December 1995

SOFT Science and Technology: Its Aims, Scope and Implementation

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General idea of SOFT science and technology (SST), one of the disciplines the Japanese government has been officially promoting, is firstly introduced. SST is science and technology for fully extracting the capacity and functions of human beings, society and hardware as well as for most effectively utilizing and operating them. Then, an example of basic research falling in SST is shown, in which we propose concept of techno-potential of a technology-based firm and discuss its meaning and limitations. Techno-potential is a new integrated concept for measuring potential technological ability.

1 Introduction: What and Why is SST?

The purpose of this research is, first, to introduce and discuss a new discipline called SOFT science and technology (in short SST) that the Japanese government has been officially promoting as a promising and necessary research area in the near future, and, then, to sketch one of the typical researches falling in SST carried out by the author himself.

It may be true that Japan has developed the economy by employing the science and technology as a driving force to achieve the material prosperity. Now, however, the people are greatly expecting the science and technology to realize a comfortable society where the people are able to feel true richness. In pursuing such a society they require harmony of the science and technology with society and human beings.

SST is science and technology for fully extracting the capacity and functions of human beings, society and hardware as well as for most effectively utilizing and operating them. The emphasis is on (1) realization of comfortable and enjoyable life by understanding the characteristics of human beings and groups as the nucleus of utilization and, on (2) the viewpoint of harmony between science and technology and society rather than that of efficiency.

SST developed so far includes the numerical methods used for setting the most efficient operating conditions for plant facilities and computer software for operating computer equipment in conformity with particular purposes. However, recently SST has widen the application targets to not only hardware such as plants and equipments but also to intellectual functions of human beings. In particular, it is expected to contribute to (1) support to intellectual activities of individuals, groups and organizations; (2) realization of living environment and social system where comfortable and reliable life can be assured; and (3) creation of harmony between hardware and human beings and society. That is, SST is now required to become more comprehensive by merging the knowledge in cultural, social and natural science into one united body and by emphasizing their bonding to human beings. SST is, of course, not almighty but expected to bring us breakthroughs for complicated problems that human beings and society face today.

The recognition of necessity of R & D on SST in Japan has been in part motivated by the catch-up policy of south east Asian countries. Indeed, emphasis of the White Paper issued by the Science and Technology Agency of Japan in the 1994 fiscal year was, in particular, on the survey of the science and technology policies of these countries: It firstly examined R & D expenditure of several countries. China expended 14.2 billion yuan in 1991 (for reference, US$1 was equivalent to 5.28 yuan (March 1991)), which is 1.59 times

as much as that in 1988 and shared some 0.72 % of the GNP. The Chinese government has encouraged R & D activities especially for strengthening the basic and high-level technology and industries.

Korea invested 4989 billion won in 1992 (US$1 was equivalent to 719.424 won (March 1991)), which is 1.2 times as much as that in the previous year. In 1992, the R & D investment in Korea shared 2.1 % of the GNP while the average rate of increase from 1981 to 1991 is a surprisingly 27.9 %. The main part of the increase was contributed by the investments by private companies. In Indonesia they spent 500 billion rupiahs in 1991 (US$1 was equivalent to 1904.762 rupiahs (March 1991)) for R & D, which shared 0.2 % of her GNP. Since most of the investment has come from the government so far, they are now trying to increase contributions from private companies. The budget for R & D of the Thai government was 3.93 billion baht in 1991 (US$1 was equivalent to 25.126 baht (March 1991)), which shared 0.16 % of the GNP and 1 % of the whole amount of the budget.

Then, the White Paper analyzed the basic and common attitude of these countries towards science and technology: All of these countries take science and technology as a driving force for national economic growth and for success of industries. They also give high priorities to specific areas including biochemistry, electronics and information science and technology. The White Paper concluded that these countries are now eagerly trying to catch up with Japan and the process so far has been in success as a whole (for example, refer to the computer memory industry in Korea).

Under these circumstances, what policies and perspectives of science and technology, then, should Japan develop? SST is one of the directions Japan has committed itself to concentrate on in order to create new perspective in the coming several decades. To promote SST, the Prime Minister's Council for Science and Technology, Japan, produced Recommendation to the 19th Inquiry titled "R & D Basic Plan on SOFT Science and Technology" in 1992. In formulating this recommendation, the Council pointed out two specific areas as its scope; *i.e.*, "SST for human beings and society as target" and "SST for hardware as target". Before examining these areas in detail, we will briefly look at the aims of SST.

2. Aims of SOFT Science and Technology

SOFT Science and technology tries to establish a new and comprehensive discipline. It should encourage:

1. Development of basic theories and methodologies of SST

   Since SST aims to handle various psychological and mental elements such as thought, behavior and value judgment, emphasis should be put on the researches in basic regions and basic theories and the methodology of R & D such as building the theoretical models, using mathematical expressions, analyzing the thought and behavior of human beings and groups.

2. Systematic promotion of SST

   Since the themes in SST related to cultural and social phenomena may not be easily evaluated quantitatively, it is especially important to carry out the R & D systematically, on a long-term basis and with flexibility.

3. Comprehensive and interdisciplinary research exchanges among natural, cultural and social science

   Since R & D in SST requires knowledge in broad areas from natural science to cultural and social science, research exchanges among them must be accelerated. Smooth communications between researchers with different backgrounds of knowledge should be promoted.

4. Communications between science and technology and society

   Since SST targets human beings and society, it is necessary and critical to set up interdisciplinary research teams involving researchers, engineers and administrative officers and to discuss sufficiently what direction the R & D should be pointed in and how its achievements should be utilized.

5. Promotion of international exchanges

   In order to make the research achievements in SST commonly available by the whole of human be-

ings as intellectual assets and to promote the diffusion of the achievements of R & D, we need to understand cultural difference and similarity among people through, say, comparative analysis, since the adequate way of implementation of the achievements varies from culture to culture.

2 Scope of SOFT Science and Technology

SST is basically classified into two categories according to the substantial targets; SST for human beings and society as targets and SST for hardware as targets.

2.1 SST for human beings and society as targets

This category of SOFT science and technology is devoted to enhancement of personal abilities and to maintenance of comfortable living standard of human beings.

To clarify intellectual activities including judgment, reasoning, learning and getting ideas, study of logical behavior is not enough but other activities, such as emotion, sensitivity and irrational behavior, are necessary to investigate. Also, since society has become more complicated, required now are systems to support coordination and consensus making among human beings of different and diversified intellectual backgrounds.

This has necessitated the analysis and clarification of coordinating activities and researches on the role to be played by computers. Since information processing by computer and artificial intelligence techniques are essential in supporting the intellectual activities of human beings, the sophistication of man-computer interface and user-friendliness of computer is required. This interface problem is particularly critical when the achievements of research are to be shared and utilized by aged and physically handicapped persons.

2.1.1 Human-SOFT: Science and technology for supporting the enhancement of intellectual activities

A. Research on the intellectual activities of human beings

1. Research on intellectual activities of human beings, such as perception, memory, reasoning, learning and creation, should be encouraged by cognitive scientific approach. This research targets, in particular, information processing and mental model formation process of human beings.

2. Researches on cooperative problem solving and coordinating work process through the clarification of cognitive activities as well as on idea formation of a group should be emphasized.

B. R &D on the methods, tools, and systems for supporting intellectual activities

In order to support the enhancement of creativity in intellectual activities, the integration of the knowledge of basic theories on the intellectual activities of individuals and organizations should be promoted by comprehensive researches in addition to independent and fragmented researches in the areas of cognitive science, behavior science and systems science. It is also important to advance investigation on thinking process of individuals as well as a group. Researches stressing the mutual actions between tools for supporting thinking and human beings are also to be promoted. The latter typically targets what we call CSCW and GDSS.

Recently DSS at higher and strategic level has been intensively investigated. In this case we have to identify each role of human beings and computers in decision making process.

1. R &D on tools for supporting logical thinking

   It covers researches on: (1) systems-theoretic considerations on characteristics of cognition of human beings including irrationality and fuzziness, (2) simulation techniques by which a system analyzer will be able to flexiblely and quickly set the structure, parameters and rules of the model, and (3) decision making support systems capable of responding to ill-structured problems.

2. R &D on tools for supporting intellectual activities such as idea formation and creation

   It is required to promote researches on tools for selecting proper information for intellectual activ-

ities as well as on tools for processing, structuring, externalizing and expressing ideas created.

3. R & D on systems for supporting the intellectual activities of a group

   Researches on multimedia communications and the development of techniques for building GDSS and CSCW which take into account social and cultural elements such as spiritual climate and traditions surrounding the group should be enhanced.

C. Research on the sophistication of human interface

1. Research on the ideal way of human interface

   It is intended to integrate the following three approaches; (1) psychological and cognitive scientific approaches pursuing the clarification of information processing functions of human beings, (2) ergonomics and neural physiological approaches pursuing the clarification of information processing from the physical aspect of human beings, and (3) basic communication-theoretic approaches pursuing reasoning mechanisms by clarifying mechanisms of information exchange between human beings.

2. Research on the influence of sophistication of human interface upon human beings and society

   Various image, sound and other sensory information, that are considered to have a great influence upon creative power and sensitivity, and interactive communication between human beings and systems should be realized by artificial techniques such as virtual reality for the sense of reality. Researches on the influence of new information environment realized by the above upon society and human beings and their activities also should be promoted.

2.1.2 Social-SOFT: Science and technology for enhancing comfort living environment and social system

Since people are now more or less satisfied with the material prosperity of modern life, their interests are in mental or emotional aspect of life and they tend to seek comfortable life. For realizing comfortable life, where people can live in a safe and relaxed manner, it is required to effectively operate living environment and social system in such a way that special care can be offered to aged and physically handicapped persons. The spiritual satisfaction cannot be easily measured quantitatively, and pursuing only the individual satisfaction may have negative effects in other aspects. To build a society where people can live with peace of mind, required are preparation for emergency, environment arranged for preventing the occurrence of danger, acquisition of the conditions indispensable for existence, and the arrangement of systems for maintaining and promoting health.

This category includes researches on:

1. Intellectual activities in organizations

   Management science and/or theory so far studied the intellectual activities in organizations by using the concepts of motivation, leadership and followership. Now new viewpoints, such as learning and subjective perception, are desperately needed to create breakthroughs.

2. Social problems by merging natural, cultural and social science into united one

   Problems surrounding human beings and society have been inevitably increased. Uncertainty and complexity involved in large-scale phenomena we now face, such as earth environmental problems, is so huge that it is necessary to advance researches on the more comprehensive technology and methods using knowledge and methods in natural, cultural and social science areas.

2.2 SST for hardware as targets

SST for hardware as targets implies science and technology for realizing and utilizing the diversified functions possessed by hardware in a harmonious manner between human beings and hardware. Their priorities can be set as follows:

A. Software for the support, substitution and expansion of the functions of human beings by hardware

Due to the development of hardware, the support, substitution and expansion of functions of the human beings are rapidly progressing. This area includes researches on

1. The support, substitution and expansion of the physical functions of human beings

   Required are researches on the intellectual ability of hardware, such as intelligent robots, that recognizes its own situation, judges and acts under various environment.

2. The support, substitution and expansion of human being's information processing

   Complexity involved in large scale problems we have to deal with is often beyond the capability of analytical approaches. Numerical solution methods, high speed solution methods and various simulation methods, hence, should be studied for problems where many elements are connected to each other and rigorous solutions cannot be easily obtained.

3. The support to coordinating activities in a group

   To clarify the roles of common sense and tacit knowledge in communications and group decision making, studies on psychological model dealing with information exchange and dialogues should be advanced.

B. Software for making the hardware gentle to or in harmony with human beings

Since hardware is now required to have the function of friendliness to and harmony with human beings, software for this purpose must be studied and developed. In this case, not only familiarity and easy use of hardware but also permitting human beings to concentrate on intellectual work of higher level through adequate role allotment between human beings and hardware is important. This may include researches on (1) voice recognition and understanding, (2) image processing, (3) natural language processing, and (4) multimedia and virtual reality.

C. Software for harmonizing hardware with society

Progress of hardware must be always seen from a broad viewpoint, and researches from the viewpoint of harmonizing the hardware with society becomes very important.

This field includes researches on (1) technologies required by aging society, (2) technologies required for harmonizing with the earth, and (3) problems emerged as a result of the progress of substitution for human being's functions by hardware.

3 Techno-potential and its activation

In this section[1] as an example of basic research in SST, we propose concept of techno-potential of a technology-based firm and discuss its meaning and limitations.

3.1 Introduction

Our concern is primarily with the identification of technological potential capability in a technology-based firm. Techno-potential, depreciated stock of R & D expenditure invested internally and/or externally to the firm, is proposed as one of indices of measuring potential technological ability. We first discuss its meaning and significance by comparing it with TFP, and by formulating it in a mathematical form. Then we point out its limitations. This argument implies the introduction of concept of reservoir of management potential, which is essential for activating invested and accumulated techno-potential and triggering an innovative outcome. We then discuss the reservoir in connection with organizational intelligence, a new paradigm of organization theory. After claiming that the reservoir is essentially related with 'humanware' including human network formation and knowledge-sharing information systems, we suggest a role of so called "soft systems approach" in activating techno-potential.

Since a variety of factors of the firm are in principle ultimately related directly or indirectly to its final performance, we find it difficult to differentiate technological contribution (factor) to it exactly from other

[1] Some parts of this section were presented at APORS 94 at Fukuoka, Japan, in July 1994.

contributions (factors).

A conventional way of doing this is to adopt the concept of TFP (Total Factor Productivity)(MITI,1992). This is introduced to express the increased rates of the productivity of the firm which cannot be explained by the increase in conventional production factors such as labor and capital. TFP is often claimed to describe structural or technological change in the firm.

However, as an index of the potential technological capability of the firm TFP has several disadvantages: TFP often involves technical problems with measurement, and, though TFP certainly excludes the contribution of labor and capital to final output, it may include not only the technological factor but also other factors such as economy of scale and structural change within the industry the firm belongs to. Techno-potential, which is defined by depreciated stock of R & D flow invested internally and/or externally to the firm, is proposed to overcome these disadvantages of TFP.

The basic framework of our research is shown by Fig.1.

Since techno-potential is a kind of stock concept, we must notice two characteristics; time lag and depreciation. That is, a certain time (*i.e.*, a waiting period) is necessary for the R & D flow to be accumulated as the stock and to bear fruit. Furthermore, it necessarily loses novelty and value as time passes.

Techno-potential, on one hand, reflects aspects of production such as labor and capital when it contributes to the production of commercially-oriented output. On the other hand, it also serves to produce non commercially-oriented output such as research papers, reports and know-how.

However, it is true that techno-potential only measures the input side of monetary investment aimed at technological improvement. In reality more monetary investment in R & D activities does not necessarily lead to a higher innovation probability. In order to identify the potential technological capability of the firm in a more 'accurate' way we introduce another concept, a reservoir of management potential, to link techno-potential with 'real' potential technological capability. The reservoir is a supporting and connecting platform for each management potential. We claim that this reservoir of management potential is, namely, organizational intelligence (Matsuda, 1992,1993).

While intelligence is in general described as the second order *expertise* which exhibits the capability of learning to learn, organizational intelligence is originally referred to as a network of potential capabilities of the organization which underpins its strategies and tactics (Matsuda, 1992,1993). In the well-known decision-making paradigm of organization theory advocated by H.A. Simon (1947), an organization is essentially understood as a network of decision-makers, where each member of the organization functions, among other things, as decision maker. One of the basic assumptions here is that value and factual premises of the organization determine the decision-making behavior of each member. This implies that when decisions are taken, value and factual premises are given conditions and the paradigm pays no attention to the process of generating these premises.

The organizational intelligence paradigm, though it has been developed from the decision-making paradigm, primarily focuses on how these premises are generated in the organization as boundary conditions for decision making. The paradigm is much more fundamental in the sense that it explicitly tries to clarify the generation of the premises, rather than accepting them as given.

Techno-potential serves as an important generator of factual premises. To generate techno-potential in an active way the firm needs to equipped with 'humanware' which includes formal and informal human networks and knowledge-sharing systems to stimulate the creativity of the persons concerned.

3.2 Formulation of Techno-potential

3.2.1 Formalization of Techno-potential

We now formulate techno-potential, *i.e.*, depreciated stock of R & D expenditure invested internally and/or externally to the firm, as accumulated relevant R & D flow with a certain time lag which depreciates. The relevant R & D flow comes as R & D expenditure inside or outside of the firm.

Then we may represent techno-potential T_t at year t

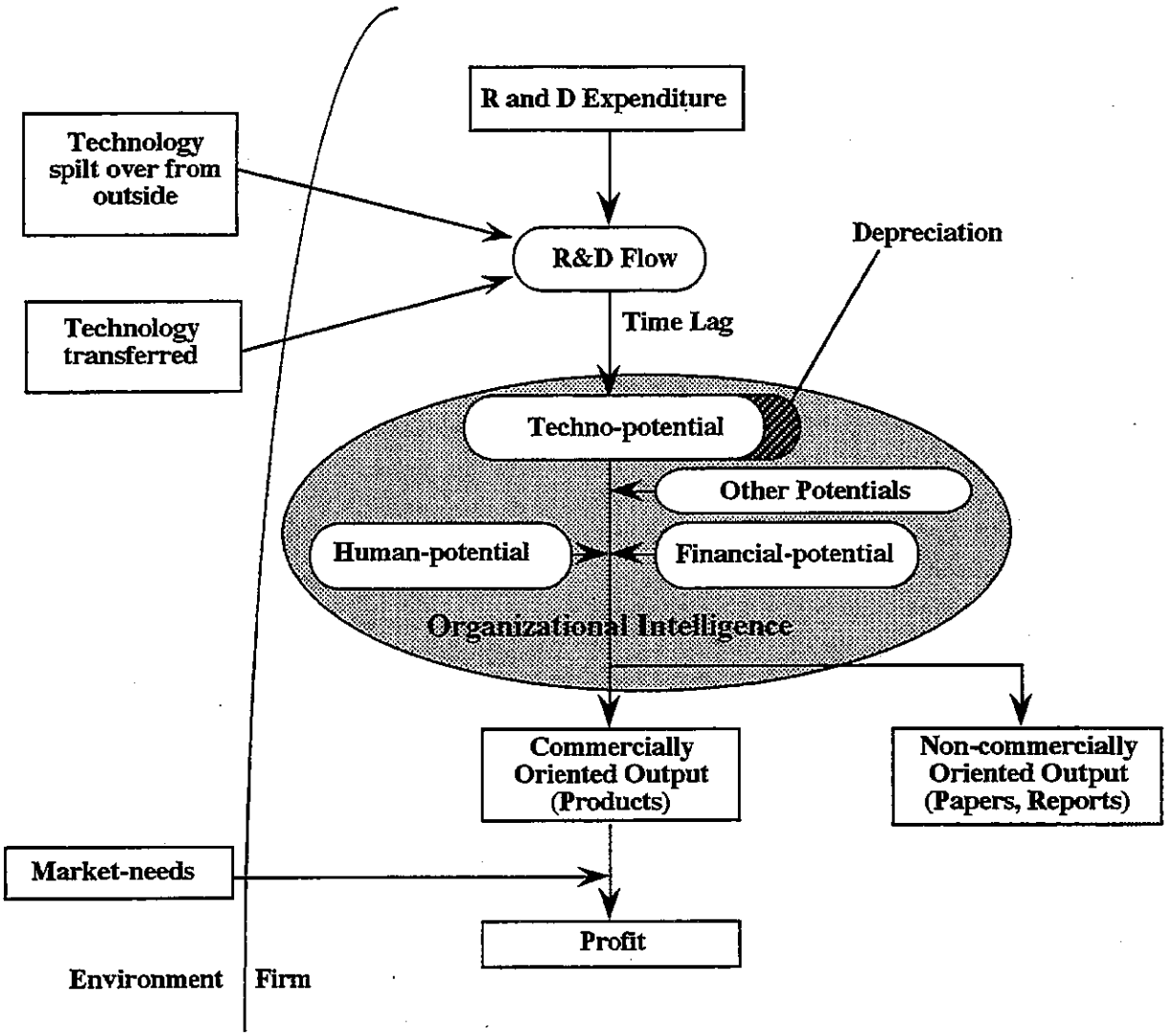

Fig. 1 Generation of Techno-potential

by

$$T_t = (1-\rho)T_{t-1} + F_t$$

where ρ denotes the depreciation rate while F_t represents R & D flow at t. The definition claims that techno-potential at t is determined by depreciated techno-potential at $t-1$ as we as by R & D flow at the time.

Let R_τ represent R & D expenditure at year τ . If the time lag is m then we have

$$F_t = (1-m_d)R_{\tau-m_i} + m_d R_{\tau-m_i-1}$$

where m_i and m_d represent the integer part and the decimal part of m, respectively. The equation adjusts the time lag for R & D expenditure to become R & D flow by distributing it to two parts. However, for simplicity, we assume m is an integer in the sequel, *i.e.*, $m_i = m$, $m_d = 0$ and $F_t = R_{\tau-m}$. We have to notice that $R_\tau = 0$ if $\tau \leq 0$.

If we suppose the R & D expenditure increases at annual rate g, we have

$$R_\tau = (1+g)R_{\tau-1}.$$

These assumptions allow us to calculate the techno-potential by

$$T_t = (1-\rho)^t T_0 + (1+g)\left(\frac{1-((1-\rho)/(1+g))^{t-m}}{g+\rho}\right)F_t$$

If we assume t is sufficiently large, then it implies that

$$T_t = \frac{1+g}{g+\rho}F_t = \frac{1}{g+\rho}F_{t+1} = \frac{1}{g+\rho}R_{t+1-m}$$

since we have $|1-\rho| < 1$ and $|(1-\rho)/(1+g)| < 1$.

Quality of technology involved in the R & D flow may be characterized by (ρ, m): If technology is associated with small ρ and large m, then we may call it basic. Otherwise, we may call the technology applied. By analyzing the final equality above, we see that if ρ decreases then T_t increases and that if m increases then T_t decreases. These observations imply that both basic and applied technologies have serious tradeoffs between ρ and m to increase techno-potential. (ρ, m) reflects characteristics of the R & D activity.

When we are interested in empirical measurement of techno-potential, we may calculate it from the R & D flow if ρ and m are estimated.

We have so far focused our interests on the relationship between techno-potential and commercially-oriented output. However, Some portion of the techno-potential may be connected to non commercially-oriented output. We need another concept, namely, the reservoir of management potential, especially to describe the other relationship.

3.3 Organizational Intelligence as a Reservoir of Management Potential

Techno-potential as discussed so far simply measures, though in a slightly adjusted manner, accumulated monetary investment aimed at technological improvement. Our ultimate concern is not with calculating these amounts mechanically but with identifying technological potential ability essential to the firm. As far as commercially-oriented output is concerned, since we observe some positive causal relationship between investment and output(*e.g.*, products), we may describe the relationship by extending the well-known production function.

However, it is extremely difficult to evaluate the potential technological ability of the firm by taking account its contribution to non commercially-oriented output; it is quite obvious that more monetary investment in R & D activities does not necessarily lead to a higher probability of innovative discovery.

These arguments naturally lead us to introduction of a concept which works as reservoir of management potential. The reservoir reserves various experiences of the firm and triggers innovative research activities. We adopt the concept of organizational intelligence as the reservoir (See Fig.2).

To create an appropriate reservoir the firm certainly needs to facilitate various management potential, especially humanware: various formal or informal human networks and information systems are, for example, necessary to encourage the sharing of knowledge among the people concerned. They may be promoted by, for instance, the appropriate education of the members as well as by encouraging them to form human networks inside and outside of the firm.

For organizational intelligence the main emphasis is on 'effervescence' as a device to expand the communicative environment, though in the relation of techno-potential to commercially-oriented output 'efficiency' is critical, *i.e.*, how efficiently R & D resources produce innovative products. As one of the possible and promising ways to activate human communication as well as to encourage the members to share knowledge and to make strategic decisions concerning their R & D activities, what we call soft systems approach (Checkland, 1981; Rosenhead, 1989; Patching, 1990) has recently attracted attention. Soft systems approach assumes, among other things, that human beings as *purposeful* rather than *purposive*; *i.e.*, it assumes that a human being does not only seek his/her given goals under given conditions but also generates his/her own goals by him/herself. Soft systems approach emphasizes the organization's members' will rather than their analytical and objective data.

The objective of soft systems approach is not to convert a problem situation into a situation without problems; what is required and attainable is to improve it in some way, to make minor and major changes depending on the will and wishes of the participants concerned. The approach is concerned with soft situations, where the problems are identified as ill-structured at the outset, and the first step towards improvement is to decide what needs to be addressed. These features typically characterize problems involved in R & D activities.

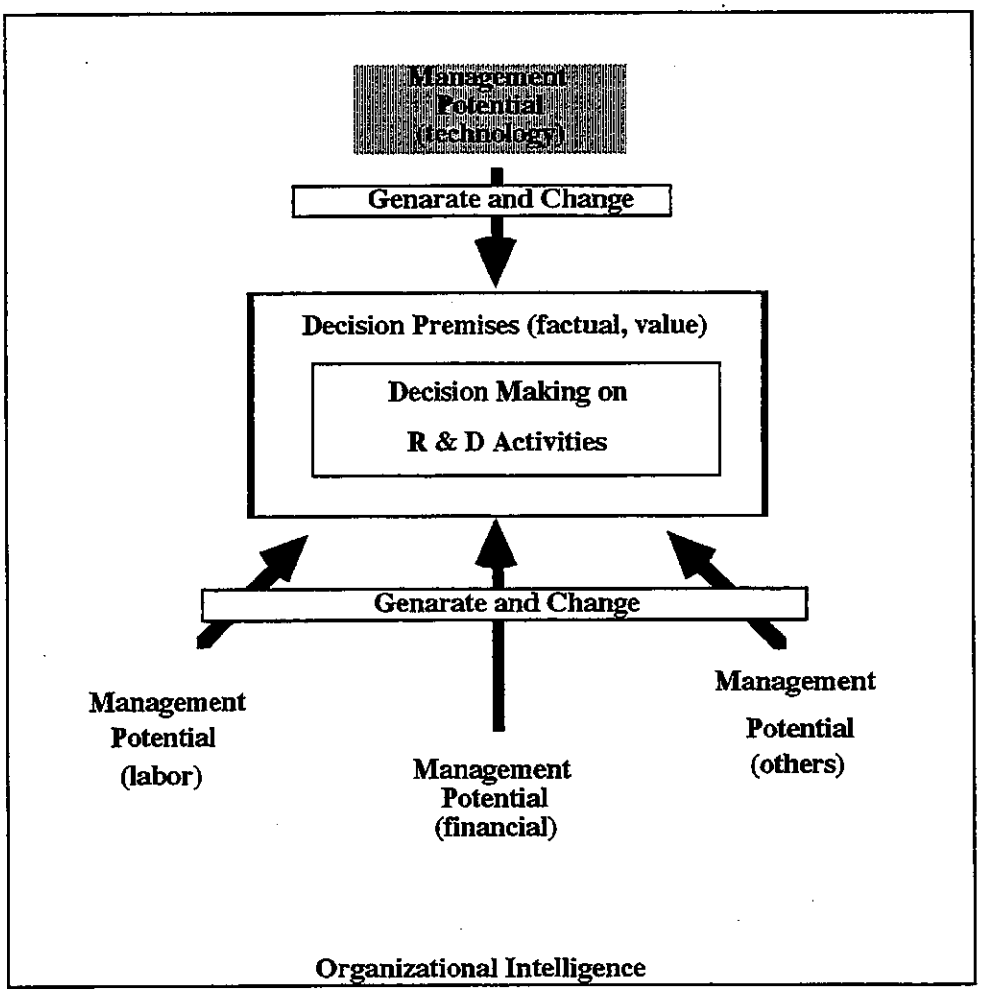

Fig. 2 Organizational Intelligence as Reservoir of Management Potential

Soft systems approach adopts debate as a device to promote the understanding of the various viewpoints of the participants, to accommodate them, to share the knowledge and to aid an agreement on change or stability. Since soft systems approach tries to identify problems rather than to find solutions, decisions about changes depend more on the outcome of debate than consideration of factors such as cost-effectiveness and so on, although these factors should be part of the discussions.

The agreement should be systematically or logically desirable, *i.e.*, as reflected in the appropriate system model or models, and must be culturally feasible, given the characteristics of the situation, the people in it, their shared experiences and their prejudices.

Soft systems approach with these characteristics and objectives certainly helps to activate organizational intelligence and to trigger an innovative outcome.

3.4 Summary

In this section we proposed and examined techno-potential, instead of conventional TFP, as such an index of the potential technological capability of a technology-based firm. After formulating the concept we clarified some characteristics of techno-potential. Then we pointed out the limitations of techno-potential as an index and emphasized the necessity of considering reservoir of management potential including the

techno-potential. Finally, we suggested a promising way, *i.e.*, via a soft systems approach, of activating the reservoir or organizational intelligence of the firm.

4 Concluding Remarks

In this paper we introduced and discussed concept of SOFT science and technology (SST) as one of the promising and important areas that Japanese government has been officially promoting. We firstly showed its aims and then outlined its scope by broadly categorizing it into two parts according to the targets, *i.e.*, SST for human beings and society as target and SST fir hardware as target. Furthermore, we sketched a research about technological potential capability of a technology-based firm as an example of implementation of SST.

Acknowledgment: The author would like to express deep thanks to anonymous referees for their helpful suggestions.

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