A Bandwagon with Few Passengers: Minimill and FINEX in Steel Industry

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Abstract: There is a general preconception that existing technologies are replaced by new ones. Christensen (1997) believed that integrated steelmaking technologies would be replaced by minimills in the steel industry. In addition, it was believed that traditional blast furnace technology in this industry would be replaced by FINEX technology. Whether it be the new technology of minimills or that of FINEX, either are vastly superior in cost when compared with existing technologies. In actuality, however, these new technologies have only replaced some existing technologies and even today are merely complementary to existing technologies. Both of these new technologies have issues with quality, and companies have not yet decided to discard existing technologies to replace them with the new ones.

Keywords: minimill, FINEX (fine ore reduction), steel industry, technology introduction

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Introduction

Much research has been conducted on replacing existing technologies with new technologies. In particular, technology management theory focuses on the fact that companies that have developed new technologies are not always able to profit from them. That said, as new technologies threaten existing technologies, many industries have seen a reversal of corporate competitiveness during the period in which both coexist. Some companies are able to successfully introduce the new technologies, while others are not (Christensen, 1997; Lynn, 1982; Tushman & Anderson, 1986). However, there is a general preconception that existing technologies are replaced by new technologies.

In production management theory, the appearance of a new production technology is believed to be a critical factor in improving the efficiency of production systems. In actuality, the minimill and FINEX technologies in steelmaking were thought to be overwhelmingly cost competitive when they first made their appearance. Minimills, which first appeared in the mid-1960s, grew to become a threat to large integrated steelmaking technologies because of their compact size even though they never fully replaced integrated steelmaking. FINEX has a much better cost structure than does blast furnace technology and has been hailed as an environment-friendly technology; however, it has not fully replaced blast furnaces either. In this paper, we consider why both of these technologies have not been able to replace existing technologies.

Minimill and Integrated Steel Technology

The asset-intensive steel industry invests enormous amounts in equipment. These investments are not only for equipment and construction; approximately half of all capital investments are used
to maintain and repair infrastructure after the infrastructure is up and running.\(^1\) There are production costs at the stage of full-scale operations after a production ramp (Byun, 2016). Keeping these investments and costs to a minimum is tied to long-term cost competitiveness, and minimills are superior to existing technologies in this regard.

Traditional integrated steelmaking technologies include iron making processes using blast furnaces, steelmaking processes (including continuous casting) using convertor furnaces, and the later rolled steel processes (hot rolling steel and cold rolling steel). By and large, steel mills with all of these processes are called “integrated steel mills” or “integrated steel works.” The large blast furnaces and convertor furnaces in these integrated steel mills set them apart from minimills.

When compared with integrated steel mills, minimill technologies are smaller in scale, as their name suggests, and have lower capital costs. Blast furnaces are used in continuous production; hence, once they begin operation, it is nearly impossible to stop production, which makes it difficult to adjust production volumes according to market circumstances. In contrast, minimills have no blast furnaces, and instead of convertor furnaces, they use small electric furnaces,\(^2\) which, when combined with continuous casting and rolled steel technologies, allows them to respond flexibly to fluctuations in demand for steel.

Minimills became commercially available in the U.S. in the

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1 In 2016, the Japan steel industry invested 705.5 billion yen, of which 49.2% went to maintenance and repairs. The rest was invested in rationalization and energy conservation (18.1%), capacity improvements (12.8%), new products and advanced products (3.0%), and research and development (2.8%) (Development Bank of Japan, 2017).

2 The production capacity of an ultra-large blast furnace currently exceeds 5 million tons annually, while the average production capacity of a minimill using an electric furnace is much smaller, at 2 million tons annually.
mid-1960s. Minimills use electricity to melt metal for recycling (steel scrap) in an electric furnace, and they are primarily used for making bar steel, wire rods, and steel plates. A minimill’s capacity is not even one-tenth of that of an integrated steel mill with blast furnaces and convertor furnaces. At the time when minimills were developed, the construction of an integrated steel mill cost approximately 6 billion dollars, while the construction of a minimill cost only about 400 million dollars. In addition, as of 1995, the production of 1 ton of steel in the U.S. required 2.3 man hours in an integrated steel mill but only 0.6 man hours in the most efficient minimills.

With their high productivity and low investment costs, minimills increased their share of the North American market rapidly, going from 0% in 1965 to 19% 10 years later in 1975, 32% by 1985, and 40% by 1995. Viewing this trend, experts predicted that minimills could conceivably have half of all steel production in the 2000s. However, minimill technology was superior in terms of both cost and flexibility, but it was not adopted by large steelmakers and did not replace existing technologies.

The weaknesses of electric furnaces include (1) the large burden of processing impurities because of their use of scrap metal; (b) a direct impact on production costs when electricity rates rise due to their massive consumption of electricity as a source of energy; and (c) the fact that they are easily impacted by the rising cost of scrap metal.

Among these, the issue of quality (a) is the largest. Pig iron made in the blast furnaces of integrated steel mills is often referred to as “virgin steel,” and in comparison, the steel made by melting scrap metal in minimills has many more impurities and is of lower quality. Thus, it is used to make products buried in the ground, such as rebar, bar steel, and section steel. While improvements to quality have been made, they have not overcome technological limitations in the production of high-value-add products (i.e., high-grade steel) such as the steel plates used in automobiles. Because of this, large
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Table 1. Competitiveness of minimill steel technology (when compared with integrated steel)

| Quality                        | Inferior (targeting mainly low-grade products; showing quality improvement) |
|-------------------------------|----------------------------------------------------------------------------|
| Cost                          | Low (construction cost: less than 10%; operating cost: much lower)         |
| Production lead time          | Short                                                                      |
| Flexibility                   | Able to manufacture according to market demand                            |

Note: The costs of constructing a sintering furnace are high, but because a sintering furnace obviates two preprocesses, overall construction costs are low.

Steelmakers hesitated to implement minimill technology despite the low depreciation and R&D costs and the practically nonexistent general and administrative expenses associated with them.

FINEX and Blast Furnace Technology

In the history of steel manufacturing, the blast furnace is the symbol of steel mills. The technologies used to make steel in blast furnaces have reigned for over a century. In this technology, the raw iron ore and coal are processed prior to melting at 1,500 °C within the blast furnace to produce steel. One reason for why there has never been a technology to replace blast furnaces is that there has never been much room to think about alternatives.

FINEX, or Fine Ore Reduction, is a direct melt reduction technology that challenges the more-than-100-year history of steel manufacturing. FINEX technology does not use a blast furnace and produces steel in a new-style sintering furnace. Figure 1 shows the differences with existing blast furnace technology.
In blast furnace technology, the raw materials, iron ore and coal, are preprocessed to make them into a mass so as to increase the burning efficiency of the blast furnace interior. In contrast, FINEX technology needs no such preprocessing because it uses powdered forms of the raw materials.

FINEX technology started in the research and development of Korean steelmaker POSCO and Austria’s VAI (Voest-Alpine Industrieanlagenbau) in the 1990s, with pilot plants going online in the mid-1990s and a 600,000 ton demonstration plant built in 2003 moving into full operation. A number 2 plant of 1.5 million tons went into operation in 2007, and so did a number 3 plant of 2 million tons in 2013. These seemed to herald the arrival of a technological turning point for the steelmaking industry. POSCO has more than 200 patents on this technology. As can be seen in Table 2, it took less
than 10 years to get up to 2 million tons of annual production capacity using FINEX. This is extremely fast, given that it took more than 20 years for blast furnace production capacity to go from 500,000 to 2 million tons.

The merits of FINEX are in its costs (C), production lead time (D), and flexibility (F) in raw materials (Table 3). With regard to cost in particular, construction costs are low and so are the procurement costs for raw material in powder form, which has made this technology attractive. The technology has also been praised for being

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**Table 2.** Production capacity of POSCO FINEX

|                | Production capacity per year (million tonnage) | Start of operation (year) |
|----------------|-----------------------------------------------|---------------------------|
| #1 FINEX      | 0.6                                           | 2003                      |
| #2 FINEX      | 1.5                                           | 2007                      |
| #3 FINEX      | 2.0                                           | 2014                      |

**Table 3.** Competitiveness of FINEX technology (when compared with blast furnace technology)

|                |                                                                 |
|----------------|----------------------------------------------------------------|
| Quality        | Inferior (used mixing with the pig iron from the blast furnace) |
| Cost           | Low (around 85% in construction cost and operating cost)       |
| Production lead time | short                                             |
| Flexibility    | Highly flexible with regard to the raw material market         |
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easy on the environment, with shortened processes.

However, there are very few steelmakers that have adopted a direct melt reduction process such as FINEX,\(^3\) with the impediment to adoption being quality. When the POSCO number 2 plant went online in 2007, its quality of steel was not as high as that made in a blast furnace,\(^4\) and while quality improved later, it is still lacking, with steel made in both blast furnaces and FINEX processes mixed for downstream processes in steel mills. In other words, there are no mills that use only FINEX—there are only those that use FINEX in parallel with blast furnace technology.

**Discussion**

Managers do not choose manufacturing infrastructure on the basis of economics alone (Stobaugh & Wells, 1984). For example, even if companies in newly developing nations with low wages introduce new equipment, engineers prefer complex, automated technologies, and thus, they may not always implement the adoption of equipment with little automation.

The reason behind why firms implement cost-optimal technologies is thought to be “gentei sareta gorisei,” or “a limited rationality.” Out of several options available, firms will choose the most satisfactory solution rather than the most optimal (Simon, 1947; Takahashi, 2015). For example, as with the two technologies discussed in this paper, of quality (Q), cost (C), delivery (D), and flexibility (F), firms will not choose to implement a technology that is lacking in Q but has superior CDF even when Q will likely improve in the

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\(^8\) Japanese companies have also researched production processes without sintering, but POSCO was the first to commercialize one. Japan’s Kobe Steel has developed “Fast Melt” and “IT Mark 3.”

\(^9\) “Quality still isn’t as high as a blast furnace, but it will be at that level within the year” (from an interview with a POSCO executive, Suzuki, 2007).
future. Improvements to $Q$ are uncertain and also mean an increase in $C$.

Minimill and FINEX technologies have the following three points in common:

A) Cost (implementation cost and production cost), production lead time, and flexibility of capacity in response to market circumstances are better with existing technologies.

B) Even when improvements are seen to be likely, quality issues remain, and even though firms that expected quality to improve aggressively implemented the technologies, other companies did not.

C) The switching costs for companies that rely on existing technologies to implement new technologies are extremely high. Thus, companies that have existing technologies use new technologies in parallel to complement existing technologies rather than to replace them.

Long-term observation is needed to see whether new technologies will replace existing technologies or merely complement them. As was noted by Christensen (1997), this fits the pattern of disruptive technologies that have garnered much attention in business management, and many express doubts (Akiike & Iwao, 2015; King & Baatartogtokh, 2015).

Christensen (1997) stressed that the difference between minimills and integrated steel mills is not only in scale but in the fact that minimills can manufacture products of the same quality but for 15% less. However, as has already been noted, scale is not the only difference between the two. Minimills have not been able to overcome their quality issues and continue to be used in processes that produce certain low-quality products. Certainly, as Christensen (1997) noted, both Japanese steelmakers and Korea’s POSCO have implemented this technology, but their reason for doing so was to
complement their integrated steelmaking technologies. Minimills were used to manufacture for markets of low-value-add products although POSCO sold its minimill to Saudi Arabia in 2006.

In addition, it is true that the quality of minimill products has steadily improved but not to the extent shown in the ever-increasing graph shown by Christensen (1997). There are technological limits to the improvements that can be made to minimill product quality. Moreover, just as the quality of high-grade automotive steel plates, for example, is always better than the quality of building steel, it may appear that quality grades are determined by product grades even though, in actuality, the quality of building steel, as well as that of the thick plate widely used in shipbuilding, is often high-grade, fully made to order.

The replacement of existing technologies by new technologies has been a major focus of technological change research to date. However, a decision to focus only on current costs or near-term quality improvement trends is myopic.

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