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A Knowledge-based Support System for Evaluating R&D Projects Based on Technological Propagation

by

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Abstract

For making effective evaluation of R & D(Research and Development) projects, we must give careful considerations on synergism of development due to technological propagation as well as individual benefits. The evaluation of technological propagation requires experts' judgments based on their experience and knowledge of technological trends. We propose a method and knowledge-based support system for evaluating R & D projects that support in assessing synergism of the projects due to technological propagation. The fundamental framework of the system consists of knowledge on technological effects and knowledge of category relations, and propagation rules based on the knowledge. We describe its applications to a case study on a group of projects for developing energy-saving technology. The fundamental framework proposed in this paper is not only useful for evaluating R & D projects, but also for developing knowledge-based systems for other purposes.

1. Introduction

Effective evaluation of R & D projects depends largely on experienced judgments of experts. A number of methods, in particular, quantitative R & D project selection methods, have been proposed for supporting such judgments[e.g.1,2]. These methods, however, have limitations as critically reviewed in Ref.[1]. One of the limitations is "inadequate treatment of project interrelationships with respect both to value contribution and to resource utilization." Another limitation is "no explicit recognition and incorporation of the experience and knowledge of the R and D manager."

In this paper we address our attention to the first limitation and propose a novel method for evaluating R & D projects which takes account of their interrelationships for technological innovation as well as their individual benefits. In particular, we give careful considerations on technological propagation among the projects. The method helps us to evaluate synergism of developments based on the propagation of technology from a project to others. Such evaluation requires extensive information on the projects, and knowledge on technological trends and related areas. The knowledge must be obtained from the experts who evaluate the projects, and from sources accumulated by experience. We propose the knowledge-based Support System for evaluating R & D projects, which is based on the method. Its knowledge is obtained from users, experts evaluating the projects, as well as prestored knowledge-base. Thus the system aims at solving the second limitation by incorporating experience and knowledge of the experts.

The fundamental framework for designing the system requires specification of knowledge-base about technological propagation. It contains knowledge of technological propagation, which consists of *knowledge on technological effects* and *knowledge of category relations* that extends the scope of consideration on propagation. Based on the knowledge-base and inference mechanisms the system outputs synergistic relations of projects in the form of networks of technological propagation. The networks aid experts in evaluating their interrelationships. We present the framework and specify inference rules for technological propagation, which were obtained through a case study of evaluating R & D projects for energy-saving technology described in Ref.[3].

The authors have proposed a method for evaluating interrelationships of R & D efforts[4,5]. It is methodologically different from that in this paper, but their purpose is the same in the sense that they both attempt to evaluate synergy of R & D efforts. They are aimed at solving the limitations of R & D project selection methods[1,2] by focusing on different aspects, and support decision making on R & D.

This paper consists of six sections. In Section 2 we describe the fundamental framework for designing the Support System. In Sections 3 and 4 we present rules for technological propagation with examples of their applications. We summarize the rules and the applications in Section 5. We conclude the papaer in Section 6 with remarks on future research.

2. Information and knowledge on technological propagation and the Support System for evaluating R & D projects

We propose the Support System for evaluating R & D projects, which has knowledge processing mechanisms and generates networks of technological propagation as illustrated in Fig.1. In Section 2.1, we discuss information and knowledge on technological propagation, and define the framework and terms on which we specify the methods for evaluating the propagation. Then we will describe the system and define the basic rule for the methods in Section 2.2.

2.1 Information and knowledge on technological propagation

Technological propagation is a general term meaning that technology is transferred from a technologically advanced agent to another agent. In this paper, it is restricted to mean that technology is transferred from an R & D project to another for the purpose of achieving the objective of the latter.

Diffusion theory has been investigated as a multidisciplinary field of research on diffusion and transfer of technology[6]. The field encompasses a broad scope of aspects of technological propagation, ranging from the transferred technology *per se* to aspects of social institutions concerned. We restrict the scope of our investigation to the information and knowledge concerning technological propagation required for evaluating synergistic

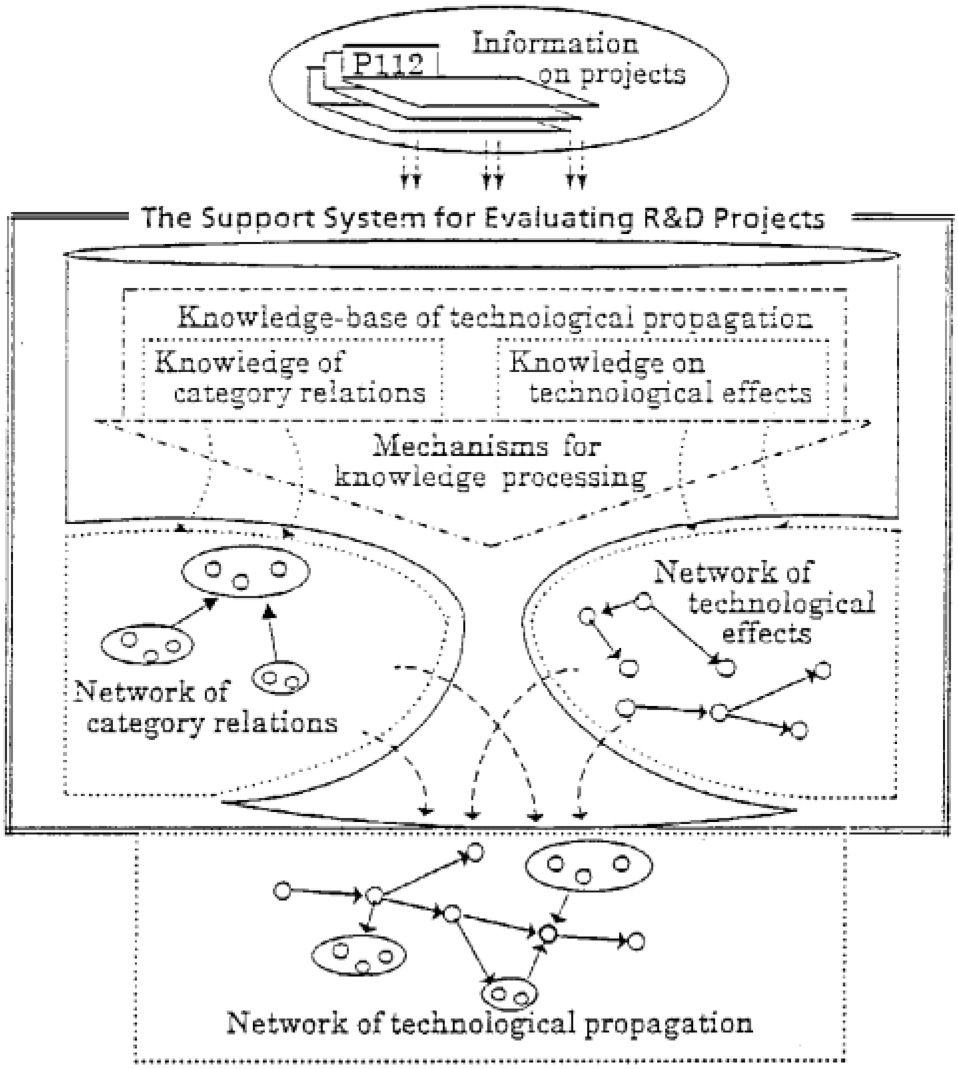

Fig.1 Processing mechanisms of the Support System

effects of R & D projects during the process of their planning. In this section, we define the framework and terms for classifying the information and knowledge sufficient to develop the Support System for the evaluation. The system has two types of knowledge on technological propagation; *knowledge on technological effects* and *knowledge of category relations* of technology.

The *knowledge on technological effects* is the basic knowledge for evaluating technological propagation. It relates an R & D project with another through the effects of propagation of technology. We consider information on technological barriers and technological effects of the projects for specifying the knowledge. A technological barrier of a project is new technology required to be developed in the project to fill the gap between its objective and the present state of technology. A technological effect of the project is a side effect of the new technology, which can be propagated to another project and employed for achieving its objective. The following is the general formula that expresses the relationship between the technological barriers and the technological effects obtained from project information.

$$Pn : Bn_1, Bn_2, ..., Bn_i \rightarrow En_1, En_2, ..., En_j \qquad (i, j \geq 1) \quad \cdots \quad (1)$$

where Pn denotes Project n, Bn_i and En_j denote its i-th technological barrier and j-th technological effect, respectively. The symbol '$\rightarrow$' denotes the relationship that we can anticipate the effects on the right-hand side as a result of overcoming the barriers on the left-hand side. We simplify the formula to a binary relation, $Pn : Bn \rightarrow En$, and call it the basic pattern (of technological propagation). A *knowledge on technological effects* is a basic pattern whose Bn and En are instantiated by a technological barrier and a technological effect of a planned R & D project.

The *knowledge of category relations* is the main knowledge for evaluating technological propagation. It is expressed in the form of relations of categories in which technology is classified. Fig.2 illustrates that a category is represented by a matrix whose columns and rows correspond to technological fields(T.F.) and technological components(T.C.), respectively. We call this matrix a category table.

The technological field specifies general grouping for classifying the subjects of technology. Examples of the technological field are nuclear power and natural energy for the case of energy technology. A technological field is further divided by technological subjects(T.S.), which specify detailed grouping of the subjects. On the other side of the matrix, the technological component specifies grouping from the viewpoint of components constituting the overall technology for each category. The slot in a category table specified by a technological subject and a technological component is called *subject-component* (denoted by S; e.g. S_a in Fig.2). Technology listed as technological barriers and technological effects of R & D projects are classified in *subject-components*. As a result, a subject-component is a set of technology specified by technological barriers and effects.

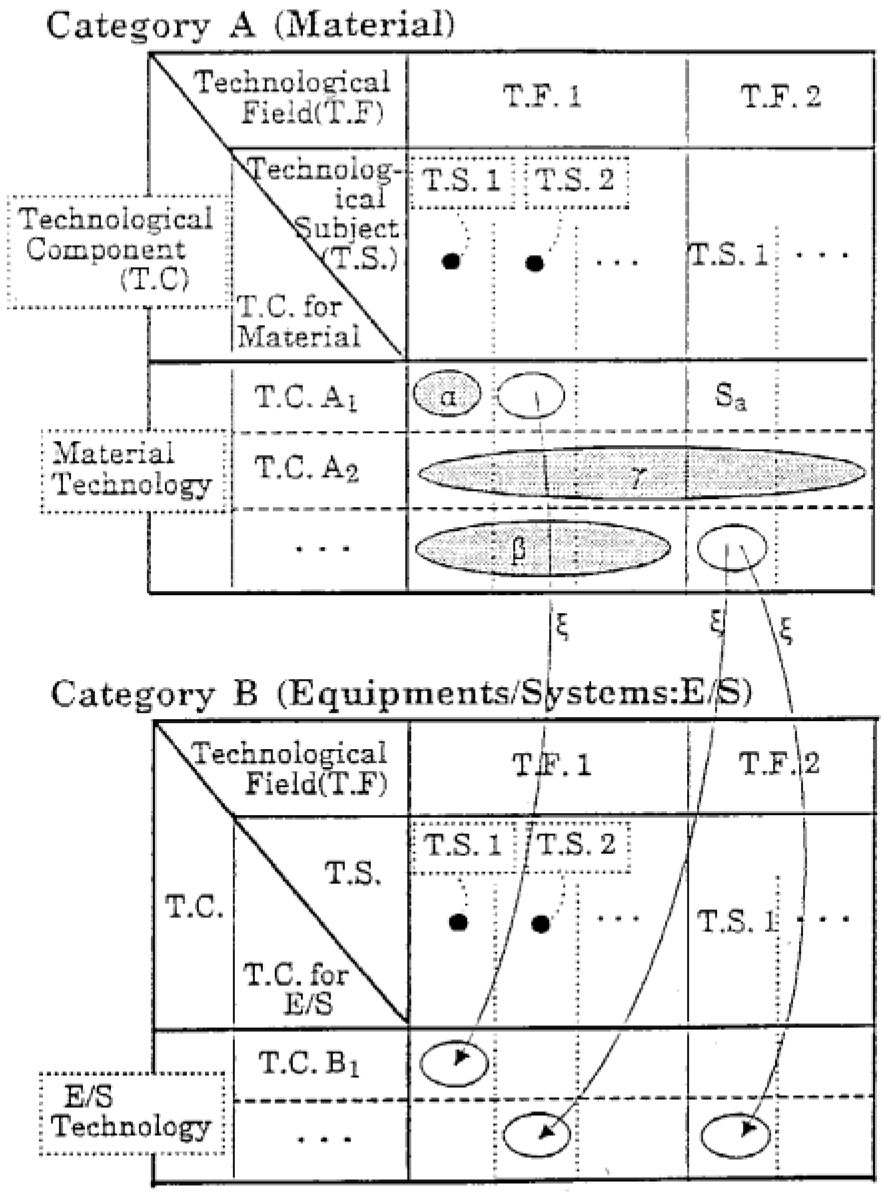

Fig.2 Knowledge patterns of technological categories and their relations

We will describe in Section 2.2 how to classify them.

Two types of *knowledge of category relations*, *knowledge of technological transfer* and *knowledge of technological level transfer*, are defined on category tables. The knowledge specifies the relations of possible propagation of technology classified in *subject-components*.

The *knowledge of technological transfer* specifies possible transfer of technology from a *subject-component* S_a to another S_b, where both S_a and S_b belong to the same T.C. (i.e. they are in the same row of a category table). It specifies the transfer due to the fact that they pertain to the common T.C. It is classified into three patterns of search for transfer as follows.

$S_a = S_b$:This pattern means that S_a and S_b are the same *subject-component* (e.g. α in Fig.2).

$S_a \approx S_b$:This pattern means that S_a and S_b are classified in the same technological component and belong to the same technological field (e.g. β in Fig.2).

$S_a \leftrightarrow S_b$:This pattern means that S_a and S_b are classified in the same technological component of a category (e.g. γ in Fig.2).

The more extensive the scope of search is, the less relevant the S's are and hence the less possibility of transfer is expected. However, as the scope extends, the search may result in finding unexpected transfer of technology. The *knowledge of technological transfer* does not specify the direction of the transfer, but it is effective for searching transfer of new technology of a project to others.

The *knowledge of technological level transfer* is knowledge of technological propagation beyond the scope of a category. It is determined by experts according to the kinds of technology to be evaluated. It specifies the relations of possible propagation of technology from a *subject-component* in a lower level category to another in a higher level category. The level of categories is derived by making use of some *knowledge of technological level transfer* . The technological propagation is directed from a lower level to a higher level.

$S_a \triangleright S_b$:This pattern means that S_a and S_b are classified in different categories, and technology in S_a of a lower level category can be used to develop that in S_b of a higher level category (e.g. ξ in Fig.2).

In Fig.2 Category A represents material technology and Category B represents equipments/systems technology. We referred to Ref.[7] to determine these categories for classifying energy-saving technology. We obtained the *knowledge of technological level transfer*

§ from Category A to Category B by referring to projects in Ref.[7]. Therefore, we specified that Category A is a lower level and Category B is a higher level: i.e. material technology is propagated and integrated in developing technology for equipments and systems.

The level of categories is basically specified by the *knowledge of technological level transfer* . There can be two methods, bottom-up method and top-down method for specifuing the level. The former method described above is suitable for evaluating a new developing field and for improving categories. The latter method determines the level of categories by accumulated technological knowledge (e.g. Ref.[7]). We can make full use of the Support System, when the level of categories is specified by the top-down method.

2.2 Project information and the Support System

Project information usually consists of the following items [e.g.3] : (i) applicable industries, (ii) purpose of the project, (iii) functions of the project, (iv) descriptions of required new technology, (v) goal to be achieved, (vi) effects of the project, (vii) schedule, (viii) risk, and (ix) estimated cost.

In this paper we pay attention to three items for evaluating synergistic relations of projects : technological barriers, technological effects and technological subject. As we have discussed in Section 2.1, technological barriers and technological effects are obtained as a part of (iv) and (vi), respectively.

We discuss how information and knowledge can be acquired and stored in the Support System. A user of the system obtains information on the technological subject of a project for classifying its purpose of development (a part of item (ii) above). When he inputs the information, he selects it from the technological subjects (T.S.) in a category table, which is stored in the knowledge-base of the system. He then classifies the technological barriers and the technological effects of the project to appropriate *subject-components* in the category table. The *subject-components* should correspond to the T.S. he has selected. Information on item (iii) above is useful for finding the T.C. corresponding to the *subject-components*. It often happens that he finds it difficult to classify the barriers and effects in the table. On this occasion, he appends a new T.S. or T.C. to the table which enables the classification. This operation extends the category table, and increases the *knowledge of* *category relations*. When the scope of a *subject-component* in the table is extensive and a number of subjects are classified in the slot, then they can be subdivided or organized by a network of technological relations[8]. These processes of modifying and updating the knowledge can be easily conducted by experts with the aid of the user interface and mechanisms of knowledge processing of the Support System.

The system outputs a network of technological effects of the projects by integrating the *knowledge on technological effects* with its mechanisms for knowledge processing (see Fig.1). It also constructs a network of category relations by integrating the *knowledge of category relations*. Furthermore, it integrates these networks for constructing a network of technological propagation among the projects. These networks can effectively support experts' judgments on the projects.

Integration of the knowledge on technological effects proceeds as follows. When an expert determines that a technological effect E_m of project Pm is equivalent to a technological barrier B_n of another project Pn (i.e. $E_m = B_n$), then *knowledge on technological effects* $Pm : B_m \rightarrow E_m$ and $Pn : B_n \rightarrow E_n$ are linked together. E_m is an effect of technology developed as a result of project Pm, and B_n is required to achieve the objective of project Pn. The Support System therefore obtains technological propagation from E_m to B_n. Thus we can obtain relations of technological propagation from project Pm to project Pn ($Pm \Rightarrow Pn$) . The new technology developed to overcome the technological barrier B_m of project Pm is transferred to another project Pn through the technological propagation to yield an indirect technological effect E_n. This inference provides us with the following basic propagation rule.

Basic propagation rule

Consider a project($Pm : B_m \rightarrow E_m$) and another project($Pn : B_n \rightarrow E_n$). If $E_m = B_n$, then we can obtain technological propagation between the projects($Pm \Rightarrow Pn$) by the transfer of E_m to B_n. As a result, we obtain the indirect effect $B_m \rightarrow E_n$.

We will extend this rule in Sections 3 and 4 to obtain networks of technological propagation.

We constructed two category tables for evaluating R & D projects for energy-saving technology. We referred to summary tables and project data in Ref.[7], and selected technological fields (T.F.), subjects (T.S.) and components (T.C.) to generate initial matrices for the category tables, which expressed initial *knowledge of category relations* and were stored in the knowledge-base of the Support System we implemented. We selected them to classify the technological barriers and the technological effects of the projects. We played the role of an expert for the field, and extended the initial matrices by modifying the knowledge-base as we classified the barriers and effects.

Table 1 Material Category

Category A (Material) barrier/effect

Technological Component (T.C.)	Technological Field (T.F.)		Natural Energy		Efficient utilization of Energy		Other
	T.C. for Material \ Technological Subject (T.S.)		solar heat utilization 101	. . .	waste heat utilization 103	. . .	100
material technology	(a) thermal storage material	latent heat	62/–		54/–		210/–
		other	60/–				
	(b) heat insulating material						82,96,98/–
	. . .		. . .	. . .	. . .		

Tables 1 and 2 show a part of the category table of material category and equipments/systems category, respectively, for classifying thermal-energy-saving technology. The upper and the lower part of a *subject-component* in the tables represent technological barriers and technological effects, respectively. A numeral in a *subject-component* indicates a project number, whose technological barrier/effect is classified in the slot. This number corresponds to the page of Ref.[3] in which the project is described. Table 3 is an example of the *knowledge of technological level transfer* from Table 1 to Table 2 (cf. ξ in Fig.2).

Table 2 Equipments/Systems Category

Category B (Equipments/Systems) barrier/effect

Technological Component (T.C.) \ Technological Field (T.F.)	Technological Subject (T.S.) / T.C. for equipments /systems	Natural Energy: solar air-conditioning 301	Natural Energy: solar power generation 302	Natural Energy: . . .	Efficient utilization of Energy: waste heat utilization 404	Efficient utilization of Energy: . . .
equipments /systems technology	. . .	. . .	. . .		. . .	
	(h) thermal storage equipments	56,58, 62 / 210	56, 62 / 210		56 / 210,250	
	. . .	. . .	. . .		. . .	

Table 3 Knowledge of technological level transfer [†]

$S_a \rhd S_b$

Category A (material) Table 1	Category B (equipments/ systems) Table 2
101a 103a	301h 302h
101b	302h
. . .	. . .

We will construct a network of technological propagation by applying the *knowledge of category relations* to Tables 1 and 2, and by using mechanisms of the Support System for knowledge processing based on the rules for technological propagation, which will be discussed in Sections 3 and 4. These rules were obtained to evaluate synergy of 35 projects,

[†] A pair of a number and an alphabet in Table 3 represents a *subject-component* S specified by the number representing T.S. and the alphabet representing T.C. in Table 1 or 2. For example, *subject-component* 101a in Table 3 stands for the *S* in Table 1 specified by T.S. 101 (solar heat utilization) and T.C. (a) (thermal storage material).

which are related to technology for saving thermal-energy and are selected out of more than 120 R & D projects[3].

3. Rules for technological propagation and their applications

In this section we extend the basic propagation rule in Section 2.2 by making use of the *knowledge of category relations*. We make use of the *knowledge of technological transfer* and the *knowledge of technological level transfer*, and define four propagation rules. We also present examples of their applications to energy-saving technology.

3.1 Propagation rule 1 : connection rule

Technological barriers and effects of an R & D project are classified and stored in category tables, hence technology of the project is contained in *subject-components*. Therefore we can replace the linkage condition $E_m = B_n$ in the basic propagation rule with the condition $S_a = S_b$, where $E_m \in S_a$ and $B_n \in S_b$, to obtain the new propagation rule below; i.e. when effect E_m and barrier B_n belong to the same *subject-component*, possibility of propagation of E_m to B_n is inferred. The technological barrier and effect classified in the same *subject-component* have something technologically in common, because their subject is the same and they pertain to the same technological component. Therefore we can expect possibilities of propagation of new technology developed in one project to another. In the basic propagation rule, an expert judges whether effect E_m and barrier B_n are the same technology. By the replaced condition, the Support System can examine the linkage through category tables, provided the expert properly classifies them in *subject-components*. Thus this new rule is more flexible for evaluating technological propagation.

Propagation rule 1 : connection rule for technological effect and barrier
Consider two projects $Pm{:}B_m \rightarrow E_m$ and $Pn{:}B_n \rightarrow E_n$, where $E_m \in S_a$ and $B_n \in S_b$. If $S_a = S_b$ (the same subject-component), then we can obtain technological propagation between the projects ($Pm \Rightarrow Pn$) by the transfer of E_m to B_n. As a result, we obtain the indirect effect $B_m \rightarrow E_n$.

≪ Example 1 ≫ ——————————————

We consider *subject-component* 302h (solar power generation ⊗ thermal storage equipments) as $S_a(=S_b)$ in Table 2.

The following projects are related to S_a.

P58 : energy self-reliant housing system

P62 : thermal storage tank of solar energy

P210 : thermal storage equipment for power generation

Because technological effect of P210,

E_{210} : thermal storage of solar heat

and technological barriers of P58 and P62.

B_{58} : thermal storage systems

B_{62} : highly efficient thermal storage tanks

are all classified in 302h(S_a) in Table 2.

Now using Propagation rule 1, we obtain the possibility of technological propagation from Project P210 to Projects P58 and P62.

3.2 Propagation rule 2 : transfer rule

We extend Propagation rule 1. We use the *knowledge of technological transfer* ($\mathbf{S_a} \approx \mathbf{S_b}$, $\mathbf{S_a} \leftrightarrow \mathbf{S_b}$) for the linkage condition to yield a new rule. This extension enables us to evaluate technological transfer of broader scope than Propagation rule 1.

Propagation rule 2 : transfer rule for technological effect and barrier
Consider two projects $Pm{:}B_m \rightarrow E_m$ and $Pn{:}B_n \rightarrow E_n$, where $E_m \in S_a$ and $B_n \in S_b$. If $S_a \approx S_b$ or $S_a \leftrightarrow S_b$, then we can obtain technological propagation between the projects ($Pm \Rightarrow Pn$) by the transfer of E_m to B_n. As a result, we obtain the indirect effect $B_m \rightarrow E_n$.

≪ Example 2 ≫ ——————————————

We use the *knowledge of technological transfer* $S_a \leftrightarrow S_b$. We consider *subject-component* 404h (waste heat utilization ⊗ thermal storage equipments) as S_a, and 301h (solar air-conditioning ⊗ thermal storage equipments) as S_b, in Table 2.

The following projects are related to S_a and S_b.

P56 : integrated housing energy system

P58 : energy self-reliant housing system

P62 : thermal storage tank of solar energy

P210 : thermal storage equipment for power generation

P250 : thermal storage system based on chemical reactions

Because technological effect E_{250} is classified in 404h ($E_{250} \in S_a$), and technological barriers B_{56}, B_{58} and B_{62} are classified in 301h ($B_{56} \in S_b$, $B_{58} \in S_b$, $B_{62} \in S_b$) in Table 2.

Now using Propagation rule 2, we obtain the following result through the *knowledge of technological transfer* ($S_a \leftrightarrow S_b$) : technological propagation is possible from Project P250 to Projects P56, P58 and P62.

3.3 Propagation rule 3 : level transfer rule

Propagation rules 1 and 2 in the preceding sections extend the scope of the linkage condition based on the *knowledge of technological transfer*. In this section and next, we utilize the *knowledge of technological level transfer*. We consider a rule for finding possible technological propagation between categories of different levels by making use of the knowledge.

Propagation rule 3 : level transfer rule for technological effect and barrier

Consider two projects $Pm : B_m \rightarrow E_m$ and $Pn : B_n \rightarrow E_n$, where $E_m \in S_a$ and $B_n \in S_b$. If $S_a \triangleright S_b$, then we can obtain technological propagation between the projects ($Pm \Rrightarrow Pn$) by the transfer of E_m to B_n. As a result, we obtain the indirect effect $B_m \rightarrow E_n$.

The direction of transfer due to this rule is determined by the knowledge of the level transfer as well as the basic technological propagation ($E_m - B_n$). The level transfer relation contributes to firmly determining the direction of transfer. Consequently, we have a firm direction of transfer as compared with the results of Propagation rules 1 and

2.

3.4 Propagation rule 4 : extended level transfer rule

In this section we consider a combination of linkage conditions of the preceding propagation rules. We have applied *knowledge of category relations* individually in Sections 3.2 and 3.3. Combination of the knowledge enables us to extend the scope of search for possible technological propagation. Here we derive a new rule by combining the linkage conditions in Propagation rules 2 and 3.

Propagation rule 4 : extended level transfer rule for technological effect and barrier

Consider two projects $Pm:B_m \rightarrow E_m$ and $Pn:B_n \rightarrow E_n$, where $E_m \in S_a$ and $B_n \in S_b$. If $S_a \approx S'_a$, $S_b \approx S'_b$ and $S'_a \triangleright S'_b$, then we can obtain technological propagation between the projects ($Pm \Rightarrow\!\!\!> Pn$) by the transfer of E_m to B_n. As a result, we obtain the indirect effect $B_m \rightarrow E_n$.

The search in this rule proceeds as follows. The first step involves the linkage condition of Propagation rule 2, which depends on the *knowledge of technological transfer* in a category ($S_a \approx S_b$). The next step is equivalent to the condition of Propagation rule 3, which depends on the *knowledge of technological level transfer* ($S'_a \triangleright S'_b$). In the third step, the search proceeds in the same manner as the first step in a category of higher level.

Propagation rules 1 through 4 in this section are useful for finding possibilities of technological propagation, which are not always evident even to experts of technology. The basic process of the evaluation depends on inferences based on the *knowledge of category relations* (*knowledge of technological transfer* and that of *technological level transfer*). The knowledge can also be used for finding technological effects through analogy of patterns of technological barriers and effects among projects[8].

4. Rules for technological propagation based on barrier relations

In this section we investigate possibilities of finding technological propagation by focusing on relations among technological barriers of various projects. There exist plans for a diversity of R & D projects; those for developing entirely new technology, those for integrating or improving conventional technology. Therefore, although technological barriers obtained as project information are carefully and concretely examined, technological effects may be considered in terms of abstract keywords. Consequently, we sometimes find it difficult to analyze technological barriers and technological effects on an equal level of abstraction. In the following we investigate propagation rules of technological barriers for such situations.

A technological barrier can be regarded as its minimum effect, because it is a target of a project and can be transferred for other purposes when it is overcome. Hence we obtain the following general formula based on technological barriers by modifying the formula expressed by (1).

$$Pn : Bn_1, Bn_2, ..., Bn_i \rightarrow Bn_1, Bn_2, ..., Bn_i \qquad (i \geq 1) \quad \cdot \cdot \cdot \quad (2)$$

where Pn denotes Project n, Bn_i denotes its i-th technological barrier. In (2), a technological barrier corresponds to its technological effect. This formula generates the propagation rules which replace the basic relational structure A for Propagation rules 1 through 4 with the relational structure B, as shown in Fig.3.

This new structure does not specify the unilateral propagation, 'Technological Effect → Technological Barrier', as the direction of propagation, but the direction is bilateral. The relation enables us to find R & D projects that are technologically relevant to a project, hence it provides effective information for evaluating effects of the project. When we take account of a direction of technological propagation by using the *knowledge of technological level transfer*, then the Support System can specify directed propagation of technology.

In the following we define four propagation rules based on the general formula (2).

4.1 Propagation rule 5 : barrier connection rule

Under the general formula (2), we obtain a rule for connecting technological barriers by using the same linkage condition as Propagation rule 1.

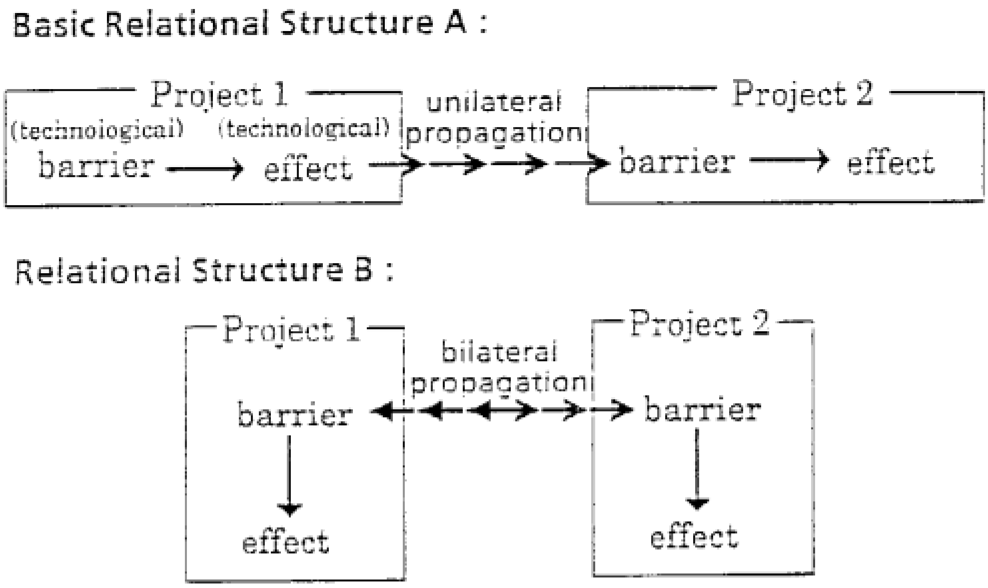

Fig.3 Two relational structures of technological propagation

Propagation rule 5 : barrier connection rule of technological barriers

Consider two projects $Pm:B_m \rightarrow E_m$ and $Pn:B_n \rightarrow E_n$, where $B_m \in S_a$ and $B_n \in S_b$. If $S_a = S_b$ (the same subject-component), then we can obtain bilateral technological propagation between the projects ($Pm \leftrightarrow Pn$).

This rule enables us to infer that new technology to overcome barrier B_m may be propagated to overcome barrier B_n, and vice versa.

≪ Example 3 ≫ ——————————————

We consider *subject-component* 301h (solar air-conditioning ⊗ thermal storage equipments) as S_a $(= S_b)$ in Table 2.

Technological barriers of the Projects P56, P58 and P62, which we have considered in Example 2, are classified in this subject, i.e. $B_{56} \in S_a$, $B_{58} \in S_a$, $B_{62} \in S_a$.

Now using Propagation rule 5, we obtain the possibility of bilateral technological propagation among Projects P56, P58 and P62.

Propagation rule 5 enables an expert to find projects that have similar technological barriers, hence the Support System can support him in creating and planning a new project whose objective is to overcome a barrier which is common to the barriers. This information is another effective output of the system for evaluating R & D projects.

4.2 Propagation rule 6 : barrier transfer rule

We use the *knowledge of technological transfer* ($S_a \approx S_b, S_a \leftrightarrow S_b$) as linkage conditions of bilateral propagation of broader scope.

Propagation rule 6 : barrier transfer rule of technological barriers

Consider two projects $Pm : B_m \rightarrow E_m$ and $Pn : B_n \rightarrow E_n$, where $B_m \in S_a$ and $B_n \in S_b$. If $S_a \approx S_b$ or $S_a \leftrightarrow S_b$, then we can obtain bilateral technological propagation between the projects ($Pm \leftrightarrow Pn$).

This rule extends the scope of search of Propagation rule 5.

4.3 Propagation rule 7 : level transfer rule of barriers

We use the *knowledge of technological level transfer* ($S_a \triangleright S_b$) instead of the linkage conditions of Propagation rule 6. This knowledge determines the direction of transfer between technological barriers.

Propagation rule 7 : level transfer rule of barriers.

Consider two projects $Pm : B_m \rightarrow E_m$ and $Pn : B_n \rightarrow E_n$, where $B_m \in S_a$ and $B_n \in S_b$. If $S_a \triangleright S_b$, then we can obtain technological propagation between the projects ($Pm => Pn$) based on the direction of transfer between categories of different levels.

Propagation rule 7 is an effective rule that determines the direction of transfer.

≪ Example 4 ≫ ————————————————

We consider *subject-component* 103a (waste heat utilization ⊗ thermal storage material) in Table 1 as S_a, and 301h (solar air-conditioning ⊗ thermal storage equipments) in Table 2 as S_b.

For these S_a and S_b we obtain the relation $S_a \triangleright S_b$ from Table 3, which expresses the knowledge of technological level transfer.

Projects P56, P58 and P62, which we have considered in Example 2, and

P54 : thermal storage system for regional air-conditioning

are related. because in Table 1. barrier

B_{54} : development of latent heat material $\in S_a$.

and in Table 2,

barriers $\{B_{56}, B_{58}, B_{62}\} \in S_b$.

Now using Propagation rule 7,we obtain the possibility of technological propagation from Project P54 to Projects P56, P58 and P62.

4.4 Propagation rule 8 : extended level transfer rule of barriers

In this section, we consider a combination of the linkage conditions of the preceding propagation rules. This rule not only extends the scope of search for relevant technology, but also determines the direction of transfer.

> **Propagation rule 8 : extended level transfer rule of barriers**
>
> *Consider two projects $Pm : B_m \rightarrow E_m$ and $Pn : B_n \rightarrow E_n$, where $B_m \in S_a$ and $B_n \in S_b$. If $S_a \approx S'_a$, $S_b \approx S'_b$ and $S'_a \triangleright S'_b$, then we can obtain technological propagation between the projects ($Pm => Pn$) based on the direction of transfer between categories of different levels.*

≪ Example 5 ≫ ——————————————

We consider *subject-component* 100b (other ⊗ heat insulating material) as S_a and 101b (solar heat utilization ⊗ heat insulating material) as S'_a in Table 1, and 301h (solar air-conditioning ⊗ thermal storage equipments) as S_b and 302h (solar power generation ⊗ thermal storage equipments) as S'_b in Table 2.

We obtain the relations $S_a \approx S'_a$ and $S_b \approx S'_b$ in Table 1 and Table 2, respectively, and the relation $S'_a \triangleright S'_b$ from Table 3.

Projects P56, P58 and P62, which we have considered in Example 2, and the following projects are related.

P82 : high performance heat insulating material for refrigerators

P96 : high temperature cooker with vacuum heat insulation

P98 : electrically controlled high pressure cooker

Because in Table 1,

barriers $\{B_{82}, B_{96}, B_{98}\} \in S_a$.

and in Table 2,

barriers $\{B_{56}, B_{58}, B_{62}\} \in S_b$.

Now using Propagation rule 7, we obtain the possibility of technological propagation from Projects P82, P96 and P98 to Projects P56, P58 and P62.

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5. Summary

Table 4 summarizes the propagation rules defined in Sections 3 and 4. The scope of search for possible propagation extends step by step from Propagation rule 1(5) to Propagation rule 4(8) with the scope of the corresponding *knowledge of category relations* tabulated in Table 4a.

These rules generate a network of technological propagation. Fig.4 illustrates the network obtained by the examples presented in the sections. It shows a part of the network we have obtained by evaluating 35 projects, and illustrates relations of technology for thermal storage.

Arrows and dotted-lined arrows in Fig.4 indicate the technological propagation obtained by Propagation rules 1 and 2. Dotted frames encircle projects related by bilateral propagations obtained by Propagation rules 5 and 6, where attached keywords indicate the T.C. common to the barriers of the projects. Double-lined arrows indicate transfer obtained by Propagation rule 8. Applications of the rules have been limited to 35 projects, but we have obtained effective information from the network on possible propagation of technology and synergy among the projects. For example, in Fig.4 we can find that new technology based on chemical reactions developed in Project P250 can not only be used for thermal storage functions (indicated by arrows) but also for heat transport (indicated by dotted-lined arrows). Fig.4 also shows explicitly various types of thermal storage equipments benefited by the technology. Furthermore, double-lined arrows indicate the possibility of propagation of technology for heat insulating material from Projects P82,

Table 4 Relations of technological propagation rules

propagation rule based on the basic pattern

propagation rule No	propagation rule Name	result	reasons for directing the propagation
1	connection rule	$Pm \rightarrow Pn$	reason A
2	transfer rule	$Pm \rightarrow Pn$	reason A
3	level transfer rule	$Pm \Rightarrow Pn$	reason A and reason B
4	extended level transfer rule	$Pm \Rightarrow Pn$	reason A and reason B

propagation rule based on barrier relations

propagation rule No	propagation rule Name	result	reasons for directing the propagation
5	barrier connection rule	$Pm \leftrightarrow Pn$	reason C
6	barrier transfer rule	$Pm \leftrightarrow Pn$	reason C
7	level transfer rule of barriers	$Pm \Rightarrow Pn$	reason B
8	extended level transfer rule of barriers	$Pm \Rightarrow Pn$	reason B

reason A : unilateral propagation from effect to barrier
reason B : knowledge of technological level transfer
reason C : bilateral propagation

Table 4a

knowledge of category relations

knowledge of technological transfer	knowledge of technological level transfer
$S_a = S_b$	—
$S_a \approx S_b$ $S_a \leftrightarrow S_b$	—
—	$S_a \triangleright S_b$
$S_a \approx S_a'$ $S_b \approx S_b'$	$S_a' \triangleright S_b'$
$S_a \approx \triangleright \approx S_b$	

Pm, Pn : Project

S_a, S_b : subject-component

P96, P98 and P54 to Projects P56, P58 and P62 for developing efficient thermal storage equipments.

Although the Support System indicates possibilities of technological propagation as in

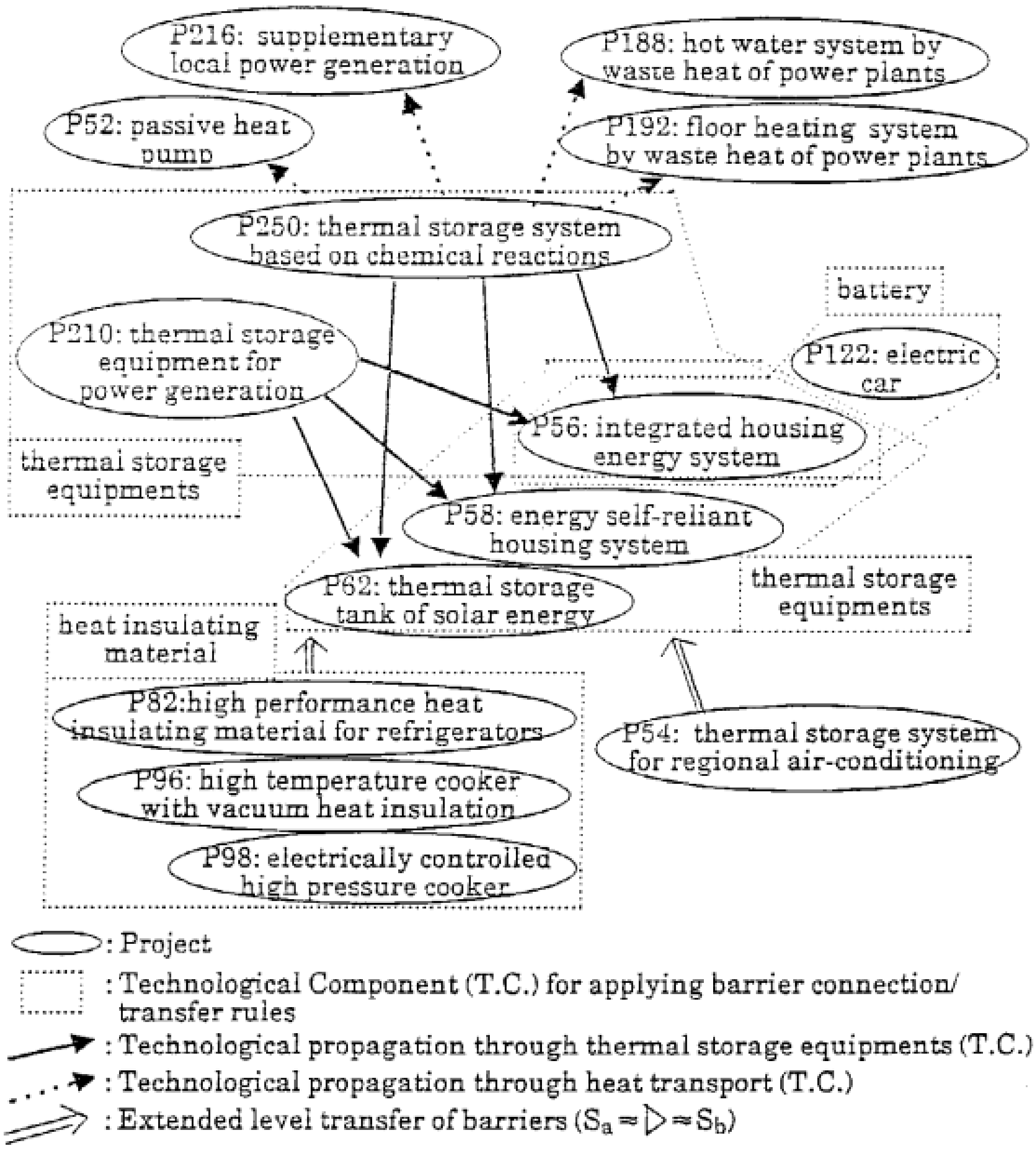

Fig.4 Network of technological propagation (a part)

Fig.4, its outputs include not only relevant and useful information for experts' evaluation of R & D projects but also irrelevant relations or those obvious to the experts. The relevance and usefulness of the outputs largely depend on its knowledge-base of the *knowledge of category relations*. When the knowledge-base reflects the experts' knowledge structure and is supplemented by the knowledge of technological trends in the field of evaluated technology, it can support their jugments effectively. We should note that as the scope of linkage conditions broadens from Propagation rule 1 (5) to Propagation rule 4 (8), it will output more irrelevant relations. Its outputs, however, may contain useful relations which experts can not immediately expect without its support.

For the limited number of projects and a small knowledge-base we obtained various results effective for evaluating R & D projects. When the Support System expands its knowledge-base and information on more projects, it will provide remarkable supporting capabilities for such evaluation.

6. Concluding Remarks

In Section 2 we have described the framework and the Support System for evaluating technological propagation and synergy among R & D projects. The system outputs networks of technological propagation from input information on the projects and a knowledge-base of the *knowledge on technological propagation* by inferencing with its mechanisms for knowledge processing. In Sections 3 and 4, we have defined the propagation rules for evaluating technological propagation based on the *knowledge of category relations*. Its knowledge-based framework can not only be utilized for evaluating R & D projects but also for other types of evaluations using knowledge-bases.

We have proposed the category table for classifying technology as the fundamental framework for the mechanisms of knowledge processing. Provided that projects' technology(barriers and effects) is properly classified in the table, the system can output effective information for evaluating the projects by appling the *knowledge of category relations*. An expert must classify project information(technological barriers and effects) to *subject-components*. We have implemented a Support System with flexible input/output interfaces which make it easy for him to manipulate category tables in the form of a knowledge-base. However, we must improve the supporting function of the system for classifying the project information.

Future research is envisaged in this direction. Another area requiring research is the methodology for integrating project information other than technological barriers and effects, such as cost, direct benefits, risk and schedule of R & D projects.

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