Hitotsubashi Journal of Commerce and Management 27 (1992) pp. 63-79. © The Hitotsubashi Academy

THE DILEMMA OF TECHNOLOGICAL LEADERSHIP: A CONCEPTUAL FRAMEWORK*

TAKERU KUSUNOKI

Abstract

This paper demonstrates that a simple proposition that technological leadership enables a firm to initiate radical product innovation is potentially misleading, and presents a conceptual framework called "the dilemma of technological leadership." Highlighting the differences between product development and technology development, which have tended to be more or less neglected, from the perspective of problem-solving, the framework shows that mechanisms embedded in a technologically leading firm impede radical product innovation, and that pursuing or establishing technological leadership itself inevitably includes some negative effects on the magnitude of product innovation. Our framework suggests that the dilemma is not simply a matter of mentality of a technological leader, but a result of natural and subjectively rational behavior of a technologically leading firm in order to make the most of its technological advantage in approaching porduct innovation, and that there would be a pitfall for a technological leader which intends to create competitive advantage through radical innovation by resorting to its rich technological capabilities.

1. *Introduction*

Since the management of product innovation has become a strategically important issue, many researchers in recent years have studied how a firm or a project may initiate innovation effectively and efficiently from various points of view. Interestingly, however, few of these literatures have explicitly focused on the relationship between product innovation and technological assets or capabilities of a firm. Most of existing studies have tended to simply assume a certain kind of positive correlation between the technological leadership and innovativeness or radicalness of the product developed. In other words, it have been more or less assumed that a technological leader has competitive advantage over firms with innovation would be realized by a technologically leading firm.

One possible reason for this tendency is that few of existing studies on product innovation have explicitly distinguished between the two different activities in the process of pro-

The first and the second section of this paper are based on Kusunoki (1992B). The author would like to thank Mr. Yaichi Aoshima, graduate student of MIT Sloan School of Management, for his constructive comments, including his contribution in improving author's English.

duct innovation; product development and technology development. Instead, existing studies consciously or unconsciously have neglected the difference between the two activities, and more or less confused product development and technology development. It may be safe to say that product development and technology development are so closely interrelated in the actual context of product innovation that it might become somewhat difficult to distinguish them, especially if one observes actually occurring phenomena. However, this does not mean that product development and technology development are the same activities. It is of great importance to make a conceptually clear distinction between these two activities, because otherwise there would emerge danger of overlooking critical aspects in the management of product innovation.

A simple proposition that technological leadership should enable a firm to be innovative in product development is potentially misleading. As is often observed, a technological leader with rich technological capability can not always succeed in realizing radical product innovation (Kusunoki, 1992A). This paper examines the difference between product development and technology development, and presents a conceptual framework called *the dilemma of technological leadership.* Paying attention to the ways of problem-solving in product and technology development, and making a conceptual distinction between the two, this framework proposes that there is a mechanism embedded in the problem-solving in a firm with technological leadership, which paradoxically impedes radical product innovation, and that a technologically leading firm could be inevitably orientated toward incremental innovation because of this inherent mechanism.

In this paper, first, we explore the difference between product development and technology development from a perspective of problem-solving. In this section, we propose that there are critical differences in the way of problem-solving between product development and technology development. Secondly, we show that pursuing or establishing technological leadership includes negative effects on radical product innovation, which result in the dilemma of technological leadership.

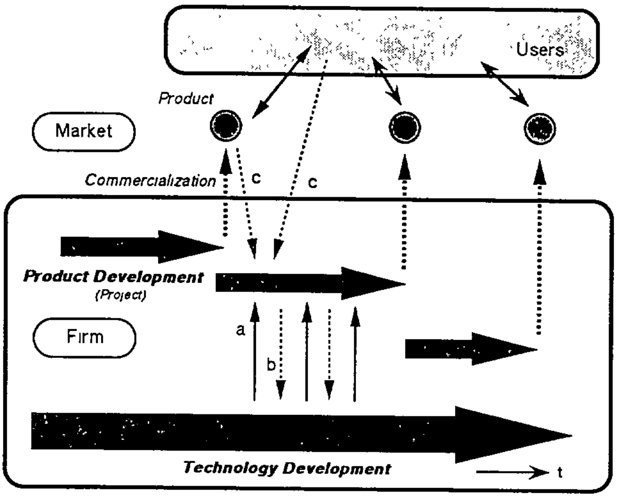
2. *Product Development and Technology Development*

2.1. Parallel progress of product development and technology development

The output of technology development is technical knowledge which is critically important as an input to product development. However, this does not simply mean that there is a linear or a sequential relationship between product development and technology development (Kline and Rosenberg, 1986). It is more comprehensible to postulate that product development and technology development progress in parallel, as shown in Figure 1.

As Figure 1 shows, the output of product development is a product, and each product development project ends in commercialization or development of a new product. Here, product innovation can be defined as the case where the new product includes entirely new functions and/or substantial progress in existing product functions. In any case, it is not technology development but product development that directly brings out product innovation.

FIGURE 1. PARALLEL PROGRESS IN PRODUCT AND TECHNOLOGY DEVELOPMENT



Product development can be regarded as an activity which transforms various individual technical knowledge into a product with a concrete form, by selecting, applying, and integrating technical knowledge which derives from technological development (indicated by arrow "a" in Figure 1). Conversely, there often emerges a need to develop particular technology in the process of porduct development, and consequently, a direction of technology development may be determined partially by requirements of product development (arrow "b" in Figure 1). Furthermore, market information such as users' needs plays an important role in product development (arrow "c" in Figure 1) (Utterback, 1974). For example, user's responses to existing products may be fed back into the product development, and may play an important role in the process.

Either product development or technology development can be described as a series of *problem-solving* (von Hippel, 1990). From the perspective of problem-solving, the goal of these two activities is to derive a specific solution, by defining and setting certain problems and solving them. This specific solution derived thorough a series of problem solving is either a new product or technical knowledge.

These two activities may have many characteristics in common. For example, either of them includes an aspect of "experiment" which is to generate information or knowledge unknown to the organization. In this sense, compared to more routine activities such as manufacturing, both product development and technology development are associated with high uncertainty. However, there are some critical differences in characteristics of problem-solving process between product development and technology development. We will conceptually describe problem-solving process in technological development and in product development, respectively.

2.2. *Problem-solving in technology development*

Problem-solving in technology development is started out by defining a general problem concerning product technology to be solved. From the problem-solving perspective, the goal of technology development is to give a particular set of solutions, "technology," to the general problem defined at the beginning. Generally, however, it is quite difficult, perhaps impossible to jump from the given general problem to specific solutions all at once. Because there is a great distance between the general problem and the final solution to be derived, and therefore, the relationship between the two is far from clear, in general.

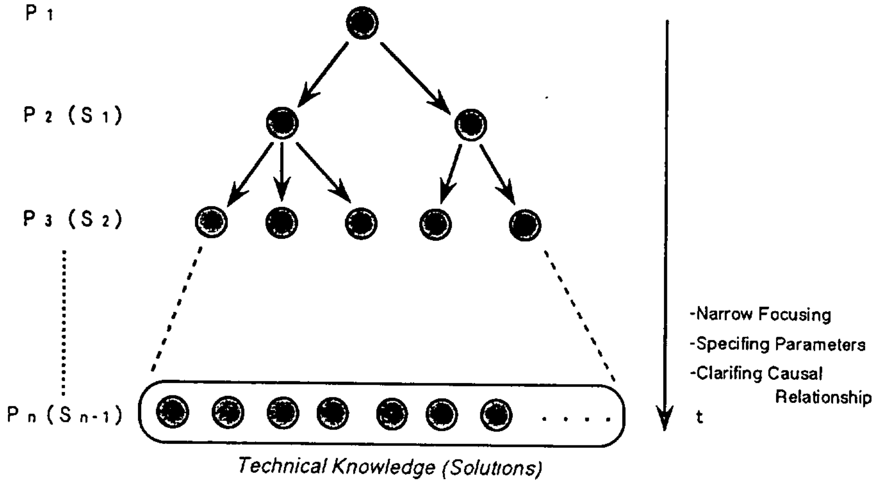
Following inherent characteristics of "technology" are associated with the difficulty mentioned above. To begin with, technology is knowledge about a causal relationship which is specified so that it becomes able to clearly predict and grasp the technological performance by considering a few specific parameters, as typically described in a patent. In other words, the solution of technology development finally appears as a set of individual technical knowledge where the causal relationship is specified enough to grasp clearly.

At the same time, however, product technology as a whole is a complex system which consists of various individual technical knowledge (Imai, 1986). Thus, the general technological problem defined at the beginning of the problem-solving is still a problem which potentially includes various parameters. In this sense, the general problem identified at the starting point of the problem-solving process is recognized not as a simple aggregation of known, specific parameters, but as a "protoptye" which implicitly encompasses many possible parameters (Jaikumar and Bohn, 1986). Therefore, it becomes so difficult to solve the general problem by deriving a single specific solution only, that an organization usually needs multiple solutions in order to solve the general problem defined at the beginning.

Therefore, problem-solving in technology development is completed not by jumping from the general, prototypical problem to a specific technical knowledge all at once, but by approaching the final set of solutions hierarchically, that is, repeatedly redefining or identifying more specified sub-problems at the lower level, which is realized by repeatedly solving a limited portion of the general problem at the higher level. In this process of hierarchical problem-solving, to solve a part of the problem by disintegrating it into less interdependent sub-problems means to specify and clarify the technical knowledge on causal relationships, at least to some extent (Simon, 1976). By descending the hierarchical problem-solving process, parameters included in the causal relationship are gradually controlled, problems concerning product technology become more specified, and as a result, the solutions become more effective and more efficient.

Figure 2 is a conceptual sketch of problem-solving in technology development. Here, the problem solving is set out by defining the technological problem at the highest level (P1), and then the prototypical problem is disintegrated into less interdependent sub-problems (P2; P3), where technical knowledge on causal relationship becomes more specified and more operationalized. As mentioned above, this hierarchical redefinition of sub-problem is also a process of deriving partial solutions (S1; S2) to the problem at the higher level. Thus, in this hierarchical problem-solving (P1→P2→P3) can be comprehended as creation of a chain of means and ends. By descending the hierarchy of problem-solving, a set of solutions is finally derived at the lowest level in the given hierarchy (Sn-1). In the problem-solving shown in Figure 2, technical knowledge on causal relationship becomes clearest at this level, and in this sense, the "technology" as an output of this problem-solving process appears as nothing but a set of solutions at the lowest level of the given problem-solving hierarchy, after all. In general, individual technical knowledge at this level would

FIGURE 2. PROBLEM-SOLVING IN TECHNOLOGY DEVELOPMENT



be more specified than so called "component technology" which is related to a physically distinct portion of the product. Hence, component technology can be assumed to consist of multiple units of technical knowledge.

Considering technology development from the problem-solving perspective as described above, we can point out some characteristics inherent in technology development. First, technology development is an incremental problem-solving process, which can be characterized by high continuity and accumulativity. As discussed above, because problem-solving in technology development progresses hierarchically, technical knowledge is accumulated only step by step. The more complex the technological problem becomes, the more steps needed in order to finally reach a set of specific solutions which are sufficiently operationalized. Thus, the more complex the technological problem is, the more continuous and accumulative the problem-solving becomes. In any case, problem-solving in technology development cannot be entirely completed all at once at a certain point of time. Instead, it keeps on progressing constantly, although each progress is incremental.

It may be worth mentioning that this does not mean that there is no leap in technical knowledge at all. As observed sometime, a leap in technical knowledge can be brought out. Even in such a case, however, it is misunderstanidng to assume that there was a leap in the process of problem-solving itself. A technological leap is brought oflt not because the hierarchical problem-solving itself becomes discrete, but because a new problem can be added into a existing set of problems, existing problems at relatively higher level can be redefined, or the way of disintegrating problems can be changed at some point of time. Thus, even if it results in a leap of technology, the process of problem-solving itself is incremental all the same. In this sense, problem-solving in technology development progresses in a hierarchical way, regardless of the nature of solutions derived.

Technical knowledge is incrementally accumulated in an organization as a certain kind of "stock," which means that every individual technical knowledge is based on a series of continuous problem-solving so far, and composes a certain system. In general, therefore, it is a difficult task for a firm to reconstruct or restructure the technical knowledge as a whole, only by taking out a part of individual technical knowledge, and then replacing it with new one. In other words, it is quite difficult to partially unlearn existing technical knowledge in the problem-solving in technology development. Although restructuring or replacement of problems at higher level is required in order to bring out a certain technological leap, this would be equal to destroying existing accumulation of technical knowledge inclusively. This is one of the reasons why a technological leap is a hard task for a firm.

Secondly, problem-solving in technology development can be characterized as a relatively closed system. As we emphasized, problem-solving in technology development is a process which is aimed to derive highly operationalized knowledge on causal relationship, by disintegrating a general problem into relatively decomposable units. This is a process of pursuing logical consistency and self-sufficiency primarily, where included parameters become gradually controlled (Sakakibara, 1982). In other words, this process of narrow focusing of technological logic is to set sub-problems at the lower level apart from various sources of influences, which turns out to strengthen the aspect of closed system in the problem-solving. This suggests that problem-solving in technology development is essentially irreversible process, which tends to be self-driven, set apart from influences from outside such as market information or managerial control, to some degree (Rosenberg, 1976). Therefore, problem-solving in technology development progresses along a trajectory with a stable direction (Doci, 1982).

Thirdly, the problem-solving can be characterized by high sustainability and high divergency, and in this sense, technology development is an activity which takes quite long time. As noted above, in this process of problem-solving, deriving a partial solutions to a problem at higher level at once leads to present a new set of sub-problems. Therefore, even if technical knowledge at the Sn-1 level is now attained through hierarchical problem-solving (Figure 2), sub-problems at the Pn level still remain unsolved there. In this sense, it is logically possible to go one step further to explore more specified knowledge on causal relationship, which is to disintegrate problems at the Pn level further into sub-problems at the Pn+1 level. Without major changes, reconstruction, and/or addition of problems at the higher level, technology development can keep on going forward to seek for solutions with a clearer causal relationship. In this sense, there is no specific end in problem-solving in technology development.

2,3. Problem-solving in product developmept

Next, we will describe a conceptual sketch of problem-solving in product development. What we emphasize here is that, different from technology development, product development needs the two-step problem-solving which consists of the disintegration of problems in the first half stage and integration of sub-problems in the next half stage.

Similar to the case of technology development, problem-solving in product development is also set out by defining a general problem at the highest level, which is related to the product to be developed or commercialized. This problem defined at the beginning may be called "product concept," in which various attributes to be embedded in the product are compressed. Product concept is defined so that it reflects the insight of organizational members concerning their technological capability and/or the market to woich the product to be introduced. The goal of problem-solving in product development is to derive a product as a solution which would realize the product concept defined at the beginning.

What differs from the case of technology development is that, in problem-solving in product development, it becomes much easier to secure a clear correspondence between the general problem, product concept and the final solution which is a product. In the case of technology development, solutions become inevitably invisible, while it is easy to grasp logically by looking at a few specific parameters or dimensions, because the solutions are specific sets of technical knowledge on particular causal relationships. Compared with this, in the case of problem-solving in product development, the solution is evaluated not by a specific parameter, but as a prototype which implicitly encompasses various dimensions. In product development, the solution becomes visible in the sense that it has a concrete form, although it is difficult to make a logically clear evaluation on the relevancy of the solution by focusing on a few specific parameters.

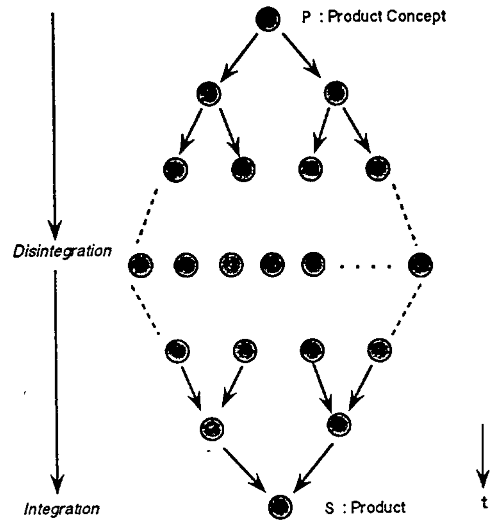
For example, consider the case of the development of Nissan's automobile called Primera (Nonaka, 1992). In the beginning of the problem-solving, the product concept of Primera was defined as "Sure, fast, and comfortable on the Autobahn." Obviously, this definition encompasses various attributes or dimensions implicitly. On the other hand, the final solution derived from the problem-solving, Primera, is also a prototype which can be evaluated by various dimensions. Here, it is easy to keep a clear correspondence between the product concept and the product as the final solution. In other words, the relevancy of the solution can be easily evaluated by putting a question whether Primera meets the requirements implied in the definition of the product concept. In this sense, problem solving in product development can be understood as a forming process where an abstract prototype (product concept) is transformed into a concrete prototype (product).

However, the argument above does not suggest that one can jump from product concept to a final solution all at once. Product development also needs hierarchical problem-solving which progresses incrementally. Because, without technical knowledge, the problem-solving could not be set forward. Similar to the case of technology development, product concept is too generally defined to be operative. As far as the problem remains too general, it is impossible to the individual technical knowledge which is needed in the process of problem-solving. Same as the case of technology development, therefore, product concept at the highest level must be specified through the hierarchical disintegration into sub-problems, until it becomes able to grasp a clear correspondence between sub-problems and and technical knowledge given.

In the case of product development, however, problem-solving does not continue divergently without limit. Once the general problem offered by product concept has been disintegrated to some extent, and it has become possible to utilize specific technical knowledge as an input, then the problem-solving goes to the next stage where individual solutions are hierarchically integrated and combined into the concrete product. In sum, problem-solving in product development can be conceptually described as the two-step process of disintegration and integration, as shown in Figure 3.

Considering the case of Primera, the product concept noted above was first disintegrated into three sub-problems; "performance in high speed," "comfortable packaging and design (the Comfort 10)," and "styling." Furthermore, for example, one sub-problem at this level, "performance in high speed," was again disintegrated into the following three sub-problems; "light weight," "engine/transmission/chasses," and "body." Repeating such

FIGURE 3. PROBLEM-SOLVING IN PRODUCT DEVELOPMENT



disintegration of a problem at the higher level, relatively operationalized sub-problems at the lower level were derived, such as "Cd-value less than 0.29," which was one of the sub-problems of "body." In sum, the purpose of this disintegration process in the problem-solving was to secure the clear compatibility between sub-problems and individual technical knowledge, in order to make sub-problems more operationalized and to increase the applicability of specific technical knowledge to the sub-problems of product development. And once this disintegration process had been completed, sub-problems which had absorbed inputs of technical knowledge were hierarchically integrated until the problem-solving resulted in the final solution with the concrete form, Primera.

The integrating process is not independent of the preceding disintegrating process. In order to reach a product which sufficiently satisfies the product concept, the integrating process need to follow the disintegrating process by reversely simulating it. The integration of sub-problems is set forward as if reversely tracing the preceding disintegrating process upward.

Considering product development process from the perspective of two-step problem-solving, here we can indicate following three distinctive characteristics of product development. First, a certain kind of discreteness is embedded in problem-solving in product development, while technology development can be characterized by continuity and accumulativity. As discussed above, problem-solving itself progresses incrementally even in product development. However, each series of problem-solving comes to an end when a new product is completely developed, which is crucially different from the case of technology development where technical knowledge are accumulated as resources. Even if the next product development project follows the preceding one, the next project may be set out with more or less different definition of product concept. Thus, by definition, discreteness is one of the important characteristics of problem-solving in product development.

Secondly, compared to technology development, problem-solving in product development can be characterized as a relatively open system. As we discussed, the final solution of problem-solving in product development is characterized as a prototype which implicitly encompasses many dimensions. In this sense, the nature of the solution is critically different from that of problem-solving in technology development which primarily pursues logical consistency thorough narrow focusing. Now that a product is generally to be introduced into market, product development cannot be indifferent to various market information into market, product development cannot be indifferent to various market information and products of competing firms. It is quite reasonable to say that problem-solving in product development needs to be a relatively open system which is exposed to various sources of influences to some extent, at least somewhere in the development process.

Thirdly, related to the first point, problem-solving in product development has an obvious end, while that in technology development can last without limits. In this sense, some kind of convergency is embedded by nature in problem-solving in product development. Therefore, the time-orientation of the problem-solving tend to be shorter, compared with technology development. Thus, as shown in Figure 1, multiple projects of product development are repeated intermittently, while technology development continues for longer time.

In this section, we presented a conceptual distinction between technological development and product development. Next, based on this distinction, we will explore the paradoxical relationship between the technological leadership a*k*d the magnitude of product innovation.

3. *Technological Leadership, Problem-solving, and Product Innovation*

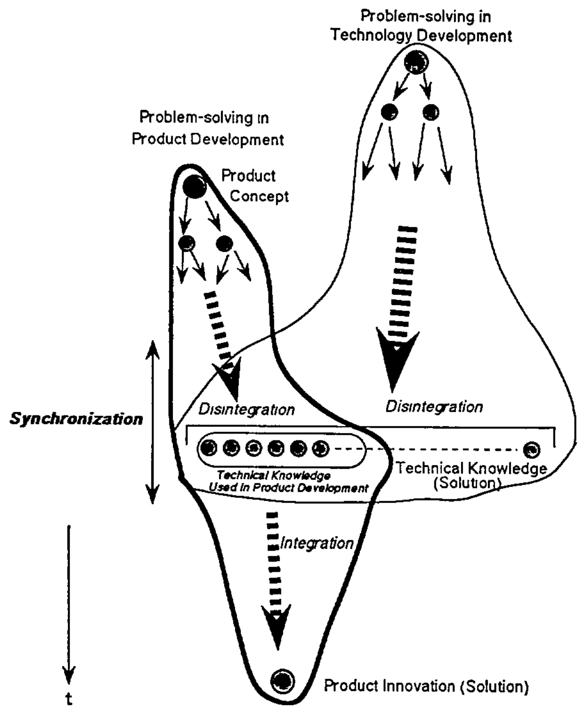
3.1. Synchronization between product development and technology developmept

Product innovation can be regarded as a special case of product development, which result in an innovative product including substantial change and/or improvement in terms of its functionality. Therefore, the process of product innovation can also be described as the two-step problem-solving, first hierarchically disintegrating problems into sub-problems, and then integrating them into a solution with a concrete form by simulating the disintegration process. As discussed in the previous section, the reason why the problem-solving takes the shape of disintegration-integration process is that, otherwise it would be difficult to operationalize the problem at the higher level, and in turn, it would become also difficult to secure sufficient compatibility between problems and individual technical knowledge which is essentially necessary to the problem-solving. This can be comprehended as the problem of "interface gap" between technology and product development. The process of product development or product innovation can be interpreted as a process where individual technical are taken in, combined, and integrated toward a particular product, by resolving the interface gap. In short, in realizing product innovation, the two different problem-solving must be *synchronized* at some level. Figure 4 shows a conceptual sketch of the synchronization between problem-solving in product development and in technology development.

Specific technical knowledge becomes able to be transferred into problem-solving in product development, only after resolving the interface gap. As shown in Figure 4, somewhere in the process of problem-solving, there must be a stage in which product development and technology development are synchronized. By synchronizing the two, specific technical knowledge is selectively transferred into product development, which gives partial solutions to sub-problems presented by product development. And then, these partial solutions are hierarchically integrated toward the final solution which may bring out product innovation. In this sense, the disintegration stage in the problem-solving can be assumed to last until the synchronization is realized.

However, how is this synchronization realized? As a simple answer to this question, we can assume that the synchronization between product development and technology development is realized through a some kind of interaction between the two. Rigidly speaking, however, the synchronization is not perfectly interactive process. In some cases of product innovation, product development itself plays a dominant role in realizing the synchronization, that is, requirements presented by product development determine the direction of the problem-solving in technology development in its early stage. In these cases, a major part of problem-solving in technology development becomes subordinate to the requirements of product development. The typical case is that technology development is set out after product development have started by setting particular product concept. On

FIGURE 4. SYNCHRONIZATION BETWEEN PRODUCT DEVELOPMENT AND TECHNOLOGY DEVELOPMENT



the contrary, in other innovation cases, technology development becomes more dominant in realizing the synchronization. In these cases, problem-solving in product development basically depends on the existing technical knowledge. In other words, problem-solving in product development is set forward so that it becomes easier to synchronize with given problem-solving in technology development.

3.2. Influence of technological leadership on the synchronization of problem-solving

Concerning the synchronization between the problem-solving in product development and in technology development, here we can propose that the magnitude of experience of problem-solving in particular technology development substantially affects the way in which the synchronization realized. More specifically, the proposition is that, the further a firm makes progress in problem-solving in technology development, the more the on-going problem-solving in technology development becomes determinant in realizing the synchronization, and consequently, in the process of product innovation, the more problem-solving in product development becomes subordinate to the given technical knowledge derived from the problem-solving in technology development. In short, in a technologically leading firm, the synchronization in the process of product innovation tends to be realized by *synchronizing product development with technology development*, rather than by *synchronizing technology development with product development.*

There are at least two reasons for this proposition, which are closely interrelated. The first reason consists in the time precedence of technology development. As we discussed in the previous section, problem-solving in technology development generally takes much longer time than in product development. Hence, it can be assumed that, if afirm establishes technological leadership over others, it has precedently accumulated a large amount of technical knowledge through a long history of problem-solving in technology development, at the time product development is set out. Under this condition, in approaching product innovation, it appears more effective and efficient, at least for the technologically leading firm, to synchronize the problem-solving in the product development with the given technical knowledge which has been already derived out of problem-solving in technology development. Otherwise, the firm might not able to take advantage of its technological capability which offers competitive edge against other firms, and furthermore, the firm might have to suffer serious sunk cost in technology development so far.

The second reason relates to the aspect of closed system of problem-solving in technology development. As discussed in the previous section, for securing logical consistency of technical knowledge through narrow focusing, the system of problem-solving in technology development needs to be closed, at least to some extent. This aspect of closed system is assumed to become more and more strengthened, as a firm makes progress in problem-solving in technology development toward the frontier of technical knowledge. Thus, the more a firm makes progress in problem-solving in technology development, the more closed system it becomes. In the case of a technologically leading firm, therefore, the problem-solving in technology development by nature presents a tightly closed system, which would be isolated from various influences from outside, and it becomes self-driven toward the frontier of technical knowledge, given the problem at the higher level. In this sense, problem-solving in technology development under technological leadership tends to become irreversible, inevitably.

In approaching product innovation under this condition, it appears quite reasonable for a technological leader to synchronize the problem-solving in the product development with that in technological development given. Because, it is quite difficult for a technological leader to flexibly cope with requirements of product development by restructuring or changing the existing direction of problem-solving in technological development. Instead, it appears more rational for a technologically leading firm to direct problem-solving in product development so that it can make the best use of technical knowledge derived from the technology development so far, because this may be the most effective and efficient way of realizing product innovation, at least in the eyes of a technological leader.

In any case, under the condition where a firm holds technological leadership, the synchronization between problem-solving in technology development and in product development cannot be realized in a perfectly interactive way. Instead, there emerges a tendency that technology development becomes predominant over product development in realizing the synchrionzation, which is rational nehavior rather than merely a psychological bias, at least subjectively. In considering the relationship between technological capability of a firm and product innovation, this tendency of a technological leader in the synchronization of problem-solving is critically important, because the nature or the magnitude of product innovation is substantially affected by the way in which the synchronization is realized.

3.3. The dilemma of technological leadership

The magnitude of product innovation can be identified along at least two dimensions; the gap of product function and the scope of innovation (Kusunoki, 1992A). The former dimension captures an innovation's impact on the product function. In the automobile, for example, this dimension refers to the gap between a newly developed product and the predecessor in terms of product function such as horsepower of an engine, fuel expenses, and so forth. The latter captures the scope of innovation's impact on a product, which varies from the overall to the limited. This dimension refers to whether innovation's impact on a product covers overall elements of the product functions, or it covers only few elements composing the limited part of product functions. Along these two dimensions, here we can get two distinctive types of product innovation concerning magnitude of innovation; radical innovation and incremental innovation. Framed in this way, radical and incremental innovation are extreme points along both dimensions. The greater the gap of product function and the wider the scope of the impact on product, the greater the magnitude of the innovation becomes, or the more radical the innovation becomes. On the contrary, the smaller the functionality gap and the more limited the scope, the more incremental such product innovation becomes.

Given the proposition regarding the influence of technological leadership on the synchronization of problem-solving, the more intensively a firm pursues technological leadership, the more problem-solving in technology development becomes predominant over that in product development in the stage of the synchronization. Consequently, in the case of typical technological leader, problem-solving in product development significantly synchronizes with, and not only unable to be independent of, but also become subordinate almost entirely to, given problem-solving in technology development. In approaching product innovation, this dominancy of on-going technology development in realizing the synchronization of problem-solving can be assumed to impede the potential possibility of radical innovation, and, on the contrary, lead the technologically leading firm toward incremental innovation, which results in the dilemma of technologival leadership.

Why the dominancy of technology development in the synchronization leads to the dilemma of technological leadership? The reason is as follows. Based on the definition above, radical innovation is characterized by a large gap of product function and wide scope of impact. Thus, in problem-solving in product development, there are at least two conditions to be satisfied in order to realize radical innovation. First, in order to realize a large gap, a firm has to nurtue technical knowledge for some time, and has to save each technical knowledge without embodying it into a particular product. Because, in the process of problem-solving in technology development, each progress in individual technical knowledge is, by definition, brought out only in an incremental way. Hence, if a firm wants to initiate radical innovation in terms of the gap of product function, the firm has to first set by aside each incremental progress in technical knowledge, at least until it takes the shape of substantial progress in technical knowledge. In developing a particular product, the embodiment of technical knowledge into the product should be left untouched, unless the firm has already reached a certain amount of technical knowledge enough to bring out a substantial gap in product function, that is, a major change at least at the component level. Secondly, in order to bring innovation with wide scope of impact out of product development, a firm needs to coordinate and/or combine different units of technical knowledge which widely cover various elements composing product functions, in the problem-solving in product development. However, in the case of a technological leader where problem-solving in product development is so tightly synchronized with technology development, these two conditions of radical innovation may be hard to satisfy. Here, we have at least two reasons for this.

The first reason is mainly related to the gap of product function. In approaching product innovation under the strong dominancy of technological development over product development in realizing the synchronization of problem-solving, problems in product development are almost automatically disintegrated into the sub-problems which correspond directly with existing technical knowledge derived from existing problem-solving in technology development. Therefore, the linkages between the disintegrated sub-problems of product development and each individual technical knowledge tend to become *excessively* clear. In other words, the interface gap between the two kinds of problem-solving tends to be resolved excessively. This is the problem of over-compatibility of sub-problems in product development with individual technical knowledge.

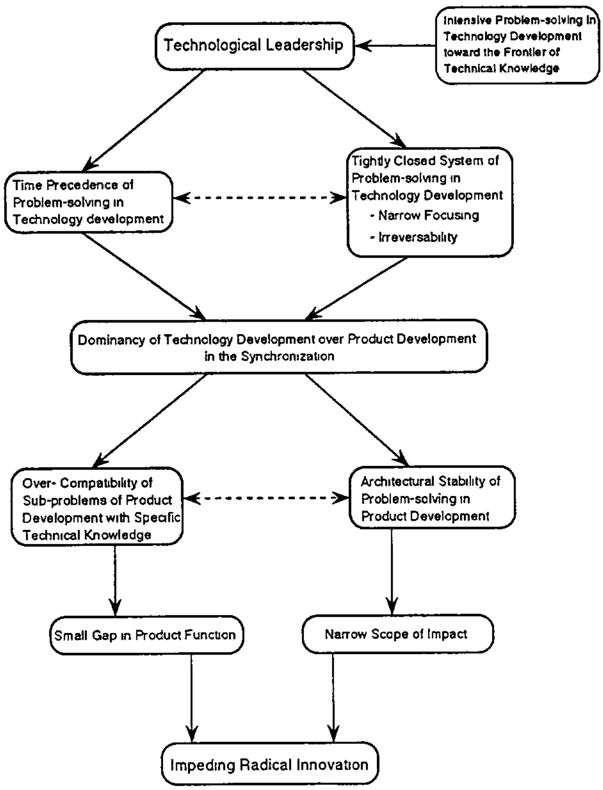
Given the situation of over-compatibility, the linkages between sub-problems of product development and individual technical knowledge become so clear that, when a technological leader intends to initiate product innovation, it becomes easy for the firm to quickly embody each incremental progress in technical knowledge into the product, without saving and nurturing technical knowledge until it take the shape of significant progress enough to create a substantial change in product function. In the eyes of the technological leader, such behavior appears to be reasonable in the sense that it enables to make the most of its distinctive advantage in terms of technological progress which other firms have not attained yet. However, because each progress in technical knowledge is by nature incremental, technological leader's problem-solving which is characterized by the over-compatibility consequently impedes the potential of realizing a massive gap in product function, and therefore, inevitably leads the technological leader to frequent, but incremental innovations with a small gap in product function.

Secondly, if there is strong dominancy of technologival development in the synchronization of problem-solving, a large part of the architecture of the pattern of a technological leader's problem-solving in product development tends to be implicitly determined in advance, so that it become easier to synchronize with the on-going problem-solving in technology development. In other words, in this case, the problem-solving in product development is set forward by simply simulating the architecture of preceding problem-solving in technology development. In this sense, the existing architecture of problem-solving in technology development is transplanted into the process of product development. As we argued, the architecture of problem-solving in technology development can be characterized as a hierarchical set of less interdependent sub-problems. Because the problem-solving in product development resorts to the simulation or the transplantation of the architecture of problem-solving in technology development, it is assumed that the product concept would be almost automatically disintegrated into sub-problems which are less interdependent, even if the product concept might potentially need a different, unique way of disintegration. If so, in the process of problem-solving in product development, it is difficult for a technological leader to coordinate interfaces between sub-problems. This may lead to a serious difficulty in creating unique combinations of technical knowledge transferred from technological development. As a result, technological leadership impedes radical innovation by narrowing the scope of innovation's impact on a product. This is the problem of architectural stability in problem-solving in product development.

These interrelated two factors, the over-compatibility and the architectural stability, compose the inherent mechanisms embedded in the problem-solving in product development of a technological leader, which impede radical innovation. Summarizing the discussion in this section, we can present the conceptual framework of the dilemma of technological leadership, as shown in Figure 5.

This framework proposes not only that a technological leader cannot always succeed in initiating radical product innovation, but that technological leadership itself paradoxically impedes radical innovarion. This is nothing but a dilemma which a technologically leading firm inevitably faces, at least to some extent, because the sources of dilemma consist in the pursuit of the technological leadership itself. The more intensively a firm pursues technological leadership, the more the firm subject to the dilemma. In this sense, the dilemma is not simply a result of some kind of failure of management, but a result of natural, intentional, and subjectively rational behavior of a technological leader in order to make the most of its technological advantage.

FIGURE 5. FRAMEWORK OF THE DILEMMA OF TECHNOLOGICAL LEADERSHIP



4. *Conclusion*

This paper first examined the difference between technology development and product development from the perspective of problem-solving. In this section, we argued that there are some differences in continuity, accumulativity, configuration, and system characteristic, between these two kinds of problem-solving. In the second part of the paper, we proposed a conceptual framework of the dilemma of technological leadership, by focusing on the influence of technological leadership on the sunchronization of problem-solving in product development and technology development, which affects the magnitude of product innovation. This framework showed that mechanisms embedded in the problem-solving in a technologically leading firm impedes radical innovation, and technological leadership includes negative effects on radical innovation in itself.

Although this paper did not examine exogenous factors, it would be interesting to explore the industrial factor which may affect the magnitude of the dilemma of technological leadership. We can suggest three exogenous factors which are likely to accelerate the dilemma, for example. First, under strong competition for product innovation among firms, the dilemma of technological leadership would be more accelerated. Because, under such situation, it would become more reasonable for a technological leader to synchronize problem-solving in product development with on-going technology development in order to make the most of its advantageous position in terms of technological progress. Secondly, the dilemma would be more significant in industries on the emerging or the fluid stage which is characterized by high possibility of radical product innovation. In industries on the maturity stage, the dilemma of technological leadership would be negligible, because there is only little possibility of radical innovation at all (Abernathy, 1978; Porter, 1980). Thirdly, the complexity of product system or product technology would affect the likelihood of the dilemma. In high-tech-oriented industries with highly complicated product system, a technological leader would be more subject to the problem of the over-compatibility and the architectual stability. The magnitude or the likelihood of the dilemma of technological leadership would vary depending on these exogenous factors at the industry level. However, it is under these situation mentioned above that a firm needs to establish technological capabilities and to initiate radical innovation as a competitive weapon.

This paper suggests that there would be a serious pitfall for a technological leader which intends to create a competitive advantage thorough radical innovation by resorting to its rich technological capabilities. And furthermore, the dilemma is not a matter of mentality of a technological leader, but reflects structural problem embedded in the way of problem-solving in order to pioneer technological development, to establish technological advantage, and to make the most of the advantage, all of which appear quite rational to a technological leader. The concepts and the framework provided by this paper suggest that, the more intensively a firm pursues technological leadership, the more elaborated management the firm needs, in order to overcome the dilemma to bring radical innovation out of rich technological resources. The understanding of the dilemma of technological leadership provides important insights into the way of exploring effective management of technology and product development in technology-oriented firms.

HITOTSUBASHI UNIVERSITY

REFERENCES

Abernathy, William J. (1978). *The Productivity Dilemma*, The Johns Hopkins University Press.

Doci, Giovanni (1982). "Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change." *Research Policy*, Vol. 11, pp. 147–162.

Henderson, Rebecca M. and Kim, B. Clark (1990). "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms,.' *Administrative Science Quarterly*, Vol. 35, No. 1, pp. 9–30.

Imai, Kenichi (1986). "Innovation, Strategy, and Organization," in K. Imai (ed.), *Innovation and Organization*, Toyo-Keizai-Shimposha. (in Japanese)

Jaikumar, R. and R. E. Bohn (1986). "The Development of Intelligent Systems for Industrial Use: A Conceptual Framework," *Research on Technological Innovation, Management and Policy*, Vol. 3, JAI Press.

Kline, Stephen J. and Nathan Rosenberg (1986). "An Overview of Innovation," in Ralph Randau and Nathan Rosenberg (eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, Washington CD: National Academy Press.

Kusunoki, Takeru (1992A). "The Continuity of Product Trajectory: A New Framework for Analyzing Strategy for Product Innovation," *Business Review*, Vol. 39, No. 2, pp. 63–91. (in Japanese)

Kusunoki, Takeru (1992B), "Product Innovation as the Disintegration-Integration Process: Synchronization between Product Development and Technology Development," *The Hitotsubashi Review*, Vol. 108, No. 5. (in Japanese)

Nonaka, Ikujiro (1992), "Managing the Global Knowledge Creation Process," *Organizational Science*, Vol. 25, No. 4, pp. 2–15. (in Japanese)

Porter, Michael E. (1980), *Competitive Strategy*, Free Press.

Rosenberg, Nathan (1976), *Perspectives on Technology*, Cambridge: Cambridge University Press.

Sakakibara, Kiyonari (1982), "Meta-Technology," *The Hitotsubashi Review*, Vol. 87, No. 3. (in Japanese)

Simon, Herbert A. (1976), *Administrative Behavior* (3rd edn.), New York: Free Press.

Utterback, James M. (1974), "Innovation in Industry and the Diffusion of Technology," *Science*, No. 183, pp. 620–626.

von Hippel, Eric (1990), "Task Partitioning: An Innovation Variable," *Research Policy*, No. 19, pp. 407–418.