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Transfer of Mining Technology and the Birth of New Technology

Industrialization and Mining Technology

Modernization in technology had an overwhelming effect on the development of mines. New, Western technology raised their productivity dramatically. In no other area did modern technology have such a profound effect. But it was precisely the combination of traditional and modern technology that gave rise to this result. That is, traditional technology was enhanced by modern technology, and for this reason, this sector of technology warrants a close look.

The Meiji government focused its efforts only on the gold and silver mines, just as the Tokugawa shogunate had done, and for good reason: silver was the basis for Japanese currency, and gold was becoming an international currency.

Under the Japanese silver standard, the price of silver was set higher than its price on the international market. The price of gold was set lower. Western silver, especially Mexican silver, when brought into Japan, had at once a value (purchasing power) three times what it had on the international market. The establishment of an unequal exchange caused an immense amount of gold to flow out of the country. To compensate, the government minted new currency to reflect the true prevailing rate, but the move was opposed by other countries.

Although Japan suffered under this internationally imposed disadvantage, it lacked the political and diplomatic power necessary to resist, and thus was unable to avoid a decline in the value of its currency, deepening inflation and increasing social and economic confusion. Peasant riots throughout Japan were frequent, creating conditions under which the nation risked losing its sovereign power. Unable to resist international pressure, Japan was forced to cope with the imposed unequal exchange and the outflow of gold by industrializing and, particularly, by developing its ore- and coal-mines.

The effort took two forms. The first was the Japanese Mining Law, which the new government promulgated in the fifth year of Meiji (1872). The law precluded foreigners from developing underground resources. Among the government's foreign advisers were some engineers who urged the introduction of highly skilled but cheap Chinese labourers and foreign capital to accelerate development. Due to the great importance the government attached to them, however, it decided their maintenance and active development would best be left to the government alone. More important, Japan still lacked the ability to manage any diplomatic problems that might have arisen had foreign capital and labour been introduced, and the intention was to avoid such a situation in advance.

Thanks thus to government promotion, the mines were developed, and, at one time, Japan was the world's largest copper-producing and -exporting country and the biggest coal-exporting country in Asia.[32]

Pressure from the Western powers on Japan to open its ports in the mid-nineteenth century was aimed partly at securing a supply of coal and water for their vessels. Until the end of the century, the major industrial power source in Japan was water and the major fuels wood and charcoal. Because steam was not a primary industrial power source, Japan had a surplus of coal for export.

The conversion from wood and charcoal to coal (that is, steam-power) in technologies other than the most advanced ones—those of manufacturing, railways, large-scale mining operations, and cotton spinning—was not made as quickly as the subsequent conversion to electricity. Nevertheless, self-sufficiency in energy was a basic condition for industrialization, and it was important in relation to raw materials as a component (M_1) of technological self-reliance.

Compared with the technology used in the newly developed coal-mines, the technology adopted in the metal mines was more complicated and sophisticated. Once coal has undergone dressing, it is then immediately available as a commodity, but ore processing requires a more complicated procedure. Furthermore, since the common practice was to refine the ores at the mine site, the technology for refining had to be added to the technology for mining.

In any case, traditionally, coal had been used only in salt-making areas after the wood supply had been exhausted, and it was transported by boat. Corresponding to the growth of the railways and the greater industrialization following the Sino-Japanese War, however, the newly developing coal-mines experienced dramatic progress. Unlike iron manufacture and the railways, which were developed by the government, the mines became the nucleus for the formation of the financial cliques, or *zaibatsu*.

One such *zaibatsu*, Sumitomo, had acquired refining technology, and was naturally eager to introduce ore- and coal-mining technology. For Mitsubishi, too, a shipping company, involvement in coal-mining was vital, and because coal was an export item, Mitsui, a trading firm, had an interest in Kyushu's coal-mines.

Mining technology and the technology for railways were linked through fuel and transportation needs to form a compound technology. At the same time, out of mining technology grew technological divisions that, from 1920 onward, evolved into separate and independent technologies.

For example, Hitachi (established in 1920), which today has some 8,000 engineers, grew out of the electrical machinery division of Hitachi Mining Co., which engaged in the repair of electric motors. Fujitsu separated in 1935 from the Furukawa Mining Co. (a copper-mining concern) to become a manufacturer of electric wires; it later moved into communications equipment, and is now involved with automation machinery. Although the railways and mining were both characterized as compound technologies, the two developed in vastly different ways.

Related to this, concern has arisen anew regarding the importance of the role played by mining technology in industrialization. In Japan, the government-owned iron manufacturers and railways (private railway companies were established later), together with the private mining and textile industries, were the four leading sectors in industrialization (i.e. technology transfer).

New Technology and Reform of the System

The important contributions modern technology made to mining, besides the technology of refining, were the following.

1. Drainage Technology

The biggest technological barrier to overcome in mining was the disposal of water. Various devices and tools had been invented prior to the arrival of modern technology, but because high-performance equipment breaks down frequently and is complicated to operate, the chief method of disposal was still human labour. Depending on the situation, hand pumps (called "box pipes") and "troughs" were the best means available. The pumps were made of wood and required manual operation, and their drainage capacity was extremely small. Consequently, more than half the mine workers were pump operators, and the older mines, with their deeper working faces, had more of these workers than the newer mines did.

In the Sado Mine, representative of Japanese gold-mines, more than 60 per cent of the workers were engaged in water removal. No worker could bear the labour for more than three years, and, in fact, this hardest of all jobs in the mines was dependent on prison labour. And, for the prisoners, there was no more dreaded labour than this. (In general, until the initial stage of modernization, much unskilled, heavy labour was borne by the nation's prison population.) In 1861, shortly before the Meiji Restoration, of 928 workers at the Besshi Copper Mine (in Shikoku), 447 were engaged in water disposal, and the rest were pitmen. Even so, the water problem forced the abandonment of an otherwise promising pit. Under these conditions, the introduction of a powerful pump could have more than doubled productivity.

Consequently, with the introduction of modern and powerful pumps, a huge labour savings was realized and the water workers were no longer needed, and promising abandoned mines were reopened.

2. Ventilation Problems

As a mine face becomes deeper or more remote from the entrance, the problem of ventilation increases. The excavation of ventilation tunnels as a part of mine development and improvements enlarged the scale of operation, and once machine-powered ventilation was introduced, the mines were freed from the restrictions imposed by natural ventilation. Before these developments, however, the ventilation problem was a serious obstacle to a full realization of the mining potential.

Under the pre-modern contracting system, miners called *yamashi* or *kanako* were paid according to the amount of mineral extracted from the ore and not on the basis of the volume of unrefined ore.[33] This system encouraged the development of a technology for dressing ores at the mine site, but the *yamashi* and *kanako* were not able to develop the technology for an integrated mining system, and, as a result, mines were usually abandoned after the rich veins near the surface had been exploited, leaving huge, albeit less accessible, reserves untouched. This inability to create a comprehensive mining system also meant that only natural ventilation or a similar "burning ventilation" method could be used. However, unlike in the metal mines, the burning ventilation system in coal-mines was extremely limited because of the great danger of gas explosions.

3. Transportation

Transportation within the mines and to the places of demand was also a serious concern. Indeed, since only human and horse transport were available, raw ores underwent primary processing at the mines just because of the restrictions of transportation. The opening of the railway solved this problem.

The possibility of development of transportation within mines from manual labour to horsepower and then to tramcars depended on the physical nature of the mine, the height and width of its shafts, and the design of the route. The full development of a mine with a unified transportation system connecting all the main shafts and its branches would be possible only by implementing modern mining methods. Investments for geological surveys, ranging from the traditional "mountain diagnosis" (the old method of looking over an area and choosing a site according to "feel") to modern boring and feasibility surveys, have to be done in advance, but these were all beyond the scope and financial capacity of the subcontracted mine operators.

Once such modern technologies were adopted, however, they inevitably led to a change in the mining policies inherited from the Tokugawa period.

Returning to the transportation problem, however, one major obstacle related to how the ore was purchased, which determined how the ore was extracted and thus even the shape and condition of the mine itself. The owner of the mines, the shogunate, contracted with the *yamashi* and the *kanako* for their operation and purchased the minerals produced from the ore. Consequently, the operator of a mine would first exploit any outcrops, putting off for as long as possible the excavation of auxiliary tunnels necessary for water drainage and smoke removal. In search of only the rich veins, operators tunnelled tortuous courses that varied in height from section to section, thus creating problems for transportation and safety maintenance. As a consequence, mines everywhere developed in the shape of a honeycomb. In 1751, the Ashio Copper Mine had as many as 1,484 entrances. The reasons for the decline of the mines toward the end of the Tokugawa shogunate are thus easy to determine. This very inefficient operational approach meant that even rich mines were abandoned after an average of only three years in operation (Murakushi 1979).

The establishment of an integrated system of mining, transportation, dressing, and metallurgy thus began to conflict sharply with the system of purchasing ore. To achieve full rationalization, it was necessary for mine owners to integrate the various workers and jobs into a single, well-organized, directly controlled production process. This became possible only at several non-governmental mines after the Meiji Restoration.

However, modern technology was introduced for the first time at government-owned mines, to which as many as 87 engineers, pitmen, and machine operators were invited from Great Britain, the United States, France, and Germany. This marked the start of modern integrated mining operations in Japan.

Among the new procedures introduced at this time, the most technologically noteworthy was step mining, which was introduced in 1868 at the Sado Gold Mine and the Ikuno Silver Mine. Six years after its introduction, the method had spread to all the leading mines in Japan. Under this method, the shafts were equipped with a hoisting whim and a rail drift, and new shafts were systematically connected and opened as necessary.

This method enhanced tremendously transportation within shafts. Even though transportation by tramcar remained dependent on manual labour and horsepower, efficiency was strikingly raised. By virtue of this new system, ore was transported to the outside by the hoisting whim—a far cry from former times, when miners were forced to crawl on hands and knees and considered themselves lucky if they could walk in a half-sitting posture. With the introduction of dynamite in 1878, efficiency in opening shafts and drifts improved dramatically. From these developments, it becomes clear how essential structural reforms are to technological transfer.

4. Pre-Conditions

The rapid gains in productivity realized by the introduction of M_2 components for drainage, ventilation, and transportation were made possible by the pre-existence of M_3 and the other five Ms. The existence of the other components provided important support for the introduction of M_2. Thus, technology transfer, the introduction only of M_2, is inexpensive and effective when fully supported by the four other components. At the same time, M_2 essentially changes the principal composition and role of each of the five Ms.

Regarding the manpower component (M_3), whatever changes might be introduced by M_2, it is important to insure that the quality of labour is protected, that is, the high level of traditional skills and the organizations of workers that help to maintain this level. Indeed, in the case of the mines, worker organizations constituted an important pre-condition of M_3.

The mines had two kinds of workers. The first was skilled workers called *jikofu* (indigenous, or local, mine workers), who had been trained from an early age for work in the mines. While most of the workers in this group were not exclusively miners, they had long experience and profound knowledge of the mines in which they toiled.

Mine work was often performed as an extension of non-mine work by small, family groups made up, for example, of parents and their children, husbands and wives, etc. Women and children were usually engaged in such auxiliary work as carrying out the ore. Because the work was dangerous, a sense of absolute trust and mutual reliance was essential to maintaining efficiency and safety.

The second group consisted of skilled workers called *watari*, or "floating" pitmen, who, as the monicker suggests, did not settle at any one mine. They moved from mine to mine at intervals of several months or a few years, enriching their experiences and accumulating more skills and also diffusing skills along the way.

Many had special skills, for example in water removal, smoke dispersal, or rock boring. Such skills were not necessarily required at all times at any one mine, but they were vital when a mine was being opened or during a period of recovery from an accident. Because of their specialized work, they were the "rich" of the poor, who earned high wages, had high mobility, and usually were unmarried. Their strong orientation toward special skills endowed them with a different way of life from the local mine workers described above.

A nation-wide organization of mine workers, called *tomoko*, acted as an information network for those in need of the specialized skills of the *watari*.[34] Before admission into the *tomoko* union, an unskilled worker would be engaged in auxiliary tasks (such as the transport of ore and debris) to become accustomed to the work in the shafts and drifts. Under the direction of skilled pitmen (called *sakiyama*), the unskilled worker accumulated skills as a pusher (called *atoyama*), covering the whole process of production, including excavation, simple dressing, and accident prevention. Once an *atoyama* had acquired a specified level of skill and experience, he became a licenced pitman and was authorized by the *tomoko* to be a skilled pitman, thus also qualifying as a master, or foreman.

As a *sakiyama*, he assumed a quasi-parental (superior-subordinate) relationship with pushers and others to form a unit for production activity and to subcontract a pit face. Generally, the *sakiyama* and his men were under the control of a principal contractor, called the *hamba* (or *naya*), for entire veins. When integrated mine operations were developed through modern technology, the *sakiyama* became directly contracted workers.

The Japanese mining industry developed rapidly at the end of the nineteenth century. As a leading industry, it experienced a sharp increase in the number of pitmen. By 1894, the total employment population reached 4,570,000, of which 100,000 were mine workers (metal-mine workers totaled 55,000 and coal-miners 43,000). The number of mine workers peaked in 1917 (176,000 at the metal mines alone). In 1922, however, this total declined drastically, to only 40,000, because of mine closings caused by the economic recession after World War I and the development of rationalization.

In the process of modernization, the pitmen's tools, the chisels and hammers of the era of the "gold-mining carpenter," became obsolete, and it now became essential for pitmen to master such modern technology as drilling with jumpers and blasting. At the same time, the acquisition of multiple skills was replaced by the need for a single skill, which led to a division of labour among pit workers, and, as a result, the *tomoko* union changed to reflect this new specialization in skills, and is said to have "begun to assume a distinct character."[35] This change represented the second phase in the transformation of mining technology.

Another important function of the *tomoko* union was for mutual assistance. Although the change in mine work caused a change in the nature of contracting, the union's policy of social security and welfare, to which nothing similar had been established in Japanese society as a whole, was maintained for the protection of its members. In addition to the assistance provided for wedding ceremonies and funerals, assistance and relief were extended to pitmen unemployed because of a mine closure in the form of providing information on employment opportunities, and aid was given to persons suffering from occupational diseases or injuries. These functions later formed a contact point with the labour union movement. In not a few cases, the *tomoko* and labour unions, by providing mutual support and exchanging knowledge and expertise, ensured the existence of both, particularly when labour movements were being oppressed under military rule. Also, the influence of the *tomoko* was widely acknowledged during the period of recovery of labour unions after World War II.

In general, because the *tomoko* were made up mainly of pitmen, whose skills found favour with the development of step-mining technology, the *tomoko* prospered. However, the indirect system of employment through subcontracting changed to a system of direct employment. The change in mining technology caused by the introduction of small rock drills meant the loss of the *tomoko*'s technological leadership, and the on-the-job training and schooling programmes given by individual companies began to assume the leading position in skill formation. Also instrumental was the transition from the selective mining of rich ores to the mass mining of ores that came with the introduction of the mechanization of dressing (and especially the introduction of the flotation method in the metal mines).

The technological changes in mining paralleled the transformation of the labour and management system from the system of contracting for the production site to a system of directly employed workers. Indeed, they corresponded to the complete transplanting of the system of modern mining technology. As a result of this process, the position of pitmen, the number of which had increased as many as 10 times in the 30 years from the end of the nineteenth century, decreased relative to the entire labour force in the metal and coal-mines. The number of factory-type workers grew to outnumber the pit workers, and their roles in the operation of the mines, which were now using a compound technology, became indispensable.

The age of the *tomoko* had started gallantly when modern technology was introduced and declined with the development of modern compound mining technology. However, the role of the *tomoko* as a pre-condition for M_3 was great in that the systematic development of modern mining technology was supported by this autonomous organization devoted to workers and their skills. Modernization of the mines thus depended on the *tomoko* as a pre-condition; the next step, independence of mining technology, required the domestic production of machines that were being imported.

From Importation to Domestic Production of Mining Machinery: Independence in the Related Sectors of Technology

Introduction of Technology—The Case of Ashio

Compared with coal-mining technology, the technology for metal mining poses greater challenges because of the complicated refining process and related equipment that is required.[36] The process of the establishment of a modern technology for an integrated production system from mining to refining was in fact a process of gradually amassing new technology. In technological terms, it was the formation of an enclave at the production site.

Mechanization and a change in the source of power started in water removal, ventilation, and transport. These improvements increased production and allowed for operations of larger scale and at higher speeds. But the pit work still required manual labour. An increase of production could thus be realized only by means of an increase in pitmen. It was typical that the mechanization of excavation was the most delayed in Japan.

The Ashio Copper Mine, which had been expropriated by the Meiji government after the Restoration, fell into private hands soon after; the government regarded it as being too far gone for reactivation. Although it had once produced an average of 1,100 tons per annum for more than 70 years (from the end of the seventeenth century), it was nearly completely abandoned as a result of extensive cave-ins, which could be attributed to the random excavation of only the richest veins that was typical under the afore-mentioned technological and structural limitations prevailing under shogunate management. In 1876, the mine was actually, by default, in the hands of the subcontractors, because the original mine owners were no longer able to meet the wage payments. When Furukawa Ichibei (1832–1903) bought it in 1877, it was like a vast honeycomb, and Furukawa was rumoured to have gone mad.[37]

But it was Furukawa who revived the mine to make it one of the most productive copper mines in Asia. He had international business experience as an executive member of a silk-trading firm, but he learned the mining business at the production site. His success in managing the Ani and Innai mines, which had also been sold to him, clearly revealed his excellent managerial skills.

His talents as an outstanding manager were shown not only by his recognition of the true value of the old Ashio mine but also—at the time he acquired the mine—by his hiring of gifted young university-trained engineers, extremely valuable human resources at that time, and his decision to buy imported machines. In other words, the establishment at a stroke of M_1 through M_4 had a tremendous impact on the company's development.

What remained for the company to attain was M_5 (markets). The beginning of the 1880s marked a world-wide overproduction of copper because of the development of copper mines in several western US states. But the substitution of iron telegraphic wire with wire made of hard copper in Europe in 1886 created new demand for copper and transformed its market. Encouraged by this new trend, Jardine, Matheson and Co., a concern well-known from its wide-ranging activities in Asia, proposed a long-term contract with Furukawa in 1888, by which Furukawa acquired, in a single stroke, a full set of M_5, which, further, made possible a complete renewal of the mine's facilities.

Furukawa succeeded in roughly 20 years' time in modernizing the Ashio Copper Mine. The first step was a careful survey of pit faces and the adoption of a direct excavation method aiming at rich veins. This method, designed to open mines from the gangway for drainage and hauling, was similar to the adit-opening method used in the West and was aimed at topping rich veins by speeding digging from the lowest level (Murakami and Hara 1982). Furukawa had successfully adopted this method at the Kusakura Mine. Five years after the purchase of the Ashio mine, the miners discovered—using this method and after digging 140 meters—the first rich vein; two years later, a second one was uncovered.

At the beginning of Meiji, every government-operated mine was unsuccessful because emphasis was given to equipment and mechanization at the expense of the development of new sources of ore, the life of a mine (Murakami and Hara 1982).

In contrast, Furukawa adopted a comprehensive development programme based on the modern method of opening a gangway; nevertheless, the company otherwise remained dependent on traditional technology. In comparison with Sumitomo, a pioneer in copper mining, Furukawa was anxious to introduce modern technology, but realization came only in later years. Even as late as 1881, Furukawa was still relying on manual crushers and leather foot-blowers instead of steam-powered crushers and ventilators (Hoshino 1982).

On the other hand, Furukawa did use blasting powder to excavate pits and introduced rail cars for transporting earth out of the mine. In all other aspects, the old methods were still in place: manual labour was the main force for digging and for hauling.

In 1885, Furukawa started to excavate the main adit, which took, indeed, 11 years to open, but, once completed, it ensured the life of the mine for roughly 100 years. The year 1885 was important in other ways for the Ashio Copper Mine: the rock-drill was introduced and the boiler-type pump was added to the manual pump for drainage. For the large-scale excavation of the main adit, engineers and equipment from several Furukawa-owned mines were used (Shoji 1982).

At the end of the same year, however, sudden flooding destroyed the mine's drainage equipment. Although the mine yielded a record 4,090 tons of copper, there was not enough capital to make possible the introduction of large-scale modern equipment. The 1888 contract with Jardine, Matheson, however, brought the company the fantastic amount of ¥60 million, which enabled it to buy modern equipment and eventually report a sharp rise in output.

The first item of equipment introduced was the steam drainage pump. Before its adoption, 10 hand pumps of two different types had been used to pump the water up gradually from the deepest levels of the mine to the shallower pits, where it would be concentrated in a single pit before finally being pumped out of the mine. More than 310 workers and 24 hours were required for this operation. But the steam pump completely eliminated the need for this. By 1890, a hydraulic power system was set up to operate an 80-hp pump for drainage, a 25-hp hoist, and a 6-hp generator for lighting. This completed electrification within the pits, and transport and drainage at the shaft were also electrified.

The refining process was also introduced in 1890. The four metallurgical processes consisted of calcination, melting, kneading, and refining; a soft-charcoal furnace was used for the calcination (15–20 days) and for deriving crude copper by the oxygen-burning method; and a round-bottomed furnace for melting ores (called "Yamashita blast," 6 hours). The whole process required 32 days and produced one ton per furnace. Not only was the process slow but the furnaces had to be repaired after every batch. However, with the adoption of the reverberating furnace for calcination, the square-type water-coated furnace for melting, and the revolving furnace for kneading (the principle was the same as for the *mabuki* refining process), the procedure was reduced to only two days and allowed for continuous processing in large quantities.

In 1898, electrolytic refining commenced with the construction of 116 electrolytic cells. Production of copper wire had begun the previous year in Honjo, Tokyo. Thus, a system of continuous production, from mining to an integrated metallurgical system, was established in 20 years' time.

In addition to the introduction of tramcars for transport and electrification in the mines, electric railways were laid between the major mine entrances and the refineries. Outside the mine, though, delivery via the Joshu and Nikko routes depended on pack-horses until 1888, when a horse-drawn carriage was introduced on the Nikko route (the width of the road was about four metres). In 1890, an overhead ropeway system using steam-power was installed, and in 1892, the horse-drawn tramcar was introduced on the Joshu route, and in 1893 on the Nikko route.

By 1890, the facilities at the Ashio Copper Mine had been modernized; the mechanized system in the pit had been electrified and the fuel for refining had been changed from charcoal to coke (completed in 1893). Despite these developments, however, as just mentioned, the transportation network outside the mine was undeveloped, and under such conditions it constituted a good example of an enclave of amassed technology.

With the opening of the national railway's Ashio line (for steam locomotives) in 1914, however, this technological enclave was "thrown open" and the technological spin-offs from the mining industry, which constituted a compound technology, that had been prepared could now flourish. The year 1914 was also the year in which drills were first produced domestically, at the Ashio mine.

A quarter-century had passed since modern mining technology had been introduced at Ashio. The mine was blessed with favourable conditions that allowed a rapid transition from technological transfer to technological offshoots.

Nevertheless, the long time required before technological self-reliance was attained (even now not fully realized) is noteworthy. Technological self-reliance was influenced by the circumstances that surrounded copper mining. Fluctuations in the international prices of copper, a primary product, particularly affected the Ashio mine, causing it to swing between boom and recession. Domestically manufactured machines (and the company's own home-made machines) were introduced at Ashio to help alleviate the difficulties caused by these fluctuations, but this had to wait until the machine industry in Japan had achieved a certain degree of progress. On the other hand, the laying of tracks for electric cars within the pit preceded the electrification of the national rail routes and the founding of the Yawata Ironworks. Finally, the discovery at Ashio of a huge deposit of high-quality Kajika ore greatly aided in coping with the depressed copper market.

The formation of a technological enclave is fatal to mine development in late-comer countries; in Japan, it contributed to severe copper poisoning and environmental destruction. The sulfurous acid gas emitted during refining is itself poisonous, and combined with rain, it forms sulfuric acid, which is highly damaging to forests. At Ashio, besides raising the river-bed and increasing flood damage, the dumping of slag from the mine made uninhabitable the mountain villages downwind from the refinery and destroyed rice fields of the villages downstream from the mine.

Environmental and pollution problems were the negative by-products of industrialization, problems that resulted especially from the technological enclave.

Domestic Production of Mining Machinery

Early on there was a strong tendency to rely, as far as possible, on domestically manufactured machinery. Thus, as early as 1877 the government-operated Miike Mine was purchasing finished machinery from the government-run machine tool plants (located at Honoura, Nagasaki; Kobe; Akabane; and Kamaishi). Also, the importation of foreign drilling machines was resisted in favour of purchasing from the government plants. Nevertheless, at this stage complete dependence on domestically manufactured machines was impossible, and so of necessity, Miike had also to rely on imports.

Miike established a foundry in 1882 and began repairing and producing pit machines and machinery for ships connected with the company. By 1887, the company had five factories: a smithery, a cannery, and plants for finishing, boiler making, and fabricating wooden models. It also made experimental steam-powered pumps and hoists.

According to Kasuga (1982), the foundry progressed into the later Miike Works through three stages: (1) 1888, when the government sold the mine to Mitsui, to 1899; (2) 1900 to 1909; and (3) 1910 to 1918.

The activities characteristic of the first stage were the repair of machines and the production of wooden transport vessels. The company employed 13 skilled workers and others from the Mitsubishi dockyard in Nagasaki, under whom—to secure and train a labour force—paid and unpaid apprentices were assigned.

At the beginning of the second stage, the company had in its employ British engineers, who designed the endless rope haulage system used for transportation in the pit. While learning design methods, the foundry workers made the leap from mere repair or improvement when they manufactured the davy pump at about the time a new mine was opened. Production costs, including the construction of the workshop, were 25 per cent lower than when the British pumps had been used. Imported goods cost three times as much as domestic products because of low yen values in foreign exchange markets.

In 1893, a three-ton iron-melting furnace was imported to be used to manufacture 30-inch special duplex pumps. They were inefficient, however, and the company imported Washington pumps and attempted, through imitation, to manufacture them themselves. By repeating the process of importation → imitation and trial production → acquisition of technology, the company acquired the ability to produce steam-pumps and transporters, but it did not yet have the technology for the design or the mass production of machinery. By the end of stage two, however, it was accepting orders from coal-mines in Kyushu to produce small- and medium-sized equipment to be used for drainage and transportation. The company thus was able to expand to producing not only for itself but also for other companies, and it had progressed from imitating design to creating its own to meet local conditions and needs.

The third stage corresponded to full mechanization in all the coal-mines and the advance of electrification. Those who had been engaged solely in electrical equipment repair and improvement were now producing electric hoists (1904) and electric endless rope haulage systems (1906). The incentive for these changes had come from the high prices of imported products, which were 40 to 80 per cent higher than the cost of producing them in-house.

In 1912, the greatest difficulties in producing cylinders were at last overcome, and a gas engine was successfully produced. This instilled tremendous self-confidence in the company's manufacturing abilities. It also promoted the electrification of the Miike Coal Mine and facilitated enlargement of the coke plant and the establishment of dye-making and zinc factories. It also marked an important starting point for the entry of technology in other, related sectors, especially in the area of machine manufacturing.

A similar process occurred at the Ashio Mine. Furukawa Electric Company was founded in 1896 to manufacture electric wires. In 1923, the company and Siemens, of Germany, founded Fuji Electric Manufacturing (later Fuji Electric) to embark on the production of heavy electrical machinery and then communications equipment. Similarly, Sumitomo's Besshi Copper Mine established Sumitomo Shindo (later Sumitomo Metals) in 1898 to process copper; Sumitomo Denko was set up in 1911 to manufacture copper wires, and Nippon Electric was established jointly with Western Electric of the United States in 1899.

The division for the repair of electrical equipment at the Hitachi Mine manufactured small electric motors. Later, it developed into Hitachi Limited, a heavy electrical equipment manufacturer. Hitachi subsequently moved into light electrical appliances. The Furukawa-affiliated Fuji Tsushinki and the Sumitomo-affiliated Nippon Electric Corporation became the two biggest manufacturers supplying telephone-related equipment to the Ministry of Communications (later Nippon Telegraph and Telephone Public Corporation). These three companies today comprise the leading electronics manufacturers. Significantly, all three began as repair divisions of mining companies. My theory of the five stages, from technology transfer to independence, is based mainly on an analysis of this sector.