) performed a uniquely detailed analysis of Minnesota taconite technology; his cost analysis of operations was the best measure available of the labor involvement in the mining, concentrating, and agglomerating operations. The Bureau's Process Evaluation Group (58) performed a completely detailed analysis of manning in a hypothetical taconite-to-pellets plant. Battelle's private report on iron ores and ironmaking (5) included some estimates of labor requirements but was far from complete. It seemed that questions of labor requirements in iron ore mining have not been irksome enough to warrant much study. Thus, the major emphasis in this study was placed on survey statistics, corroborated by detailed cost analyses.

Sources of Survey Statistics

The best known source of statistics concerning employment and earnings in the United States is the U.S. Department of Labor, Bureau of Labor Statistics (BLS). Also well known is the series provided by the U.S. Department of Commerce, Bureau of the Census, in its Census of Mineral Industries (MIC), taken every 5 years. A lesser known source of employment statistics in the mineral industries of the United States is the U.S. Department of the Interior, Bureau of Mines. Trade associations also collect statistical details, usually of production, shipments, and sales. Each source has different objectives; thus, their scopes, collection methods, and coverages vary considerably.

The Bureau of Labor Statistics cooperates with State agencies in collecting and publishing data each month on employment, hours, and earnings from a sample of establishments in all nonagricultural activities including government. Respondents participate voluntarily in the industry employment statistics program. The statistics are classified in accordance with the Standard Industrial Classification (SIC). Iron mining is reported monthly in Employment and Earnings (59). Long-run series are published in BLS bulletins (60-61).

The U.S. Bureau of the Census, in its Census of the Mineral Industries (52), conducts mandatory comprehensive surveys of establishments¹³ engaged in mining activities (as defined in SIC) at 4- to 5-year intervals. The 1967 census is the latest complete census available (beginning with the 1972 census, the intervals will be 5 years). Published tabulations show comparative figures for industries and States (where confidentiality considerations permit) on the more important measures of the activity of mining establishments, such as employment, payrolls, value of shipments, expenditures for plant and equipment, value added in mining, selected materials consumed, and energy used.

The Federal Bureau of Mines, among its other functions, gathers and publishes statistics on the production and value of minerals, both nationally and internationally, by means of voluntary canvasses. Injury experience and work time in the mineral industries have been the subjects of a mandatory canvass.¹⁴ Because the injury information is subjected to detailed analysis, the correlative employment data are collected in considerably more detail, and the coverage is more complete than similar statistics reported by BLS or MIC. Bureau of Mines employment data are limited to workers at mines and mills (including development and exploration workers), but they include supervisory and clerical employees.¹⁵ Neither the total number of employees nor payroll figures are collected because those statistics are developed from the BLS canvass.

Trade associations in some industries gather and publish statistical data. Such statistics may be compiled from other sources, or they may have been developed by the trade association itself primarily for the use of its membership and customers. The American Iron and Steel Institute (AISI), for example, publishes aggregated statistics of hourly wage earners and salaried employees, hourly worker employment costs, and total annual employment costs. It also publishes production information (2). The American Iron Ore Association compiles and publishes iron ore production, transportation, and consumption information but does not compile any employment or payroll statistics (3).

The Bureau of Mines covers production workers in greater detail than either the BLS or the MIC employment data for the mineral industries. Bureau of Mines data differentiate between workers in mines and in mills

¹³A mineral establishment is defined generally as a single physical location where mineral operations are conducted; for example, a mine only, in which operations are conducted as a unit or are unified by common management or joint handling of some part of the mining or preparation process. A company with operations at more than one location is required to submit a report for each location. Establishment reports differ substantially from those prepared on a company basis which not only combine activities at different locations but also include the manufacturing and business activities of companies primarily engaged in mining. For a complete description, see the introduction to the 1967 census (52).

¹⁴This responsibility was transferred July 1, 1973, to the Mining Enforcement and Safety Administration in the U.S. Department of the Interior.

¹⁵The Minerals Yearbook publishes separate series for mines and mills in the chapter on Employment and Accidents. Total employment and ore production are tabulated together by State in the chapter on Iron Ore.

(beneficiation plants); they also distinguish between employment in underground mines, the associated maintenance shops, and open pit mines. Office workers at the mine are classified separately. Coverage usually is virtually complete and is adjusted to full coverage by estimating the relatively few nonrespondents. The canvass is performed annually.

For the objectives for this study, that is, to view iron ore mining and beneficiation as production processes, for which we need to estimate the inputs of selected factors classified by production process, the Bureau of Mines employment and production statistics provided the only source.

A comparative listing of the statistics of employment in the United States iron ore industry reported by Bureau of Mines, BLS, and Bureau of the Census covering the period 1950-72 is shown in table 3. Differences arise from the manifold differences in the respective canvasses. Systematic differences are evident between the Census and BLS reports of employment: the BLS figure is larger, on the average, by 6 percent of total employment and 12 percent of production worker employment. The Bureau of Mines figure is headed "average number of men working daily"; this measure is derived from an annual canvass by dividing the total number of manshifts by the average number of working days in the year reported by each mine. This figure used to be close to the BLS employment statistic, averaging 4 percent higher in 1950-62. Since that time the BLS and Bureau of Mines statistics have moved apart. The Bureau of Mines figure has fallen off faster than the BLS employment statistic. The era of pellets has brought with it the continuous operation of the mining, milling and pelletizing facilities. The average number of days worked in 1970 was 295 in mines (5.7 days per week), and 334 in mills (6.4 days per week). These aggregate statistics are confirmed by the experiences of others, who have reported 6-day-per-week (18 shifts per week) operations in mines and continuous operation of pellet mills (21 shifts per week).

TABLE 3. - Comparison of U.S. iron ore industry employment statistics reported by the U.S. Bureau of Mines (BuMines), the U.S. Bureau of Labor Statistics (BLS), and the U.S. Bureau of the Census (BuCensus), 1950-72

| | All employees, thousands | | Production workers, thousands | | Average number working daily, thousands, BuMines |
|-----------|-----------------------------|------|----------------------------------|------|---|
| | BuCensus | BLS | BuCensus | BLS | |
| 1950..... | - | 35.5 | - | 31.6 | 31.1 |
| 1951..... | - | 37.7 | - | 33.5 | 34.3 |
| 1952..... | - | 33.5 | - | 29.0 | 35.7 |
| 1953..... | - | 40.1 | - | 35.0 | 35.3 |
| 1954..... | 34.2 | 35.2 | 28.2 | 30.2 | 32.0 |
| 1955..... | - | 34.2 | - | 29.4 | 29.0 |
| 1956..... | - | 35.1 | - | 30.1 | 31.9 |
| 1957..... | - | 39.4 | - | 34.0 | 30.9 |
| 1958..... | 30.1 | 31.8 | 22.5 | 26.8 | 27.2 |
| 1959..... | - | 27.7 | - | 23.0 | 28.4 |
| 1960..... | - | 33.2 | - | 28.6 | 27.6 |
| 1961..... | - | 26.9 | - | 22.3 | 22.8 |
| 1962..... | - | 25.2 | - | 21.0 | 21.0 |
| 1963..... | 23.1 | 24.1 | 18.1 | 20.4 | 18.2 |
| 1964..... | - | 24.6 | - | 21.0 | 19.7 |
| 1965..... | - | 25.9 | - | 22.0 | 20.8 |
| 1966..... | - | 26.0 | - | 21.8 | 20.3 |
| 1967..... | 22.6 | 25.6 | 18.0 | 21.3 | 18.9 |
| 1968..... | - | 25.3 | - | 20.8 | 18.5 |
| 1969..... | - | 25.5 | - | 20.7 | 18.6 |
| 1970..... | - | 25.6 | - | 20.9 | 17.1 |
| 1971..... | - | 23.7 | - | 19.2 | 15.9 |
| 1972..... | ¹ 19.8 | 20.1 | ¹ 15.3 | 16.1 | ¹ 14.0 |

¹Preliminary.

Sources: BuMines--Minerals Yearbooks 1950-72.
BLS (61, pp. 7-8).
BuCensus (52, p. 10A-3).

Production statistics were obtained chiefly from the Bureau of Mines canvass. It gathers virtually complete statistical data on domestic mineral extraction and processing in terms of type, quantity, and value. Specialized information gathered from the statistical efforts of trade associations also was utilized.

Method of Analysis

The objective of the labor requirement study was to describe and analyze labor as a physical input to the production process. Both cross-section and intertemporal analyses were performed. Highly detailed analyses of leading operations were examined to aid in interpreting the empirical data and to identify trends into the near future.

Employment and production statistics covering the time period 1963-70 were collated from the two independent Bureau of Mines canvasses of each mine and mill operation in the domestic iron ore industry covering employment and injuries, and production and value. A total of 6,000 punchcards were prepared. The formats of these cards are listed in appendix table A-13.

The data collation effort marked the first time that these separate data series had been merged since the late 1930's. Over that extended interval, the organization of the two data streams had diverged, to no one's surprise. A great deal of auditing was required to bring the information together in a consistent fashion for the various classifications of mining and milling activity and also to bring together consistent runs of data over the timespan of this study.

Aggregate Labor Requirements

Employment in the U.S. iron ore mining industry diminished by about 40 percent from 1950 to 1972, from 35,500 in 1950 to 20,100 in 1972 (table 3). Over this timespan, the ratio of production employees to other employees diminished from about 8:1 to 4:1. Employment of nonproduction workers was steady (about 4,000), but the number of production workers declined from 31,000 in 1950 to only 16,000 in 1972. Because of this decline, the annual production payroll only doubled from 1950 to 1972--that is, from \$99.6 million to \$196.1 million (table 4)--although the average annual wage of the production worker in 1972 rose to three times the 1950 amount, from \$3,197 to \$9,694.

The distribution of production workers between mines and mills changed radically over the study period. Table 5 shows that in 1950 there were about 28,000 positions in mines and 3,000 in mills, but that by 1971 the number in mines had shrunk to 10,000, while those in mills had increased to 6,000. Furthermore, the average number of working days per year also underwent changes. In the early 1950's, mines worked on the average a steady 270 days per year; milling was more seasonal, averaging about 240 days. By the late 1960's both had increased, but milling had increased much more so. In 1971, mining operations averaged 301 days because of increasingly continuous operations. Milling, on the other hand, had risen to about 325 days, suggesting a change from a seasonal occupation to a round-the-clock, 365-day-per-year operation.

TABLE 4. - Wages, earnings, and payrolls in the U.S. iron mining industry, 1950-72

| Year | Production worker wages, hours and earnings ¹ | | | Payrolls, millions | | | |
|----------|--|----------------------|-------------------------|------------------------------|-----------------------|-----------------------|-----------------------------------|
| | Average hourly wage | Average weekly hours | Average annual earnings | Production workers | | All employees | |
| | | | | BuMines and BLS ² | BuCensus ³ | BuCensus ³ | BuMines and BuCensus ⁴ |
| 1950.... | \$1.51 | 40.6 | \$3,197 | \$99.6 | - | - | - |
| 1951.... | 1.70 | 42.1 | 3,732 | 128.4 | - | - | - |
| 1952.... | 1.82 | 43.5 | 4,139 | 115.2 | - | - | - |
| 1953.... | 2.13 | 42.1 | 4,676 | 142.4 | - | - | - |
| 1954.... | 2.16 | 37.5 | 4,224 | 106.2 | \$119.7 | \$156.9 | \$139.2 |
| 1955.... | 2.29 | 39.9 | 4,764 | 105.3 | - | - | - |
| 1956.... | 2.42 | 39.5 | 4,998 | 121.9 | - | - | - |
| 1957.... | 2.61 | 39.1 | 5,321 | 135.6 | - | - | - |
| 1958.... | 2.76 | 35.8 | 5,152 | 97.5 | 116.3 | 169.0 | 141.7 |
| 1959.... | 2.87 | 37.4 | 5,597 | 120.0 | - | - | - |
| 1960.... | 2.89 | 39.7 | 5,599 | 157.3 | - | - | - |
| 1961.... | 3.00 | 38.5 | 6,023 | 128.2 | - | - | - |
| 1962.... | 3.07 | 39.8 | 6,371 | 127.7 | - | - | - |
| 1963.... | 3.07 | 39.1 | 6,259 | 117.5 | 112.8 | 161.6 | 168.3 |
| 1964.... | 3.13 | 40.2 | 6,579 | 138.7 | - | - | - |
| 1965.... | 3.16 | 40.9 | 6,739 | 146.6 | - | - | - |
| 1966.... | 3.28 | 42.1 | 7,200 | 152.3 | - | - | - |
| 1967.... | 3.30 | 42.0 | 7,227 | 144.8 | 133.4 | 185.9 | 201.8 |
| 1968.... | 3.47 | 41.7 | 7,566 | 154.2 | - | - | - |
| 1969.... | 3.70 | 41.4 | 7,987 | 159.0 | - | - | - |
| 1970.... | 3.90 | 41.9 | 8,521 | 173.4 | - | - | - |
| 1971.... | 4.19 | 40.5 | 8,848 | 178.6 | - | - | - |
| 1972.... | 4.50 | 41.2 | 9,694 | ⁵ 196.1 | ⁵ 155.7 | ⁵ 220.2 | ⁵ 277.3 |

¹BLS (61).²Federal Bureau of Mines data for number of man-hours worked, and U.S. Bureau of Labor Statistics data for average hourly rate.³U.S. Bureau of Census data for the 1954, 1958, 1963, and 1967 census years.⁴Federal Bureau of Mines average annual production payroll multiplied by the ratio of U.S. Bureau of Census total payroll to production worker payrolls.⁵Preliminary.

TABLE 5. - Employment at iron ore mines and mills (beneficiation plants), 1950-71

| Year | Average number men working daily | | | Average number days worked | | Manshifts, thousands | | | Man-hours worked, thousands | | | Man-hours, average per shift | | |
|-----------------------|----------------------------------|-------|--------|----------------------------|-------|----------------------|-------|-------|-----------------------------|--------|--------|------------------------------|-------|-----------------|
| | Mines | Mills | Total | Mines | Mills | Mines | Mills | Total | Mines | Mills | Total | Mines | Mills | Mines and mills |
| 1950.... | 27,686 | 3,401 | 31,087 | 268 | 239 | 7,407 | 814 | 8,221 | 59,406 | 6,568 | 65,974 | 8.02 | 8.07 | 8.03 |
| 1951.... | 30,576 | 3,756 | 34,332 | 276 | 250 | 8,446 | 937 | 9,383 | 67,931 | 7,588 | 75,519 | 8.04 | 8.10 | 8.05 |
| 1952.... | 31,802 | 3,914 | 35,716 | 248 | 222 | 7,880 | 869 | 8,749 | 63,308 | 7,037 | 70,345 | 8.03 | 8.10 | 8.04 |
| 1953.... | 30,862 | 4,439 | 35,301 | 270 | 244 | 8,335 | 1,083 | 9,418 | 66,840 | 8,722 | 75,562 | 8.02 | 8.05 | 8.02 |
| 1954.... | 27,840 | 4,153 | 31,993 | 220 | 226 | 6,132 | 939 | 7,071 | 49,177 | 7,574 | 56,751 | 8.02 | 8.07 | 8.03 |
| 1955.... | 24,954 | 4,055 | 29,009 | 245 | 258 | 6,105 | 1,044 | 7,149 | 48,941 | 8,383 | 57,324 | 8.02 | 8.03 | 8.02 |
| 1956.... | 26,817 | 5,114 | 31,931 | 234 | 241 | 6,281 | 1,231 | 7,512 | 50,376 | 9,937 | 60,313 | 8.02 | 8.07 | 8.03 |
| 1957.... | 25,669 | 5,218 | 30,887 | 252 | 262 | 6,480 | 1,367 | 7,847 | 51,958 | 11,004 | 62,962 | 8.02 | 8.05 | 8.02 |
| 1958.... | 21,382 | 5,857 | 27,239 | 206 | 246 | 4,411 | 1,441 | 5,852 | 35,374 | 11,536 | 46,910 | 8.02 | 8.01 | 8.02 |
| 1959.... | 22,099 | 6,324 | 28,423 | 179 | 196 | 3,966 | 1,240 | 5,206 | 31,823 | 10,035 | 41,858 | 8.02 | 8.09 | 8.04 |
| 1960.... | 21,170 | 6,413 | 27,583 | 242 | 258 | 5,131 | 1,653 | 6,784 | 41,158 | 13,320 | 54,478 | 8.02 | 8.06 | 8.03 |
| 1961.... | 17,251 | 5,515 | 22,766 | 224 | 266 | 3,868 | 1,468 | 5,336 | 31,027 | 11,777 | 42,804 | 8.02 | 8.02 | 8.02 |
| 1962.... | 16,165 | 4,868 | 21,033 | 234 | 283 | 3,776 | 1,376 | 5,152 | 30,481 | 11,130 | 41,611 | 8.07 | 8.09 | 8.08 |
| 1963.... | 13,353 | 4,856 | 18,209 | 251 | 287 | 3,357 | 1,392 | 4,749 | 27,079 | 11,189 | 38,268 | 8.07 | 8.04 | 8.06 |
| 1964.... | 14,189 | 5,534 | 19,723 | 258 | 293 | 3,659 | 1,622 | 5,281 | 29,443 | 12,944 | 42,387 | 8.05 | 7.98 | 8.03 |
| 1965.... | 14,439 | 6,334 | 20,773 | 273 | 288 | 3,942 | 1,823 | 5,765 | 31,752 | 14,651 | 46,403 | 8.05 | 8.04 | 8.05 |
| 1966.... | 14,056 | 6,293 | 20,349 | 277 | 299 | 3,898 | 1,881 | 5,779 | 31,360 | 15,090 | 46,450 | 8.05 | 8.02 | 8.04 |
| 1967.... | 12,722 | 6,137 | 18,859 | 282 | 305 | 3,600 | 1,875 | 5,475 | 28,859 | 15,032 | 43,891 | 8.02 | 8.02 | 8.02 |
| 1968.... | 11,890 | 6,579 | 18,469 | 285 | 321 | 3,415 | 2,129 | 5,544 | 27,388 | 17,071 | 44,459 | 8.02 | 8.02 | 8.02 |
| 1969.... | 11,477 | 7,169 | 18,646 | 274 | 304 | 3,141 | 2,177 | 5,318 | 25,195 | 17,439 | 42,634 | 8.02 | 8.01 | 8.02 |
| 1970.... | 10,752 | 6,588 | 17,340 | 295 | 334 | 3,170 | 2,203 | 5,373 | 25,416 | 17,641 | 43,057 | 8.02 | 8.01 | 8.01 |
| 1971 ¹ ... | 9,800 | 6,100 | 15,900 | 301 | 325 | - | - | - | 23,631 | 15,754 | 39,205 | - | - | - |

¹Preliminary.

Source: BuMinerals Minerals Yearbooks, 1950-71, ch. on Injury Experience and Worktime in the Mineral Industries, tables 1 and 2.

Labor requirements in relation to production have changed remarkably in response to the changes in mining and milling technology. Table 6 displays the labor requirements, in man-hours per long ton of product, for processing crude ore, usable ore, and iron contained in usable ore over the period 1960-72. Separate tabulations are provided for the U.S. total, the Lake Superior district, and the remaining districts. Looking first at the total U.S. figures, in 1960 the labor requirement averaged 0.35 man-hour per ton of crude ore, 0.61 man-hour per ton of usable ore, and 1.15 man-hours per ton of iron contained in usable ore. By 1972, the labor requirements for crude ore, usable ore, and iron had shrunken to 0.19, 0.47, and 0.78 man-hour per long ton of product, respectively.

TABLE 6. - Labor requirements of the U.S. iron ore industry for all districts and for the Lake Superior and remaining districts, man-hours per long ton of product, 1960-72

| Year | United States total, all districts | | | Lake Superior district ¹ | | | Remaining districts ² | | |
|--------|------------------------------------|------------|----------------------------|-------------------------------------|------------|----------------------------|----------------------------------|------------|----------------------------|
| | Crude ore | Usable ore | Iron contained, usable ore | Crude ore | Usable ore | Iron contained, usable ore | Crude ore | Usable ore | Iron contained, usable ore |
| 1960.. | 0.35 | 0.61 | 1.15 | 0.31 | 0.55 | 1.02 | 0.49 | 0.91 | 1.78 |
| 1961.. | .31 | .60 | 1.11 | .28 | .56 | 1.01 | .42 | .74 | 1.45 |
| 1962.. | .29 | .58 | 1.06 | .26 | .52 | .93 | .41 | .81 | 1.59 |
| 1963.. | .25 | .52 | .93 | .22 | .46 | .82 | .34 | .72 | 1.32 |
| 1964.. | .25 | .53 | .94 | .22 | .46 | .81 | .37 | .73 | 1.33 |
| 1965.. | .26 | .53 | .93 | .22 | .46 | .82 | .39 | .73 | 1.27 |
| 1966.. | .25 | .52 | .90 | .22 | .46 | .80 | .36 | .71 | 1.21 |
| 1967.. | .24 | .53 | .91 | .21 | .47 | .81 | .36 | .72 | 1.22 |
| 1968.. | .23 | .52 | .89 | .20 | .46 | .79 | .35 | .72 | 1.27 |
| 1969.. | .21 | .49 | .81 | .18 | .43 | .71 | .32 | .71 | 1.21 |
| 1970.. | .21 | .49 | .82 | .18 | .43 | .72 | .32 | .71 | 1.20 |
| 1971.. | .20 | .49 | .82 | .17 | .43 | .70 | .32 | .76 | 1.27 |
| 1972.. | .19 | .47 | .78 | .17 | .42 | .69 | .30 | .70 | 1.16 |

¹Includes Minnesota, Michigan, and Wisconsin data for 1960-65 and 1970-72.

Excludes Wisconsin data for 1966-69.

²Includes Southeastern, Northeastern, and Western States data and data undistributed by State.

Source: BuMines Minerals Yearbooks 1960-72.

This improvement in labor requirements nearly offset the rise in wages of production workers from 1960 to 1972 (table 4). The average labor requirement per unit of iron-in-ore had fallen 32 percent (1.15 to 0.78 man-hours); in terms of a constant outlay for labor, that was equivalent to an increase of 47 percent in wages. Actually, wages had increased 56 percent in current dollars, from \$2.89 to \$4.50, so the payroll cost per unit of iron-in-ore actually increased 8 percent in current dollars. However, in that period the BLS Consumer Price Index rose 41 percent;¹⁶ thus, in terms of aggregate purchasing power, labor's share dropped 23 percent.

¹⁶1960: 88.7; 1972: 125.3 (1967 = 100).

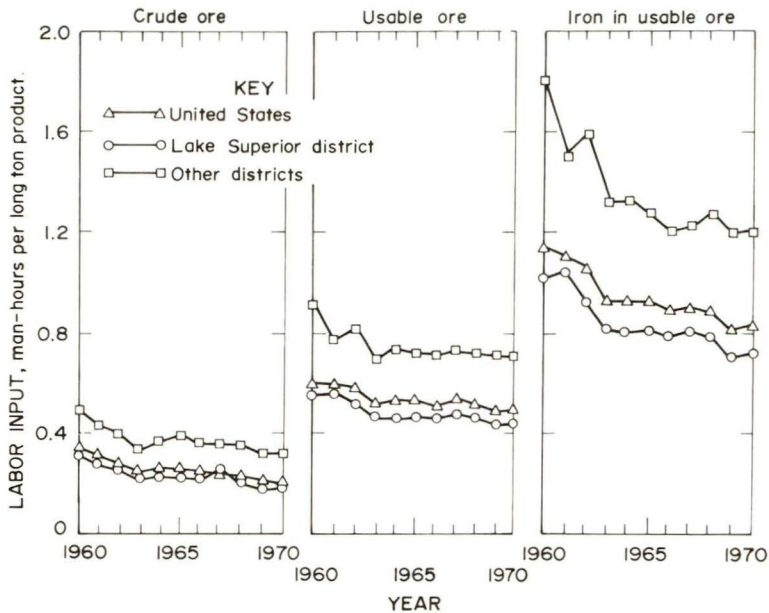


FIGURE 5. - Trends in Labor requirements for U.S. iron ore production, 1960-70.

together, one might extrapolate from the trends in table 6. To do so, however, would invite error. The 1960-72 period, as described in the foregoing section on the organization of production, was one of substitution of ore sources and continued implementation of beneficiation and agglomeration. To the extent that these operations are laborsaving, the trends pictured in figure 5 may simply be reflective of the progressive implementation of new technology. For example, 56 percent of the usable ore was produced by beneficiation in 1960, and 92 percent in 1970 (appendix table A-3). The implementation of new laborsaving technology was reaching saturation by 1970; further diminution in average labor requirements likely would be much smaller in magnitude. Only a cross-sectional analysis can provide a response to such questions.

Cross-Sectional Analysis of Labor Requirements

A detailed mine-by-mine analysis of labor requirements in mining and in milling was undertaken using the collated Bureau of Mines employment and production statistics. The point of beginning is the mining of crude ore. The yardstick of production is the long ton of crude ore rather than the long ton of contained iron that had been used in the preceding sections. In the preceding section, the emphasis was upon labor requirements as a cost per unit of output, the iron unit, because iron ore is priced on its metallic content. By contrast, the objective of the present analysis is to measure labor involvement in the physical production of iron ore. Labor is expended in mining crude ore regardless of whether any useful product emerges. Furthermore, the rate of crude ore production determines the size of a mining project, and the input

The downward trend in labor requirements listed in table 6 is illustrated in figure 5. The aggregate experience of the industry reflected similar currents of change in the Lake Superior district and in the remaining districts. The Lake Superior district produced 80 percent of the total iron contained in usable ore while using only 70 percent of the total labor.

The time series of labor requirements provides a basis for projection. Whether the area of consideration is the United States, the Lake Superior district, or the other districts taken

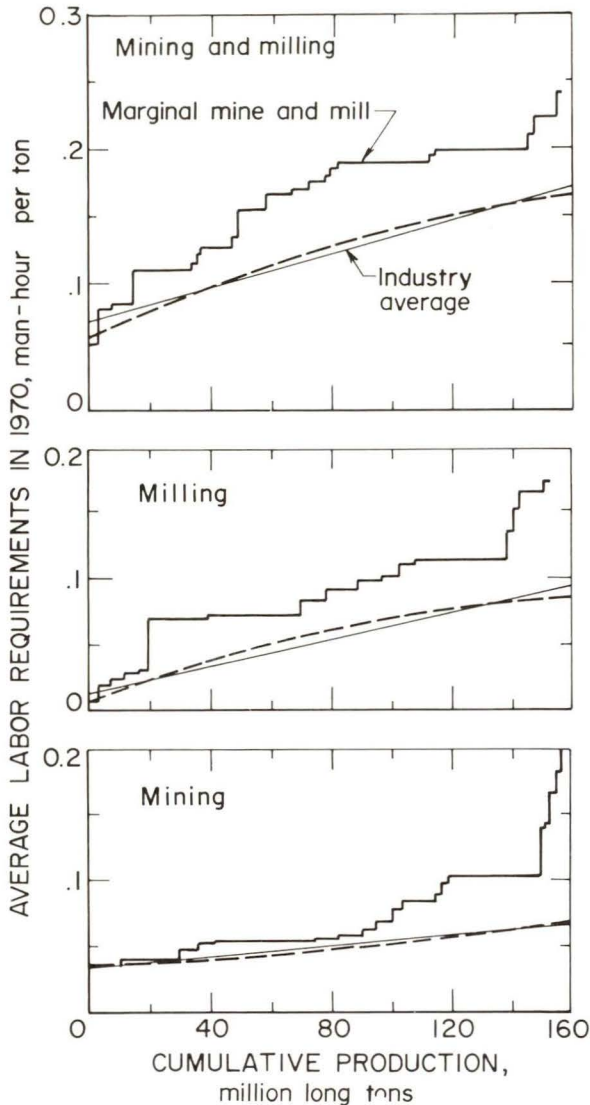


FIGURE 6. - Labor requirements schedules for iron mines and mills in the Lake Superior district of the United States, 1970.

those mines whose average labor usage fell within that limit, about 40 million tons; to increase the rate of production to 120 million tons, it would be necessary to bring into production mines that incurred average labor inputs up to 1.0 man-hour per ton.

rate of crude ore to be processed principally determines the size of the beneficiation plant.¹⁷

The average labor requirement in each mine during 1970 was determined by dividing the reported annual crude ore production into the reported man-hours of mine employment. In the Lake Superior district, the average labor requirement in open pit mines ranged from 0.035 to 0.180 man-hour per long ton crude ore produced. In the other States, the average labor requirement ranged from 0.023 to 0.300 man-hour per long ton crude ore. Underground iron ore mining in the United States averaged from 0.34 to 0.92 man-hour per long ton crude ore.

Figure 6 depicts the 1970 experience in the Lake Superior district open pit mines. To construct each chart, the mines were arrayed in increasing order of average labor requirements (man-hours per ton). Total labor input to a mine (man-hours) was regarded as an area [man-hours per ton (y-measure) \times tons produced (x-measure)], but only the top-most portion of the block was plotted. The staircase plot is the profile running from the least-cost operating unit to the highest cost. To economists, this staircase plot is a representation of the unit labor cost of the marginal mine. For example, if mining labor requirements beyond 0.05 man-hour per long ton crude ore could not be afforded, annual production might be confined to

¹⁷This important distinction was brought to the attention of the authors by Dr. John K. Hammes, who pointed out that the magnitude of crude material to be handled is a fundamental measurement in the provisioning of capital and, presumably, labor to mining and beneficiating projects. He included overburden removal in his remarks, but the stripping ratio is poorly reported, so this analysis does not deal separately with stripping.

The marginal cost staircase can be used to estimate an average cost curve. Retaining the same ordering of mines, their respective employment and output statistics are summed separately, and for each mine the cumulated production is divided into the cumulated employment to provide an estimate of average aggregate labor requirements to support that level of total crude ore production. The average cost curve at the left-hand end represents only the least-cost mine. At the right-hand end, it expresses the cumulation of all of the experience to the left. In the ordinary case of rising costs (fig. 6), the locus of the average cost curve is below the marginal cost curve.

The marginal cost curves in figure 6 and others to follow should be interpreted in their economic context.¹⁸ Supply schedules are representations of cost functions, $C = f(Q)$, relating total cost (C) and production (Q). The basic model of cost is the producing module, and the important questions center around whether in given circumstances it is worthwhile to increase production by one unit, the marginal unit, whose cost is the first derivative, $\frac{dC}{dQ}$. The producing module might be the simplest machine or an aggregation of increasing complexity: a department, plant, firm, industry, or an entire economy. The more aggregated the module considered, the more likely that measurements are available, but the more restricted is the interpretation of the meaning of marginal cost. To determine the marginal labor requirement in a mining crew, the questioner would have to specify the timeframe for producing that marginal ton (year, month, day, hour), how intensive the base production rate (conversely, how much slack time), and all of the surrounding physical circumstances. Inevitably, conditions would change, so the replies would be "averaged" anyway. The marginal cost concept remains an abstraction at the lowest level of aggregation. A rough estimation of marginal cost can be gleaned from figure 6. Because the supply schedule of each mine would have an arrangement similar to figure 6, figure 6 can be imagined as made up of a set of supply schedules for the individual mines placed side by side. In that view, the average cost curve of each mine (which are presented here as a flat step in figure 6) would have an upward slope intersecting the stepvalue at the total output. Continuing the analogy, the marginal cost curve of each mine would be above its average cost curve. Thus, we can be confident that the marginal cost of operations in each mine at its 1970 average rate of production would be higher than the respective steps shown in figure 6.

At higher levels of aggregation, the marginal cost conception becomes less precise in concept but more precise in measurement. In figure 6, the producing module is an entire mine. For purposes of estimation, the curves presume that each mine would continue to operate at the same rates of labor input and crude ore production. The marginal curve implies that to draw out additional production, the next higher cost mine would resume production; the curve really measures marginal cost of mines, but it is scaled in tonnage along the x-axis to depict the variation in the sizes of mines.

The curves in figure 6 are believed to be an accurate representation of the mine-level supply schedule of labor cost in iron ore mining because 1970

¹⁸The authors presume that a minor fraction of readers have retained a precise notion of supply schedules.

was a year marked by fewer upsets than usual; it was the year of calm before 1971, the year of labor contract renewal in iron and steel.

Figure 6 depicts also the labor requirements in the Lake Superior district for milling and for the combined mining and milling operations. Ranking was performed only in respect to the specific operation; the rank order of a mill in this chart is likely to be different than the rank of its mine in the lower chart. In the same manner, the uppermost chart was constructed to rank total labor requirements.

The interpretation of average cost curves is unusual. The line of best fit can be estimated by ordinary regression methods. Any interpretation of it, however, must take into account that the aggregativeness of the data points increases with each additional mine included in moving from left to right, and the variance likewise diminishes. This arrangement is inherently heteroscedastic and the ordinary evaluations of regression statistics do not apply.

In figure 6 the average cost curves are displayed in two forms: The full curve is the linear line of best fit, and the broken curve is the best parabolic fit. Both curves were fitted by least-squares regression. The regression statistics are listed in table 7. The slope coefficients (b , b' , c') are very small (10^{-5} to 10^{-13}) of necessity: They are scaling coefficients to be multiplied with production quantities up to nearly 200×10^6 tons in order to estimate a number in the neighborhood of (0.01-1.1). In mining, the sign of the quadratic coefficient (c') was usually positive, indicating an acceleration of labor cost in moving from least-cost to maximum-cost mining operations; in milling, however, the sign was negative in each district, suggesting an approach to some maximum labor requirement in milling. However, in each pair the linear and parabolic curves run close together. Statistical examination of the linear and parabolic relationships failed to disclose any significantly greater explanation of the total variance in the average cost information by the parabolic relationship; therefore, these average cost curves are regarded as essentially linear.¹⁹

¹⁹This is an application of Occam's Razor; the philosophical principle that the simpler explanation is to be preferred to the more complex one.

TABLE 7. - Regression parameters of average labor requirement schedules in U.S. iron ore industry, 1970

$$\text{Linear: } \hat{M} = a + b Q$$

$$\text{Parabolic: } \hat{M}' = a' + b'Q + c'Q^2$$

Q cumulative crude ore production, 10^3 long tons
H cumulative labor input, 10^3 man-hours
 \hat{M} average labor requirements (H/Q)
 \hat{M}' calculated estimate of M

| | Linear | | Parabolic | | |
|------------------------|---------|-----------------------|-----------|------------------------|-------------------------|
| | a | b | a' | b' | c' |
| Mining: | | | | | |
| Open pit: | | | | | |
| Great Lakes district | 0.0289 | 2.29×10^{-7} | 0.0351 | 4.66×10^{-8} | 1.01×10^{-12} |
| Other districts..... | .000469 | 4.26×10^{-6} | .00189 | 3.99×10^{-6} | 8.14×10^{-12} |
| Underground..... | .312 | 2.48×10^{-5} | .279 | 3.79×10^{-5} | -9.05×10^{-10} |
| All..... | .00882 | 4.12×10^{-7} | .0285 | -8.96×10^{-8} | 2.18×10^{-12} |
| Milling: | | | | | |
| Great Lakes district.. | .0122 | 5.06×10^{-7} | .00598 | 8.42×10^{-7} | -2.21×10^{-12} |
| Other districts..... | .0242 | 2.65×10^{-6} | .0192 | 3.45×10^{-6} | -2.05×10^{-11} |
| All..... | .0142 | 4.23×10^{-7} | .00826 | 6.64×10^{-7} | -1.26×10^{-12} |
| Mining and milling: | | | | | |
| Great Lakes district.. | .0709 | 6.18×10^{-7} | .0600 | 1.00×10^{-6} | -2.16×10^{-12} |
| Other districts..... | .0416 | 8.86×10^{-6} | .0860 | 1.39×10^{-6} | 1.90×10^{-10} |
| All..... | .0653 | 6.50×10^{-7} | .0729 | 4.32×10^{-7} | 9.74×10^{-13} |

Source: Annual canvasses by the Bureau of Mines of employment and production in iron ore mining.

Average labor requirement schedules revealed characteristic differences between mining methods, between mining and milling, and between districts. Measures of these differences are listed in table 8. Figure 7 indicates the comparative levels of labor inputs and rates of crude ore production associated with the mining methods, milling operations, and mining districts. It is a graphic display of the relationships implicit in the iron ore production tabulations. The bulk of the ore is produced in the Lake Superior district open pit mines; a similar proportion is milled at the mines in that district. The supply curves rise far more gently than in the "other" States both for mining and for milling. Underground mines have an even steeper labor requirement supply curve. One inference from these supply curves is that an incremented expansion of production, say, in units of millions of tons per year, could be accomplished in the Lake Superior district with far less disturbance to the cost structures than in the other States.

TABLE 8. - Details of labor requirement in U.S. iron ore industry, 1970

| | Average labor requirement in 1970, average man-hours per long ton crude ore | | | | | |
|--------------------------|---|----------|-----------------------|---------|-----------------------|-------|
| | Production included (Q), million short tons | Per mine | | | Industry | |
| | | Minimum | At (Q/2) ¹ | Maximum | At (Q/2) ² | Total |
| Mining: | | | | | | |
| Open pit: | | | | | | |
| Great Lakes district | 157.0 | 0.034 | 0.055 | 0.179 | 0.047 | 0.069 |
| Other districts..... | 25.5 | .023 | .116 | .227 | .085 | .117 |
| Underground..... | 11.9 | .338 | .623 | .921 | .506 | .633 |
| All..... | 196.3 | .023 | .057 | .921 | .046 | .113 |
| Milling: | | | | | | |
| Great Lakes district.. | 150.0 | .017 | .082 | .171 | .059 | .086 |
| Other districts..... | 33.8 | .017 | .111 | .234 | .073 | .114 |
| All..... | 183.8 | .017 | .090 | .234 | .061 | .091 |
| Both mining and milling: | | | | | | |
| Great Lakes district.. | 159.7 | .053 | .182 | .748 | .128 | .170 |
| Other districts..... | 36.4 | .082 | .283 | 1.10 | .211 | .397 |
| All..... | 196.6 | .053 | .187 | 1.10 | .142 | .214 |

¹(Q/2) denotes the production median in the labor requirement schedule. For example, in the first row, Q = 157.0; (Q/2) = 78.5, and the value in the table represents the mine that occupied that median position in the labor requirement schedule.

²Similar arrangement to footnote 1 but the value in the table is the average cost of the low-cost half of production.

The proportional distribution of labor requirements was composed by expressing the cumulative production as a percent of total production in the district. Figure 8 presents the information of figure 7 scaled in percentage terms. The labor requirement schedules in figure 8 for open pit mining do not differ much between the Lake Superior district and the "Other States" group in the slopes of the relationships. As to level, however, the "other" States required almost twice as much labor. Likewise, in milling, the slopes are similar in both sets when plotted as a function of relative production, though, again, the "other" States showed a generally higher level. Apparently the operations in the "other" States have locational advantages (including the grade of ore), which have permitted a generally higher level of labor input. This correspondence of slopes in the labor requirement schedules of the two groupings of States also suggested that the elasticity of labor requirement with respect to production²⁰ is quite similar between the two groupings.

²⁰The elasticity (λ) of average labor requirements ($\bar{L} = \frac{L}{Q}$) with respect to output (Q) is as follows:

$$\lambda = \frac{dL}{L} \div \frac{dQ}{Q} = \frac{Q^2}{L} \cdot \frac{d}{dQ} \frac{L}{Q} = \frac{Q^2}{L} \cdot \frac{1}{Q^2} Q \frac{dL}{dQ} - L = \frac{Q}{L} \cdot \frac{dL}{dQ} - 1 = \kappa - 1.$$

where κ is the elasticity of L with respect to Q. Analysis of cost elasticity is a fundamental method of estimating cost functions.

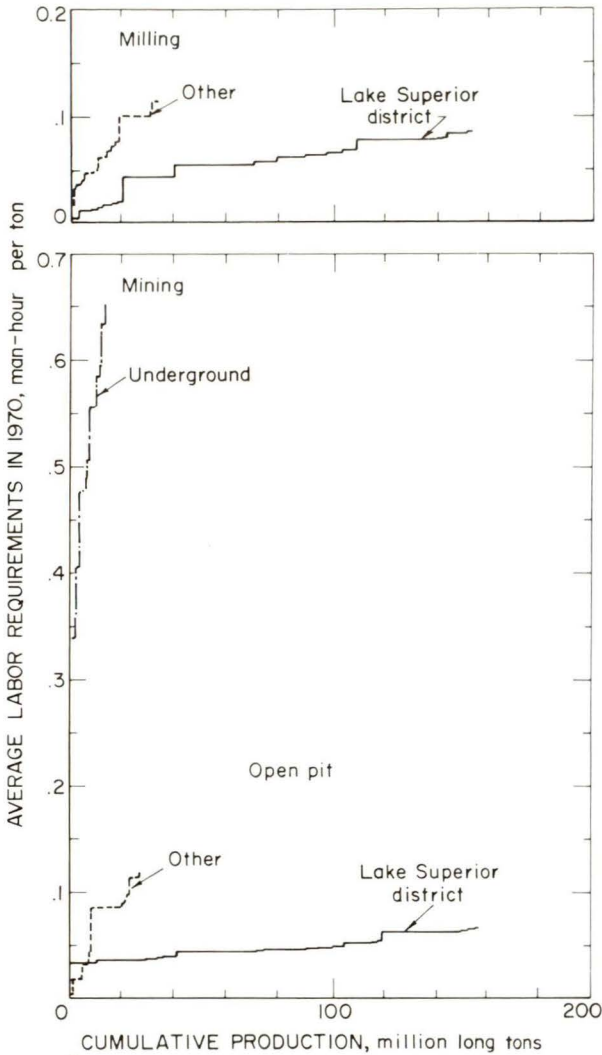


FIGURE 7. - Average labor requirements schedules for U.S. iron mines and mills in the Lake Superior and other districts, 1970.

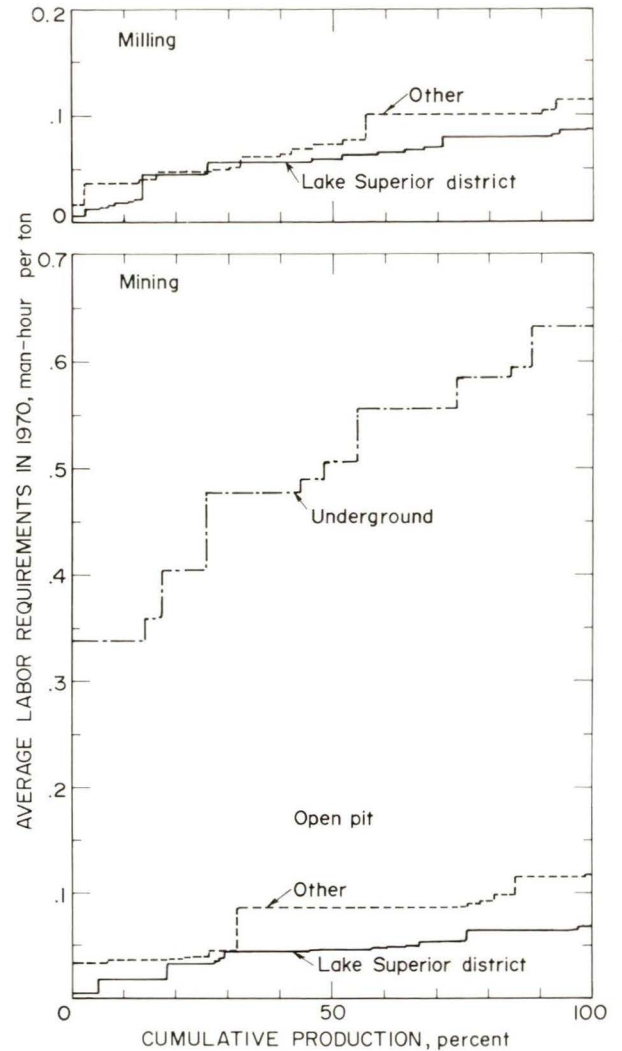


FIGURE 8. - Average labor requirements schedules scaled to proportion of output from mines, mills, and districts, 1970.

Figure 9 summarizes the labor requirement analysis. These curves were constructed from information representing more than 90 percent of the iron ore mined in 1970 and therefore may be taken as representative of the entire industry. They can be compared with the intertemporal aggregate curves for crude ore in figure 5. Taken together, the intertemporal movement of labor requirements and the supply curve of labor requirements for mining and milling crude ore show a possibility for diminishing the labor requirement per unit of crude ore in the future by as much as it was diminished in the decade of the 60's. However, the rate of improvement in labor requirements probably will slow down because the easiest opportunities have already been grasped. For example, when taconite mining, beneficiation, and agglomeration were substituted for an exhausted direct-shipment ore production operation, labor requirements were

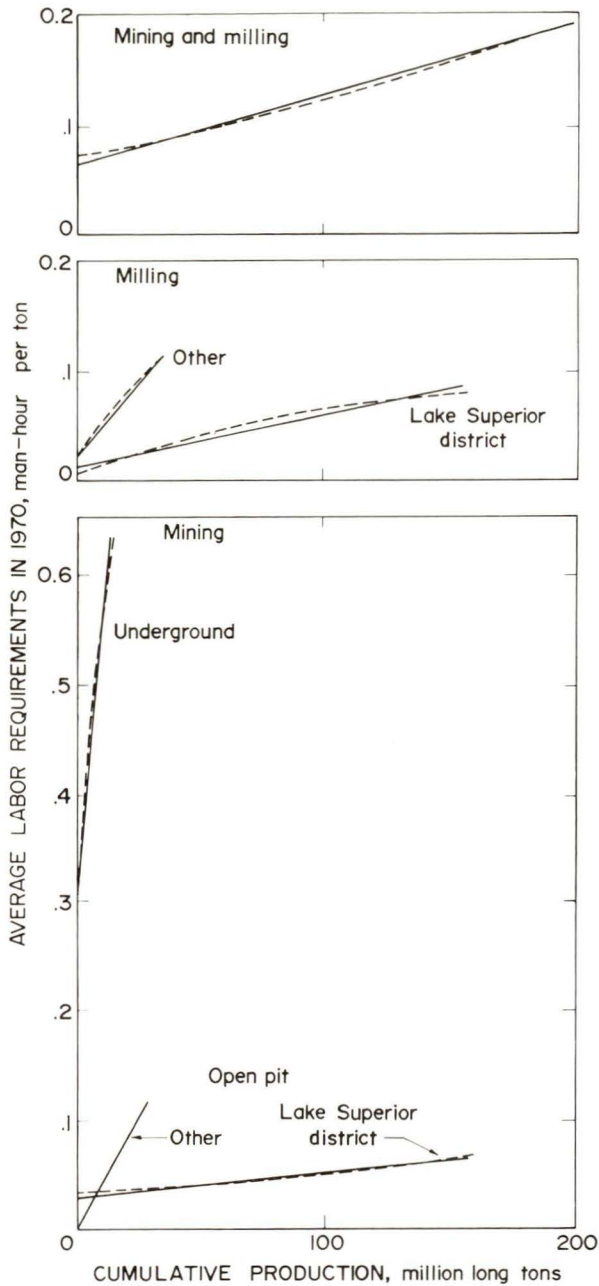


FIGURE 9. - Average labor requirements curves for mining and milling in the Lake Superior and other districts, and for combined operations in the United States, 1970.

of capital for labor in mining and milling.

Economies From Plant Expansion and From Learning

Average labor requirements have been reduced significantly by plant expansions and by improvements in work organization. The initial complement of

markedly reduced, but how to achieve similar gains with respect to contemporary taconite-to-pellets plants is not immediately obvious.

A Constraint on the Use of Labor

Evidences of a constraint upon labor usage first were noticed in reviewing the statistics of pellet plants. A study of six taconite-to-pellet plants (fig. 10) had shown the influence of the improved technology which had been implemented in the plants that came on-stream around 1967. Especially, these intertemporal curves showed that the median labor usage in mining and the median labor usage in milling summed to a value much greater than the median of the combined operations. Labor usage seemed to be limited to about 0.18 man-hour per ton crude ore (fig. 10, I).

The interprocess relationship was disclosed by rank correlation. Labor requirements for mining and for milling in these six plants covering the years 1969, 1970, and 1971 were correlated by rank (fig. 10, III). Two effects were evident: First, one plant was consistently best or next to best with regard to labor requirements, both for mining and for milling. Second, the other five plants showed a near-perfect inverse relationship between labor requirements in mining and in milling. Apparently, the total labor requirement is subject to a limit, and within that limit, the relative allocations to mining and to milling will vary inversely. Without similarly detailed capital expenditure information, there seems to be no way to shed added light upon the relative allocations of capital investment into these two processes, and the substitutability

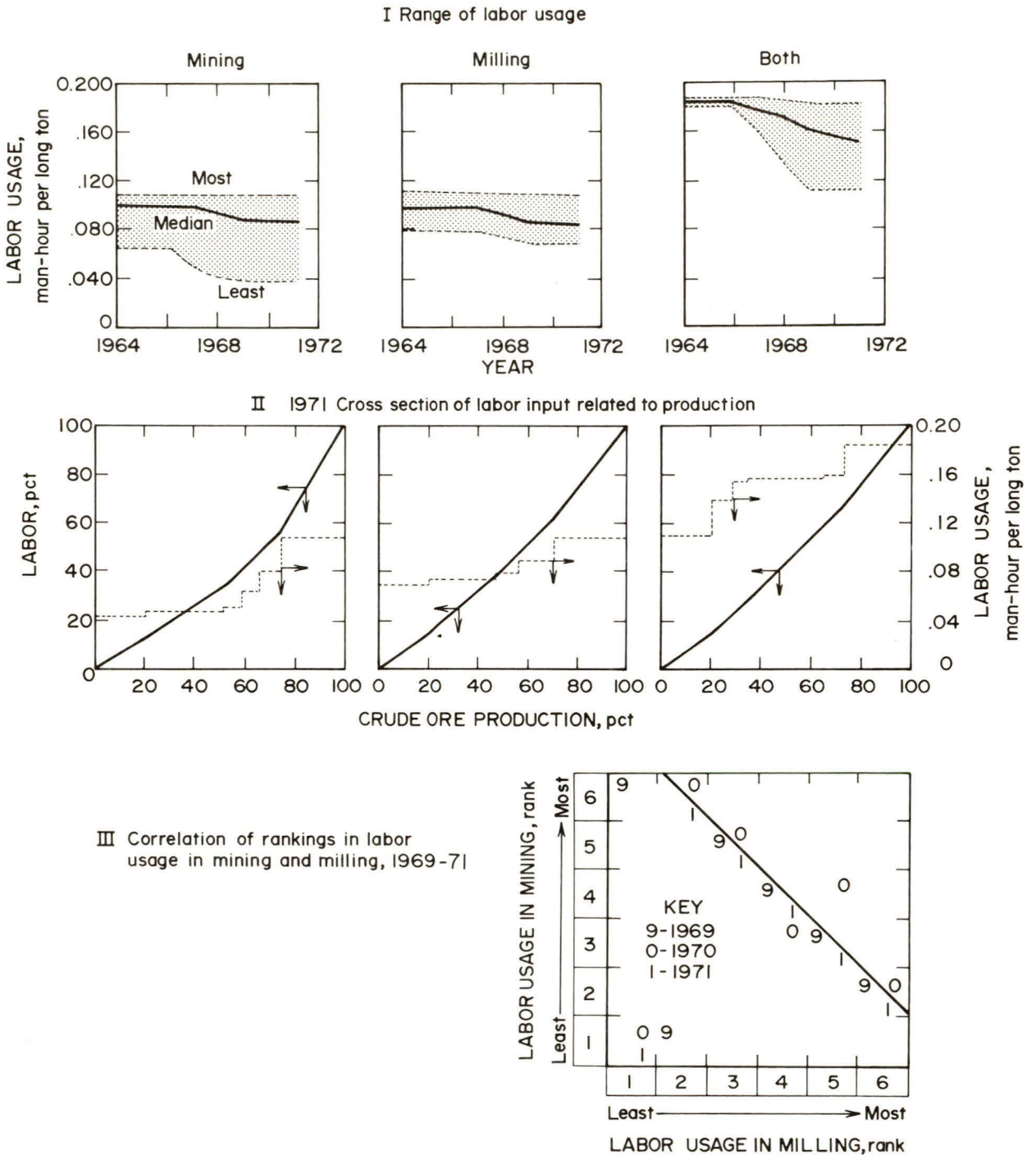


FIGURE 10. - Characteristics of labor usage by selected Lake Superior pellet producers. I, Range of labor usage among producers in mining, milling, and both operations, 1964-71; II, 1971 cross section, n = 6; and III, rank correlation of labor usage in mining and milling, 1969-71.

facilities required for mining projects oftentimes confers abundant capacity for expansion when conditions warrant. Then, after the first wave of pellet plant construction, future expansion probably would be by enlargement of existing operations. At least seven examples have been observed already in the United States and Canada. However, sorting out the consequences for labor requirements is difficult because the prior conditions of imbalance have varied so widely among the various mines and mills.

Effects of expansion and of "learning by doing" in new plants are illustrated in figure 11. This set of graphs depicts the intertemporal movements of labor requirements in 10 U.S. pellet plants from 1964 through 1972, expressed in each instance as an index based on 1970 = 100.²¹ The general trend to 1970 resulted mostly from expansions in older plants and learning in new ones. The clustering in 1971 and 1972 indicates a stabilization of production practice in well-established mines and mills.

Detailed Process Cost Analysis

The other approach for estimating labor requirements in mineral operations is to construct normative estimates from detailed process analyses. Such measures vary essentially from plant experience data because they tend to be idealized and to ignore the costs of imperfections in the operation of equipment, labor, and management, as well. They have the undoubted benefit of being more particularized. Whether an investigator can obtain such studies, provided they exist, oftentimes depends upon contacts with knowledgeable persons.

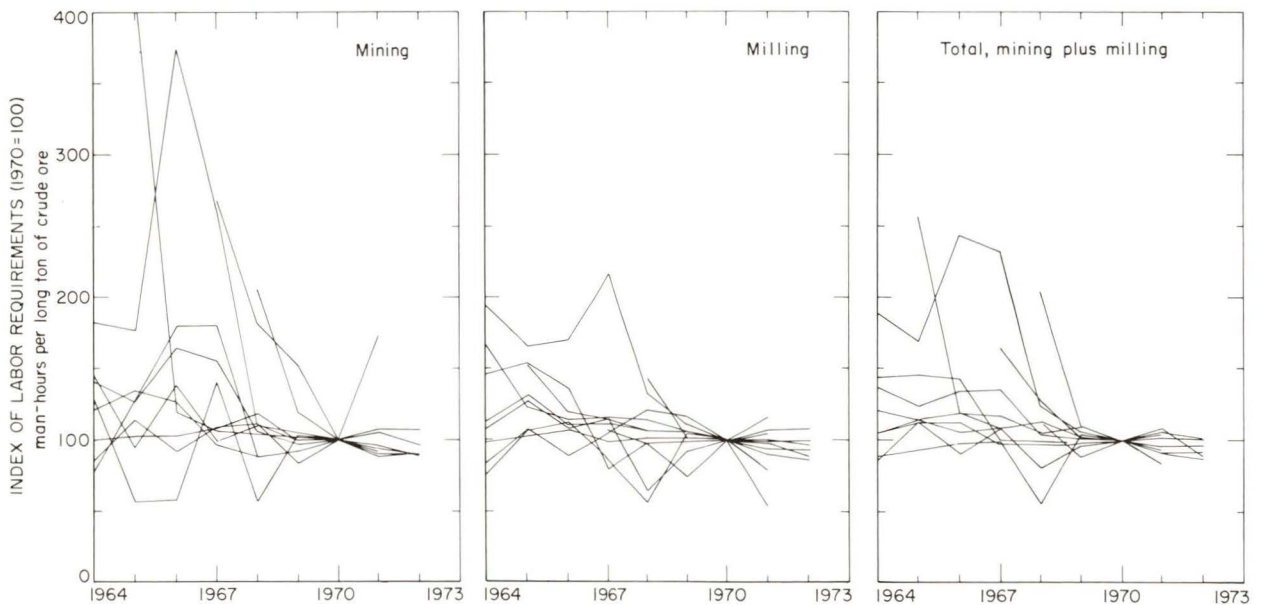


FIGURE 11. - Comparative movements in labor requirements per unit of crude ore processed at 10 Lake Superior plants, 1964-72.

²¹The curves intentionally were drawn to mask comparisons between specific plants.

In the case of iron ore mining, the investigators were fortunate to have been referred to a detailed analysis of the iron ore mining and pellet processing industry in the mid-sixties, by Hammes (18). This well-known report was based on his doctoral dissertation (17), which included detailed cost tables. From those detailed tables, the present investigators separated the details of labor requirements for mining, beneficiating, and agglomerating, for comparison to the employment and production information reported to the Bureau of Mines. The study included five mines and pellet plants in the Lake Superior district for the years 1964-66. These estimates are plotted in figure 12.

The method of estimation was devised by the present investigators independently of any knowledge of the reported labor requirements from these plants, that is to say, there was no prior knowledge of these specific plants' labor requirement experience to bias the investigators' decisions. Further, this pattern of estimation was extended to two Canadian plants, and the measures of the labor input resulting were close to the reported information on these plants.

The results of this comparison are shown in figure 13 as a chart of deviations plotted against the labor input reported to the Bureau of Mines. In this comparison, the unit of measure is the long ton of pellet product because this was the measure in which the cost analysis was reported.

It is striking that the difference between the estimated labor requirement calculated by the investigators and the employment reported to the Bureau of Mines appeared to be closely related to the reported labor input. The set of points representing mining provides the basis for a linear curve that, if extrapolated back to zero difference, would suggest a value of about 0.085 man-hour in mining. This relationship, a 45° slope, suggests a 1:1 relationship between the difference and the reported labor input.

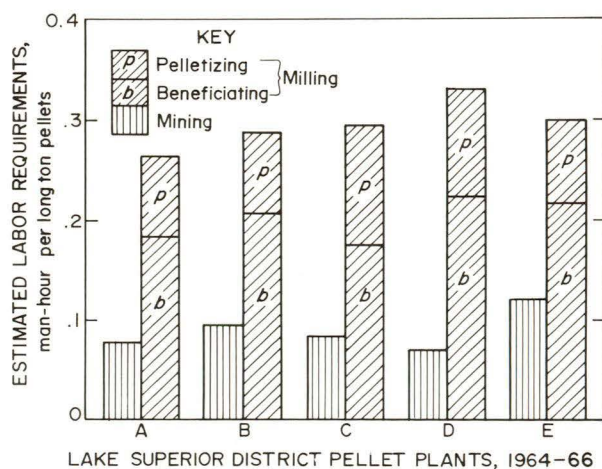


FIGURE 12. - Estimated labor requirements for mining, beneficiation, and pelletizing in five Lake Superior district plants, 1964-66, adapted from reference 17.

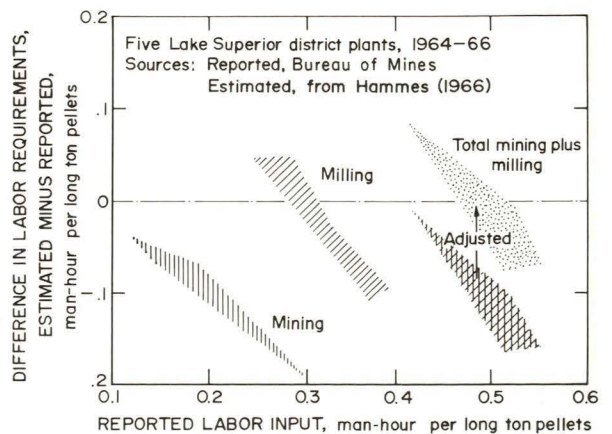


FIGURE 13. - Analysis of differences between estimated and reported labor requirements in mining, milling, and both operations.

Similar types of relationships were observed for milling and for total labor involvement. The forms of these relationships suggest that in the compilation of engineering cost estimates there is an idealization and rationalization of cost components. This consistent body of information provides the basis for consistent estimates of labor requirements, among other things. If the costs are estimated consistently low, as seems to be the case in the mining category in figure 13, this may suggest that the mining literature errs on the optimistic side. By comparison, in the beneficiation and agglomeration operations, the differences are distributed nearly symmetrical about zero, suggesting that in this manufacturing type of process the estimation procedure lies closer to reality.

Estimates of total labor requirements invariably were low; that is, the labor requirements calculated from the employment and production statistics reported to the Bureau of Mines were higher than those estimated by the authors from Hammes' study. A closer examination of the data suggested a downward bias of approximately 0.09 man-hour per ton pellets in the estimated data, principally in the mining operation, by exclusion of overhead labor. There may have been a tendency to allocate overhead labor to the mine rather than the mill in the employment statistics supplied to the Bureau of Mines.

The analysis of cost engineering data permits two conclusions. First, the Bureau of Mines canvasses had obtained valid responses from the mining, concentrating, and agglomerating operations, because these data were consistent with the cost engineering factors in these operations.²² As a result the labor requirements schedules depicted in figures 6-9 reflected the needs for labor inputs. Second, this method of comparative analysis should be useful generally in performing analyses of disparate streams of information, especially in mineral industries less well documented than iron ore.

CAPITAL REQUIREMENTS

The estimation of capital requirements for iron ore production was more difficult and less detailed than the estimation of labor requirements. Compared with labor, the notion of capital itself is less sharply defined, and the statistical base is very much poorer. In economic usage, capital is not money; it is the stock of plant, equipment, raw materials, and other physical necessities of production. Capital goods are aids in the production of things that eventually will be used by consumers. Investment is the construction of a capital good; in the national accounts, investment means the purchase of investment goods produced during the year. (Investment in iron mining in 1970 was the quantity of capital goods produced for that purpose in that year.) Capital is consumed by wearing out producers' goods or by obsolescence. These meanings exclude expenditures for an existing factory or for securities. (The factory had been counted as investment when it was built; securities are

²²This point can be illustrated by imagining a contrary case, where the calculated differences in figure 13 had occurred randomly without regard to labor input; in such a case, the magnitudes of the differences would have suggested that the measurements were too unreliable to be useful.

interests in money.) For this study, capital requirements refer to the gross investment for new mine developments, including expenditures for plant and equipment, construction expense, and working capital during construction and operation.

The estimation of capital requirements was hampered by the sparsity of reported data. There is a quarterly series on new plant and equipment expenditures in the entire U.S. mining industry, calculated by the Bureau of Economic Analysis (BEA) from a canvass of corporations that are engaged principally in mining.²³ However, capital expenditures intended for iron ore mining are reported for the most part under manufacturing because most iron ore producers are subsidiaries of steel producers. The only direct source is the Census of Mineral Industries (MIC); once every 5 years, it reports expenditures on plant and equipment from a canvass of establishments (see table 2), but the information was too infrequent and too aggregated to be helpful in this study.

The principal source of information concerning U.S. developments was the announcements of major mining projects, which often include estimates of capital expenditures for plant and equipment. Financial reporting services also develop and publish such information. The analysis of production showed that all further expansions of iron mining capacity probably would be devoted to mass mining, beneficiation, and pelletizing. The authors were able to construct a fairly complete listing of capital expenditures for pellet plants in the United States and Canada (table 9). This information, however, was of limited utility because it was not associated with economic measures sufficient for detailed analysis.

²³Published quarterly in Survey of Current Business (53).

TABLE 9. - Gross capital investment related to capacity in selected United States and Canadian iron ore mines and pellet plants, 1970

(Arranged in order of increasing capital cost per unit of iron production)

| Mine or plant | State or Province | Pellet capacity, million short tons iron-in-pellets | | Gross capital investment per unit of annual capacity, 1967 dollars per short ton iron-in-pellet | |
|----------------------------------|-------------------|---|------------|---|---|
| | | Mine/plant | Cumulative | Mine/plant | Average of cumulative investment and capacity |
| Pioneer ¹ | Michigan... | 1.02 | 1.0 | 5.38 | 5.4 |
| Caland ² | Ontario.... | .70 | 1.7 | 22.37 | 12.3 |
| Black River Falls.. | Wisconsin.. | .58 | 2.3 | 31.71 | 17.2 |
| Steep Rock ³ | Ontario.... | .93 | 3.2 | 33.64 | 21.9 |
| Hilton..... | Quebec..... | .67 | 3.9 | 34.53 | 24.1 |
| Meramec..... | Missouri... | 1.51 | 5.4 | 37.35 | 27.8 |
| Carol ⁴ | Labrador... | 7.21 | 12.6 | 40.27 | 34.9 |
| Adams..... | Ontario.... | .79 | 13.4 | 41.07 | 35.3 |
| Atlantic City..... | Wyoming.... | 1.19 | 14.6 | 41.67 | 35.8 |
| National..... | Minnesota.. | 1.74 | 16.3 | 42.48 | 36.5 |
| Republic..... | Michigan... | 1.72 | 18.1 | 44.69 | 37.3 |
| Empire..... | ...do..... | 2.28 | 20.3 | 45.85 | 38.3 |
| Eveleth..... | Minnesota.. | 1.14 | 21.5 | 46.61 | 38.7 |
| Groveland..... | Michigan... | 1.46 | 22.9 | 46.70 | 39.2 |
| Butler..... | Minnesota.. | 1.45 | 24.4 | 49.41 | 39.8 |
| Eagle Mills..... | Michigan... | .55 | 24.9 | 51.53 | 40.1 |
| Moose Mountain..... | Ontario.... | .42 | 25.4 | 52.39 | 40.3 |
| Griffith..... | ...do..... | 1.08 | 26.4 | 55.42 | 40.9 |
| Wabush..... | Labrador... | 4.31 | 30.1 | 60.04 | 43.6 |
| Humboldt..... | Michigan... | .54 | 31.3 | 60.52 | 43.9 |
| Minntac..... | Minnesota.. | 3.21 | 34.5 | 61.83 | 45.5 |
| Quebec Cartier ⁵ | Quebec..... | 6.51 | 41.0 | 65.55 | 48.7 |
| Reserve..... | Minnesota.. | 7.21 | 48.2 | 66.70 | 51.4 |
| Erie..... | ...do..... | 7.13 | 55.4 | 71.11 | 53.9 |
| Marmoraton..... | Ontario.... | .37 | 55.7 | 74.82 | 54.1 |
| Sherman..... | ...do..... | .70 | 56.4 | 78.50 | 54.4 |

¹Pelletize natural ore from existing mine.

²Pelletize natural ore, including new mine.

³Beneficiate and pelletize, existing mine.

⁴Exclusive of railway, powerplant, and townsite.

⁵Estimated, by adding \$38 million for pelletizing to published cost.

The only source of information known to the authors concerning capital requirements and production information is the annual statistics of the Canadian iron mining industry (48). Canada is a major supplier of iron ore to the United States; its iron ores move in competition to nearly all of the U.S. production, and its iron ore developments have been financed largely by U.S. mining firms. Thus, the Canadian statistics likely would provide a close

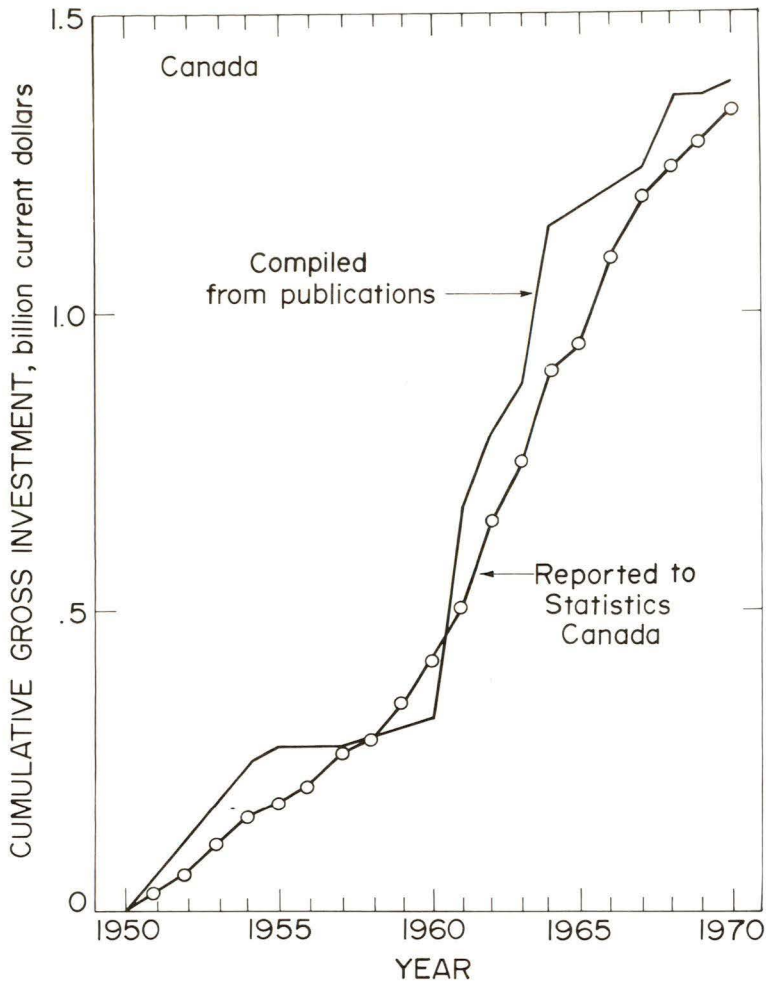


FIGURE 14. - Cumulative gross investment in iron mining and milling, Canada, 1950-70.

measure of U.S. production. The fit between the published statistics and publications of estimates of expansions in the Canadian industry (28) is shown in figure 14. Considering that the announcements of expansions and the incurring of expenses for a plant and equipment may lag by perhaps as much as 4 years, the curves in figure 14 suggest a useful fit between the two sources. They suggest further that the announced estimates of expenditures over the course of time are fairly close to the actual magnitude of expenditures.

An intertemporal comparison of capital expenditures per annual ton of iron production capacity was desired. For this purpose, the capital investments reported for individual projects in the United States and Canada were brought together by (1) attributing the entire capital expenditure for a project to the year in which production began and by

(2) deflating the cost estimates to 1967 constant dollars.

Selecting a cost index was not simple. Several indexes are commonly used (40):

Chemical Engineering--Plant construction.

Marshall and Swift--Mining and milling.

Engineering News-Record--Construction.

BLS--Wholesale price index of mining machinery and equipment.

They are difficult to compare because they have different base years, thus the values for a given time period differ greatly. These indexes were brought together by expressing the 1967 value of each as the base and then expressing

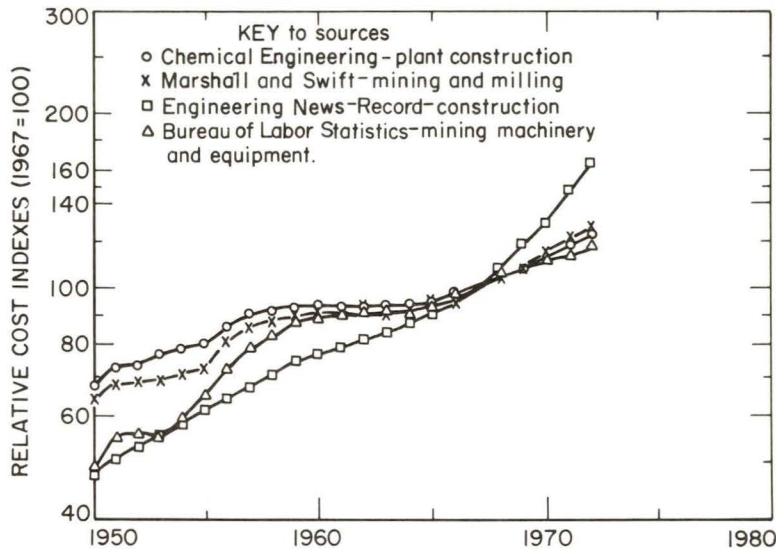


FIGURE 15: - Trends in cost indexes related to iron ore mining and milling, 1950-72.

the published indexes for each year 1950-72 as an index relative to 1967 = 100 (appendix table A-14). The comparison is shown in figure 15. The Chemical Engineering, Marshall and Swift, and BLS indexes have tracked one another closely since 1960 or so. The BLS index is for equipment "in the crate," whereas the other indexes are for plant and equipment "in place." The authors selected the Marshall and Swift index because it is the most particularized series available.

Figure 16 presents a capital supply schedule similar to those developed for labor requirements in the preceding section. To estimate the capital requirements of each project per unit of iron production, the respective investments per ton of pellets were divided by the iron concentrations reported for the respective pellet products to the American Iron Ore Association (3) and to the Canadian Department of Mines, Energy, and Natural Resources (28).

To construct the average cost schedule in figure 16, the low values at the beginning of the staircase were omitted, but the high values at the upper end were included. At the lower end, the costs of adding pellet plants to existing iron ore mining operations were excluded because they are unrepresentative of complete developments. At the high end, the costs embraced developments that included expenditures for such major infrastructures such as railroads, utility plants, and townsites; they were included because they do not affect the average cost curve for pellet supply from projects of lesser cost (to the left), and the inclusion of the high cost information does provide a measure of the total expenditures for complete development of new mines. Thus, the average cost curve is conservative in the sense that at no point in its run can it be considered as biased low.

The most striking point about the capital supply schedule is how widely capital requirements vary between plants. Table 9 (and fig. 16) exhibits capital costs, in constant 1967 dollars per short ton of iron-in-ore, ranging from \$32 to \$79, a ratio of 2-1/2 to 1. The average cost of the industry in the same unit of measure was \$54. These figures should be interpreted carefully because they represent a wide spectrum of complexity from the simplest add-on to a complete development: mine, mill townsite, and transportation. Most especially, this range of outlays cannot be interpreted to signify the existence of much slack in the cost structure.

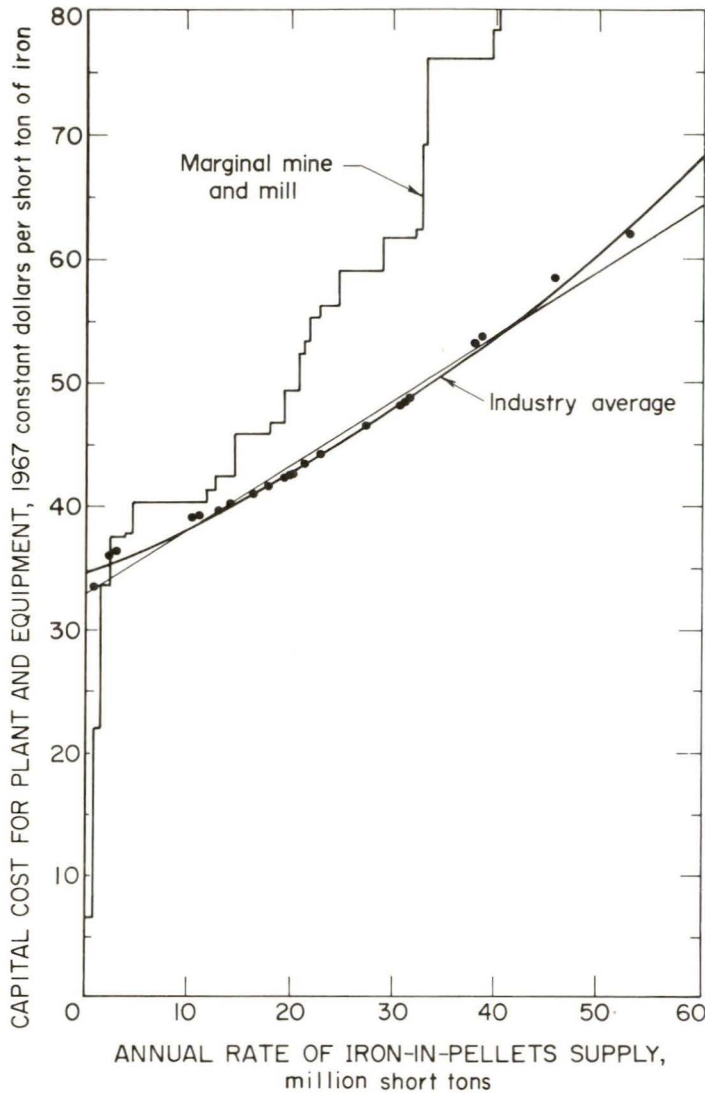


FIGURE 16. - Capital supply schedule for iron ore pellets, United States and Canada.

payments to owners (K) before deductions for indirect business taxes and capital consumption allowances (depreciation). The full curve, simply a connection between successive years, orients the view to the intertemporal relationship. The two broken curves are independent linear plots of an envelope for the relationship; their slopes turned out to be essentially parallel. A regression analysis of the logarithms of the payments to L and K was found to be essentially linear, implying a constant exponential distribution of value added (VA) between labor and owners. Over the 1951-70 period, the distribution relation is

$$VA = 2.33 L^{0.38} K^{0.58} e^{0.004t}, t_{1951} = 0.$$

The annual Canadian statistics were sufficiently complete to permit a further economic analysis of modern iron ore mining projects. In 1950, the Canadian iron ore industry was small: It shipped 3.7 million long tons of natural ore, about the same as in the preceding 5 years. By 1970 it was a major supplier to the world, shipping 7.6 million tons of natural ores and 40 million tons of highly concentrated products (pellets, concentrates, and sinter) valued at \$576 million (28). The difference between 1950 and 1970 was the consequence of investing \$1.4 billion (Canadian) in that period.

Annual Canadian statistics also include payrolls and value added (48), thus permitting the estimation of income distribution. Figure 17 is a plot of the distribution of income from iron ore production. Gross income, measured by value added, is distributed between the respective annual payments to labor payrolls (L) and to the residual component of value added; that is, the gross

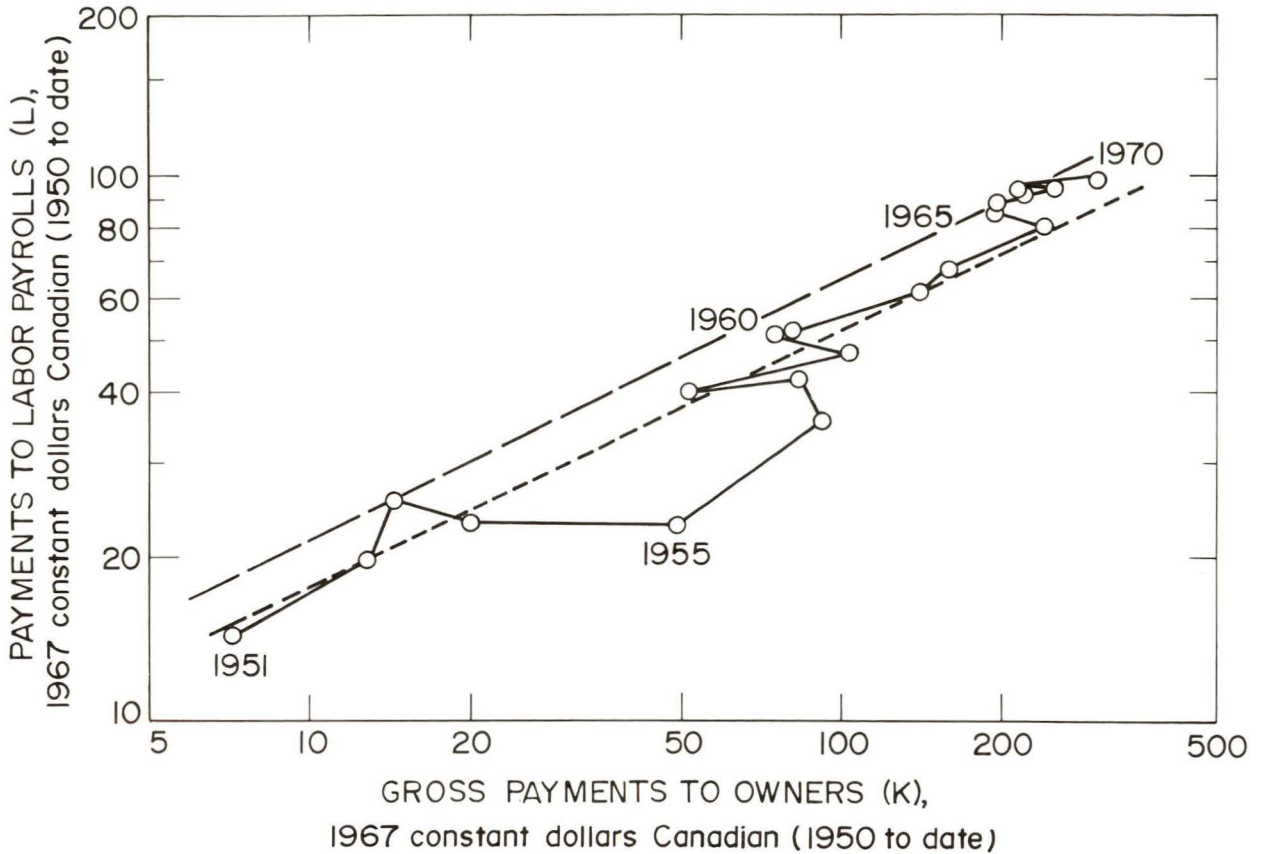


FIGURE 17. - Distribution of value added to labor payrolls (L) and to owners (K), Canada, 1951-70.

The exponents measure the shares to labor (L) and to owners (K). They sum to 0.96, implying a Cobb-Douglas production function. The rate of technological progress is 0.004t, that is, 0.4 percent per year.

The same series of Canadian statistics also permitted the cumulation of measurements of investment, employment, payroll, and output (fig. 18). The runs of data were arranged to show differences from 1956; this focused attention upon the era of concentrators and pellet plants by excluding the initial phase of the Iron Ore Company of Canada project, when only direct shipping ore was produced. Economic measures derived from these data are presented in figure 19. The point of beginning is 1962 rather than 1956 because the intervening period was one of diminished demand and erratic operations in iron and steel. The upper chart presents curves of gross capital requirements per ton of iron produced (K/Q) and the labor requirements per ton of iron produced (L/Q). In both curves, the 1969 experience is spuriously high as a result of a work stoppage that curtailed shipments; for the same reason, the 1970 results probably are biased low.

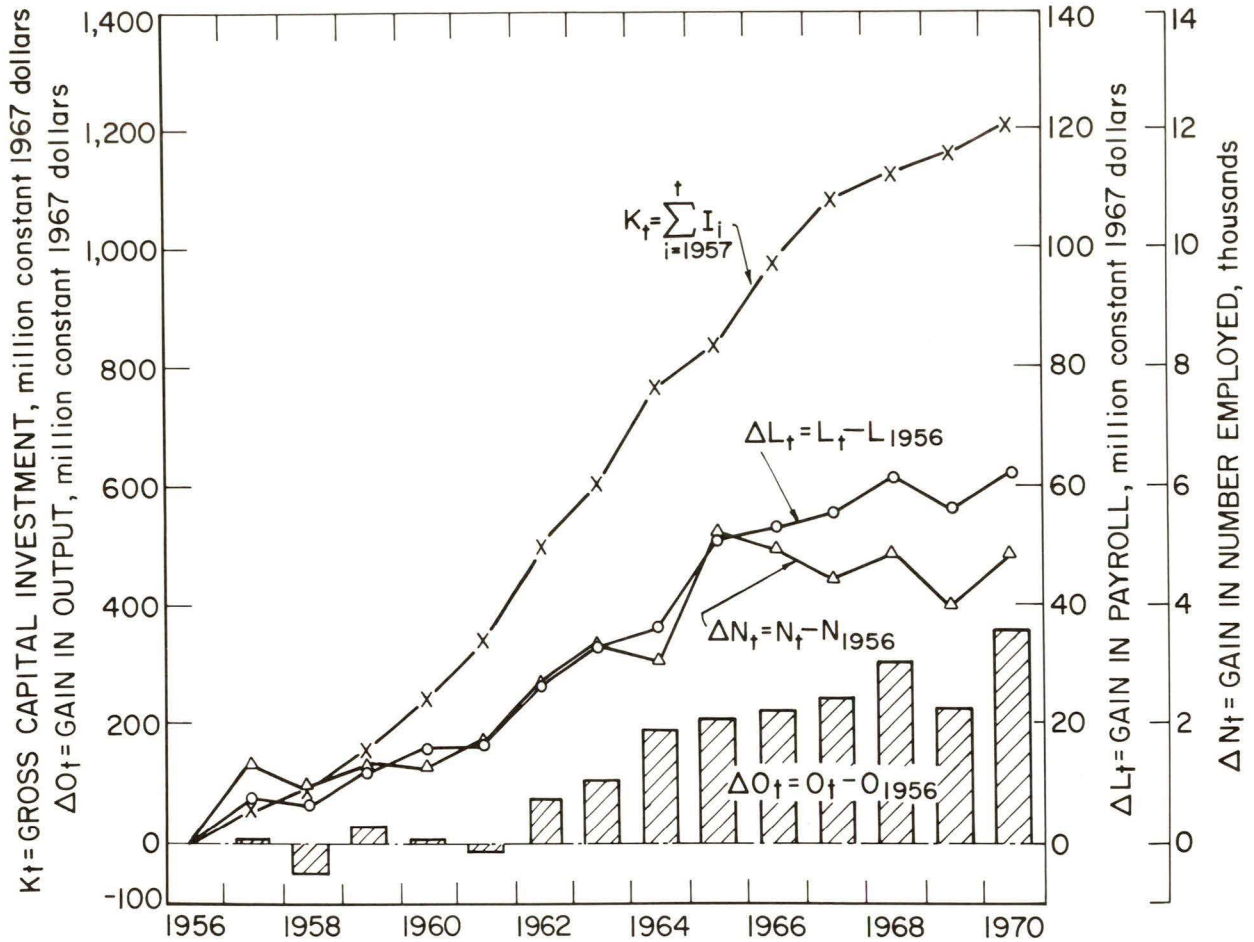


FIGURE 18. - Cumulative changes in Canadian iron ore industry, 1956 to 1970. Gross investment (K), employment (N), payroll (L), and output (O).

The trend relationships in figure 19 permitted several interesting conclusions to be drawn. Most important, the capital requirements for Canadian pellets appear to have converged on a value of \$70 (constant 1967 dollars) per annual net ton of iron-in-pellets capacity, or \$0.784 per long ton iron unit. In the United States iron ore industry, the average value per long ton of iron-in-pellets f.o.b. mines in 1967 was approximately \$19.30, leading to an estimation of a gross capital:output ratio of 4.06; by comparison, the lower chart in figure 19 suggests that the Canadian gross capital:output ratio was converging on about 3.90, only 4 percent less. These comparative measurements give credibility to the assertions made earlier of similarities between the iron ore industry in Canada and the United States.

The trends in figure 19 likewise permitted a comparison of labor requirements between the United States and Canada. The Canadian requirements converged on 0.65 man-hour per gross ton iron-in-usable ore. By way of comparison, the 1970 average in the Lake Superior District was 0.72 man-hour on

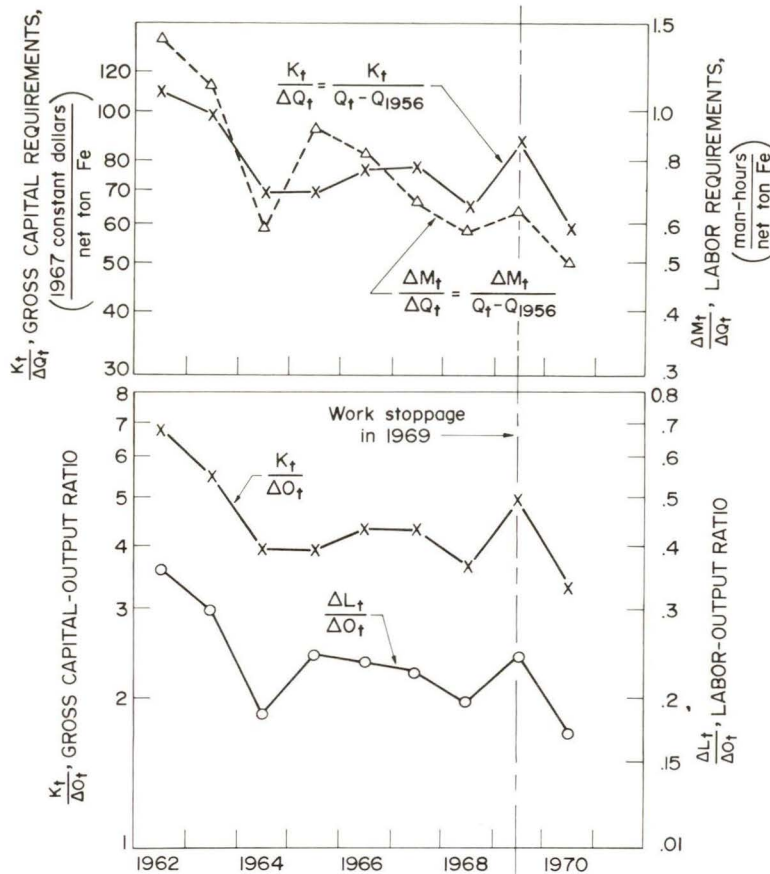


FIGURE 19. - Trends in economic measures of iron ore production, Canada, 1962-70. Capital requirements (K/Q), labor requirements (M/Q), capital-output ratio (K/O), and labor-output ratio (L/O).

FORECASTING CAPITAL AND LABOR REQUIREMENTS

Planning Horizon

The planning horizon of this study is the year 2000. It is a practical choice in relation to the objectives of this study.

An entire industry has a much slower rate of response than its individual firms.²⁵ A quarter-century may be less than one life cycle of replacement in

the same basis (table 6). In Canada that year, the average iron content of usable ore was 61.7 percent and the concentration ratio was 2.13²⁴ leading to labor estimates of 0.40 man-hour per long ton of usable ore and 0.19 man-hour per ton crude ore. The same set of measures permitted, finally, an estimate of the labor: output ratio, which has converged on 0.20 (fig. 19).

These several measures of Canadian experiences and their close correspondence to contemporaneous experience in the United States permit a conclusion of competitiveness between the two major source areas: Eastern Canada and Lake Superior district. To economic analysts the connotations of the annual Canadian series are much broader: These statistics provide a set of experiences that can be related directly to other industries and thence to the national accounts.

²⁴98.4 million long tons crude ore mined; 46.1 million long tons usable ore produced, averaging 61.7 percent iron (28, pp. 131-132).

²⁵This is a logical necessity: Given a characteristic that is changing monotonically in time, at rates which vary between individuals, the mean of the population will change at a slower rate than the leading individuals simply because the mean gives equal effect to both leaders and laggards.

comparison with the rates of change observed in transforming its technology or its organization (including its resources and its products).

The taconite revolution is a case in point. Mr. E. W. Davis worked on taconite technology for nearly 40 years (1914-51) at the University of Minnesota before the first commercial plant was announced.²⁶ Now, 24 years later, the transformation to concentrates is still taking place despite the virtually complete acceptance of the taconite technology. The old technology will persist wherever it is cheaper.

Those who plan for firms may object that the planning horizon extends beyond the limit of practical foreseeability. In the context of the firm, that point would be conceded. Periods beyond 5 years may be too remote for planning markets for manufactured products, though natural resource firms historically have taken positions in resources decades ahead. Recent experience of the authors suggests that mining firms are foreshortening their planning horizons drastically, some to 5 years. This likely has resulted from the threefold effects of a growing appreciation of capital budgeting theory, the very high discounting of future income resulting from inflation, and uncertainties in the political climates surrounding mineral extraction projects both here and abroad.

Aggregate Demand for the Mineral

Composition of the Markets

Future requirements for factor inputs of capital and labor will depend directly on the market demand for iron ore, the availability of resources, and the technology of mining. All of these considerations are obvious from the descriptions and analyses in the foregoing sections. Less obvious but no less important is the relation between the demand for iron ore and the markets for primary metal products. Unlike fuels and the other nonmetallic minerals, which mostly are sold and consumed in their mineral forms, the metallic minerals, as a class, become useful only after chemical reduction has divested their mineral identity. This condition is notably true of iron ore, the demand for which is derived from the aggregate demand for a variety of primary iron and steel products. When an extended planning horizon is involved, as in this study, the composition of future markets becomes an important issue.

A remarkable feature of the distribution of demand among sectors of the economy is that this distribution has changed very little over the past 15 years, although the period was one of intensive technological substitution of materials. The Bureau of Mines examined each of the principal market sectors for primary iron and steel products seeking to detect differential growth compared with the entire economy, trends in the intensity of steel consumption, and possible displacements. Low, high, and probable projections were prepared

²⁶Reference 11, pp. 18-20. Actually, pilot operations began in the fourth year (1918); large-scale pilot plant operations on concentrates for sinter were carried on from 1922-24 (fig. 4), and by 1939 the prospects were strong enough to warrant forming the Erie Mining Co.

based on contingent probabilities (table 10). Construction materials provide the largest market for iron, followed closely by transportation equipment; each category accounts for about 30 percent of the total. Industrial machinery accounts for about 20 percent; packaging, about 8 percent; household appliances, 6 percent; and piping, about 5 percent. The category marked "Other" has been on the rise, and it reflects principally the growing importance of sales by steel service centers. The connotation for this analysis is that table 10 provides little basis for forecasting substantial changes in the distribution of the demand for primary iron products to the year 2000.

TABLE 10. - United States projections and forecasts for iron demand by end use, 1968, 1970, and 2000

(Million short tons iron content)

| | Demand | | Contingency forecasts, 2000 | | | Distribution of demand, percent | |
|---|--------|-------|-----------------------------|------|----------|---------------------------------|---------------|
| | 1968 | 1970 | Range | | Probable | 1970 | Probable 2000 |
| | | | Low | High | | | |
| Construction materials..... | 32.0 | 29.0 | 48 | 68 | 65 | 25 | 30 |
| Transportation, equipment.. | 30.1 | 26.3 | 43 | 70 | 60 | 23 | 27 |
| Industrial machinery..... | 21.4 | 20.4 | 21 | 49 | 32 | 17 | 15 |
| Cans and containers..... | 7.9 | 8.5 | 10 | 14 | 12 | 7 | 6 |
| Pipes, tubes, and equipment | 5.6 | 4.9 | 6 | 11 | 10 | 4 | 4 |
| Household appliances and equipment..... | 6.1 | 6.0 | 7 | 10 | 10 | 5 | 4 |
| Other..... | 16.9 | 21.8 | 27 | 32 | 31 | 19 | 14 |
| Total..... | 120.0 | 116.9 | - | - | 220 | 100 | 100 |

Source: Bureau of Mines; updated from BuMines Bull. 650 (43, p. 306).

The absence of trend in the distribution of markets suggests a similar lack of trend in the mix of product forms in steel mill products and castings. The demand for iron products is expressed in orders for specific forms of products. Thus, industrial machinery makes much use of bars; the packaging industry is almost entirely concerned with light-gage flat-rolled products; construction materials consume nearly all of the structurals produced, and so on. These expectations are borne out in the distribution of types of primary iron and steel product shipments from 1955 to date. Table 11 indicates that about 5 out of 6 tons continues to be supplied in the form of steel mill products and that the castings industries have experienced similar stability in their shares of the market for primary iron and steel products.

TABLE 11. - Shipments of primary iron and steel product types, 1955, 1964, 1970¹

(Quantities in million short tons)

| Years | Steel mill products | | Iron and steel castings | | | | | | Total castings and mill products | |
|-------|---------------------|------|-------------------------|------|-----------|-----|----------|-----|----------------------------------|-----|
| | Quantity | Pct | Gray iron | | Malleable | | Steel | | Quantity | pct |
| | | | Quantity | Pct | Quantity | Pct | Quantity | Pct | | |
| 1955 | 84.7 | 83.0 | 14.8 | 14.5 | 1.1 | 1.1 | 1.5 | 1.5 | 102.1 | 100 |
| 1964 | 85.0 | 83.3 | 14.3 | 14.0 | 1.0 | 1.0 | 1.8 | 1.8 | 102.1 | 100 |
| 1970 | 90.8 | 84.6 | 13.9 | 13.0 | .9 | .8 | 1.7 | 1.6 | 107.3 | 100 |

¹Complete 1955-72 series appendix table A-15.

Source: Survey of Current Business (53).

Similar indications of stability were observed in the distribution of steel mill products. Between 1955 and 1970, demand grew from 82 to 97 million tons, but the leading component, sheet products (including strip), changed only from 38.1 percent in 1955 to 39.5 percent in 1970 (table 12). The other two major types of flat rolled products, tin mill products and pipe, were 6.9 percent and 11.7 percent, respectively, in 1955, totaling 18.6 percent, and 7.4 percent and 9.6 percent, respectively, in 1970, totaling 17.0 percent. Taken together with sheet and strip, these three product forms aggregated 57 percent of the apparent U.S. supply in both 1955 and 1970. Bars and tool steel totaled about 16 percent, and semifinished products accounted for 5 percent in both years. This pattern of stability persisting over 15 years and extending over a 20-percent expansion of the market makes it difficult to project any substantial change in the menu of steel mill products demanded.

TABLE 12. - United States supply of steel mill products, 1955, 1964, 1970¹

| | Percent of total supply | | |
|----------------------------|-------------------------|-------|-------|
| | 1955 | 1964 | 1970 |
| Semifinish..... | 5.3 | 5.2 | 5.4 |
| Shapes and plates..... | 14.1 | 17.4 | 16.4 |
| Rails and accessories..... | 2.5 | 1.5 | 1.6 |
| Bars and tool steel..... | 15.9 | 16.2 | 16.1 |
| Pipe..... | 11.7 | 9.8 | 9.6 |
| Wire..... | 5.5 | 4.4 | 4.0 |
| Tin mill products..... | 6.9 | 6.5 | 7.4 |
| Sheet..... | 38.1 | 39.0 | 39.5 |
| Total..... | 100.0 | 100.0 | 100.0 |

¹Details of U.S. net shipments, exports, imports, and apparent supply are listed in appendix table A-16.

Source: AISI (2).

The shares of primary and secondary iron likewise have exhibited great stability. Statistics reach back only to 1955, but since that time, except for temporary shortages in pig iron capacity, a ratio of 73 percent pig iron:27 percent purchased iron and steel scrap has persisted (table 13). With respect to the shares of these commodities in the supply of iron, the ratio is nearly the same; pig iron is composed of about 93 percent Fe; cast iron scrap is about 94 percent Fe, and new steel scrap is composed of about 99 percent Fe, but oxidation of light-gage steel scrap may diminish its iron content to as little as 95 percent Fe. Taken together, the most likely ratio of primary iron-in-pig:secondary iron-in-scrap is 72:28, close to the respective commodity ratio of 73:27.

TABLE 13. - Consumption of pig iron and purchased iron and steel scrap in the iron and steel industry, 1955, 1957, 1964, 1970

(Million short tons)

| Year | Pig iron | Iron and steel scrap | | | Total pig iron and purchased scrap | |
|-----------|----------|----------------------|-----------------------|--------------------------------------|------------------------------------|-------------------|
| | | Total consumption | Home scrap production | Apparent purchased scrap consumption | Quantity | Percent pig iron |
| 1955..... | 77.2 | 80.4 | 45.5 | 34.9 | 112.1 | ¹ 68.9 |
| 1957..... | 76.4 | 72.6 | 44.0 | 28.6 | 105.0 | 72.7 |
| 1964..... | 86.4 | 84.0 | 52.3 | 31.8 | 118.1 | 73.1 |
| 1970..... | 90.1 | 85.6 | 52.6 | 33.0 | 123.1 | 73.2 |

¹Limited by pig iron capacity.

Complete 1955-72 series in appendix table A-17.

Source: BuMines Minerals Yearbooks.

These repeated indications of stability in the composition of the market for iron are remarkable in view of the concurrent paroxysms in ferrous metallurgical technology and marketing. Within the timeframe of this review there has been a thoroughgoing displacement of traditional, say, pre-1950, technology in iron and steel. The movements into foreign ore supplies and highly concentrated and manufactured iron ore agglomerates were sketched at the outset. Concurrently, the traditional art of blast furnace smelting was displaced: Between 1950 and 1970 the coke requirement in the leading furnaces was reduced from just under 0.9 ton per net ton pig iron in 1950 (fig. 20, Indiana and Illinois), the same level as 1889,²⁷ to roughly 0.6 ton in 1970²⁸ by developing and implementing improvements in the theory and practice of burden preparation and furnace construction and operation.

²⁷Hogan (22, p. 44) lists 1,714 pounds for the 11-foot-diameter Edgar Thomson "F" furnace in 1889 (pre-Mesabi ore); 1,761 pounds for the 20-foot-9-inch-diameter South No. 6 in 1919 (all-Mesabi ore), and 1,766 pounds for the 27-foot-6-inch-diameter Edgar Thomson No. 1 and 2 furnaces in 1945 (all-Mesabi ore).

²⁸After correcting for injecting supplemental fuels not shown in figure 20.

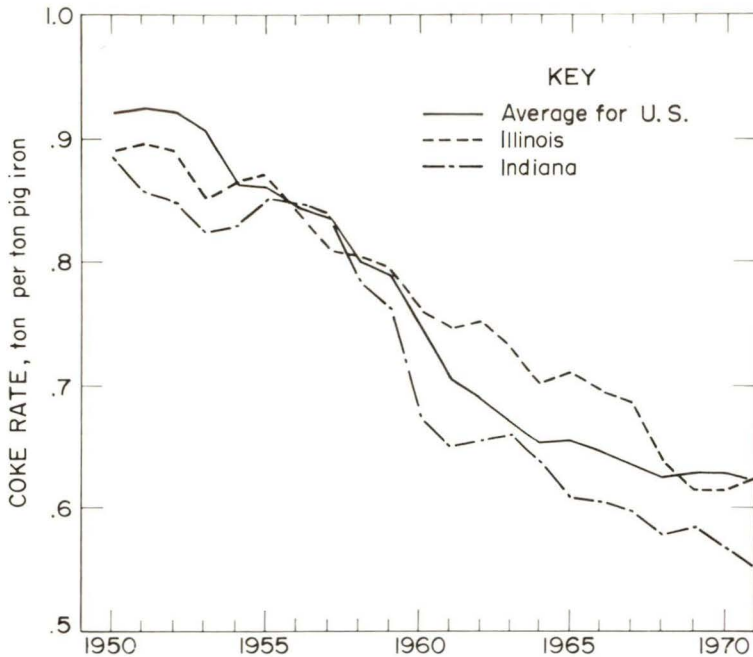


FIGURE 20. - Trends in blast furnace coke rate, 1950-71, United States and two leading States.

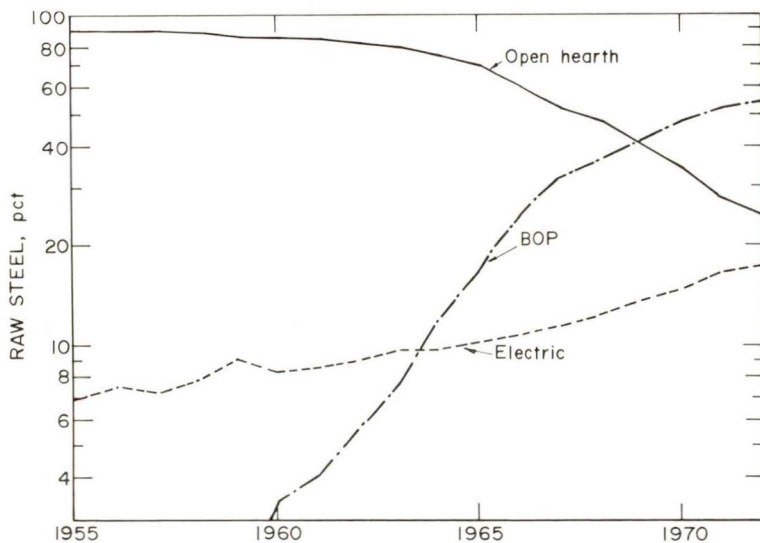


FIGURE 21. - Trends in the proportion of raw steel produced, by process, 1955-72.

Likewise, steelmaking practice was revolutionized: A new process--basic oxygen converting--came upon the scene in the mid-fifties and, two decades later, has relegated the traditional open hearth to the margin (fig. 21). Developments equally radical have taken place in refining (vacuum degassing, deoxidation to a few parts per million), casting (continuous), rolling (wide-strip), and marketing (the capture of one-sixth of the market by imports). All things considered, the only credible forecast of the markets for iron and steel is for a continuation of things pretty much as we know them but with an expansion at a rate related to the aggregate of the demands of the consuming sectors.

Forecasted Aggregate Demand

Forecasts of the demand for iron in the United States and the rest of the world to the year 2000 have been published by the Bureau of Mines in *Mineral Facts and Problems, 1970 Edition* (43, p. 305). These forecasts were based on 1968 data. Table 14 displays these forecasts updated to 1970; they were aggregated from forecasts of contingent demand (low, probable, high) for iron products. Growth rates in the United States are likely to average about 2.0 percent for primary iron and 2.4 percent for

secondary iron, leading to a total demand of 220 million short tons of iron in 2000. In this view, the demand in 2000 likely would be met by a doubling of secondary iron production and a growth of about 90 percent in primary iron production. The projected demand for primary iron is depicted in figure 22.

This degree of expansion in demand measures the need for projections of capital investment and labor force, the objectives of this study.

TABLE 14. - Forecasts of iron demand: United States and rest of world

(Million short tons iron content)

| | Demand, 1970 | 2000 forecast range | | Probable Demand | | Growth rate 1970-2000, percent |
|---------------------------|-----------------|---------------------------|--------|--------------------|--------|--------------------------------------|
| | | Low | High | 1985 | 2000 | |
| | | | | | | |
| United States: | | | | | | |
| Primary..... | 84 | 110 | 177 | 113 | 153 | 2.0 |
| Secondary..... | 33 | 52 | 77 | 47 | 67 | 2.4 |
| Total..... | 117 | 162 | 254 | 160 | 220 | 2.1 |
| Cumulative (primary) | - | 2,880 | 3,690 | 1,450 | 3,400 | - |
| Rest of the World: | | | | | | |
| Primary..... | 393 | 675 | 900 | 553 | 780 | 2.3 |
| Secondary..... | 131 | 225 | 300 | 184 | 260 | 2.3 |
| Total..... | 524 | 900 | 1,200 | 737 | 1,040 | 2.3 |
| Cumulative (primary) | - | 15,460 | 18,100 | 6,950 | 16,730 | - |

Source: Bureau of Mines; updated from BuMines Bull. 650 (43, p. 305; 54, p. 245) and reference 55, p. 63.

Resource Availability

Iron ore reserves of the United States have been estimated and published by the Bureau of Mines in Mineral Facts and Problems, 1970 Edition (43, p. 298). Reserves total 10.5 billion long tons and potential ore is listed as 96 billion tons for a total resource base of 107 billion tons; the reserves include an estimated 3 billion tons of taconite ore that have been proven. These quantities are within 5 percent of the estimates published by the United Nations in 1970 (50). Both sets are based on a 1969 compilation by the U.S. Geological Survey; it published estimates in 1973 of 9 billion long tons of reserves and 99 billion long tons of identified resources (reserves plus potential ores)²⁹ in its compendium, United States Mineral Resources (8).

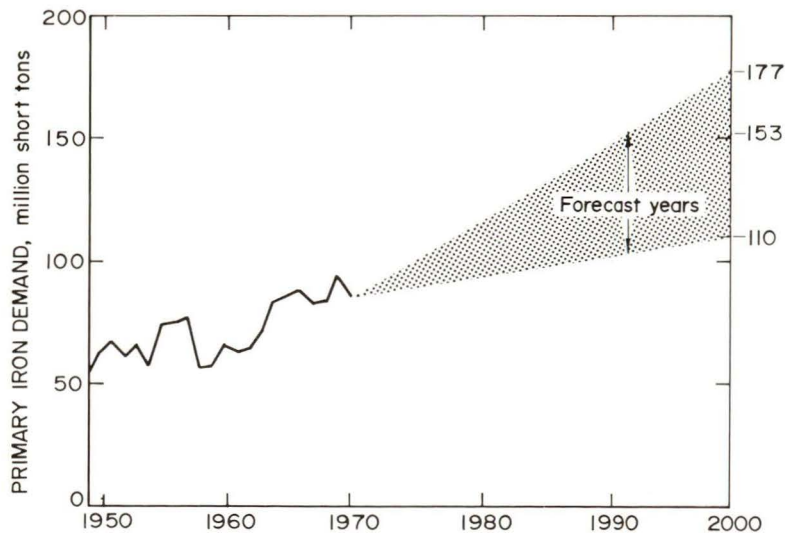


FIGURE 22. - Projected U.S. demand for primary iron, 1970-2000 (43, 55).

²⁹Converted from the metric tonnage listed in reference 24, p. 304.

Projections for the production of domestic iron ores were based on continuing to consume iron-in-ore at a ratio of 67 percent domestic production and 33 percent imported, and to export sufficient domestic ore to maintain the 70 percent domestic-30 percent foreign shares in the net U.S. supply. Whether this projection will be realized will depend on cost and availability.

A supply schedule for domestic iron ore (43, p. 311) is shown in figure 23. At the average 1968 price of \$15.40 per short tons of iron-in-ore f.o.b. mine, the reserves total about 2 billion short tons of recoverable iron; this supply is denoted by the broken segment of the curve. The steeply rising supply curve reflects the increased average cost of performing beneficiation and agglomeration upon an increasing proportion of the iron minerals mined.

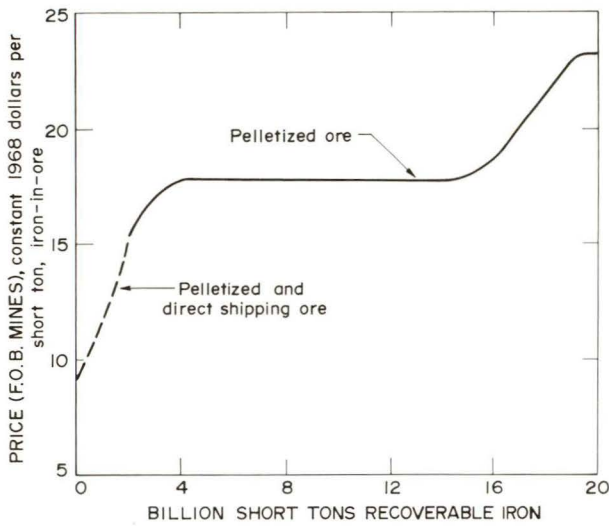


FIGURE 23. - Price-availability schedule for U.S. iron ore resources, 1970 (43).

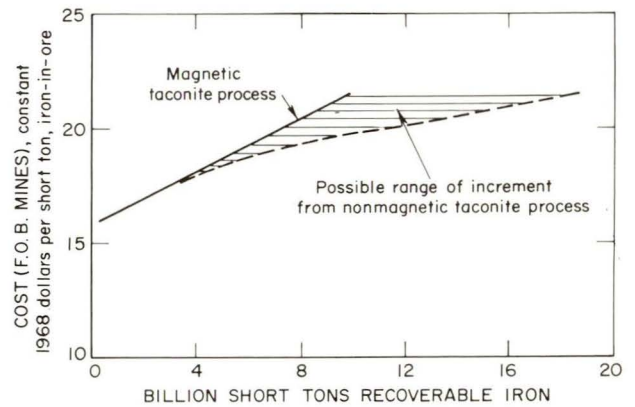


FIGURE 24. - Economic supply schedule for Minnesota taconites, 1970 (34).

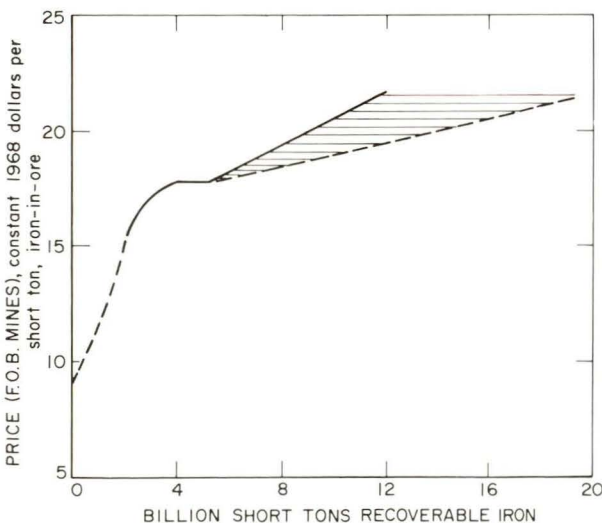


FIGURE 25. - Combined price-availability schedule.

The cumulative consumption of domestic iron units to the year 2000 has been estimated to range between 2.2 and 2.7 billion short tons (54, p. 245). This quantity is represented in figure 23 by the steeply rising broken curve (0.0 to 2.2 billion short tons) and the lower portion of the rising solid curve segment. These successive segments represent also the rate of cost increase in U.S. ore mining to the year 2000, given current technology. By comparison, foreign ores are abundant at current price levels (they already supply one-third of the U.S. market). Thus, this rising curve also provides a measure of future growth in the competitive pressures on domestic producers.

Figure 23 brings out a second relation of consequence. The rising solid curve connotes substitution by nonmagnetic taconites as the known resources of magnetic taconites become exhausted. Intensive use of concentrates processed from these nonmagnetic minerals likely will be needed before the year 2000 to meet the cumulative demand for domestic iron ore (30, p. 37).

A generalized system of estimating iron ore reserves has been developed by Michelson, Polta, and Peterson (34); see figure 24. Its use is suggested as a framework for the consistent estimation of reserves against price, that is, the supply schedules of ore minerals. A combined supply curve from figures 23 and 24 is shown in figure 25.

The question of resource availability includes foreign resources to the extent that they participate in meeting the contemporary demand for the mineral in the United States or whether they may be expected to do so before the year 2000. In the case of iron ore, there seems to be no question as to the availability of ample resources to meet domestic demand at current prices (constant dollars). Over the last 20 years the reserves of iron ore in the world have more than tripled as a result of large-scale explorations that have marked out truly mammoth deposits. A factor of growing importance in the competitive posture of these deposits likely will be transportation costs. A detailed analysis of these considerations has been published by Manners (31).

Supply of Mineral Product

Descriptions concerning the types of minerals produced and the sources of supply are updated by the Bureau of Mines annually in the Minerals Yearbook (57) and every 5 years in Mineral Facts and Problems (54). In the case of iron ore a stability in the sources of supply has been observed since about 1958. See table A-1. This tabulation shows that nearly all of the iron ore consumed in the United States in 1950 originated in domestic mines, a pattern that had existed for many years. Yet, only 8 years later, one-third of the ore consumed was imported, and nearly all had originated in Canadian and Latin American developments that had been opened up since 1950. Significantly, those developments produced much higher grade products, which in some instances exceeded 60 percent iron.

Since 1958, there has been a remarkable stability in the overall proportions of domestic and foreign iron ore consumption in the United States (fig. 3). Whether this 2-to-1 split reflects an equilibrium between increasing imports and rising pressures for import tariffs, or the aggregate judgment

of producers to limit the dependence on foreign sources, cannot be readily ascertained, but in any event, the statistics established the stability. This relationship has tended to reflect the regional distribution of raw steel production in the United States because transportation charges put most foreign ores, with the exception of those from eastern Canada, out of reach in the steel plants of Illinois, Indiana, and Michigan.

Capital and Labor Forecasts

Basis for Projection

The preceding sections provide a framework for projecting the capital and labor requirements to support the iron ore supply to the U.S. economy in 2000. The most likely future can be forecast by working back from market demand to mineral supply. Continuing stability is foreseen in the composition of the market for iron. The forecast is for growth averaging 2.1 percent per year in demand for iron-in-primary iron and steel products, reaching 220 million short tons in 2000 (table 14). The share of primary iron in the supply of raw iron to the domestic iron and steel industry³⁰ may move slightly lower, to perhaps 70 percent in pig iron by 2000, compared with 72 percent primary-28 percent secondary iron in recent years. The forecast demand for primary iron in 2000 ranges from 110 to 177 million short tons iron-in-ore; the most likely figure is 153 million short tons (table 14).

Compared with 1970's demand, 84 million short tons, a need is evident for a much enlarged supply of iron-in-ore by 2000. The needed growth in annual capacity is forecast between 26 and 93 million short tons, probably 69 million short tons. Of the latter quantity, the need by 1985 is for an additional 29 million short tons iron-in-ore, about half the total supply in 1970.

The inputs of capital and labor required to support such an expansion of iron ore supply were estimated from the studies reported in the foregoing sections of this report. Capital requirements were categorized in three levels of capital intensity: Low, intermediate, and high. Labor requirements were categorized in the same terms. These intensity measures were scaled as input per ton of output capacity. These three categories then were related to the three projected levels of demand to generate 3 × 3 contingency tables of the respective factor requirements, ranging from the corner conditions of minimum outlay (least intensity and least growth in demand) to maximum outlay (maximum intensity and maximum growth in demand).

Capital intensity was categorized by reference to the gross investment schedule listed in table 9. The capital intensity was measured by the gross investment per unit of annual capacity and was expressed in constant 1967 dollars per short ton annual capacity of iron-in-pellets. In table 9, the projects ranged from \$5.38 to \$78.50 in capital intensity, but complete developments, including mine, concentrator, and pellet plant, came to over \$30. As a low-end figure, \$35 was selected to represent the simplest and least-intense category of capital requirement. This amount might be

³⁰Including foundries.

considered by some as too low for a complete mine and plant, but it seems ample to represent the cost of expansion in an existing development. At the high end, \$75 was selected to represent those large-scale "greenfield" developments that have included amenities, such as utilities, railroads, docks and townsites; the high level also represents projects that were built initially with excess capacity. The intermediate level, \$55, is not merely the midpoint; it represents closely the average capital intensity of U.S. and Canadian pellet plants in 1970, \$54.40 constant 1967 dollars per short ton iron-in-pellets (table 9). Also, this intermediate value represents satisfactorily the large number of projects falling between \$45 and \$65. These capital intensity levels are exhibited in table 15; the equivalent amounts per long ton of 65 percent-iron pellets also are listed as a convenience to readers.

TABLE 15. - Range of capital expenditures for iron ore pellet production capacity

| Intensity of capital requirement ¹ | Expenditures for plant and equipment (constant 1967 dollars per unit of annual capacity) | | |
|---|--|--------------|------|
| | Low | Intermediate | High |
| Unit of production: | | | |
| Pellets (65 pct Fe).....long ton.. | 25 | 40 | 55 |
| Equivalent iron-in-ore....short ton.. | 35 | 55 | 75 |

¹Selected from table 9. Intermediate is approximately the average cost of the industry.

Labor intensity was categorized by reference to the 1970 experience of the industry. Table 16 exhibits the U.S. and Canadian averages as well as pertinent details from 10 pellet producers in the Lake Superior district. The aggregate average of the U.S. industry is not an appropriate statistic for projection; it credits obsolete and efficient operations equally. The low-side labor intensity for pellet production was taken as 0.49 man-hour per short ton iron-in-pellets (derived from 0.12 man-hour per long ton crude ore). The high-side figure selected in similar fashion was 0.78 man-hour. Figure 10 illustrates these relations. Both of these levels are representative of going operations in the United States. Both are suitable statistics for projection, for two reasons: (1) The complement of labor in an existing plant becomes well fixed as an established working practice; only by expansion can the the existing intensity of labor be diluted. (2) The technology of concentrating and pelletizing already is highly developed, so laborsaving measures tend to be slight and to cost dearly in capital, itself an expensive commodity.

TABLE 16. - Labor requirements for iron ore pellet production

| | Production labor, man-hours per unit of output | | | | | |
|---|--|---------------------|------------------------|-------------------------------|------|------|
| | 1970 Canada | United States, 1970 | | | | |
| | | All districts | Lake Superior district | | | |
| | | | All | 10 pellet plants ¹ | | |
| | | | Av | Low ² | High | |
| Unit of production: | | | | | | |
| Crude ore.....long ton.. | 0.14 | 0.21 | 0.21 | 0.16 | 0.12 | 0.18 |
| Usable ore.....do..... | .42 | .49 | .43 | - | - | - |
| Iron-in-ore.....do..... | .65 | .82 | .72 | .73 | .55 | .87 |
| Do.....short ton.. | .58 | .73 | .64 | .65 | .49 | .78 |
| Representative labor intensities, per short ton iron-in-ore: | | | | | | |
| Low..... | - | - | - | - | .49 | - |
| Intermediate..... | .58 | - | - | - | - | - |
| High..... | - | - | - | - | - | .78 |

¹All open pit mines. These plants accounted for 47 percent of the iron produced by U.S. mines in 1970. Best practice represents at least 20 percent of iron production from mines and mills in the sample, thus, represents at least 10 percent of the U.S. production.

²Best practice, man-hour per long ton crude ore, is as follows: Mine, 0.04; mill, 0.07; and total, 0.12.

Sources: United States--Table 7 and Bureau of Mines data. Canada--Statistics Canada (48).

The intermediate level of labor intensity was selected to project a likely future aggregate level of labor involvement. For this purpose, the 1970 average of 0.58 man-hour in the Canadian iron ore industry was selected. There are several reasons for this selection. First, the employment statistics are comparable in coverage; therefore, that statistic could be used. Second, the Canadian mines and plants are as a whole younger than the U.S. industry, hence the Canadian experience reflects U.S. trends. Third, both the Canadian and the domestic producers are owned and operated by largely the same firms, so the information and the incentives to improve efficiency are present to bring the labor intensity of U.S. operations into line with the Canadian experience. Thus, the three levels of labor intensity were selected: Low, 0.49 man-hour; intermediate, 0.58 man-hour; and high, 0.78 man-hour, each per short ton iron-in-ore.

Contingent Forecasts of Factor Requirements

Capital and labor requirements to support growth in U.S. demand for iron ore to 2000 were forecast in a series of contingency tables. Reference has been made already to the three-level categories of capital intensity and labor intensity. In separate tables, the three categories of factor intensity were arrayed against the three projections of demand in 2000--low, high, and probable--as well as the probable demand in 1985. These tables appear in table 17.

TABLE 17. - Contingent forecasts of capital and labor requirements to support growth in U.S. demands for iron ore to 2000

| | Planning horizon | | | | | |
|---|------------------|---------------------------|--------|----------|--------|--------------------------------------|
| | Actual, 1970 | 2000 forecast range | | Probable | | Growth rate 1970-2000, percent |
| | | | | Demand | | |
| | | Low | High | 1985 | 2000 | |
| DEMAND RATE, MILLION SHORT TONS IRON-IN-ORE PER YEAR ¹ | | | | | | |
| Total..... | 117 | 162 | 254 | 160 | 220 | 2.1 |
| Less, secondary: | | | | | | |
| Percent of total..... | (28.2) | (32.1) | (30.3) | (29.4) | (30.5) | - |
| Quantity..... | 33 | 52 | 77 | 47 | 67 | 2.4 |
| Primary..... | 84 | 110 | 177 | 113 | 153 | 2.0 |
| Increase from 1970..... | - | 26 | 93 | 29 | 69 | - |
| FACTOR REQUIRMENTS TO SUPPORT INCREASE IN PRIMARY IRON DEMAND | | | | | | |
| Capital expenditures, million constant 1967 dollars: | | | | | | |
| Low intensity: \$35..... | - | 910 | 3,260 | 1,020 | 2,420 | - |
| Intermediate intensity: \$55 | - | 1,430 | 5,120 | 1,600 | 3,800 | - |
| High intensity: \$75..... | - | 1,950 | 6,970 | 2,180 | 5,170 | - |
| Labor input, thousand man-years: ² | | | | | | |
| Low intensity: 0.49..... | - | 6.1 | 21.9 | 6.8 | 16.3 | - |
| Intermediate intensity: 0.58 | - | 7.3 | 25.9 | 8.1 | 19.2 | - |
| High intensity: 0.78..... | - | 9.8 | 34.9 | 10.9 | 25.9 | - |

¹Figures in parentheses represent percent.

²At 2,080 man-hours per year. This measure makes no allowance for absences, hence, it understates the labor force required.

Capital

The capital requirements of the iron ore mining industry to support the forecast growth in demand to 2000 will likely total \$3.8 billion constant 1967 dollars. That amount is the aggregate investment to provide the probable increase in capacity, 69 million short tons per year of iron-in-ore, at the intermediate level of capital intensity, \$55 constant 1967 dollars per short ton iron-in-ore annual capacity. This quantity of ore capacity might be provided for as little as \$2.4 billion or as much as \$5.2 billion, depending on whether the expansion would take place by incrementing existing facilities, or by embarking on greenfield projects respectively. To put these projections in perspective, the shipments of concentrates (including pellets and sinter) assaying over 60 percent Fe by U.S. and Canadian producers in 1970 totaled 62.5 million short tons of iron-in-ore. Thus the thrust of the most likely expansion of demand is to re-create 110 percent of the 1970 industry by the year 2000. Considering that the entire 1970 industry had been created since 1951, the projected expansion seems easy to imagine. Whether the capital requirements--about \$55 per annual ton in 1967 dollars--can be maintained is another question entirely. If the industry sets about doubling its plants, perhaps the total bill will be more reflective of the \$35 intensity level. To the extent that the demand must be met by new projects, the \$75 level will

be likely. Expansions since 1970, Empire (Michigan), Minntac (Minnesota), Carol Lake (Labrador), and Sept-Iles (Quebec), lend support to the low-level projection. Amounts forecasted for the new projects at Tilden (Michigan) and Hibbing (Minnesota) are closer to the intermediate-level of capital intensity. All in all, the best estimate for expansion along the path of the past decade or so is the intermediate-level, \$3.8 billion constant 1967 dollars.

The other contingency pairs are interesting from the sets of extreme conditions they may reflect. For example, the low-low set projects to only \$0.9 billion if only one third the expansion was needed (26 versus 69 million tons); such a pessimistic growth rate obviously would connote minimum cost increments to existing capacity.³¹ At the other extreme, the high-high set requires numerous new projects to provide the acceleration in flow needed for the projected capacity in 2000 (the total growth of 93 million tons iron-in-ore would be one-third larger than the probable growth, 69 million tons), biasing the average capital intensity above the \$55 figure.

Labor

Labor requirements to support the projected expansion in iron ore supply in the year 2000 likely will total 19,200 persons. This is the projection of the intermediate level of labor intensity and the likely increase in demand for iron in the United States (table 17). This requirement compares with the 1970 requirement of about 30,000 (21,500 in United States and an estimated 8,500 in foreign production to supply the ore imported that year). The expansion in supply will increase the 1970 labor requirement by about two-thirds. The arguments advanced in the case of capital, previously mentioned, also seem applicable to the other contingency pairs of demand and labor intensity.

International Supply of Iron Ore to the United States

The international distribution of iron ore production is a very important determinant of iron ore supply. It was pointed out earlier that within the timespan of this study the United States has moved away from a 3-century position of self-sufficiency, and a virtually closed economy of iron ore supply, to a position of consuming 30 percent foreign iron-in-ore. This large change in the international distribution of iron ore supply has not been matched by any significant increase in the export of primary iron and steel products in the past 2 decades, with the result that a recurring trade deficit in iron has developed.

Generally, the foreign supply of iron ore has been developed from direct foreign investments by the U.S. firms that would consume the iron ore concentrates or pellets produced. Thus, a substantial outflow of capital has occurred. Finally, the growth in production of foreign ores has created skilled-worker jobs in those nations during a period when employment in U.S. iron ore mines has fallen by one-third. Therefore, the future distribution of international iron ore supply to the United States is an important question.

³¹Under the conditions prevailing at the time of this writing (1974-75) interest rates are too high to permit expansion beyond, say 5 years growth.

Two Alternative Patterns of Supply

There have been two divergent projections of iron ore supply to the year 2000, both prepared in the Bureau of Mines. Both use the same statistical sources, but reach quite different conclusions as to the international organization of production in 2000. The background of the projected demand for iron is not in question. The only question is: What will be the trend in the domestic share of iron ore supply?

The statistical basis for both studies is the time trend in the share of foreign ores in the U.S. supply. The annual relationships since 1950 were presented in figure 3. The two alternative patterns are based on the respective perceptions of

- (A) No trend, a steady use of about one-third foreign ore in U.S. furnaces since 1958. This will be referred to as the pattern of constant shares. These projections were published in the chapter on Iron (43) in the 1970 Edition of Mineral Facts and Problems (54).
- (B) A slowly falling rate of U.S. production since 1950, leading to a continuing decline in the U.S. share of iron ore supply to U.S. consumers. This will be referred to as the declining share pattern of U.S. supply and the increasing share pattern of foreign supply. The projections were published in the first annual report of the Secretary of the Interior under the Mining and Minerals Policy Act, in 1972 (55).

The charts in figure 3 provide support for both patterns. The upper chart supports the constant shares pattern. This chart depicts the proportional share of foreign ore in the U.S. supply annually. The ordinate is scaled logarithmically to provide a linear curve of a constant rate of growth in the ratio³² of foreign ore to the total ore supply. From 1958 to 1970 there is no trend of any consequence; the relation has been that of constant shares in primary iron supply--70 percent domestic, 30 percent foreign.

The lower chart in figure 3 supports the notion of a declining share pattern for domestic iron ore in the total U.S. supply. In 1950-55, the consumption of domestic ore exceeded 100 million long tons in 4 out of 6 years. Since, that mark has been reached only once, in 1969. The linear lower chart shows this trend clearly. These trends are confirmed by the 1950-70 trends in U.S. production. Figure 26 depicts the respective trends in ore production: upward, in crude ore; downward, in usable ore, and down then up, in iron-in-ore. Although the upward trend in average iron content brought the iron-in-ore production back up to the 1950 level by 1965, the high-volume years--1951, 1953, and 1955-57--were sufficient to cast a declining trend on the 1950-70 experience taken as a whole. Figures 3 and 26 thus stand for the proposition of a slight decline in U.S. production, or at best, a static rate of iron supply from domestic ores since 1950, with future growth in iron demand being captured by foreign suppliers of ore.

³²This is the familiar semilog plot of stock market chartists.

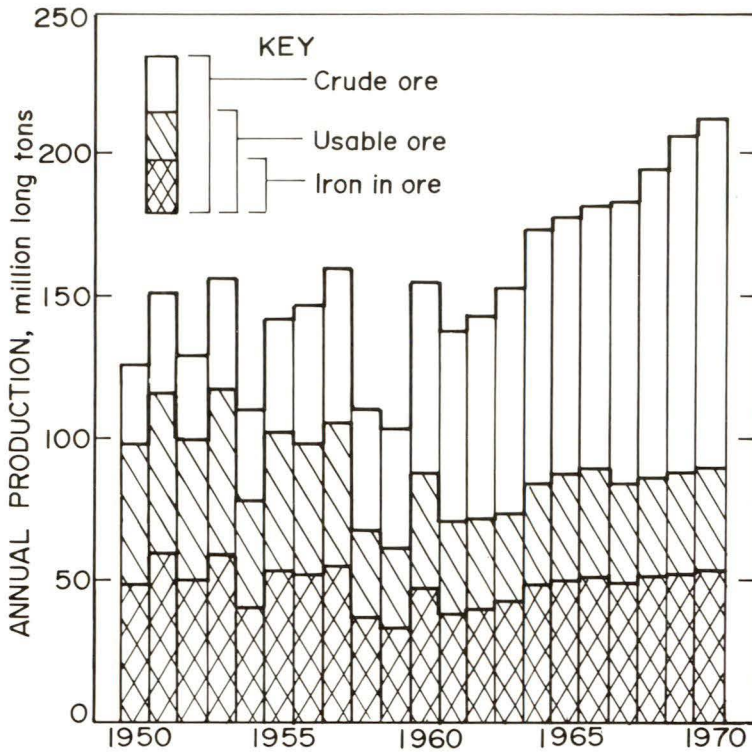


FIGURE 26. - Trends of iron ore production in the United States, 1950-70.

Projected Domestic and Foreign Shares in Supply

The projections of domestic and foreign shares in the U.S. supply of iron ore are presented in table 18. The pattern of constant shares implies that domestic ores will provide the same 70 percent share in 2000. The most likely attribution in 2000 is 107 million short tons iron-in-ore from U.S. mines and 46 million tons from foreign sources, both sources growing at an average annual rate of 2.0 percent. At the extremes of the forecast range, the demands on U.S. and foreign sources would be 77 and 33 million tons at the low end, respectively, and 124 and 53 million tons at the high end, respectively.

TABLE 18. - Domestic and foreign shares of growth in U.S. iron ore supply to 2000 under two alternative patterns of international supply

| Share pattern Source of ore | Demand rate for primary iron, million short tons iron-in-ore per year | | | | | |
|--|---|---------------------|------|-----------------|------|--------------------------------|
| | Actual, 1970 | 2000 Forecast range | | Probable Demand | | Growth rate 1970-2000, percent |
| | | Low | High | 1985 | 2000 | |
| | | | | | | |
| Total..... | 84 | 110 | 177 | 113 | 153 | 2.0 |
| Projected pattern of international supply: | | | | | | |
| A. Constant U.S. share: | | | | | | |
| United States..... | 59 | 77 | 124 | 79 | 107 | 2.0 |
| Foreign..... | 25 | 33 | 53 | 34 | 46 | 2.0 |
| B. Declining U.S. share: | | | | | | |
| United States..... | 59 | 50 | 50 | 51 | 50 | -.5 |
| Foreign..... | 25 | 60 | 127 | 62 | 103 | 4.8 |
| Change from 1970 pattern of supply: | | | | | | |
| United States: | | | | | | |
| A. Constant share..... | - | 18 | 65 | 20 | 48 | - |
| B. Declining share..... | - | -9 | -9 | -8 | -9 | - |
| Foreign: | | | | | | |
| A. Constant share..... | - | 8 | 28 | 9 | 21 | - |
| B. Increasing share..... | - | 35 | 102 | 37 | 78 | - |

The pattern of a declining U.S. share is quite different. It projects as the most likely state of affairs in 2000 a flow of only 50 million short tons iron-in-ore from U.S. producers, 9 million tons less than 1970. This results from applying to the 1970-2000 timespan an average annual decline of 0.5 percent, which in turn had been estimated from the trend of the 1950-70 time series. By the same relations, the share of foreign production would be assumed to increase to provide the differences between the 50 million short tons iron-in-ore supplied by U.S. mines and the total demand for primary iron, 153 million tons. The difference, 103 million short tons iron-in-ore in 2000 provided from foreign sources, would represent the culmination of an average annual growth in foreign supply of 4.8 percent since 1970.³³

The principal concern of this study is for the locational consequences of the growth in iron ore demand to 2000. The lower bank of table 18 is addressed to this concern. For iron mining in the United States, the alternate visions of the future include the constant share projections of a likely 48 million short tons iron-in-ore added capacity, probably all as pellets or other concentrated forms, a more than doubling of existing capacity for that type of product. In the same pattern, the low end would suggest only 18 million tons more output.³⁴ The high-end addition to 1970 output, 65 million short tons iron-in-ore, would call for sustained construction of capacity in the United States at double the rate experienced from the early fifties to 1970; in fact, this rate of construction may take place, merely to replace 1970 capacity for natural ores and concentrates assaying less than 60 percent Fe (25 million short tons iron-in-ore) and to support the probable rate of expansion (48 million tons), a total increase of 73 million tons by 2000. Thus, the good news for U.S. producers.

The bad news for U.S. producers is seen in the declining share forecast. In this pattern, the U.S. production of iron-in-ore would drop by 8 million tons to 1985, and an additional million to 2000, a total drop of 9 million tons per year. Even in this pessimistic forecast, a need is implied to upgrade or replace about 16 million short tons iron-in-ore capacity (about 26 million long tons ore) to bring the laggards up to and beyond 60 percent iron concentration.

By the same arguments, the growth in foreign ore production will take shape either as a constant share of a growing market, or as a strongly growing share according to one's choice: Pattern A or B.

The projections of an increasing share for foreign ore in the U.S. market are the largest figures developed. They represent the entire projected growth in demand from 1970 to 2000 and the substitution for 9 million short tons iron-in-ore of contemporary U.S. production. The figures call for 35 million tons at the low end to 102 million tons at the high end (about three times the existing U.S. capacity for >60 percent Fe product). The most likely figure is 78 million short tons iron-in-ore.

³³This is a very high rate of growth in mineral supply, especially for sustained growth over the span of a generation. By comparison, the estimated growth rate of GNP to 2000 is 4.0 percent (62).

³⁴A quantity already attainable in expansions and new projects since 1970.

Domestic and Foreign Requirements for Capital

The future requirements of capital for iron mining investments in the United States and in foreign nations can be projected by associating the projected rates of iron supply to the United States from the nations with their projected levels of capital intensity, in table 19. Each of the two alternative patterns of international expansion in supply were related to the previously selected levels of capital intensity. Four contingency tables are included. Each tabulation presents the high and low levels of capital intensity applied to the projected national iron supply conditions, which, in turn, were calculated by applying the projected national share to the projected U.S. demand for iron. These projections assume that the mineral deposits to be developed would be similar in capital requirements to those referred to herein.

TABLE 19. - Capital requirement projections, United States and foreign, for growth in U.S. iron ore supply to 2000

| Source of ore Share pattern Capital intensity | Cumulative capital expenditures for new capacity, million constant 1967 dollars ¹ | | | |
|---|--|-------|---------------------------------|-------|
| | Range of forecast demand and requirement, 2000 | | Probable demand and requirement | |
| | Low | High | 1985 | 2000 |
| United States: | | | | |
| A. Constant share..... | (18) | (65) | (20) | (48) |
| Low: \$35/tFe/yr..... | 630 | 2,280 | 700 | 1,680 |
| High: \$75/tFe/yr..... | 1,350 | 4,880 | 1,500 | 3,600 |
| B. Declining share..... | (-9) | (-9) | (-8) | (-9) |
| Low: \$35/tFe/yr..... | -320 | -320 | -280 | -320 |
| High: \$75/tFe/yr..... | -675 | -675 | -600 | -675 |
| Foreign: | | | | |
| A. Constant share..... | (8) | (28) | (9) | (21) |
| Low: \$35/tFe/yr..... | 280 | 980 | 320 | 740 |
| High: \$75/tFe/yr..... | 600 | 2,100 | 675 | 1,580 |
| B. Increasing share..... | (35) | (102) | (37) | (78) |
| Low: \$35/tFe/yr..... | 1,230 | 3,570 | 1,300 | 2,730 |
| High: \$75/tFe/yr..... | 2,630 | 7,650 | 2,780 | 5,850 |

¹Figures in parentheses represent million tons of iron-in-ore per year.

The capital requirements for additional U.S. mining capacity are displayed in the top two tables. The topmost table is constructed on the assumption of constant shares. The projected U.S. demand for iron was extended by the 70 percent constant U.S. share of supply to obtain the quantities in parentheses, the projections of U.S. supply under the constant shares pattern. These supply quantities were extended in turn by the capital intensity estimates to arrive at the capital requirements corresponding to the low and high levels of capital intensity. Thus, the probable demand for iron in 2000 connotes a demand for an additional 48 million short tons iron-in-ore in 2000 from U.S. producers, assuming the 70 percent constant share. To support that added capacity, the capital requirement would vary between \$1.68 billion and \$3.60 billion depending on the level of capital intensity foreseen. The same arrangement of material is followed throughout table 19.

For the most part the capital requirements listed in table 19 are smaller than in table 17. The reason, of course, is that the total amounts listed in table 17 have been decomposed in table 19 into pairs of tables representing the projected requirements of U.S. and foreign producers. The one set of exceptions is the foreign requirements under the projection of increasing foreign share. Because the tabulations in table 19 are more disaggregated, the remarks concerning capital intensity and magnitude of expansion in table 17 apply with even more force. For example, in the uppermost bank, the capital requirements of U.S. producers to 2000 might range from \$0.63 billion to \$4.88 billion, corresponding to the low-low and the high-high pairs of demand-intensity conditions.

In the constant share projection, the most likely condition of demand is for the construction of an additional supply capacity of 48 million net tons of iron-in-ore from 1970 to 2000, say, 1.6 million tons per year as an average increase. By comparison, the 56 million tons capacity listed in table 9 was built from scratch at an average rate of 3 million tons per year. Thus, the projected rate of increase is much less than the firms have handled successfully, so the managerial capability can be presumed. Given the present complement of pellet and concentrate operations, the expansion of 48 million tons might be achieved half from expanding existing plants and half from new projects. By adding a pelletizing kiln and the upstream facilities to 16 of the existing plants, half of the expansion would be obtained.³⁵ The remainder presumably would be supplied by new developments. The intermediate level of capital intensity, \$55 per short ton Fe per year, would be the most likely basis for projection; the capital requirement would total \$2.64 billion constant 1967 dollars.

The next table down, the United States under a declining share, connotes on the surface a disinvestment of \$0.32 to \$0.68 billion constant 1967 dollars. Such would be merely an accounting necessity for balancing table 19; in actuality, there would be further developments to improve the quality of product in respect to a total market for 50 million tons iron-in-ore rather than the 59-million-ton market in 1970. This example points up the purpose of this study: To measure the magnitudes of the factor inputs required to support expansion in the iron ore supply to the United States and not to specify in any manner the factor requirements for replacing exhausted and obsolete mines and mills.

The capital requirements for expansion of foreign supply have great interest in the light of recent developments in the international relationships of mineral supply. In the wake of the 1973 embargo on oil, foreign supply has taken on immediate connotations of the security of physical supply as well as trade balances, investment outflows, and labor force employment. At this point it is sufficient to note the very great ranges in the projections of capital requirements of foreign projects, depending on the pattern of international supply. For example, at the low-low corner, the constant

³⁵A pellet kiln producing 2.0 million long tons per year 65 percent Fe pellets:
 $2 \times 10^6 \times 0.65 \times 1.12 = 1.46 \times 10^6$ short tons per year iron-in-ore.
 $(1.46 \times 10^6) \times 16 = 23.4 \times 10^6$ short tons per year iron-in-ore.

shares pattern projected cumulative foreign investment of only \$0.28 billion constant 1967 dollars by 2000, but the increasing share pattern projected \$1.23 billion, four times as much. At the high-high corner, the respective projections were \$2.10 billion, assuming constant shares, and \$7.65 billion, assuming the increasing foreign share in supply. By comparison, the entire 56 million tons of existing U.S. and Canadian capacity listed in table 9 represented an investment of \$3.0 billion constant 1967 dollars. The projections of investments likely to be required for foreign supply appear in the right-hand column of table 19. Depending on the assumptions of share pattern and capital intensity, the requirement is projected between \$0.74 billion and \$5.85 billion constant 1967 dollars.

Under a forecast of constant shares, the capital requirement for foreign iron ore production would be likely to range between \$0.74 to \$1.58 billion, low and high. If a single projection is desired, the most likely value is that based on the intermediate level of capital intensity, \$55 constant 1967 dollars per annual short ton capacity of iron-in-ore, applied to a constant 30 percent share of the most likely demand in 2000: A cumulative foreign investment of \$1.16 billion to provide an additional flow of 21 million short tons per year of iron-in-ore by the year 2000.

The foreign investment projection would become extremely large under the assumption of increasing foreign shares in iron ore supply. The projections of capital requirements by 2000 in table 19 range from \$2.73 to \$5.85 billion constant 1967 dollars, corresponding to low and high intensities of capital usage. The heart of the matter is the projected need for providing 78 million short tons additional capacity by 2000; this implies an average annual growth of 3 million tons in foreign ore supply, about 4 million long tons pellets.³⁶ That magnitude of growth is close to the rate of combined growth of concentrate capacity in the United States and Canada from 1954 to 1970. Likely, a succession of new foreign deposits would be developed with all of the ancillary facilities. In that event, the average capital intensity would be to the high side; the cumulative capital requirement likely would exceed the intermediate level of \$4.29 billion and might verge on the high-intensity amount, \$5.85 billion. Midway between, at a capital intensity of \$65, the cumulative investment to 2000 would be \$5.07 billion constant 1967 dollars.

Domestic and Foreign Requirements for Labor

An international analysis of labor input requirements was constructed in the same fashion as that of capital requirements. The results are presented in table 20. The upper section of table 20 is identical to table 19 in its arrangement; it needs no comment. The lower three sections of table 20 express the heart of the labor requirement analysis; they focus on the implications for the size of the U.S. labor force.

³⁶ $3 \times 10^6 \div 0.65 \div 1.12 = 4.12 \times 10^6$ long tons 65 percent Fe pellets.

TABLE 20. - Labor requirement projections, United States and foreign, for growth in U.S. iron ore supply to 2000

| Source of ore Share pattern Labor intensity | Labor input, thousands of 2,080-hour man-years, per year ¹ | | | |
|--|--|-------|------------------------------------|-------|
| | Range of forecast demand and requirement, 2000 | | Probable demand and requirement | |
| | Low | High | 1985 | 2000 |
| ADDITIONAL LABOR INPUT FOR EXPANSION OF ORE SUPPLY | | | | |
| United States: | | | | |
| A. Constant share..... | (18) | (65) | (20) | (48) |
| Low: 0.49 man-hr/tFe..... | 4.2 | 15.3 | 4.7 | 11.3 |
| High: 0.78 man-hr/tFe..... | 6.8 | 24.4 | 7.5 | 18.0 |
| B. Declining share..... | (-9) | (-9) | (-8) | (-9) |
| Low: 0.49 man-hr/tFe..... | -2.1 | -2.1 | -1.9 | -2.1 |
| High: 0.78 man-hr/tFe..... | -3.4 | -3.4 | -3.0 | -3.4 |
| Foreign: | | | | |
| A. Constant share..... | (8) | (28) | (9) | (21) |
| Low: 0.49 man-hr/tFe..... | 1.9 | 6.6 | 2.1 | 4.9 |
| High: 0.78 man-hr/tFe..... | 3.0 | 10.5 | 3.4 | 7.9 |
| B. Increasing share..... | (35) | (102) | (37) | (78) |
| Low: 0.49 man-hr/tFe..... | 8.2 | 24.0 | 8.7 | 18.4 |
| High: 0.78 man-hr/tFe..... | 13.1 | 38.3 | 13.9 | 29.3 |
| DECREASE IN LABOR REQUIREMENT OF 1970-SIZE U.S. IRON ORE INDUSTRY | | | | |
| Production..... | (59) | (59) | (59) | (59) |
| Labor intensity ² | | | | |
| Average U.S.: 0.73 man-hr/tFe... | 20.7 | 20.7 | 20.7 | 20.7 |
| Projected U.S.: 0.58 man-hr/tFe. | 16.5 | 16.5 | 16.5 | 16.5 |
| Difference..... | -4.2 | -4.2 | -4.2 | -4.2 |
| NET ADDITIONAL LABOR INPUT TO U.S. IRON ORE INDUSTRY | | | | |
| A. Constant share..... | (18) | (65) | (20) | (48) |
| Low: 0.49 man-hr/tFe..... | 0.0 | 11.1 | 0.5 | 7.1 |
| High: 0.78 man-hr/tFe..... | 2.6 | 20.2 | 3.3 | 13.8 |
| B. Declining share..... | (-9) | (-9) | (-8) | (-9) |
| Low: 0.49 man-hr/tFe..... | -6.3 | -6.3 | -6.1 | -6.3 |
| High: 0.78 man-hr/tFe..... | -7.6 | -7.6 | -7.2 | -7.6 |
| TOTAL LABOR INPUT TO U.S. IRON ORE INDUSTRY | | | | |
| A. Constant share..... | (77) | (124) | (79) | (107) |
| Low: 0.49 man-hr/tFe..... | 20.7 | 31.8 | 21.2 | 27.8 |
| High: 0.78 man-hr/tFe..... | 23.3 | 40.9 | 24.0 | 34.5 |
| B. Declining share..... | (50) | (50) | (51) | (50) |
| Low: 0.49 man-hr/tFe..... | 14.4 | 14.4 | 14.6 | 14.4 |
| High: 0.78 man-hr/tFe..... | 13.1 | 13.1 | 13.5 | 13.1 |

¹Figures in parentheses represent million tons of iron-in-ore per year.

²Projected U.S. labor intensity is based on 1970 Canada average. Actually, several U.S. plants are under that level. See table 16.

The second section of table 20 provides a projection of the labor requirement to operate the 1970-size iron ore industry in the year 2000. The indication is for a decrease of 4.2 thousand man-years, to a "best practice" labor input of 16.5 thousand man-years per year.

The third section exhibits projections of the net additional labor input to iron ore production in the United States. These projections were obtained from the additional labor input requirements projected for expansion of supply (the topmost section) by subtracting the "best practice" reduction (4.2 thousand man-years from the 1970 labor input, thereby deriving a set of projections of net additions to the labor input for future iron ore production in the United States. Under the constant share assumption, the man-year projections in 2000 range from no change, for the low-low corner pair, to 20.2 thousand at the high-high corner. At the probable level of growth in U.S. supply (48 million tons), the additional labor input is estimated as ranging from 7.1 to 13.8 thousand man-years. These estimates are derived respectively from the additional labor inputs resulting from expansion of ore supply (uppermost section of table 20): 11.3 thousand man-years at the low level of labor intensity (0.49 man-hours per short ton iron-in-ore), and 18.0 thousand at the high level (0.78 man-hours per ton). From each, the decrease of 4.2 thousand man-years was subtracted to reflect the effect on the 1970 industry of going to "best practice," leaving the respective net increases from 1970 of 7.1 and 13.8 thousand man-years. The projections under the assumption of a declining share of U.S. production were calculated in the same manner; under the conditions of that assumption each projection was negative, and the high-intensity projections were more negative than the low-intensity sets.

The lowermost section of table 20 presents projections of the total labor input required to produce iron ore in the United States in 2000. Under the assumption of a constant 70 percent share in the supply of iron ore to the United States, the projection of the most likely demand for iron implies labor inputs ranging from 27.8 thousand to 34.5 thousand man-years in 2000. These compare with 20.7 thousand man-years in 1970. At the intermediate level of labor intensity, 0.58 man-hour per short ton iron-in-ore, the projection would be for 29.8 thousand man-years of labor input in 2000 to produce 107 million short tons iron-in-ore, an increase of 81 percent in output based on 1970 from an increase of 47 percent in labor input. Under the assumption of a declining share, the labor input would decline also, to about 14,000 man-years.

Summary of Projections

The most likely projections are gathered together in table 21. The alternative patterns of growth (constant shares and declining U.S. share) are compared for their respective effects on the international production of iron-in-ore in 1985 and 2000 and the associated requirements of capital and labor. Capital requirements are expressed as the cumulative gross investment (billion constant 1967 dollars) required to provide the projected increases in annual productive capacity. Labor requirements are expressed as the net input of labor (thousand man-years per year, at 2,080 man-hours per man-year) to operate that increase in capacity. Similar comparisons were drawn up for United States and for foreign production of iron-in-ore to supply the U.S. market, but no estimates of foreign labor inputs were developed. The cumulative effects also were developed, especially with regard to iron ore production.

TABLE 21. - Projected growth in domestic and foreign supplies of iron, and associated capital and labor requirements under two alternative international patterns, 1970, 1985, 2000

(Iron ore: million short tons iron-in-ore;
Capital: billion constant 1967 dollars;
Labor: thousand 2,080-hour man-years.)

| | 1970 | 1985 | | | 2000 | | |
|---------------------------------------|------|----------------------|---------------------------|--------------------|----------------------|---------------------------|--------------------|
| | | Constant shares (CS) | Declining U.S. share (DS) | Difference (DS-CS) | Constant shares (CS) | Declining U.S. share (DS) | Difference (DS-CS) |
| U.S. producers: | | | | | | | |
| Iron ore..... | 59 | 79 | 51 | -28 | 107 | 50 | -57 |
| Capacity increase.. | - | 20 | -8 | - | 48 | -9 | - |
| Capital requirements: | | | | | | | |
| Intensity (dollars per ton per year). | - | 55 | None | - | 55 | None | - |
| Cumulative gross investment..... | - | 1.10 | None | -1.10 | 2.64 | None | -2.64 |
| Labor requirements: | | | | | | | |
| Intensity (man-hours per ton Fe). | 0.73 | 0.58 | 0.58 | 0.0 | 0.58 | 0.58 | 0.0 |
| Labor input..... | 20.7 | 22.0 | 14.2 | -7.8 | 29.8 | 13.9 | -15.9 |
| Net increase since 1970..... | - | 1.3 | -6.5 | - | 9.1 | -6.8 | - |
| Foreign producers: | | | | | | | |
| Iron ore..... | 25 | 34 | 62 | 28 | 46 | 103 | 57 |
| Capacity increase.. | - | 9 | 37 | - | 21 | 78 | - |
| Capital requirements: | | | | | | | |
| Intensity (dollars per ton per year). | - | 55 | 65 | 10 | 55 | 65 | 10 |
| Cumulative gross investment..... | - | 0.50 | 2.41 | 1.91 | 1.16 | 5.07 | 3.91 |
| Cumulative effects: | | | | | | | |
| U.S. producers: | | | | | | | |
| Gross investment... | - | 1.10 | None | -1.10 | 2.64 | None | -2.64 |
| Production..... | - | 1,020 | 820 | -200 | 2,390 | 1,590 | -800 |
| Foreign producers: | | | | | | | |
| Gross investment... | - | 0.50 | 2.41 | 1.91 | 1.16 | 5.07 | 3.91 |
| Production..... | - | 430 | 630 | 200 | 1,010 | 1,810 | 800 |
| Total supply: | | | | | | | |
| Gross investment.... | - | 1.60 | 2.41 | 0.81 | 3.80 | 5.07 | 1.27 |

Supply Pattern of Constant Shares

The constant shares pattern projects a continuation of the status quo in the attribution of iron production to national sources. Looking ahead from 1970 to 2000, the probable forecast is for a cumulative gross investment for expansion in U.S. production totaling \$2.64 billion, and in 2000, a labor

input of 29,800 man-years (44 percent more than 1970) to produce 107 million tons iron (81 percent more than 1970). The average rates of growth would be 1.2 percent in labor and 2.0 percent in iron produced, compared with 4.0 percent expected growth in GNP (62). Iron production would cumulate 2.39 billion tons, valued at \$36.5 billion 1967 dollars.³⁷ Cumulative payments to labor at \$3.32 per ton³⁸ would total \$7.9 billion 1967 dollars.

Foreign production would maintain its share of supply by expanding at the same rate. The flow of imported iron ore would increase from 25 million tons iron in 1970 to 46 million tons iron in 2000. The 1970-2000 cumulative supply from foreign sources to the U.S. is projected at 1.01 billion tons, valued, as previously mentioned, at \$15.4 billion 1967 dollars. To support this expansion in supply, gross capital investments totaling \$1.16 billion would have been made. On the assumption that the U.S. consumers of iron ore had provided the capital to expand the mining capacity,³⁹ the cumulated gross investment would be accounted a capital outflow from the United States. The combined outflow to 2000 in trade and investment would total \$16.6 billion constant 1967 dollars. Both of these deficit items in the foreign accounts of the United States presumably could be handled without difficulty inasmuch as they would grow at an average rate of 2.0 percent while GNP was growing at 4.0 percent.

Supply Pattern of a Declining U.S. Share

The pattern of the declining U.S. share in iron ore supply projects a slight decrease in U.S. production, one-half of 1 percent annually from 1970 to 2000. Foreign sources are foreseen as making up for the U.S. decrease and also supplying all of the expansion in demand. By 1985, U.S. production will have decreased to 51 million tons annually and then to 50 million tons by 2000; there would be no need for investment in additional capacity, and the labor requirements would have dropped back to 13.9 thousand man-years per year, one-third less than 1970. Cumulative production of iron 1970-2000 would total 1.59 billion tons, valued at \$24.3 billion 1967 dollars; payrolls would cumulate \$5.3 billion 1967 dollars.

The increasing foreign share in this pattern requires a very high growth rate of production with accompanying problems. The projected production rate in 2000 is 103 million tons, four times the 25-million-ton rate in 1970, and equivalent to a growth of 4.8 percent per year. To support the added expansion, several large-scale mining developments of high capital intensity would be required, with the likely result the raising of the average capital intensity to \$65 per ton of annual capacity, for a cumulative gross investment of \$5.07 billion dollars (assuming that the mineral deposits to be developed would be similar in capital requirements to those referred to herein). Production would cumulate 1.81 billion tons, valued as above at \$27.6 billion. The combined deficit in the foreign accounts of the United States would be \$32.7 billion over the 1970-2000 timespan, an average of more than \$1 billion per year.

³⁷The average value of iron ore production at U.S. mines in 1967 was \$9.92 per long ton; the average content was 58.1 percent (57). $9.92 \div 0.581 \div 1.12 = \15.25 per short ton iron-in-ore.

³⁸See table 2. The amount listed therein for 1967 is for long tons.

³⁹A justified assumption for existing pellet producers, which characteristically have been financed on the credit of the consuming steel firms.

Comparison of the Two Patterns

The declining U.S. share pattern is best understood by a comparison with the constant shares pattern, the pattern of recent experience. By comparison, the declining share pattern shows by 2000 (1) displacement of 800 million tons of domestic iron production; (2) \$2.64 billion gross investment to expand foreign capacity instead of U.S. capacity; (3) \$1.27 billion extra gross investment in foreign capacity to (a) replace the decline in U.S. production and (b) to pay for the higher capital intensity required, and (4) 15,900 fewer jobs in U.S. mines (actually, 6,800 fewer than in 1970).

The declining share patterns show cumulative losses in U.S. production of \$12.2 billion in the value of ore mined (\$36.5 billion and \$24.3 billion), and \$2.6 billion in payrolls.

The differences between constant shares and increasing foreign share are accelerated in the foreign accounts. The foreign supply capacity would be increased by 57 million tons beyond the constant share pattern by 2000; this quantity is equivalent to the combined U.S. and Canadian capacity in 1970. By 2000, the capital outflow for investment in expansions of that additional capacity would have accumulated to \$3.91 billion, and the trade deficit for the additional 800 million tons of iron imported since 1970 would have added up to \$12.2 billion, for a total additional outflow of \$16.1 billion over the 1970-2000 period. In the preceding discussion of the relation of foreign accounts to the constant shares pattern, the point was developed that the cumulated deficit of \$16.7 billion was equivalent to a 2 percent growth annually. By coincidence the difference computed herein (16.1 billion) is of that magnitude, so it can be stated that from 1970 to 2000, the foreign account deficits attributable to iron ore investment and trade may grow at the rate of 2.0 percent under the constant share pattern of expansion, and an additional 1.9 percent under the declining U.S. share pattern for a total growth of 3.9 percent under the declining U.S. share pattern of expansion. Although this projected total rate of growth in the deficit is no larger than the projected growth in GNP, the question may be raised whether a growth in deficit at twice the growth of that sector of the economy can be long sustained.

Discussion of Results

The alternative views of 2000 presented in table 21 reflect the remarkably divergent consequences of projecting two interpretations of recent history in iron ore supply. They raise issues concerning, first, the information content of the projections and, second, what may be the most likely pattern of supply.

Information Content of the Projections

The thrust of this issue is whether the measurement system underlying these projections has enough information to support the quantities projected. This includes the method of projecting, the estimations of the demand for iron, the form of iron ore product supplied, the technology of production,

the intensities of capital and labor inputs, and other technologic and economic considerations.

Method of Projection

A direct projection of capital and labor requirements would have been ideal, but no basis exists. There is no regular canvass of capital expenditures for iron ore mining in the United States. The employment canvasses of the Bureau of Mines and BLS are not associated with measures of production, shipments, and value. Any projections necessarily had to be indirect, obtained by extending the projected demand by the contingent levels of factor intensities. The projections of demand for iron had been carefully performed and were taken to represent a good estimate of the long-range demand for iron in 1985 and 2000. To minimize the error in estimating factor requirements, the factor intensities of capital and labor were estimated from examinations of mine-by-mine investment and employment data. The factor intensities exhibited in the supply schedules are far more detailed than anything heretofore available.

Estimated Demand for Iron

The projections of demand for iron and the production of primary iron and steel products are regarded as highly accurate. This assertion is based upon the demonstrated stability of the market for primary metal products. This market, it must be remembered, reflects a derived, not a final, demand. The final demand is for consumption goods; from that, the demand for primary iron and steel products in manufacturing, construction, and other industries is derived. Thus, the menu of steel product forms demanded reflects the choice of products by final manufacturing and other industries, especially since international supply of primary metal products has become prominent. Any projection of substantial change in the shares of these markets held by various forms of steel products, or for other types of iron-containing metal products, would, to be credible, require a clear specification of underlying changes in the structure of the metal-consuming industries.

Iron-Ore Product Supplied

The projection of the form of iron ore product to be supplied has become relatively simple. For several years, agglomerated concentrates assaying over 60 percent iron have been accepted as the preferred feed for blast furnace ironmaking. Pellets have become the principal form, though sinter is provided also. The natural ores will become an even smaller component of supply. Expansions in iron ore capacity into the foreseeable future will produce concentrated agglomerates, and will require the corresponding inputs of capital and labor to support them. Even if new technologies of ore reduction and refining emerge, such as "instant steelmaking," it seems clear enough that they will start from concentrates because chemical methods of transforming ore into metal cannot compete with the existing physical methods of concentrating crude ores.

Technology of Iron Ore Production

The trend of technology in iron ore mining and concentrating also appears to be stable except for developments in environmental maintenance. The contemporary technology of iron ore mining and concentrating was developed out of an immense amount of experimentation, and it has displaced a simple operation with a highly sophisticated sequence of mining and processing operations. This new era in iron mining still remains to be implemented for about one-third of U.S. production. Environmental maintenance will become increasingly complicated and costly, but the requirements and the costs to achieve them are still being worked out, so these measures were not incorporated expressly in this analysis.

Factor Intensities

The ranges of factor intensities encompassed in the low, intermediate, and high values may seem too large to be useful. Actually, the intention was to select values that represented a range of costs, this range implying a similar range of physical requirements. The presumption was that identical developments ought to cost the same, and that the ranges in costs reflected actual differences between projects in their physical arrangements. Also, information about plant expansions showed that a 2-million-ton-per-year scale of operations has become a module of production and that there is not much of a return to scale in expanding existing plants. Thus, the path of expansion foreseen is essentially that of providing additional modules to expand existing facilities, or to install similar modules when developing a new facility.

The range of capital intensity, \$35 to \$75 per ton of capacity, obviously embraced a very great spread in the array of structures and equipment provided. It would have been even greater if water transport and general-carrier rail transport had been included.

The expectations of capital intensity also are based on conditions of development equivalent to those experienced over the past 2 decades in the United States and Canada. To the degree that future projects are undertaken in other localities less accessible or less well endowed with skilled workers, even higher intensities of capital input might be required. It is worth pointing out that the cheaper developments occur first; by inference, the future will tend to be more costly.

Other Technologic and Economic Considerations

Well-informed readers may, at this point, experience a sense of disquiet, especially with regard to the omission of obviously important matters relating to their discipline. Too, they may feel that the development of the study was uneven; that the findings do not square with their own experience, or that a specific canvass of producers ought to have been undertaken. The authors acknowledge the likelihood of such impressions, for they have experienced these themselves.

Omissions of important matters of mining technology and economics inevitably occurred because the authors limited the body of the report of the descriptions and analysis undertaken in this work.

The development of the study was uneven because the data sources were uneven. Where the statistics were abundant and well audited, as in the Bureau of Mines coverage of employment and production, a detailed mine-by-mine analysis was carried out for 1 year, and in segments of the industry for runs of years. Where published trade association and government statistics were adequate, as in the markets for steel mill products, a detailed analysis of the composition of the market was performed. Where the data were meager and often ill defined, as in the expenditures for plant and equipment, the authors simply prospected for information from any source, brought together whatever they could find, and tailored the analysis to the limits of the data.

There is no disagreement with the proposition that a canvass of producers concerning capital and labor requirements might have been useful. The immediate need, however, was to analyze with some thoroughness the existing data sources. Thereby one might specify a basis for designing an effective canvass. Too, as a matter of methodology, the authors were concerned to develop a method that could be applied to studies of other minerals in which the data streams are much less well developed.

Differentiation of Mineral Processes

Mineral technologists may object to the apparent lack of differentiation with regard to mining methods, kinds of haulage systems, and types of mineral beneficiation processes. Haven't the authors in effect lumped together all the various settings of mineral deposits and the variety of beneficiation flow sheets which exist? This objection is well founded in principle; in application, however, it fails if the data are too poor. The authors took their classifications no finer than the measurements; they went as far as the statistics would take them. To develop the statistical reporting in fine enough detail to differentiate processes of iron ore mining and beneficiation would require far more detailed and frequent reporting, and, most difficult, separate reporting for each mine and mill, not merely by firms.

Inferring that the analytical framework of this report implies a homogeneous technology from mine to mine would be erroneous. The authors recognized that there is no "average" mine or mill. (Try to image the average of a horizontal rotary kiln and a vertical shaft kiln!) Further, any such implication of a homogeneous technology would lead to a suggestion that the wide variation among producers in capital costs per unit of capacity (see table 9) had resulted from managerial inefficiencies. Because the design and management of these projects had been concentrated in a few firms, the more likely suggestion is that the management has been much more homogeneous than the mineral suites and that the differences in capital cost reflect least-cost technologies over a range of geologic and market constraints.

Actually, the issue of differentiation in technology was raised and was dealt with in the analysis of the constraint on labor in mining and beneficiation processes. The entire discussion at that point implicitly negated any presumption of a homogeneous technology.

Description of Mineral Technology

Descriptive materials concerning details of iron mining and milling were excluded because this technology is well described elsewhere in authoritative presentations. The two-volume work, Blast Furnace--Theory and Practice (49), contains three extended chapters on the theory and practice of iron ore deposits and mining (9), beneficiating and concentrating (16), and pelletizing (12). English and Greaves published a useful review of pelletizing experience (15). Hammes' study provided detailed comparisons of costs among a variety of pellet plants (17).⁴⁰ Descriptions of iron ore and iron making in a worldwide context are given in reports by the United Nations (51) and Battelle (5). The Stanford report to NEMO (35) includes a highly detailed analysis of cost structures in Minnesota.⁴¹ A profile of mining and milling practice in the United States has appeared recently (46).

Description of Process Cost Analysis

The literature concerning cost analysis and estimation was included only where it supplied specific information. The work of Michelson and coworkers (34) was referred to because they developed a method of wide generality to determine economic supply schedules for beneficiating Mesabi taconites by both magnetic and nonmagnetic processes. A sensitivity analysis approach to determine process choice and scale of operations has been demonstrated by Bennett and coworkers (6). Process equipment costs for mining and beneficiation can be estimated by the methods of Parkinson and Mular (40). A computer program for equipment and labor costs has been published by Johnson and Peters (27). A systematic analysis of taconite mining and processing technology has been presented by Hays (20).

Descriptions of Relevant Economic Studies

The authors likewise omitted descriptions of economic studies of iron mining, again to avoid repetition of material available elsewhere. This literature includes large-scale studies of employment and output, capital formation and financing, productivity trends, technological change, taxation, transportation, and imports, but the data were too aggregated to provide any detailed information to this study. They did, however, provide an indispensable background for judgments.

The principal source for economic descriptions of iron mining was the studies of the National Bureau of Economic Research (NBER). Barger and Schurr studied output, employment, and productivity in mining over the period 1899-1939 (4); iron ore was covered extensively, and they provided a detailed description of the currents of change, from underground selective mining by hand in the early days, to the opening of Mesabi pits with steam shovels and mechanized haulage, and the subsequent development of mass mining and beneficiation. Borenstein's work on capital and output trends in mining from 1870 to

⁴⁰More readily available in a summary report (18) or in the Battelle report (5, p. IV-27).

⁴¹Salient tables appear also in references 41 and 42.

1948 (7) was incorporated into a monograph (10) summarizing the major trends in real capital formation since 1880, in financing since 1900, and the forces determining those trends. This work included estimations of the capital stock in mining and provided an essential segment of Kuznets' monumental analysis of capital in the U.S. economy (26). Kendrick analyzed the growth of productivity in mining, that is, the output per unit of input, in an NBER study (23). He devised a measure of total factor productivity and allocated the gain between the capital and labor. Growth in output of iron ore in the United States was reviewed critically by Herfindahl (21), who constructed tables of annual production and value covering the period 1839-1909.

Future Pattern of International Supply

The international pattern of iron ore supply to the United States likely will develop somewhere between the two patterns exhibited in table 21. The declining share pattern has been upset already by a succession of expansion projects in the United States. The constant share pattern may be upset by growing sophistication in the international marketing of iron ore. Over-shadowing all is a new awareness of access to mineral supply as an important component of the economies in both producing and consuming nations.

The declining share pattern contemplated a gradual decline in U.S. production, meanwhile foreseeing the replacement of depleted natural ore properties by new producers of agglomerated concentrates. By 1972, the shipments of agglomerates from U.S. mines totaled 39.4 million short tons iron-in-ore, a quantity only 11 million tons less than the capacity needed to reach the 2000 forecast. Any new plants would be expected to produce pellets assaying at least 64 percent iron; thus, the forecast would be for construction of approximately 15 million long tons of pellet capacity by 2000. This projection already has been exceeded. Expansions in capacity and new projects totaling 27 million long tons of pellets have been announced since 1972: Tilden, Michigan (4 million tons); Empire, Michigan (1.8 million tons); Hibbing, Minnesota (5.4 million tons); National, Minnesota (3.4 million tons); Eveleth, Minnesota (3.6 million tons); Minntac, Minnesota (6 million tons), and Virginia, Minnesota (2.6 million tons).

The constant share pattern may be upset by a combination of locational forces both in the United States and abroad. Expansion in steelmaking capacity shows signs of taking place preferentially along the continental margins of the United States. Too, a heightened interest in direct reduction of iron would require iron ore of much lower gangue content than the conventional Lake Superior and eastern Canada pellet products. Both conditions would create demands for foreign ores, especially those from South America. At the same time, very large developments of high-grade ores have been announced, especially in Brazil.

The development of exceedingly large bulk carriers and triangular routings for multicommodity transport suggests that the day is fast coming when the price of ore anywhere in the world will differ by no more than perhaps the transportation charge from Mesabi mines to Lower Lake ports. In such a world, and considering the generally higher grade of foreign ores, it

is difficult to project a continued constant 70 percent share for U.S. producers in the U.S. supply of iron ore. This theme is developed by Manners (31). Comparative transportation costs have been reviewed also by Hammes (17), Morris (35), Klinger (25), and Lafleur (28).

Cartelization efforts by exporting nations may result in an increasing share for domestic supply. The success of the oil exporting nations in controlling rates of production and market prices since 1972 did not go unnoticed; an association of copper exporting nations was formed, and it is easy to imagine the emergence of a similar agency of iron ore exporting nations. The dependence of our economy on oil is not much different from our dependence on steel. In the event of a cartel of iron ore exporters, the prospect of higher prices and the risk of unilateral withdrawal of supply each would tend to foster expansion of domestic supply. For security of supply, a program of government support for domestic iron production might be required.

Environmental maintenance may impose a bias upon the projections of international supply. An obvious question is whether expansion of the U.S. supply might be undertaken at foreign sites to avoid the expense of controlling pollution in domestic operations. Over the near term such a course might succeed; in the long run other nations can be expected to prize (and price) their environments equally to ours. The long-run effect should be negligible on the pattern of iron ore supply.

Taxation policies, whether domestic or foreign, are recognized as affecting the capital and labor requirements in principle. In the first place, taxation forces a redistribution of income from production: The governing body becomes a sharer of income. Secondly, taxation will affect income inversely to the extent that the incidence of the tax can be shifted to the purchaser. A thorough analysis of the effects of a variety of taxes upon the iron ore industry in Minnesota was performed by Morris (35). Further recourse to taxation is likely, both domestic and foreign, to deal with public policy issues.

Capital requirements for foreign expansion are an important question for both the domestic iron ore producers and consumers. The implementation of mass mining, beneficiation, and pelletizing has been based upon investments secured by the credit of the pellet-consuming steel firms (19). Conceivably, this will continue to be the foundation for financing expansions in the foreign supply of iron ore to the steel industry of the United States. In reality, then, the capital is supplied by domestic firms.

Whether the future before the year 2000 will bring about a significant supply of capital in other iron ore producing countries is a question which is beyond the scope of this report. We can be content with the observation that in the developing countries with their great need for capital goods to raise the standard of living for their people and with their relatively rapid growth in population, there would seem to be a continuing scarcity of capital for their own needs. On the other hand, the economy of the United States is looked upon as a principal source of investment funds.

On balance, the constant shares pattern of iron ore supply provides the closest model of the future presently available to us. Although any of the aforementioned considerations might alter the supply pattern significantly, the most likely expectation is for a continuation of the 70 percent United States-30 percent foreign sharing of expansion in iron ore supply at an average growth rate of 2.0 percent to 2000, supported by a cumulative gross investment of \$3.8 billion constant 1967 dollars and a labor force in the United States of 29,800.

Summary of Results

1. The organization of iron ore production since 1950 was analyzed. Technologic change was categorized in terms of changes in geographic and geologic settings, the intensity of capital investment required, the declining use of labor, and the immensity of scale in operations.
2. Average labor requirements in United States iron ore mines in 1970, expressed as man-hours per long ton crude ore, for mining ranged fortyfold from 0.023 to 0.921, and averaged 0.113; for milling ranged fourteenfold, from 0.017 to 0.234, and averaged 0.091; and for both mining and milling, ranged twentyfold, from 0.053 to 1.10, and averaged 0.214. Within mining methods and districts the variability between mines generally was much less: underground mining, threefold; open pit mining in the Lake Superior district, fivefold, and in the other districts, tenfold; milling in the Lake Superior district, tenfold, and in the other districts, fourteen fold. Average labor requirements were as follows: Open pit mining in the Lake Superior district, 0.069, other districts, 0.117; underground mining, 0.633; milling in the Lake Superior district, 0.086, other districts, 0.114; both mining and milling in the Lake Superior districts, 0.170, other districts, 0.397.
3. Average cost supply schedules of labor requirements for U.S. iron ore mining in 1970 were constructed for the various operations, methods, and districts. Each was found to be essentially linear, indicative of a constant rate of increase in average cost with increasing production. Fittings of the data to parabolic curves suggested an acceleration of average cost in open pit mining and deceleration in milling.
4. An intertemporal analysis of labor requirements for pellet production in the Lake Superior district disclosed a constraint on the total use of labor: High-labor mines were associated with low-labor mills and the converse as well. There was a near-perfect inverse relation between the rankings of labor requirements in mining and milling.
5. Economies in the labor requirements of pellet plants were realized both from learning during the first few years of operation, and from expansions later on. The learning process effectively reduced the labor requirements by increasing the output of the labor complement in a plant. Expansions reduced the labor requirement by making fuller use of prior facilities and staff.

6. Process cost analysis methods of estimating labor requirements in five pellet plants provided overall accurate measures of milling operations, but low estimates in mining, both by comparison to the Bureau of Mines canvasses of employment and production.

7. Capital investment requirements for iron ore pellet capacity were estimated by analyzing the reported expenditures for developments in the United States and Canada, including mining, beneficiating, and agglomerating facilities. The cost per net ton iron-in-ore annual capacity ranged from \$32 to \$79 and averaged \$54, all in 1967 constant dollars. The 2-1/2-fold range of costs represented the spectrum of developments from the simplest to the most complex and complete.

8. Canadian statistics permitted an economic analysis of investment and production. The distribution of income 1951-70 showed a linear relation in the logarithms of labor's share (L) and the gross share to owners (K), and indicated a production function:

$$VA = 2.33 L^{0.38} K^{0.58} e^{0.004t}.$$

Since 1962, the capital requirements for iron ore pellet capacity in Canada have converged on (a) \$70 constant 1967 dollars per annual net ton of iron-in-pellets capacity, equivalent to \$0.784 per long ton unit, and (b) a capital:output ratio of 3.90. The same series indicated a trend to 0.65 man-hour per long ton iron-in usable ore and a labor:output ratio of 0.20.

9. Future demand for iron to 2000 is likely to follow the present pattern of distribution among market sectors and among product forms.

10. An elaboration of the price-availability curve for iron (the economic supply schedule) was developed by incorporating a stochastic analysis of Mesabi taconite reserves.

11. Detailed contingent projections of capital and labor requirements to 2000 were developed incorporating three levels each of requirements (factor intensities) for capital and for labor, and two alternative patterns of domestic and foreign sharings in iron ore supply.

12. The declining share pattern projects an absolute decline of iron-in-ore production in the United States, to 50 million tons in 2000, (an average annual decline of 0.5 percent) with all of that decline plus all growth in demand to be supplied by foreign sources. However, the wave of expansions and new projects in the Lake Superior district will increase the 1970 pellet capacity of U.S. producers by one-half by 1977, and will substantially exceed the declining-share projection of U.S. capacity in 2000.

13. The constant shares pattern projects a continuation of the established 70 percent United States-30 percent foreign shares in the supply of iron-in-ore to the iron smelters of the United States at an average growth rate of 2.0 percent to 2000 supported by a cumulative gross investment of \$3.8 billion 1967 constant dollars and a labor force in the United States of 29.8 thousand.

CONCLUSIONS

1. Cross-sectional and intertemporal analyses of labor requirements in iron ore mining and beneficiation can be derived from Bureau of Mines canvasses of employment and production. Labor requirements in the aggregate will continue to decline, for four reasons: Abandonments of obsolete operations, expansions in existing plants, improvements in technology, and larger scale of operations. The indication for 2000 is for an aggregate requirement of 0.58 man-hour per short ton iron-in-ore and about 0.40 in the best operation.

2. Capital requirements for new iron ore capacity can be estimated roughly from trade announcements and news stories. The only statistical series related to the U.S. supply is that concerning Canadian mines. Capital requirements likely will continue to range between \$35 and \$75 per annual short ton iron-in-ore capacity (constant 1967 dollars) depending on the complexity of the project, and will average about \$55. The cumulative gross capital investment for expansion of U.S. supply to 2000 likely will be \$3.8 billion constant 1967 dollars.

3. The future pattern of iron ore supply to the United States likely will be close to the established pattern of constant shares: 70 percent United States-30 percent foreign. The capital and labor requirements to support the projected likely supply in 2000, 153 million short tons iron-in-ore, will be \$3.8 billion constant 1967 dollars gross investment and a labor force of 29,800 in the United States.

A PROPOSED METHODOLOGY OF FORECASTING CAPITAL AND LABOR REQUIREMENTS IN THE MINERAL INDUSTRIES

The foregoing analysis also provided an experience for constructing, retrospectively, a more generalized framework of analysis. The detailed framework is listed in table 22. In common with other exercises in hindsight, this framework is an improvement over the foregoing study in comprehensiveness, generality, and order. However, it follows the iron ore study closely; the main differences are in details of transportation which were omitted from the study.

TABLE 22. - Outline for projecting capital and labor requirements in mining

1. Project the organization of production
 - 1.1 Identify feasible mining and milling technologies
 - 1.2 Relate technologies to mineral types, and to locations
 - 1.3 Analyze trends in substitution of new technologies
 - 1.4 Analyze the structure of the industry
 - 1.5 Project the mix of technologies to be employed

2. Analyze labor requirements
 - 2.1 Examine reported statistics
 - 2.1.1 Employment
 - 2.1.1.1 Government
 - 2.1.1.2 Trade associations
 - 2.1.1.3 Other sources
 - 2.1.2 Production
 - 2.1.2.1 Government
 - 2.1.2.2 Trade associations
 - 2.1.2.3 Other sources
 - 2.2 Relate employment and projection to derive labor requirement
 - 2.2.1 Per ton crude mineral
 - 2.2.2 Per unit of marketable mineral
 - 2.3 Perform mine-by-mine analysis from Bureau of Mines statistics
 - 2.3.1 Intertemporal
 - 2.3.1.1 All United States
 - 2.3.1.2 Regional
 - 2.3.2 Cross section, selected years
 - 2.3.2.1 Array in increasing order: cost of marginal mine
 - 2.3.2.2 The aggregate average: supply schedule
 - 2.3.3 Functional labor requirements
 - 2.3.3.1 Mining
 - 2.3.3.1.1 Open pit
 - 2.3.3.1.2 Underground
 - 2.3.3.1.3 Other surface methods
 - 2.3.3.1.4 Do also by regions
 - 2.3.3.2 Milling
 - 2.3.3.2.1 Do by regions
 - 2.3.3.3 Combined operations
 - 2.3.3.3.1 Cross-section analysis
 - 2.3.3.3.2 Constraints upon labor usage
 - 2.4 Examine detailed process analysis data
 - 2.4.1 Search literature
 - 2.4.2 Develop data
 - 2.4.2.1 Interview
 - 2.4.2.2 Canvass
 - 2.4.3 Compare with plant experience
 - 2.5 Changes resulting from plant expansion

TABLE 22. - Outline for projecting capital and labor requirements in mining--Continued

- 3. Analyze capital requirements
 - 3.1 Examine reported statistics
 - 3.1.1 Expenditures on plant and equipment
 - 3.1.1.1 Government
 - 3.1.1.1.1 See foreign statistics also
 - 3.1.1.2 Trade news
 - 3.1.1.3 Process cost analyses
 - 3.1.2 Working capital
 - 3.1.3 Cost indexes of plant and equipment
 - 3.2 Relate capital expenditures and production
 - 3.2.1 Per unit of crude mineral
 - 3.2.2 Per unit of marketable mineral
 - 3.3 Perform detailed analysis of projects
 - 3.3.1 Intertemporal
 - 3.3.1.1 United States
 - 3.3.1.2 Principal foreign
 - 3.3.2 Cross section
 - 3.3.2.1 Array in increasing costs: costs of marginal mine
 - 3.3.2.2 The aggregate average: supply schedule
 - 3.3.3 Functional capital requirements
 - 3.4 Examine detailed process analysis data
 - 3.4.1 Search literature
 - 3.4.2 Develop data
 - 3.4.2.1 Interview
 - 3.4.2.2 Canvass
 - 3.4.3 Compare with plant experience
 - 3.5 Changes resulting from plant expansion
- 4. Project supply of product demanded (in the case of metallic minerals, primary metal products)
 - 4.1 Identify producing industries
 - 4.2 Analyze trends in product types
 - 4.2.1 Relate to market sector demands
 - 4.3 Analyze trends in product forms
 - 4.3.1 Relate to market sector demands
 - 4.4 Project the composition of supply
 - 4.4.1 Product types
 - 4.4.2 Product forms
- 5. Project supply of mineral produced
 - 5.1 Identify mineral types
 - 5.2 Identify sources of supply
 - 5.2.1 Domestic
 - 5.2.2 Foreign
 - 5.3 Analyze trends in production by mineral and area
 - 5.4 Analyze trends in transportation
 - 5.5 Analyze coupling of source area and transportation
 - 5.6 Project sources for least cost supply

TABLE 22. - Outline for projecting capital and labor requirements in mining--Continued

- 6. Project resource availability as a function of price
 - 6.1 Survey reserves by location
 - 6.2 Determine availability--price curves for the United States and other major producing nations
 - 6.3 Determine trends in the share of United States supply provided by nations
 - 6.4 Project shares of United States supply, by nation
 - 6.5 Project price needed to draw out cumulative supply to target year
 - 6.6 If price rise is indicated, feedback to reevaluate demand

- 7. Project capital and labor requirements
 - 7.1 Select basis for projection
 - 7.1.1 Average of industry is erroneous (reflects vintage technology)
 - 7.1.2 Identify best practice plants (most efficient factor productivity)
 - 7.1.3 Really a projection of productivity change
 - 7.2 Select base year for projection
 - 7.3 Select target year of projection
 - 7.4 Project unit requirements of capital and labor
 - 7.5 Cumulate requirements of factors

The outline in table 22 has the further value of providing a checklist of the data and statistics necessary for analysis. To the degree that the data sources are lacking, one then can foresee and identify the gaps in the desired measures of capital and labor activity.

One step further, the outline in table 22 provides a foundation for a program of gathering essential statistics on the operation of the producing establishments in the mineral industries. For example, it is clear that a canvass of expenditures on plant and equipment and on repair and maintenance is needed if the problems of the mineral industries are to be understood by policymakers. It is also evident that the speed of response will be some multiple of the reporting period. All things being equal, a quarterly canvass will evoke response at least four times faster than an annual one. In another context, frequent reporting of stripping requirements and restorative measures will provide a basis for support of rational efforts to weigh their impacts on the strength and dependability of our mineral supply.

In summary, the outline of analysis in table 22 describes a methodology that has been demonstrated in the study of iron ore mining; this outline provides a checklist for planning analyses of other mineral industries, permits an evaluation of the gaps occasioned by lack of data, and further, provides a foundation for the design of a program of statistics gathering to provide useful operating, financial and economic analysis to policymakers.

RECOMMENDATIONS

1. Establish a periodic canvass of iron mining production to obtain coordinated measures of production, employment, and financial factors by producing departments and establishments.
2. Conduct the canvass quarterly for a timely response to changes in external conditions.
3. Extend to other mineral industries the canvasses and methods of analysis established for iron mining.

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APPENDIX

TABLE A-1. - Foreign trade in iron ore related to U.S. consumption, 1950-72

(Million long tons)

| Year | Imports | Exports | Net imports | U.S. consumption | Percent imported ore in U.S. consumption | |
|-----------|---------|---------|-------------|------------------|--|---------------|
| | | | | | Net of exports | Gross imports |
| 1950..... | 8.3 | 2.6 | 5.7 | 106.6 | 5.4 | 7.8 |
| 1951..... | 10.1 | 4.3 | 5.8 | 114.8 | 5.1 | 8.8 |
| 1952..... | 9.8 | 5.1 | 4.7 | 100.6 | 4.7 | 9.7 |
| 1953..... | 11.1 | 4.3 | 6.8 | 122.1 | 5.6 | 9.1 |
| 1954..... | 15.8 | 3.2 | 12.6 | 94.2 | 13.4 | 16.8 |
| 1955..... | 23.5 | 4.5 | 19.0 | 125.0 | 15.2 | 18.8 |
| 1956..... | 30.4 | 5.5 | 24.9 | 125.2 | 19.9 | 24.3 |
| 1957..... | 33.7 | 5.0 | 28.7 | 129.4 | 22.2 | 26.0 |
| 1958..... | 27.5 | 3.6 | 23.9 | 91.9 | 26.0 | 29.9 |
| 1959..... | 35.6 | 3.0 | 32.6 | 93.7 | 34.9 | 38.2 |
| 1960..... | 34.6 | 5.2 | 29.4 | 108.1 | 27.1 | 32.0 |
| 1961..... | 25.8 | 5.0 | 20.8 | 99.3 | 20.9 | 26.0 |
| 1962..... | 33.4 | 5.9 | 27.5 | 99.6 | 27.6 | 33.5 |
| 1963..... | 33.3 | 6.8 | 26.5 | 112.5 | 23.6 | 29.6 |
| 1964..... | 42.4 | 7.0 | 35.4 | 132.3 | 26.8 | 32.0 |
| 1965..... | 45.1 | 7.1 | 38.0 | 131.9 | 28.8 | 34.2 |
| 1966..... | 46.3 | 7.8 | 38.5 | 134.1 | 28.7 | 34.5 |
| 1967..... | 44.6 | 5.9 | 38.7 | 127.4 | 30.4 | 35.0 |
| 1968..... | 43.9 | 5.9 | 38.0 | 131.8 | 28.8 | 33.3 |
| 1969..... | 40.7 | 5.2 | 35.5 | 140.2 | 25.3 | 29.0 |
| 1970..... | 44.9 | 5.5 | 39.4 | 131.6 | 29.9 | 34.1 |
| 1971..... | 40.1 | 3.1 | 37.0 | 116.2 | 31.8 | 34.5 |
| 1972..... | 35.8 | 2.1 | 33.7 | 126.9 | 26.6 | 28.2 |

Source: BuMines Minerals Yearbooks 1950-72.

TABLE A-2. - Crude, usable, and byproduct iron ore, concentration ratio and natural iron content of total usable ore, total U.S. production, 1950-72, thousand long tons unless otherwise specified¹

| Year | Crude ore | Usable ore | Byproduct ore | Total usable ore ² | Concentration ratio, crude-to-usable ore | Iron in total usable ore, percent |
|-----------|-----------|------------|---------------|-------------------------------|--|-----------------------------------|
| 1950..... | 125,739 | 97,470 | 575 | 98,045 | 1.29-1 | 49 |
| 1951..... | 152,114 | 115,936 | 569 | 116,505 | 1.31-1 | 51 |
| 1952..... | 128,390 | 97,314 | 604 | 97,918 | 1.32-1 | 50 |
| 1953..... | 156,612 | 117,377 | 617 | 117,995 | 1.33-1 | 50 |
| 1954..... | 109,286 | 77,293 | 836 | 78,129 | 1.41-1 | 51 |
| 1955..... | 142,328 | 101,965 | 1,034 | 102,999 | 1.40-1 | 51 |
| 1956..... | 146,126 | 96,792 | 1,085 | 97,877 | 1.51-1 | 51 |
| 1957..... | 160,825 | 105,338 | 810 | 106,148 | 1.53-1 | 51 |
| 1958..... | 109,815 | 66,970 | 739 | 67,709 | 1.64-1 | 53 |
| 1959..... | 102,584 | 59,485 | 791 | 60,276 | 1.72-1 | 53 |
| 1960..... | 154,901 | 87,993 | 791 | 88,784 | 1.76-1 | 54 |
| 1961..... | 136,585 | 70,653 | 676 | 71,329 | 1.93-1 | 55 |
| 1962..... | 143,303 | 71,250 | 579 | 71,829 | 2.01-1 | 55 |
| 1963..... | 152,776 | 72,842 | 757 | 73,599 | 2.10-1 | 56 |
| 1964..... | 173,615 | 83,804 | 1,032 | 84,836 | 2.07-1 | 57 |
| 1965..... | 177,941 | 86,634 | 805 | 87,439 | 2.05-1 | 57 |
| 1966..... | 182,379 | 89,356 | 791 | 90,147 | 2.05-1 | 57 |
| 1967..... | 183,397 | 83,407 | 772 | 84,179 | 2.20-1 | 58 |
| 1968..... | 195,932 | 85,137 | 728 | 85,865 | 2.30-1 | 59 |
| 1969..... | 207,143 | 87,599 | 729 | 88,328 | 2.36-1 | 59 |
| 1970..... | 212,459 | 88,925 | 835 | 89,760 | 2.39-1 | 59 |
| 1971..... | 196,397 | 80,047 | 715 | 80,762 | 2.45-1 | 60 |
| 1972..... | 187,648 | 75,124 | 310 | 75,434 | 2.50-1 | 61 |

¹Excludes ore containing 5 percent or more manganese.

²Data may not add to totals due to independent rounding.

Source: BuMinerals Yearbooks 1950-72.

TABLE A-3. - Beneficiated iron ore shipped from mines in the United States, 1950-72, thousand long tons unless otherwise specified¹

| Year | Beneficiated | Total usable | Proportion of beneficiated to total usable, percent |
|-----------|--------------|--------------|---|
| 1950..... | 26,718 | 97,151 | 27.5 |
| 1951..... | 30,665 | 115,661 | 26.5 |
| 1952..... | 27,024 | 97,375 | 27.8 |
| 1953..... | 35,896 | 117,198 | 30.6 |
| 1954..... | 27,756 | 76,126 | 36.5 |
| 1955..... | 36,182 | 105,241 | 34.4 |
| 1956..... | 38,260 | 96,945 | 39.5 |
| 1957..... | 42,027 | 104,157 | 40.3 |
| 1958..... | 31,968 | 66,288 | 48.2 |
| 1959..... | 30,363 | 59,164 | 51.3 |
| 1960..... | 46,012 | 82,963 | 55.5 |
| 1961..... | 46,125 | 72,379 | 63.7 |
| 1962..... | 46,942 | 69,969 | 67.1 |
| 1963..... | 57,277 | 73,564 | 77.9 |
| 1964..... | 64,329 | 84,300 | 76.3 |
| 1965..... | 64,667 | 84,073 | 76.9 |
| 1966..... | 70,451 | 90,041 | 78.2 |
| 1967..... | 66,243 | 82,415 | 80.4 |
| 1968..... | 72,781 | 81,934 | 88.8 |
| 1969..... | 80,157 | 89,854 | 89.2 |
| 1970..... | 79,779 | 87,176 | 91.5 |
| 1971..... | 70,456 | 77,106 | 91.4 |
| 1972..... | 72,011 | 77,883 | 92.5 |

¹Excludes byproduct ore and ore containing 5 percent or more manganese.

Source: BuMines Minerals Yearbooks 1950-72.

TABLE A-4. - Usable iron ore produced in the United States, by type of product, 1950-72,
thousand long tons unless otherwise specified¹

| Year | Direct shipping ore | Agglomerates ² | Concentrates | Total usable ore ³ | Iron content, natural, percent |
|-------------------------------------|---------------------|---------------------------|--------------|-------------------------------|--------------------------------|
| PRODUCTION | | | | | |
| 1950..... | 70,309 | 4,350 | 22,811 | 97,470 | 49.4 |
| 1951..... | 85,282 | 4,945 | 25,709 | 115,936 | 50.7 |
| 1952..... | 70,358 | 4,918 | 22,037 | 97,314 | 50.2 |
| 1953..... | 82,164 | 6,052 | 29,162 | 117,377 | 50.4 |
| 1954..... | 49,106 | 5,014 | 23,173 | 77,293 | 50.8 |
| 1955..... | 66,746 | 6,447 | 28,772 | 101,965 | 51.1 |
| 1956..... | 59,895 | 9,554 | 27,343 | 96,792 | 51.3 |
| 1957..... | 64,503 | 11,580 | 29,255 | 105,338 | 51.3 |
| 1958..... | 36,229 | 8,857 | 21,873 | 66,959 | 53.0 |
| 1959..... | 29,975 | 9,539 | 19,971 | 59,485 | 53.2 |
| 1960..... | 38,968 | 16,384 | 32,643 | 87,995 | 53.5 |
| 1961..... | 25,924 | 16,099 | 28,630 | 70,653 | 54.5 |
| 1962..... | 22,132 | 20,659 | 28,459 | 71,250 | 54.8 |
| 1963..... | 15,218 | 26,435 | 31,189 | 72,842 | 56.1 |
| 1964..... | 21,725 | 30,714 | 31,365 | 83,804 | 56 |
| 1965..... | 19,681 | 34,615 | 32,338 | 86,634 | 57 |
| 1966..... | 19,575 | 40,084 | 29,697 | 89,356 | 57 |
| 1967..... | 16,198 | 44,338 | 22,871 | 83,407 | 58 |
| 1968..... | 9,565 | 50,377 | 25,194 | 85,136 | 58 |
| 1969..... | 9,790 | 54,316 | 23,493 | 87,599 | 59 |
| 1970..... | 6,979 | 57,149 | 24,797 | 88,925 | 59 |
| 1971..... | 5,757 | 54,511 | 19,779 | 80,047 | 60 |
| 1972..... | 5,830 | 54,620 | 14,674 | 75,124 | 61 |
| DISTRIBUTION OF PRODUCTION, PERCENT | | | | | |
| 1950..... | 72.1 | 4.5 | 23.4 | 100.0 | - |
| 1951..... | 73.6 | 4.3 | 22.2 | 100.0 | - |
| 1952..... | 72.3 | 5.1 | 22.6 | 100.0 | - |
| 1953..... | 70.0 | 5.2 | 24.8 | 100.0 | - |
| 1954..... | 63.5 | 6.5 | 30.0 | 100.0 | - |
| 1955..... | 65.5 | 6.3 | 28.2 | 100.0 | - |
| 1956..... | 61.9 | 9.9 | 28.2 | 100.0 | - |
| 1957..... | 61.2 | 11.0 | 27.8 | 100.0 | - |
| 1958..... | 54.1 | 13.2 | 32.7 | 100.0 | - |
| 1959..... | 50.4 | 16.0 | 33.6 | 100.0 | - |
| 1960..... | 44.3 | 18.6 | 37.1 | 100.0 | - |
| 1961..... | 36.7 | 22.8 | 40.5 | 100.0 | - |
| 1962..... | 31.1 | 29.0 | 39.9 | 100.0 | - |
| 1963..... | 20.9 | 36.3 | 42.8 | 100.0 | - |
| 1964..... | 25.9 | 36.6 | 37.4 | 100.0 | - |
| 1965..... | 22.7 | 40.0 | 37.3 | 100.0 | - |
| 1966..... | 21.9 | 44.9 | 33.2 | 100.0 | - |
| 1967..... | 19.4 | 53.2 | 27.4 | 100.0 | - |
| 1968..... | 11.2 | 59.2 | 29.6 | 100.0 | - |
| 1969..... | 11.2 | 62.0 | 26.8 | 100.0 | - |
| 1970..... | 7.8 | 64.3 | 27.9 | 100.0 | - |
| 1971..... | 7.2 | 68.1 | 24.7 | 100.0 | - |
| 1972..... | 7.8 | 72.7 | 19.5 | 100.0 | - |

¹Exclusive of ore containing 5 percent or more manganese.

²Excludes byproduct ore and is exclusive of agglomerates produced at consuming plants.

³Data may not add to totals due to independent rounding.

Source: BuMines Minerals Yearbooks 1950-72.

TABLE A-5. - Crude iron ore mined in the United States, by mining method, 1950-72, thousand long tons unless otherwise specified¹

| Year | Open pit | Underground | Total ore mined ² | Open pit, percent | Underground, percent |
|-----------|----------|-------------|------------------------------|-------------------|----------------------|
| 1950..... | 96,868 | 28,872 | 125,739 | 77.0 | 23.0 |
| 1951..... | 120,162 | 31,952 | 152,114 | 79.0 | 21.0 |
| 1952..... | 100,209 | 28,181 | 128,390 | 78.1 | 21.9 |
| 1953..... | 124,240 | 32,373 | 156,612 | 79.3 | 20.7 |
| 1954..... | 84,742 | 24,222 | 108,964 | 77.7 | 22.3 |
| 1955..... | 114,706 | 27,623 | 142,328 | 81.0 | 19.0 |
| 1956..... | 119,724 | 26,373 | 146,098 | 81.9 | 18.1 |
| 1957..... | 130,224 | 30,601 | 160,825 | 81.0 | 19.0 |
| 1958..... | 91,558 | 18,244 | 109,802 | 83.4 | 16.6 |
| 1959..... | 87,079 | 15,505 | 102,584 | 84.9 | 15.1 |
| 1960..... | 135,179 | 19,716 | 154,894 | 87.3 | 12.7 |
| 1961..... | 120,813 | 15,772 | 136,585 | 88.5 | 11.5 |
| 1962..... | 122,676 | 20,626 | 143,303 | 85.6 | 14.4 |
| 1963..... | 144,204 | 8,572 | 152,776 | 94.4 | 5.6 |
| 1964..... | 162,635 | 10,979 | 173,615 | 93.7 | 6.3 |
| 1965..... | 160,355 | 17,586 | 177,941 | 90.1 | 9.9 |
| 1966..... | 164,165 | 18,214 | 182,379 | 90.0 | 10.0 |
| 1967..... | 169,582 | 13,815 | 183,397 | 92.5 | 7.5 |
| 1968..... | 183,229 | 12,703 | 195,932 | 93.5 | 6.5 |
| 1969..... | 193,860 | 13,283 | 207,143 | 93.6 | 6.4 |
| 1970..... | 199,252 | 13,209 | 212,459 | 93.8 | 6.2 |
| 1971..... | 185,145 | 11,252 | 196,397 | 94.3 | 5.7 |
| 1972..... | 177,082 | 10,566 | 187,648 | 94.4 | 5.6 |

¹Exclusive of ore containing 5 percent or more manganese.

²Data may not add to totals due to independent rounding.

Source: BuMines Minerals Yearbooks 1950-72.

TABLE A-6. - Crude and usable iron ore mined in the United States, by variety, 1950-72¹

| Year | Quantity mined, thousand long tons | | | | Distribution of varieties, percent | | |
|------------|---------------------------------------|--------|-----------|--------------------|---------------------------------------|-------------------|-----------------------|
| | Hematite | Brown | Magnetite | Total ² | Hematite, percent | Brown, percent | Magnetite, percent |
| CRUDE ORE | | | | | | | |
| 1950.... | 104,392 | 8,406 | 12,941 | 125,739 | 83.0 | 6.7 | 10.3 |
| 1951.... | 123,340 | 11,208 | 17,566 | 152,114 | 81.1 | 7.4 | 11.5 |
| 1952.... | 101,162 | 9,977 | 17,251 | 128,390 | 78.8 | 7.8 | 13.4 |
| 1953.... | 126,835 | 9,112 | 20,665 | 156,612 | 81.0 | 5.8 | 13.2 |
| 1954.... | 84,401 | 8,630 | 16,256 | 109,286 | 77.4 | 7.6 | 15.0 |
| 1955.... | 119,744 | 8,524 | 14,059 | 142,328 | 84.0 | 6.0 | 10.0 |
| 1956.... | 105,430 | 10,967 | 29,730 | 146,126 | 72.1 | 7.5 | 20.4 |
| 1957.... | 114,645 | 11,409 | 34,771 | 160,825 | 71.3 | 7.1 | 21.6 |
| 1958.... | 51,136 | 8,507 | 50,160 | 109,802 | 46.6 | 7.7 | 45.7 |
| 1959.... | 60,010 | 8,217 | 34,357 | 102,584 | 58.5 | 8.0 | 33.5 |
| 1960.... | 97,806 | 6,038 | 51,057 | 154,901 | 63.1 | 3.9 | 33.0 |
| 1961.... | 80,048 | 5,184 | 51,353 | 136,585 | 58.6 | 3.8 | 37.6 |
| 1962.... | 73,064 | 11,413 | 58,825 | 143,303 | 51.0 | 8.0 | 41.0 |
| 1963.... | 76,373 | 9,801 | 66,601 | 152,776 | 50.0 | 6.4 | 43.6 |
| 1964.... | 80,757 | 6,312 | 86,546 | 173,615 | 46.5 | 3.6 | 49.8 |
| 1965.... | 80,235 | 7,956 | 89,750 | 177,941 | 45.1 | 4.5 | 50.4 |
| 1966.... | 74,552 | 8,744 | 99,083 | 182,379 | 40.9 | 4.8 | 54.3 |
| 1967.... | 70,136 | 6,389 | 106,872 | 183,397 | 38.2 | 3.5 | 58.3 |
| 1968.... | 58,150 | 4,134 | 133,646 | 195,932 | 29.7 | 2.1 | 68.2 |
| 1969.... | 59,799 | 4,799 | 142,544 | 207,143 | 28.9 | 2.3 | 68.8 |
| 1970.... | 57,210 | 5,818 | 149,431 | 212,459 | 26.9 | 2.7 | 70.3 |
| 1971.... | 46,994 | 5,603 | 143,800 | 196,397 | 23.9 | 2.9 | 73.2 |
| 1972.... | 35,097 | 4,858 | 147,693 | 187,648 | 18.7 | 2.6 | 78.7 |
| USABLE ORE | | | | | | | |
| 1950.... | 87,156 | 2,615 | 7,699 | 97,470 | 89.4 | 2.7 | 7.9 |
| 1951.... | 101,531 | 3,015 | 11,390 | 115,936 | 87.6 | 2.6 | 9.8 |
| 1952.... | 83,516 | 2,730 | 11,069 | 97,314 | 85.8 | 2.8 | 11.4 |
| 1953.... | 102,553 | 2,238 | 12,586 | 117,377 | 87.4 | 1.9 | 10.7 |
| 1954.... | 66,384 | 2,315 | 8,593 | 77,293 | 85.9 | 3.0 | 11.1 |
| 1955.... | 92,958 | 2,457 | 6,550 | 101,965 | 91.2 | 2.4 | 6.4 |
| 1956.... | 81,144 | 3,202 | 12,446 | 96,792 | 83.8 | 3.3 | 12.9 |
| 1957.... | 86,691 | 3,250 | 15,397 | 105,338 | 82.3 | 3.1 | 14.6 |
| 1958.... | 50,931 | 3,843 | 12,183 | 66,970 | 76.1 | 5.7 | 18.2 |
| 1959.... | 44,236 | 2,381 | 12,867 | 59,485 | 74.4 | 4.0 | 21.6 |
| 1960.... | 68,147 | 1,641 | 18,205 | 87,993 | 77.4 | 1.9 | 20.7 |
| 1961.... | 50,883 | 1,473 | 18,295 | 70,653 | 72.0 | 2.1 | 25.9 |
| 1962.... | 46,863 | 3,599 | 20,788 | 71,250 | 65.8 | 5.1 | 29.2 |
| 1963.... | 46,509 | 2,443 | 23,891 | 72,841 | 63.9 | 3.4 | 32.8 |
| 1964.... | 47,603 | 1,806 | 34,395 | 83,804 | 56.8 | 2.2 | 41.0 |
| 1965.... | 47,043 | 2,664 | 36,927 | 86,634 | 54.3 | 3.1 | 42.6 |
| 1966.... | 46,602 | 2,913 | 39,841 | 89,356 | 52.2 | 3.3 | 44.6 |
| 1967.... | 40,991 | 1,760 | 40,656 | 83,407 | 49.1 | 2.1 | 48.7 |
| 1968.... | 34,627 | 1,177 | 49,331 | 85,137 | 40.7 | 1.4 | 57.9 |
| 1969.... | 34,958 | 1,343 | 51,299 | 87,599 | 39.9 | 1.5 | 58.6 |
| 1970.... | 33,584 | 1,550 | 53,792 | 88,925 | 37.8 | 1.7 | 60.5 |
| 1971.... | 27,345 | 1,408 | 51,294 | 80,047 | 34.2 | 1.7 | 64.1 |
| 1972.... | 21,595 | 1,184 | 52,344 | 75,124 | 28.7 | 1.6 | 69.7 |

¹Exclusive of ores containing 5 percent or more manganese.²Data may not add to totals due to independent rounding.

Source: BuMinerals Minerals Yearbooks 1950-72.

TABLE A-7. - Shipments of beneficiated iron ore in the United States,
by concentrating process, 1957-68,
thousand long tons¹

| Year | Method of beneficiation | | | | | | |
|-----------------------|-------------------------|--------|------------------|------------------|----------|-----------|---------------|
| | Washed | Jigged | High- density | Other gravity | Magnetic | Flotation | Miscellaneous |
| 1957.... | 11,508 | 988 | 7,906 | 5,614 | 759 | 191 | 2,595 |
| 1958.... | 6,053 | 1,226 | 6,165 | 3,325 | 1,249 | - | 307 |
| 1959.... | 6,148 | 1,196 | 4,757 | 2,550 | 1,653 | 77 | 9 |
| 1960.... | 9,682 | 1,477 | 9,620 | 4,388 | 3,763 | 12 | 750 |
| 1961.... | 8,889 | 1,554 | 6,634 | 4,255 | 2,162 | 22 | 817 |
| 1962.... | 9,521 | 1,421 | 6,435 | 3,784 | 1,494 | 32 | 565 |
| 1963.... | 10,546 | 1,970 | 7,325 | 4,077 | 2,264 | 43 | 379 |
| 1964.... | 10,619 | 1,421 | 11,152 | 2,398 | 3,423 | - | 223 |
| 1965.... | 10,781 | 1,204 | 10,390 | 2,095 | 3,109 | - | 1,524 |
| 1966.... | 10,922 | 1,535 | 11,310 | 1,447 | 2,535 | - | 1,346 |
| 1967.... | 8,420 | 1,517 | 7,566 | 1,322 | 2,042 | - | 785 |
| 1968 ² ... | 9,383 | 1,877 | 7,652 | 1,516 | 2,032 | - | 560 |

¹Excludes concentrates agglomerated but includes byproduct ore.

²Similar data not available after 1968.

Source: American Iron Ore Association (3).

TABLE A-8. - Percentage of the U.S. iron ore output by the Lake Superior and all other districts, 1960-72

| Year | Crude ore | Usable ore | Iron contained, usable ore |
|--|-----------|------------|-------------------------------|
| UNITED STATES TOTAL OUTPUT, THOUSAND LONG TONS | | | |
| 1960..... | 156,120 | 88,618 | 47,345 |
| 1961..... | 137,433 | 70,796 | 38,490 |
| 1962..... | 143,921 | 71,391 | 39,102 |
| 1963..... | 153,304 | 73,237 | 41,019 |
| 1964..... | 174,007 | 83,972 | 47,232 |
| 1965..... | 177,941 | 87,842 | 50,070 |
| 1966..... | 183,207 | 89,758 | 51,841 |
| 1967..... | 183,397 | 83,365 | 48,410 |
| 1968..... | 196,375 | 85,262 | 49,962 |
| 1969..... | 206,671 | 87,561 | 52,774 |
| 1970..... | 212,460 | 88,925 | 52,830 |
| 1971..... | 196,397 | 80,047 | 48,200 |
| 1972..... | 187,648 | 75,124 | 45,649 |
| PERCENT OF TOTAL OUTPUT, LAKE SUPERIOR DISTRICT ¹ | | | |
| 1960..... | 80.9 | 81.7 | 82.6 |
| 1961..... | 77.4 | 75.4 | 76.6 |
| 1962..... | 78.1 | 78.0 | 79.4 |
| 1963..... | 76.9 | 77.2 | 77.7 |
| 1964..... | 76.7 | 75.4 | 75.9 |
| 1965..... | 77.5 | 75.6 | 75.6 |
| 1966..... | 77.4 | 76.9 | 70.7 |
| 1967..... | 78.9 | 77.0 | 76.7 |
| 1968..... | 80.0 | 77.8 | 78.4 |
| 1969..... | 79.9 | 78.5 | 78.9 |
| 1970..... | 79.8 | 78.3 | 78.4 |
| 1971..... | 80.8 | 80.0 | 80.2 |
| 1972..... | 82.9 | 81.9 | 81.9 |
| PERCENT OF TOTAL OUTPUT, ALL OTHER DISTRICTS ² | | | |
| 1960..... | 19.1 | 18.3 | 17.4 |
| 1961..... | 22.6 | 24.6 | 23.4 |
| 1962..... | 21.9 | 22.0 | 20.6 |
| 1963..... | 23.1 | 22.8 | 22.3 |
| 1964..... | 23.3 | 24.6 | 24.1 |
| 1965..... | 22.5 | 24.4 | 24.4 |
| 1966..... | 22.6 | 23.1 | 29.3 |
| 1967..... | 21.1 | 23.0 | 23.3 |
| 1968..... | 20.0 | 22.2 | 21.6 |
| 1969..... | 20.1 | 21.5 | 21.1 |
| 1970..... | 20.2 | 21.7 | 21.6 |
| 1971..... | 19.2 | 20.0 | 19.8 |
| 1972..... | 17.1 | 18.1 | 18.1 |

¹Includes Minnesota, Michigan, and Wisconsin data for 1960-65 and 1970-72.

Excludes Wisconsin data for 1966-69.

²Includes Southeastern, Northeastern, and Western States data and data undistributed by States.

Source: BuMines Minerals Yearbooks 1960-72.

TABLE A-9. - Crude and usable iron ore, ratio of concentration, and natural iron content of usable ore mined in the United States, by district and States,¹ 1950-72, thousand long tons unless otherwise specified²

| Year | Crude ore | Usable ore | Concentration ratio | Iron in usable ore, percent | Crude ore | Usable ore | Concentration ratio | Iron in usable ore, percent | Crude ore | Usable ore | Concentration ratio | Iron in usable ore, percent |
|------|------------------------|------------|---------------------|-----------------------------|---------------------|------------|---------------------|-----------------------------|---------------------|------------|---------------------|-----------------------------|
| | Lake Superior District | | | | Southeastern States | | | | Northeastern States | | | |
| 1950 | 96,561 | 79,627 | 1.21-1 | 50 | 11,910 | 7,508 | 1.59-1 | 37 | 9,576 | 4,475 | 2.14-1 | 61 |
| 1951 | 115,846 | 93,947 | 1.23-1 | 51 | 14,480 | 8,587 | 1.69-1 | 38 | 10,787 | 5,181 | 2.08-1 | 61 |
| 1952 | 94,933 | 77,095 | 1.23-1 | 50 | 12,978 | 7,624 | 1.70-1 | 38 | 10,182 | 4,426 | 2.30-1 | 61 |
| 1953 | 120,425 | 95,655 | 1.26-1 | 50 | 11,978 | 7,692 | 1.56-1 | 38 | 12,025 | 5,162 | 2.33-1 | 62 |
| 1954 | 80,725 | 60,994 | 1.32-1 | 51 | 10,737 | 6,150 | 1.75-1 | 38 | 9,759 | 4,084 | 2.39-1 | 63 |
| 1955 | 109,118 | 83,255 | 1.31-1 | 51 | 11,010 | 7,106 | 1.55-1 | 37 | 11,086 | 4,650 | 2.38-1 | 68 |
| 1956 | 110,050 | 77,817 | 1.41-1 | 51 | 11,117 | 6,035 | 1.84-1 | 39 | 11,623 | 4,867 | 2.39-1 | 62 |
| 1957 | 122,768 | 83,530 | 1.47-1 | 52 | 12,068 | 6,749 | 1.79-1 | 38 | 12,116 | 4,962 | 2.44-1 | 62 |
| 1958 | 84,445 | 51,777 | 1.63-1 | 54 | 5,898 | 3,827 | 1.54-1 | 38 | 8,666 | 3,412 | 2.54-1 | 62 |
| 1959 | 74,081 | 43,950 | 1.69-1 | 54 | 8,194 | 4,350 | 1.88-1 | 39 | 9,024 | 3,669 | 2.46-1 | 62 |
| 1960 | 125,082 | 71,792 | 1.74-1 | 54 | 7,627 | 4,365 | 1.75-1 | 39 | 11,128 | 4,125 | 2.70-1 | 62 |
| 1961 | 105,505 | 53,207 | 1.98-1 | 55 | 6,150 | 3,539 | 1.74-1 | 37 | 9,806 | 4,048 | 2.42-1 | 62 |
| 1962 | 111,829 | 55,556 | 2.01-1 | 56 | 7,357 | 3,186 | 2.31-1 | 30 | 11,232 | 4,584 | 2.45-1 | 63 |
| 1963 | 117,314 | 56,132 | 2.09-1 | 56 | 6,547 | 2,419 | 2.71-1 | 37 | 11,344 | 4,922 | 2.30-1 | 63 |
| 1964 | 133,109 | 63,107 | 2.11-1 | 56 | 6,901 | 2,546 | 2.71-1 | 37 | 12,678 | 5,214 | 2.43-1 | 64 |
| 1965 | 137,887 | 66,432 | 2.08-1 | 57 | 5,800 | 1,964 | 2.95-1 | 42 | 12,206 | 5,173 | 2.36-1 | 64 |
| 1966 | 140,898 | 68,602 | 2.05-1 | 57 | 5,813 | 2,028 | 2.87-1 | 38 | 11,355 | 4,652 | 2.44-1 | 63 |
| 1967 | 144,789 | 64,229 | 2.25-1 | 58 | 4,720 | 1,889 | 2.50-1 | 41 | 10,329 | 4,197 | 2.46-1 | 64 |
| 1968 | 156,598 | 66,224 | 2.36-1 | 59 | 3,059 | 1,509 | 2.03-1 | 40 | 10,075 | 3,963 | 2.54-1 | 63 |
| 1969 | 165,539 | 68,730 | 2.41-1 | 59 | 3,127 | 1,437 | 2.18-1 | 40 | 9,575 | 3,800 | 2.52-1 | 63 |
| 1970 | 169,529 | 69,636 | 2.43-1 | 60 | 3,277 | 1,484 | 2.21-1 | 46 | 9,177 | 3,491 | 2.63-1 | 63 |
| 1971 | 158,668 | 64,034 | 2.48-1 | 60 | 1,757 | 527 | 3.33-1 | 48 | 7,787 | 3,158 | 2.47-1 | 63 |
| 1972 | 155,495 | 61,550 | 2.53-1 | 61 | 1,280 | 433 | 2.96-1 | 48 | 6,818 | 2,612 | 2.61-1 | 64 |
| | Western States | | | | Undistributed | | | | | | | |
| 1950 | 7,693 | 5,861 | 1.31-1 | 51 | - | - | - | - | | | | |
| 1951 | 10,962 | 8,181 | 1.34-1 | 53 | - | - | - | - | | | | |
| 1952 | 10,158 | 8,030 | 1.27-1 | 54 | - | - | - | - | | | | |
| 1953 | 12,184 | 8,869 | 1.37-1 | 53 | - | - | - | - | | | | |
| 1954 | 8,066 | 6,065 | 1.33-1 | 53 | - | - | - | - | | | | |
| 1955 | 11,114 | 6,954 | 1.60-1 | 53 | - | - | - | - | | | | |
| 1956 | 13,335 | 8,073 | 1.65-1 | 52 | - | - | - | - | | | | |
| 1957 | 6,720 | 6,467 | 1.04-1 | 44 | 7,153 | 3,630 | 1.97-1 | 49 | | | | |
| 1958 | 5,572 | 5,178 | 1.08-1 | 52 | 5,234 | 2,776 | 1.89-1 | 46 | | | | |
| 1959 | 4,794 | 4,356 | 1.10-1 | 53 | 6,491 | 3,160 | 2.05-1 | 47 | | | | |
| 1960 | 5,327 | 4,583 | 1.16-1 | 52 | 5,736 | 3,127 | 1.83-1 | 50 | | | | |
| 1961 | 5,828 | 4,850 | 1.20-1 | 54 | 9,296 | 5,007 | 1.86-1 | 43 | | | | |
| 1962 | 6,350 | 4,438 | 1.43-1 | 53 | 6,535 | 3,485 | 1.88-1 | 54 | | | | |
| 1963 | 7,805 | 4,531 | 1.72-1 | 55 | 9,766 | 4,838 | 2.02-1 | 55 | | | | |
| 1964 | 9,399 | 6,187 | 1.52-1 | 55 | 11,528 | 6,750 | 1.71-1 | 56 | | | | |
| 1965 | 10,996 | 7,438 | 1.48-1 | 58 | 11,052 | 5,627 | 1.96-1 | 60 | | | | |
| 1966 | 11,191 | 7,011 | 1.60-1 | 59 | 13,122 | 7,063 | 1.86-1 | 59 | | | | |
| 1967 | 8,449 | 5,358 | 1.58-1 | 60 | 15,110 | 7,734 | 1.95-1 | 59 | | | | |
| 1968 | 8,424 | 3,827 | 2.20-1 | 47 | 17,776 | 9,614 | 1.85-1 | 58 | | | | |
| 1969 | 10,084 | 4,067 | 2.48-1 | 54 | 18,818 | 9,565 | 1.97-1 | 61 | | | | |
| 1970 | 9,783 | 3,977 | 2.46-1 | 56 | 20,693 | 10,337 | 2.00-1 | 61 | | | | |
| 1971 | 28,185 | 12,328 | 2.29-1 | 59 | - | - | - | - | | | | |
| 1972 | 24,054 | 10,529 | 2.28-1 | 60 | - | - | - | - | | | | |

¹States included in regional aggregations are listed in table A-18.

²Excludes ore containing 5 percent or more manganese.

Source: BuMines Minerals Yearbooks 1950-72.

TABLE A-11. - Number of iron ore mines operated in the United States annually, by State, 1950-72

| State | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 |
|------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Alabama..... | 37 | 44 | 40 | 30 | 33 | 32 | 48 | 47 | 30 | 31 | 28 | 27 | 24 | 24 | 22 | 24 | 19 | 15 | 7 | 9 | 8 | 3 | 3 |
| Arizona..... | - | - | - | - | - | - | - | - | - | - | - | (1) | (1) | (1) | 3 | 3 | 3 | 3 | 3 | 1 | 1 | 1 | 1 |
| Arkansas..... | 1 | 2 | 1 | 1 | 2 | - | 3 | 1 | 1 | - | - | - | 1 | (1) | 1 | - | - | - | - | - | - | - | - |
| California..... | 2 | 2 | 3 | 4 | 2 | 2 | 3 | 6 | 2 | 2 | 3 | (1) | (1) | (1) | 4 | 4 | 3 | 3 | 3 | (1) | (1) | (1) | (1) |
| Colorado..... | - | - | - | 1 | 1 | 1 | 1 | 2 | 1 | 3 | 4 | 4 | (1) | (1) | 5 | 3 | 3 | 2 | 3 | (1) | (1) | (1) | (1) |
| Georgia..... | 11 | 12 | 13 | 12 | 11 | 12 | 25 | 23 | 11 | 9 | 9 | 11 | 10 | 8 | 11 | 17 | 17 | 11 | 3 | (2) | (2) | 33 | 33 |
| Idaho..... | - | - | - | - | - | - | 1 | 1 | 1 | 1 | 3 | 3 | 3 | 3 | 1 | 3 | 3 | 2 | 2 | (1) | (1) | (1) | (1) |
| Kentucky..... | - | - | - | - | - | - | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Michigan..... | 37 | 39 | 41 | 41 | 40 | 40 | 37 | 33 | 29 | 27 | 27 | 23 | 24 | 20 | 16 | 21 | 17 | 15 | 11 | 10 | 7 | 7 | 5 |
| Minnesota..... | 130 | 146 | 171 | 182 | 130 | 166 | 152 | 143 | 95 | 95 | 107 | 74 | 69 | 71 | 57 | 74 | 59 | 45 | 50 | 37 | 28 | 32 | 18 |
| Mississippi..... | - | - | - | - | - | - | 1 | 1 | 1 | - | - | - | - | - | - | 1 | 1 | 1 | - | - | - | - | - |
| Missouri..... | 3 | 6 | 5 | 10 | 8 | 12 | 21 | 42 | 26 | 12 | 20 | 10 | 11 | 8 | 5 | 3 | 6 | 3 | 2 | (1) | (1) | 2 | 2 |
| Montana..... | - | - | - | 1 | 1 | 1 | 2 | 2 | 3 | 3 | 2 | 3 | 2 | 2 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 |
| Nevada..... | 1 | 5 | 12 | 8 | 6 | 8 | 10 | 11 | 8 | 11 | 14 | 17 | 13 | 7 | 6 | 5 | 6 | 4 | 4 | (1) | (1) | (1) | (1) |
| New Jersey..... | 4 | 4 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| New Mexico..... | 1 | 3 | 5 | 4 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | (1) | 2 | 1 | 3 | 2 | 3 | (1) | (1) | (1) | (1) |
| New York..... | 7 | 7 | 6 | 6 | 6 | 5 | 5 | 5 | 4 | 5 | 5 | 5 | (5) | (5) | (5) | (5) | (5) | 67 | 65 | 65 | 65 | 65 | 64 |
| North Carolina.. | - | - | - | - | - | - | - | - | - | 1 | 1 | - | - | - | - | - | - | - | - | (2) | (2) | (3) | (3) |
| Oregon..... | - | - | - | - | - | 1 | 1 | 1 | - | - | - | - | (1) | - | - | - | - | - | - | - | - | - | - |
| Pennsylvania.... | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | (4) | (4) | (4) | (4) | (5) | (5) | (5) | (5) | (5) | (6) | (6) | (6) | (6) | (6) | (6) |
| South Dakota.... | - | - | - | 1 | 1 | 1 | 1 | 1 | - | - | 1 | 1 | 2 | - | - | - | - | - | - | - | - | - | - |
| Tennessee..... | - | 3 | 3 | 1 | 3 | 3 | 2 | 3 | - | 3 | 3 | (1) | (1) | (1) | - | - | - | - | - | - | - | - | - |
| Texas..... | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | (1) | (1) | (1) | 4 | 5 | 6 | 6 | 3 | (1) | (1) | (1) | (1) |
| Utah..... | 5 | 6 | 6 | 8 | 7 | 6 | 10 | 10 | 9 | 11 | 7 | 6 | 6 | 6 | 7 | 6 | 6 | 5 | 6 | 6 | 4 | 4 | 4 |
| Virginia..... | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Washington..... | - | - | - | - | - | 1 | 1 | 1 | 1 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Wisconsin..... | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 4 | 2 | 2 | 2 | 2 | 1 | 1 | - | - | - | 1 | 1 | 1 | 1 |
| Wyoming..... | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 2 | 3 | 2 | (1) | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 3 | 3 | 3 | 3 |
| Undistributed... | - | - | - | - | - | - | - | - | - | - | - | 16 | 19 | 16 | - | - | - | - | - | 19 | 16 | 12 | 13 |
| Total..... | 247 | 288 | 320 | 325 | 266 | 305 | 341 | 349 | 238 | 233 | 247 | 206 | 200 | 179 | 158 | 183 | 164 | 131 | 111 | 92 | 74 | 74 | 58 |

¹Included in "Undistributed."

²Alabama includes Georgia and North Carolina.

³Georgia includes North Carolina.

⁴New Jersey includes Pennsylvania.

⁵New Jersey includes Pennsylvania and New York.

⁶New York includes Pennsylvania.

Source: BuMines Minerals Yearbooks 1950-72.

TABLE A-12. - General statistics of the iron ore industry, 1954-72

| | 1954 | 1958 | 1963 | 1967 | 1972 ¹ |
|---|-------|-------|-------|-------|-------------------|
| Establishments: | | | | | |
| Total..... | 225 | 243 | 208 | 146 | 114 |
| With less than 20 employees.....percent.. | 40 | 47 | 51 | 46 | 48 |
| With 500 or more employees.....do..... | 4 | 5 | 4 | 9 | NA |
| Usable ore produced.....million long tons.. | 78.2 | 66.9 | 73.8 | 85.9 | 76.4 |
| Value of shipments and receipts | | | | | |
| million dollars | 547.2 | 664.5 | 762.2 | 953.4 | 1,066.2 |
| Capital expenditures.....do..... | 85.0 | 42.6 | 96.6 | 108.8 | 60.1 |
| Selected expenses: | | | | | |
| Supplies, fuels, and purchased | | | | | |
| electric energy.....do..... | 99.2 | 106.8 | 161.6 | 222.1 | NA |
| Minerals received for | | | | | |
| treatment or agglomeration.....do..... | 12.8 | 64.7 | 64.6 | 91.9 | NA |
| Contract work.....do..... | 47.5 | 29.4 | 55.5 | 37.3 | NA |
| Purchased machinery installed.....do..... | 37.0 | 18.5 | 27.9 | 49.0 | 41.0 |
| Value added in mining.....do..... | 435.7 | 487.7 | 549.3 | 661.9 | 702.2 |
| Employment: | | | | | |
| All employees.....thousand.. | 34.2 | 30.1 | 23.1 | 22.6 | 19.8 |
| Payroll.....million dollars.. | 156.9 | 169.0 | 161.6 | 185.9 | 220.2 |
| Production, development and exploration: | | | | | |
| Number.....thousand.. | 28.2 | 22.5 | 18.1 | 18.0 | 15.3 |
| Man-hours.....millions.. | 53.3 | 39.9 | 34.5 | 36.2 | 30.2 |
| Wages.....million dollars.. | 119.7 | 116.3 | 112.8 | 133.4 | 155.7 |

¹Preliminary Report, 1972 Census of Mineral Industries, Report MIC72(P)-10A, January 1974, p. 2.

NA Not available.

Source: Census of Mineral Industries (52, p. 10A-3).

TABLE A-13. - Content of data cardsA. Production, composition, use, and value

CARD 1

Subject--CRUDE ORE PRODUCTION
 Source --Posting sheets "Crude ore"

| <u>Column</u> | <u>Field</u> | <u>Description</u> |
|---------------|--------------------------|------------------------------------|
| 1 | Card No. | "1" |
| 2 | Year | Last digit of year |
| 3- 4 | State | Two-digit code. |
| 5-14 | Company | First ten characters, run together |
| 15-24 | Mine name | First ten characters, run together |
| 25 | Type ore | Initial letter of ore type name |
| 26-33 | Stocks, 12/31 last year | Tons |
| 34-41 | Production, Underground | Tons |
| 42-49 | Production, Open-pit | Tons |
| 50-57 | Shipments, Direct | Tons |
| 58-65 | Shipments, Concentrators | Tons |
| 66-73 | Stocks, 12/31 this year | Tons |
| 74 | Consent to disclose | "0"--NS; "1"--Yes; "2"--No |

CARD 2

Subject--USABLE ORE PRODUCTION
 Source--Posting sheets "Usable ore"

| <u>Column</u> | <u>Field</u> | <u>Description</u> |
|---------------|--------------------------|-------------------------------------|
| 1 | Card No. | "2" |
| 2 | Year | Last digit of year |
| 3- 4 | State | Two-digit code. |
| 5- 8 | Company | First four characters, run together |
| 9-12 | Mine name | First four characters, run together |
| 13 | Type ore | Initial letter of ore type name |
| 14-20 | Stocks, 12/31 last year | Tons |
| 21-27 | Production, Direct ship | Tons |
| 28-34 | Production, Concentrates | Tons |
| 35-41 | Production, Agglomerates | Tons |
| 42 | Form, product | Initial letter of product type name |
| 64-70 | Stocks, 12/31 this year | Tons |
| 71-77 | Iron content | Tons |

TABLE A-13. - Content of data cards--ContinuedA. Production, composition, use and value--Continued

CARD 3

Subject--USE, VALUE, COMPOSITION
Source--Posting sheets

| <u>Column</u> | <u>Field</u> | <u>Description</u> |
|---------------|--|-------------------------------------|
| 1 | Card No. | "3" |
| 2 | Year | Last digit of year |
| 3- 4 | State | Two-digit code. |
| 5- 8 | Company | First four characters, run together |
| 9-12 | Mine name | First four characters, run together |
| 13 | Type ore | Initial letter of ore type name |
| 14-17 | Use | First four characters, run together |
| 18-24 | Direct Ship., Quantity | Tons |
| 25-31 | Direct Ship., Value | Tons |
| 32-38 | Concentrates, Quantity | Tons |
| 39-45 | Concentrates, Value | Tons |
| 46-52 | Agglomerates, Quantity | Tons |
| 53-59 | Agglomerates, Value | Tons |
| 60-63 | Composition, Fe | 4 digits, 61/62 decimal |
| 64-65 | Composition, Mn | 2 digits, 64/65 decimal |
| 66-68 | Composition, P | 3 digits, 65/66 decimal |
| 69-71 | Composition, S | 3 digits, 68/69 decimal |
| 72-74 | Composition, S ₁ O ₂ | 3 digits, 73/74 decimal |
| 75-76 | Composition, CaO | 2 digits, 75/76 decimal |
| 77-80 | Composition, Moist | 4 digits, 78/79 decimal |

B. Employment and Injuries

ONE CARD

Subject--EMPLOYMENT AND INJURIES
Source-- Accident Analysis Listing

| <u>Column</u> | <u>Field</u> | <u>Description</u> |
|---------------|-------------------|-------------------------|
| 1- 2 | Year | Last two digits of year |
| 3- 4 | State | Two digit code |
| 5- 9 | Mine no. | Five digit code |
| 10-11 | Department | Two digit code |
| 12-17 | Old Mine no. | Six digit code |
| 41-43 | Men working daily | Average number |
| 44-46 | Days worked | In the year |
| 47-52 | Man-shifts | Total |
| 53-54 | Shift hours | Total |
| 55-61 | Man-hours | Total |
| 62-69 | Production | Total |
| 71-72 | Fatalities | Total |
| 73-74 | Non-fatals | Total |
| 75-77 | Days lost | Total |

TABLE A-14. - Price indexes for plant and equipment

| Index base..... | BLS mining machinery and equipment 1967 = 100 | Marshall and Swift | | Chemical Engi- neering, plant construction 1957-9 = 100 | Engineering News-Record, construction 1913 = 100 |
|-----------------|--|-------------------------------|-------------------------------------|--|---|
| | | All industry 1926 = 100 | Mining and milling 1926 = 100 | | |
| 1950..... | 48.5 | 168 | 171 | 74 | 510 |
| 1951..... | 54.9 | 180 | 181 | 80 | 543 |
| 1952..... | 55.4 | 181 | 182 | 81 | 569 |
| 1953..... | 54.9 | 183 | 184 | 85 | 600 |
| 1954..... | 60.3 | 185 | 187 | 86 | 628 |
| 1955..... | 64.8 | 191 | 193 | 88 | 660 |
| 1956..... | 72.1 | 209 | 216 | 94 | 692 |
| 1957..... | 78.9 | 225 | 228 | 99 | 724 |
| 1958..... | 83.3 | 229 | 234 | 100 | 759 |
| 1959..... | 87.2 | 235 | 237 | 102 | 797 |
| 1960..... | 88.4 | 238 | 241 | 102 | 824 |
| 1961..... | 89.6 | 237 | 239 | 102 | 847 |
| 1962..... | 90.1 | 239 | 240 | 102 | 872 |
| 1963..... | 90.7 | 239 | 240 | 102 | 901 |
| 1964..... | 91.9 | 242 | 243 | 103 | 936 |
| 1965..... | 94.2 | 245 | 245 | 104 | 971 |
| 1966..... | 97.1 | 253 | 253 | 107 | 1,019 |
| 1967..... | 100.0 | 263 | 264 | 110 | 1,070 |
| 1968..... | 103.4 | 273 | 273 | 115 | 1,155 |
| 1969..... | 106.6 | 285 | 286 | 119 | 1,269 |
| 1970..... | 111.1 | 303 | 303 | 124 | 1,386 |
| 1971..... | 113.8 | 321 | 321 | 132 | 1,581 |
| 1972..... | 117.2 | 332 | 332 | 137 | 1,753 |

CONFORMED TO COMMON BASE (1967 = 100).

| | | | | | |
|-----------|-------|---|-------|-------|-------|
| 1950..... | 48.5 | - | 64.8 | 67.3 | 47.7 |
| 1951..... | 54.9 | - | 68.6 | 72.7 | 50.8 |
| 1952..... | 55.4 | - | 69.0 | 73.6 | 53.2 |
| 1953..... | 54.9 | - | 69.7 | 77.3 | 56.1 |
| 1954..... | 60.3 | - | 70.8 | 78.2 | 58.7 |
| 1955..... | 64.8 | - | 73.1 | 80.0 | 61.7 |
| 1956..... | 72.1 | - | 81.8 | 85.5 | 64.7 |
| 1957..... | 78.9 | - | 86.4 | 90.0 | 67.7 |
| 1958..... | 83.3 | - | 88.6 | 90.9 | 70.9 |
| 1959..... | 87.2 | - | 89.8 | 92.7 | 74.5 |
| 1960..... | 88.4 | - | 91.3 | 92.7 | 77.0 |
| 1961..... | 89.6 | - | 90.5 | 92.7 | 79.2 |
| 1962..... | 90.1 | - | 90.9 | 92.7 | 81.5 |
| 1963..... | 90.7 | - | 90.9 | 92.7 | 84.2 |
| 1964..... | 91.9 | - | 92.5 | 93.6 | 87.5 |
| 1965..... | 94.2 | - | 92.8 | 94.6 | 90.8 |
| 1966..... | 97.1 | - | 95.8 | 97.3 | 95.2 |
| 1967..... | 100.0 | - | 100.0 | 100.0 | 100.0 |
| 1968..... | 103.4 | - | 103.4 | 104.6 | 107.9 |
| 1969..... | 106.6 | - | 108.3 | 108.2 | 118.6 |
| 1970..... | 111.1 | - | 114.8 | 112.7 | 129.5 |
| 1971..... | 113.8 | - | 121.6 | 120.0 | 147.8 |
| 1972..... | 117.2 | - | 125.8 | 124.5 | 163.8 |

Sources: BLS, Code 1192; Parkinson and Mular (40); Chemical Engineering, and Engineering News-Record.

TABLE A-15. - Types of primary iron and steel product shipments, 1955-72

(Quantities in million short tons)

| Year | Steel mill products | | Iron and steel castings | | | | | | Total castings and mill products | |
|------|---------------------|------|-------------------------|------|-----------|-----|----------|-----|----------------------------------|-----|
| | | | Gray iron | | Malleable | | Steel | | | |
| | Quantity | Pct | Quantity | Pct | Quantity | Pct | Quantity | Pct | Quantity | Pct |
| 1955 | 84.7 | 82.7 | 14.8 | 14.5 | 1.1 | 1.1 | 1.5 | 1.5 | 102.2 | 100 |
| 1956 | 83.3 | 83.3 | 13.9 | 13.9 | 1.0 | 1.0 | 1.9 | 1.9 | 100.0 | 100 |
| 1957 | 80.0 | 82.9 | 12.7 | 13.3 | .9 | .9 | 1.8 | 1.9 | 95.2 | 100 |
| 1958 | 59.9 | 83.2 | 10.4 | 14.4 | .7 | .9 | 1.1 | 1.6 | 72.1 | 100 |
| 1959 | 69.4 | 82.6 | 12.3 | 14.6 | .9 | 1.1 | 1.4 | 1.7 | 84.0 | 100 |
| 1960 | 71.1 | 83.7 | 11.6 | 13.6 | .8 | 1.0 | 1.4 | 1.6 | 85.0 | 100 |
| 1961 | 66.1 | 83.8 | 10.8 | 13.7 | .7 | .9 | 1.2 | 1.5 | 78.9 | 100 |
| 1962 | 70.6 | 83.6 | 11.6 | 13.7 | .9 | 1.0 | 1.4 | 1.7 | 84.4 | 100 |
| 1963 | 75.6 | 83.3 | 12.8 | 14.1 | .9 | 1.0 | 1.5 | 1.7 | 90.8 | 100 |
| 1964 | 84.9 | 83.2 | 14.3 | 14.0 | 1.0 | 1.0 | 1.8 | 1.8 | 102.1 | 100 |
| 1965 | 92.7 | 83.1 | 15.7 | 14.1 | 1.1 | 1.0 | 2.0 | 1.8 | 111.5 | 100 |
| 1966 | 90.0 | 82.6 | 15.7 | 14.4 | 1.1 | 1.0 | 2.2 | 2.0 | 109.0 | 100 |
| 1967 | 83.9 | 83.0 | 14.3 | 14.2 | 1.0 | 1.0 | 1.9 | 1.8 | 101.1 | 100 |
| 1968 | 91.9 | 83.7 | 15.1 | 13.8 | 1.0 | .9 | 1.7 | 1.6 | 109.7 | 100 |
| 1969 | 93.9 | 83.2 | 15.9 | 14.1 | 1.2 | 1.0 | 1.9 | 1.7 | 112.9 | 100 |
| 1970 | 90.8 | 84.6 | 14.0 | 13.0 | .9 | .8 | 1.7 | 1.6 | 107.3 | 100 |
| 1971 | 87.0 | 84.2 | 13.8 | 13.4 | .9 | .9 | 1.6 | 1.5 | 103.3 | 100 |
| 1972 | 91.8 | 83.7 | 15.3 | 14.0 | 1.0 | .9 | 1.6 | 1.4 | 109.7 | 100 |

Source: Survey of Current Business (53).

TABLE A-16. - United States supply of steel mill products, 1955, 1964, 1970

(Thousand short tons)

| | Semi- finish | Shapes and plates | Rails and acces- sories | Bars and tool steel | Pipe and tubing | Wire and wire prod- ucts | Tin mill prod- ucts | Sheets and strip | Total |
|----------------------|-----------------|-------------------------|----------------------------------|------------------------------|-----------------------|--------------------------------------|------------------------------|------------------------|--------|
| 1955: | | | | | | | | | |
| Net shipments..... | 4,819 | 11,891 | 2,132 | 12,955 | 9,836 | 4,330 | 6,402 | 32,353 | 84,717 |
| Less, exports..... | 721 | 505 | 74 | 205 | 350 | 48 | 773 | 1,194 | 3,871 |
| Plus, imports..... | 194 | 112 | 7 | 286 | 77 | 244 | - | 40 | 960 |
| Apparent supply..... | 4,292 | 11,498 | 2,065 | 13,036 | 9,563 | 4,526 | 5,629 | 31,199 | 81,806 |
| Percent of total. | 5.2 | 14.1 | 2.5 | 15.9 | 11.7 | 5.5 | 6.9 | 38.1 | 100.0 |
| 1964: | | | | | | | | | |
| Net shipments..... | 4,229 | 14,576 | 1,395 | 13,199 | 8,137 | 3,105 | 6,083 | 34,222 | 84,945 |
| Less, exports..... | 920 | 426 | 58 | 175 | 286 | 54 | 418 | 1,105 | 3,442 |
| Plus, imports..... | 1,298 | 1,100 | 14 | 1,174 | 790 | 809 | 88 | 1,167 | 6,439 |
| Apparent supply..... | 4,607 | 15,250 | 1,351 | 14,198 | 8,641 | 3,860 | 5,753 | 34,284 | 87,942 |
| Percent of total. | 5.2 | 17.3 | 1.5 | 16.1 | 9.8 | 4.4 | 6.5 | 39.0 | 100.0 |
| 1970: | | | | | | | | | |
| Net shipments..... | 7,387 | 14,125 | 1,590 | 14,577 | 7,778 | 2,998 | 7,243 | 35,101 | 90,798 |
| Less, exports..... | 3,344 | 374 | 99 | 324 | 324 | 41 | 422 | 2,135 | 7,062 |
| Plus, imports..... | 1,226 | 2,155 | 72 | 1,363 | 1,927 | 886 | 335 | 5,400 | 13,365 |
| Apparent supply..... | 5,269 | 15,906 | 1,563 | 15,616 | 9,381 | 3,843 | 7,156 | 38,366 | 97,101 |
| Percent of total. | 5.4 | 16.4 | 1.6 | 16.1 | 9.7 | 4.0 | 7.4 | 39.5 | 100.0 |

Source: AISI (2).

TABLE A-17. - Consumption of pig iron and purchased iron and steel scrap in the iron and steel industry, 1955-72

| Year | Pig iron | Iron and steel scrap | | | Total pig iron and purchased scrap | |
|-----------|----------|----------------------|-----------------------|--------------------------------------|------------------------------------|------------------|
| | | Total consumption | Home scrap production | Apparent purchased scrap consumption | Quantity | Percent pig iron |
| 1955..... | 77.2 | 80.4 | 45.5 | 34.9 | 112.1 | 68.9 |
| 1956..... | 75.0 | 79.3 | 43.7 | 35.6 | 110.6 | 68.0 |
| 1957..... | 76.4 | 72.6 | 44.0 | 28.6 | 105.0 | 72.7 |
| 1958..... | 57.3 | 55.5 | 33.7 | 21.7 | 79.0 | 72.5 |
| 1959..... | 61.8 | 65.0 | 37.4 | 27.6 | 89.3 | 69.1 |
| 1960..... | 66.6 | 65.6 | 39.6 | 25.9 | 92.6 | 72.0 |
| 1961..... | 65.8 | 63.5 | 38.5 | 25.0 | 90.8 | 72.4 |
| 1962..... | 66.6 | 65.3 | 40.6 | 24.7 | 91.3 | 73.0 |
| 1963..... | 72.7 | 74.0 | 44.7 | 29.4 | 102.1 | 71.2 |
| 1964..... | 86.4 | 84.0 | 52.3 | 31.8 | 118.1 | 73.1 |
| 1965..... | 88.9 | 89.7 | 55.2 | 34.4 | 123.4 | 72.1 |
| 1966..... | 91.8 | 90.8 | 55.5 | 35.4 | 127.2 | 72.2 |
| 1967..... | 87.4 | 84.7 | 52.3 | 32.4 | 119.8 | 72.9 |
| 1968..... | 90.0 | 87.1 | 53.5 | 33.5 | 123.5 | 72.9 |
| 1969..... | 94.6 | 94.8 | 56.3 | 38.5 | 133.2 | 71.1 |
| 1970..... | 90.1 | 85.6 | 52.6 | 33.0 | 123.1 | 73.2 |
| 1971..... | 81.2 | 82.6 | 49.2 | 33.4 | 114.6 | 70.9 |
| 1972..... | 89.1 | 93.4 | 51.2 | 42.2 | 131.3 | 67.9 |

Source: BuMines Minerals Yearbooks 1955-72.

TABLE A-18. - Classifications of iron ore statistics by State into regional aggregations, 1955-73

| State | American Iron Ore Association | U.S. Bureau of Mines |
|----------------|-------------------------------|--------------------------|
| Michigan | } U.S. Great Lakes Area | } Lake Superior district |
| Minnesota | | |
| Wisconsin | | |
| New Jersey | } U.S. Northeastern Area | } Northeastern States |
| New York | | |
| Pennsylvania | | |
| Alabama | } U.S. Southern Area | } Southeastern States |
| Georgia | | |
| Kentucky | | |
| Mississippi | | |
| North Carolina | | |
| Tennessee | | |
| Virginia | | |
| Arkansas | } U.S. Western Area | } Western States |
| Missouri | | |
| New Mexico | | |
| Texas | | |
| California | | |
| Colorado | | |
| Idaho | | |
| Montana | | |
| Nevada | | |
| Oregon | | |
| South Dakota | | |
| Utah | | |
| Washington | | |
| Wyoming | | |

LEGEND

- ▨ Lake Superior district
- ▨ Other States

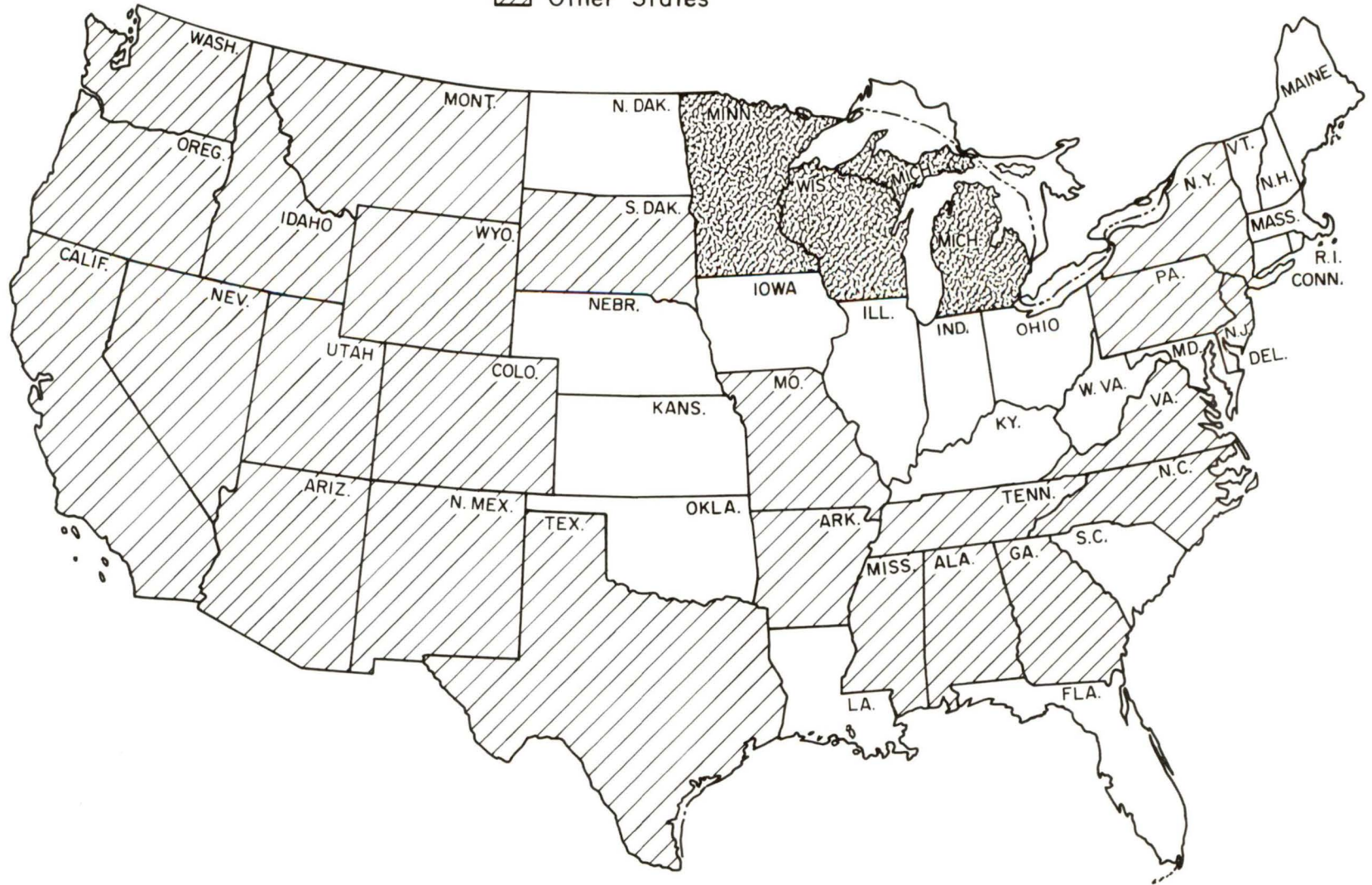


FIGURE A-1. - States in which iron ore production has been reported since 1950.

