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Theoretical Summary: A Preliminary Examination and an Interim Conclusion

Technology in Theory—The Five Ms

Although science and technology are closely interrelated, each is relatively autonomous, perhaps similar to civilization and culture. Where civilization is universal, culture is individual. Today we live in an industrial civilization, an age in which nations are often ranked according to the level of their technological development. Such a narrow basis, however, overlooks cultural differences among nations.

At the same time, cultural differences are often taken to mean the superiority or inferiority of one culture to another. It should be too obvious to mention that cultural differences are not equivalent to differences in value.

By the same token, neither the wooden weaving machine nor the one made of metal has an advantage in principle over the other. Their mechanisms are based on the same scientific principle, and in this sense they are equal in value. They differ in durability or efficiency, perhaps, but these and similar differences should not be assumed to indicate the superiority of one over the other.

Any evaluation of them from the perspective of national development should also consider, besides productivity, the relative advantage for each of manufacturing operationability, procurement, maintenance, and repair to the indigenous user. The relative advantage of the wooden or the metal loom will depend on the production purpose and on what sort of consumer need its products must satisfy. For example, one option may be mass production and mass consumption; or goods may need to be produced and consumed in small quantities. The particular needs and conditions will determine relative advantage.

No society or culture exists without a technology of its own. Similarly, no community or culture today can avoid contact with the outside world, with foreign technologies, a fact that may hold fortunate or unfortunate consequences. As pre-modern, pre-industrial societies and cultures confront problems of population increase, many have been made keenly aware of the limitations of their traditional technologies. Consequently, there is an eagerness to introduce modern foreign technology. But the demand for new technology is often unaccompanied by the pre-conditions required by new technology, and this poses a difficult problem. Moreover, because the creation of these pre-conditions often makes it necessary to bring about changes in the traditional values and social organization, conflicts are bound to result. The Japanese experience shows that what minimizes conflict is the attainment of a national consensus, which is a matter of political leadership and of cultural legitimacy.

Confronted with powerful modern technology from abroad, Japan was at first seized with awe and confusion. This soon yielded, however, to a national realization of the need to absorb modern technology. After the initial blind rejection in some corners of society, the country recognized the importance of modern technology. While this both contributed to and resulted from political stability, by the time of the Meiji Restoration, Japan had achieved a high degree of social integration, which was an obvious aid to the formation of a national consensus. The high degree of social integration was due in part to the country's small size and to its several hundred years of complete isolation from the outside world.

In the years before the country opened its doors, the samurai class was the first to recognize the power of modern weapons. Many of the leaders of the new Meiji regime, in visits to Europe and the United States, marvelled at the West's industrial technologies, especially those in marine transportation, railways, and mining.[12] Also, ordinary Japanese, terrified by the contagious diseases that raged as an immediate result of the opening of the country, experienced the miraculous effects of modern medical science and technology and marvelled at this just as much as they did at the strange, new products, devices, and machines from the West.

The Japanese experience began with a naïve, overwhelming encounter with modern technologies, which, however, quickly inspired a national zeal to master and possess them.

Today's developing countries have not had so dramatic and innocent an encounter with modern technologies. They have been using technologies far more refined and sophisticated than those that so shocked the Japanese more than a century ago, but what they have been using and enjoying have not always been suitable for the purposes of their development. Developing countries often lack a national consensus as to the purpose and priorities of development, and their expectations are frequently too great. Finally, the way in which technology has been used has possibly not always been wise.

Definition of Technology

To assure an effective dialogue, it may be necessary for us to agree on the concept of technology. In general terms, it comprises all scientific knowledge deliberately and purposefully used for production, distribution, consumption, and utilization of goods, services, and information, especially that which concerns mechanical apparatus and systems.

This definition of technology, mindful especially of modern industrial technologies, could be useful in considering nearly all the chief problems of development in the developing countries. Of course it may require adjustments, but, in any case, what is important is to enrich our dialogue, more than seeking a definition of technology as an end in itself.

The scientific rationality present in traditional technologies have often been overlooked. Overconcern for the high efficiency of modern technologies may conceal the presence of scientific principles in use by the scientifically illiterate. The Japanese have been guilty of this neglect. Furthermore, an exaggerated reliance on rationalism is apt to oversimplify matters, to elevate technology to the point of being a panacea. This kind of thinking, often ridiculed as being an engineer's way of thinking, lacks concern for important cultural values.

Technology should be evaluated not in relation to its principles alone but in the light of its contributions to the development of the society and country in which it is at work. There are technologies that have served otherwise, of course, but for our purposes, the most desirable use of technology is to serve the national development of the less-developed countries.

The practical experiences of development have shown that because technology—though applied according to scientific principles—is affected by such factors as natural conditions, natural resources and their processing and transportation, and how the technology is used, the attainment of one and the same technological aim may take widely different forms in different countries and regions.

Therefore, unlike science, which is universal in nature, technology consists of intermediated knowledge and skills, which are largely conditioned by geographical, social, cultural, and historical factors. In other words, a scientific principle becomes a technology only when it is intermediated by these factors.[13] Technology becomes stable only after such modification, and is free to disseminate only after it has been stabilized.

The Five Components of Technology

Technology consists of the following five elements, or what we may call the five Ms:

1. Raw materials and resources (including energy): M_1
2. Machines and equipment: M_2
3. Manpower (engineers and skilled workers): M_3
4. Management (technology management and management technology): M_4
5. Markets for technology and its products: M_5

Modern technology must have all of these elements to function properly.

Money and information are also indispensable components. The monetary aspect has been discussed more than adequately elsewhere, so we will ignore it here. As for information, technology requires various types and levels of information, which control and integrate the five Ms. The collection of information is itself a technology that requires a certain level and range of knowledge, a processing system, and a capability to make full use of the relevant instruments and equipment. The more advanced a technology, the greater the amount of information required, and also the higher the level of intellectual capability needed to collect and analyse it.

The effective functioning of technology requires information processing technology, which in turn lends information itself an objective value and cost. Hence, information becomes a central aspect of the managerial policy of an enterprise and, as such, an object of legal protection.

The notion of the five Ms helps us locate problems wherever they might exist in the relationship between development and technology. For example, the same machine will give qualitatively different results depending on the country or company where it is being used.[14] Knowledge of the five Ms is useful in making possible the attainment of the same results from the same machine, or, if not, in finding out what makes it impossible to get the same results.

The five Ms are not present, however, in the same way at all times and places. They exist in different proportions in different countries, enterprises, and factories. This explains the differences among countries in national technology formation. This fact may also be useful for studying comparative national advantages from the viewpoint of an ideal international division of labour in technological development.

From the viewpoint of development strategy, a strategically selected area of technology means a strategically selected industrial sector, which, moreover, takes into consideration the particular characteristics of the goods to be produced. The choice of technology would then need to be made taking into consideration the development levels of allied areas of technology and the links among them. If a technology was chosen where such links were non-existent, they would need to be created, and, in such a case, it would be necessary to conduct a careful feasibility study on the basis of the five Ms as to the appropriate level and scale of the chosen technology. The success of this would depend on the R. & D. capability of the country or enterprise importing the technology.

In regard to the technological self-reliance of a country, native engineers should ultimately play the most important role in R. & D. Foreign engineers and technologists can and should play only a supplementary role. This is an essential finding of our project on the Japanese experience. This is because, in spite of the diachronic, trans-cultural nature of technology, it cannot function independently of the society and culture in which it is expected to function. Only members of that society can make the best use of a technology. In other words, only native engineers can adapt a foreign technology to their country's climate and history, can intermediate, stabilize, disseminate, and, finally, root it firmly in their country.

The Japanese Engineer

Just as technologies have both synchronic and diachronic aspects, engineers may also be so characterized. In some countries, it is necessary for technologists to go abroad for their education, and it is natural that, as a result, foreign technology will be applied in these countries. However, if technologies are to be developed and modified so as to serve national development instead of being always something foreign, the role of native engineers is decisive. Bearing this in mind, let us now discuss the Japanese engineer.

In the advanced and now in the developing countries, there has been a marked tendency for engineers to categorize themselves by function, a trend perhaps paralleling the development of modern technology. In the case of the Japanese engineer, however, he was responsible for a broad range of tasks and functions. Thus, design engineers were also shop-floor manufacturing engineers, and likewise, the shop-floor engineer was expected to develop expertise and experience in the area of design.

Whether the Japanese experience should be made a model in this regard must be left to the developing countries to decide. However, if a technology is being transferred from Japan, for example, it will be necessary to investigate whatever particularly Japanese characteristics might underlie the technology; otherwise, the recipient might find it difficult to see why the technology has failed to perform as well as it did in Japan should such a problem occur.

There is the complaint in many developing countries that Japan and other technology-exporting countries have merely sold their machines and equipment and kept the most important know-how to themselves. These complaints are, in fact, not without foundation, depressing as this is to us and to other investigators. But it must be borne in mind that when a technology is transferred, the culture of that technology is not transferred with it.

One important characteristic of the Japanese engineer is that the functional division of engineering into design, operation, and manufacturing is only relative and temporary. Engineers may be classified by function in a relative sense, but they are not confined to it throughout their careers.

Thus, electrical engineers, mechanical engineers, and civil engineers are not functionally restricted to these disciplines; they are expected to have as wide a range of engineering knowledge as possible, encompassing technologies that reach beyond their own specialties. This has allowed for overlap among the different branches of technology during the period of technological innovation that has been occurring since the 1970s.

Furthermore, Japanese engineers are expected, above all, to be shop-floor leaders, to be able to solve actual problems side-by-side with the workers. They are expected to cover for any shortage of skilled labour and to conduct on-the-job training to increase workers' skills. These are the most important elements setting the Japanese engineer apart.

Because Japanese engineers are usually assigned to design or manufacturing only after on-the-job experience, they are capable of making minor improvements or modifications in production processes and in the design and manufacture of machines to enhance their efficiency and safety. The Japanese engineer first moves horizontally from one sector to another, sectors not necessarily of primary concern to him, on the basis of which he gradually builds himself into a full-fledged engineer. Instead of climbing vertically, then, to become a specialist, the Japanese engineer becomes an all-rounder in technology.[15]

Therefore, when we talk about the characteristics of Japanese technology, we are also referring to the peculiar way of training engineers in addition to technology control and management.

The point here is not that this approach is better than others; the important thing is that Japan became self-reliant in technology aided by this particular way of training its engineers. That the birth of this type of engineer took place in the initial stages of industrialization, when the absolute number of engineers was small, may prove to be useful information when studying the problems of development and technology.

It might be of interest to add that, even in the days when there were few engineers, they did not occupy very high positions at their work places, and their social status was not high. Their salaries were relatively good, but they usually had only limited power. Perhaps this is a phenomenon peculiar to a technologically less-developed country; we met many engineers in the developing countries we investigated who had much to complain about because of their social positions. Their problems were similar to the ones Japanese engineers once faced.

Japanese trained engineers first began assuming leading corporate positions in the 1910s and 1920s, a period when the country had succeeded, for the first time, in developing indigenous modern technology. Engineers began to widely occupy the highest executive posts in corporations only after World War II, when corporations became owners of technology and possessed what amounted to armies of engineers.

In considering the relationship between scientists and engineers in the initial years of industrialization, attention should be paid to the following two relational aspects.

The Relationship between Engineers and Techno-Scientists

The two now belong to categories relatively independent of each other, though they were interchangeable at earlier stages. The techno-scientist's primary job has been to collect technological information from different parts of the world and analyse it. Although this group has formed a key part of the core for technological development in Japan, their work has centred on basic research and experimentation, being removed from shop-floor operations, though the distance has been shortened somewhat in recent years.

Techno-scientists have long served as advisers to the state in the formulating of Japanese science and technology policies, whereas Japanese engineers began only recently to make themselves heard from the shop-floor in terms of national technology policy.

Finally, at the earlier stages of industrialization, techno-scientists made great efforts to train successors as well as skilled workers in new fields. Their contributions to the education of engineers and skilled manpower since the end of the last century have created a bridge between science and technology; bonds like those between a master and his disciples were forged between techno-scientists and engineers (though new problems arose later). Such bonds, and the camaraderie among fellow-students, aided the growth of industry-university co-operation, especially in the areas of technology that played a leading role in the formation of a national technology network and in which Japanese technology has risen to world prominence.

Workers' Attitudes towards Engineers

In the earlier stages of industrialization, when the number of engineers was small, a higher or specialized education was evidence of one's family's elevated social status. Not surprisingly, engineers enjoyed more favourable circumstances in terms of both the status and conditions of employment; yet in spite of that—or because of it—engineers were always the shop-floor leaders, and the workers, though sometimes the envious subordinates, held those superiors who could competently address and solve their problems on the shop-floor in high regard. If their superiors were incompetent, the workers would remain obedient, but, at the same time, lose the incentive to work hard, for the quality of shop-floor leadership had a direct effect on worker safety, productivity, and wages.

Japanese workers dislike having designs and specifications changed while work is under way and will sometimes even openly oppose any such changes. The European-style functionalistic attitude of workers, who may not object to such alterations so long as they receive their due pay, is rare in Japan, where the attitude of both workers and engineers towards technological skill and competency is strict. Even labour union leaders are not likely to be elected merely on the basis of their capabilities to organize and bargain. In the early years of the labour movement, all union leaders were workers of outstanding skill. This reveals the great importance Japanese workers place on labour and skill, not unlike the value an artisan places on craftsmanship.

It was natural that such ethics should have been reflected in both the consciousness and roles of engineers, and thus the Japanese engineer was formed.

The Five Stages towards Technological Self-Reliance

The Japanese experience has shown that, if technology transfers are eventually to lead to technological self-reliance in a given nation, it must create its own style of integrating the five Ms and its own corps of native engineers.

The Japanese road to technological self-reliance was marked by a series of painful efforts and several stages extending for more than a century.

Although the work of our project was based on case-studies in diverse sectors of industrial technology, we may generalize them and divide the history of development of modern technology into the following five stages:

1. Acquisition of operational techniques (operations)
2. Maintenance of new machines and equipment (maintenance)
3. Repairs and minor modifications of foreign technologies and equipment, both in the system and in operations (repairs and modifications)
4. Designing and planning (original design and creation of a system)
5. Domestic manufacturing (self-reliance in technology)

To attain complete self-reliance in technology, none of these five stages may be skipped. The advantage of a late starter is the possibility to economize on the time, money, and energy to be spent at each stage of development. It is not necessary, nor is it possible, for every country to attain complete self-reliance in technology or to develop all areas of technology in an autarkic manner. What a late starter must do is choose a sector of technology in which it has an advantage, taking into account its own development needs and the optimal types, levels, and scales of technology.

We have outlined these five stages of technology development because, as many shop-floor engineers and historians of technology have pointed out, there is no such thing as a leap in technology. We hope this breakdown will serve as a useful tool when considering the relationship between a nation's development and technology. Judging from discussions of the subject, it seems there is a tendency for the argument to jump from stage 1 to stage 5, to the problem of manpower or to the politics of technology, with little attention given to stages 2 and 3.

To clarify what is presently the most urgent of the technology problems of each developing country, it might be useful to combine the five stages with the five Ms of technology. Modern technologies are interrelated. Therefore, even if national self-reliance in each transferred technology were attained through the five stages, the path would not be straight, but would, rather, follow a spiral course to self-reliance. Thus, a technology enclave, a technology transfer at the hands of a transnational corporation, having no intention of developing the related technology outside its own sphere, would not contribute to the formation of a national technology network in the host country, and we can, therefore, disregard cases of this kind here.

Modification of the Five Stages

The five stages of technology development may need some modification for selected technology transfers. For example, reversing the order of stages 2 and 3 may be appropriate: this may apply to transfers in a country that has reached a level of technological development characterized by comparatively simple machines and facilities. One of our collaborators, Professor Hoshino Yoshiro, drew our attention to the existence of this situation in China.

According to Hoshino, where individual skilled workers are capable of improving machines, for example, there may be a lag in establishing a national maintenance standard, and this would bear directly upon stage 4. Therefore, the order of stages 2 and 3 might be reversed.[16]

On the other hand, in such a complex technological system as a manufacturing plant, the maintenance technology should be established first. Repairs and minor improvements or modifications will be possible only once that has been done. In countries unable to manufacture basic automobile parts and accessories, for example, maintenance technology is vital.

To take examples from Japan, a world-famous clock and watch maker started business as an importer and repairer of foreign clocks. A well-known manufacturer of electrical appliances began as the engine-repairing section of a mining company. To begin with maintenance and repairs and go upstream to higher technological areas is a quite ordinary way to accumulate technological capacity.

In our field-work at several factories, we found that maintenance training through the periodic dismantling of machines and equipment for overhaul is very important to maintain the efficiency of machines. We also learned that the dismantling itself was regarded as an apt index for evaluating mechanics' skills. In recent years, however, several chemical plants have increasingly entrusted maintenance work to outside specialists; some engineers have criticized this division of technological labour, saying it will lead to a diminishment in workers' skills. It should be noted, though, that there are now cases in some areas of technology, especially in those of already mature technologies, where skills in maintenance and repair do not always lead to the enhancement of operational skills. The question of whether to build up a maintenance technology for each industrial technology or to leave it to outside specialists should be a matter of choice for each country.

There is another important consideration regarding the five stages of technology development. The five stages as a whole have information as a common factor on the one hand and manufacturing capability as a common factor on the other, just as the five Ms of technology have financial resources in common on the one side and information on the other. That is, the same technology may be observed in use at different levels of the five stages in different countries because of their divergent information and manufacturing systems and capacities. Therefore, it might be better in some cases to order machines and equipment from foreign manufacturers if they can design them to suit the user's domestic conditions, instead of trying to manufacture them domestically.

But constant reliance on foreign technology is undesirable. Developing a national/local capability in maintenance and repairs and in making modifications is important because foreign technologies often lack uniformity in their standardization; this is a result of the society in which they originated. Nevertheless, it cannot be denied that establishing a stable connection with specialized foreign enterprises may be a choice a developing country wishes to make.

Three Elements of Technology Management: Eliminating *Muri*, *Muda*, and *Mura*

Modern machines and tools have become increasingly maintenance-free. This has been made possible through the development of stronger materials. But unlike their predecessors, modern equipment is less flexible with respect to function and durability. In any case, handling skill, support services, energy supply, etc., still have an effect on the output and durability of the equipment.[17]

Even when the technology is embodied in the final goods, in an automobile or a machine tool, for example, it—and the skills that applied it—will affect the output and service life of the goods. In production technologies, handling and control affect the efficiency and quality of the products even more, and, thus, the quality of management in the enterprise that owns the technology is of great importance.

For example, at the Amagasaki mill of Kobe Steel, there is the slogan "Eliminate '*Muri*,' '*Muda*,' and '*Mura*'" (*muri*—to overwork or do something forcibly; *muda*—to waste, diseconomy; and *mura*—irregularity or inconsistency). This watchword, emphasizing rationality, safety, efficiency, economy, and a high standard of quality control, pin-points the essence of factory management and technology control today.

During our visit to the mill, I noticed that, although most Japanese were impressed by the slogan, representatives from developing countries seemed unmoved. The difference in response seemed not to indicate any personal disagreements; it merely reflected the state of technological affairs in the visitors' home countries. The questions they asked the factory staff centred mostly on such matters as the strategic placement of the steel mill's technology in regard to defence from sea-based attacks, labour management, and QC circles—matters taken for granted by the Japanese.

In addition to concern for cost, quality, and security, prompt delivery might also be mentioned, for it is what clients especially demand of producers of intermediate goods. In automatic production, for example, where assembly lines handle hundreds of component parts and accessories, delivery dates and times have a decisive importance in maintaining productivity. The higher the level of technology, the more important the punctuality of delivery, because such technologies are dependent on complex, wide-ranging support sectors. A refined delivery schedule enhances performance, and a poor schedule creates operational diseconomy. Toyota's "just in time" delivery system (the Kanban method), for example, eliminates the necessity to stock many spare parts and to maintain large warehouses, which, in turn, reduces production costs considerably.

Obviously, this system requires punctual deliveries to maintain a high level of productivity. Since punctual deliveries over long distances depend on good communications, information, transportation, and other services, some of which are beyond the manufacturer's direct control, there must be some safeguards against unexpected snags and losses. An essential factor in technology and factory management is to be constantly prepared to overcome any crisis that threatens to disrupt constant full-scale operations.

Factors such as these constitute the heart of technology management and control, though they are often overlooked by technology users, and this is one difficulty Japanese technology exporters have sometimes encountered, even in the industrialized countries.

In the light of the experiences of the developing countries, the five stages of technology development might be supplemented by another one preceding the first; namely, a careful assessment of the costs and benefits likely to result from a transfer of technology. Even should a country find it necessary to transfer a technology, it might lack the right conditions to do so. For instance, where large-scale equipment must be introduced, the necessary port and transportation facilities may be lacking. Feasibility studies carried out before technology transfer, however, might reveal important difficulties. For example, even if it is found indispensable to prepare or build infrastructural facilities to make a transfer possible, it might be determined that, if the infrastructure were built, it would be needed only at the time of the transfer and would later prove useless. The costs, including the cost of maintenance and administration of the infrastructure, would then be ruled too high to carry out the transfer.

Many developing countries are also often obliged to import technologies that are too large for their needs, but they would have to have an exceptionally high level of R. & D. capacity and engineering ability—both usually rare in developing countries—to modify the scale of the technology. As a result of this difficulty, technology transfers to developing countries often prove unsuccessful.

The question of economic rationality in the choice of technology also arises. If the technology importer is a private enterprise and alert to economic rationality, it will likely modify its transfer policy to avoid diseconomy. However, the transfer of a technology to answer the technological needs of the state may present a different case.

The needs of the state have often been those of the political or administrative élite, who tend to pursue only the latest technologies and equipment. As a result, the maintenance, management, and the products themselves are apt to be inferior, yet expensive. This can be expected because the élite lack the required expertise and an alertness to the aforementioned three elements of technology control.

Japan is a good example of this. Many of the early, state-run factories using newly introduced foreign technologies proved unsuccessful. Once in private hands, however, they exhibited significant improvement in both managerial and technological capabilities.

Kamaishi Ironworks, for example, modified the foreign technology it had taken over from the state to suit the raw materials that were locally available; further, it reduced its scale to stabilize operations. Two important reasons for the failure of its predecessor were the original design by foreign experts, who had introduced their technology to Japan without modification, and the Japanese government's policies on technology. It was Japanese engineers who had to remove the difficulties.

We heard similar stories in the developing countries we visited. The quality-control movement that Japanese experts tried to introduce there did not at first prove successful, but after a change in management, it was learned, the movement was proposed anew by native engineers and successfully realized.

A Chinese scholar stated that he was impressed that in Japan a thorough preliminary cost-benefit assessment was usually made before a technology transfer. This is taken for granted in Japan, but the remarks remind us that technology transfers often occur under the auspices of development aid, in which cases primary importance is attached to government needs, and the analytical assessment of the technological and economic rationality of the transfers is ignored. The urgency of development tends to justify these sorts of technology transfers to developing countries that are unconcerned with techno-economic rationalism. It is important to remember, however, that modern technology is primarily based on economics, even if it cannot be free from national and international politics.

It may also be added that technology, like economics, will be sure to stagnate without free and fair competition, and so will the quality of engineers. Where engineers and skilled workers are few, the ability to develop technology is difficult to foster. In Japan, the technologies that remained long under government control developed and spread more slowly than those that did not.

For example, the spread of telephones under government administration in the 50 years they were in use before World War II was incomparably slower than in the 30 post-war years when the telephone business was in the private sector. In pre-war days, because extension of telephone lines was very slow, even having a telephone was considered a symbol of wealth and social status, and telephone owners tended to support the restricted availability of telephone access. The extension of telephone lines was made both possible and necessary through innovations in telephone technology and the increased popular demand for telephones, resulting from the greater income of the people and changes in their life-styles. In sum, state-run businesses tend to be slow to respond to a nation's needs.

Though bureaucratic control of technology may cause greater difficulties than market-oriented, privately run, business-oriented management, the bureaucracy itself is not the same in different countries and in different times. The intention here is not to suggest that bureaucratic control is always inefficient and uneconomical; nevertheless, a monopoly on technology, whether state or private, is not good for its diffusion.

Part 3

Epilogue