JPRS-JST-88-020
14 SEPTEMBER 1988

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7TH ARTIFICIAL INTELLIGENCE SYMPOSIUM

JPRS-JST-88-020
14 SEPTEMBER 1988

SCIENCE & TECHNOLOGY

JAPAN

7th ARTIFICIAL INTELLIGENCE SYMPOSIUM

[Selections from the 7th Artificial Intelligence Symposium held in Tokyo 22-23 Mar 88]

43063809 Tokyo DAINANAKAI CHISHIKI KOGAKU SYMPOSIUM in Japanese 22-23 Mar 88

CONTENTS

Problems in Structuring Large-Scale Expert System

43063809a Tokyo DAINANAKAI CHISHIKI KOGAKU SYMPOSIUM in Japanese
22-23 Mar 88 pp 1-6

[Article by Shigenbu Kobayashi, Tokyo Institute of Technology, and Katsuhiko Yui and Masaharu Moritani, Nippon Steel Corp.: "Analysis of Problem Characteristics and Problem-Solving Functions"]

[Excerpt] The problems in regard to an expert system are largely divided into analysis and synthesis types. An analysis type problem is one in which, given the construction of a system and the features of its subsystem, the system's features are inferred. On the other hand, a synthesis type problem is one in which, given the features of a system, the system construction and its subsystem's features are inferred so that they can be realized. Generally speaking, given the construction of a system and its subsystem's features, there is only one choice for the system's features, whereas given the system's features, the choices for the subsystem features and system construction are infinite. Herein lies the basic difficulty in synthesis type problems. With the exception of sorting and diagnostic problems, which are relatively simple, with rather complicated analysis type problems, several constraints must be satisfied, and how to overcome the problem of an exponential number of combinations is regarded as a primary theme.

A synthesis type problem is inherently combinative in nature. The most general approach to synthesis type problems is the generate and check method, which involves generating a temporary construction of a system, obtaining the features of the system through analysis, and searching for an optimum system by conducting repeated evaluations. This method is also referred to as synthesis by analysis. In this sense, it can be said that synthesis type problems involve analysis.

In the engineering field, analysis and synthesis problems are subdivided as follows:

Analysis problems:

1) Interpreting problem: analyzing data observed through instrumentation or a sensor, inferring the system's condition and thereby providing it with physical characteristics.

2) Diagnostic problem: identifying the causes of an anomaly or failure in the system utilizing causal relationships between the data observed and the system or knowledge on the intended model.
3) Control problem: monitoring the system's condition and controlling the system so as to allow its condition to remain as predesigned.

Synthesis problems:

1) Schedule problem: systematizing the actions available in order to realize a given target.
2) Design problem: combining the components of the system in order to realize the requirement specifications of the system's input and output when they are provided and to decide on the internal specifications of each component.

Table 1 shows the features, basic tasks and problem-solving functions with regard to individual problems. As is apparent from the table, there is a greater difference in the types of tasks and relevant problem-solving functions required for analysis type problems from those required for synthesis type problems. In analysis type, it is clear that the approach to interpreting problems must be different from that to control problems. Incidentally, care should be taken to ascertain that the actual problems are combinations of the typical ones shown in Table 1.

A great number of tools have so far been developed and utilized to support the structuring of expert systems. These tools, however, offer universal mechanisms, not dependent on the construction of areas at issue in their expression and utilization of knowledge, in pursuit of versatility. It should be recognized that for this reason, these mechanisms offer only knowledge expression and problem-solving ability at very low levels, thus placing a very heavy burden on knowledge engineers.

To fill this gap, it is necessary to summarize the basic tasks and problem-solving functions extracted from each problem area in the form of package libraries available for general purposes and utilize them in combination as required.

Table 1. Features, Basic Tasks, and Problem Solving-Functions in Individual Problem Areas

Feature	Basic task	Problem-solving function
Analysis Type Problem		
Interpreting problem		
1. Higher-order correlation between time and space data	1. Extraction of features	1. Classification of hierarchy
2. Presence of noise	2. Imperfect collation with model	2. Model retrieval function
3. Presence of errors	3. Identification of system construction	3. Evaluation function for partial construction
4. Lack of necessary data	4. Inference of system conditions	4. Hierarchical generate and check method
5. Connection with signal processing technology	5. Processing of ambiguity	5. Inference of uncertainty
6. Utilization of object models	6. Processing of imperfection	6. Inference of hypotheses
7. Handling sensory data	7. Variety of interpreting	7. Cooperative inference
Diagnostic problem		
1. Utilization of design-level knowledge	1. Hierarchical expression of abnormal phenomena	1. Phenomenon driven inference
2. Utilization of experiential knowledge	2. Hierarchical expression of system construction	2. Target driven inference
3. Uncertainty of experiential knowledge	3. Involving tasks for interpreting problems	3. Inference of uncertainty
4. Utilization of operating data	4. Selective decision of measuring points	4. Inference of hypotheses
5. Time and cost for instrumentation	5. Identification of causes of anomalies	5. Cooperative inference
6. Necessity of abstraction of knowledge	6. Efficiency by shallow models	6. Harmony between efficiency and perfection
7. Inference control of interactive diagnoses	7. Perfection of deep models	7. Cost/effect analysis

[continued]

[Continuation of Table 1]

Feature	Basic task	Problem-solving function
[Continuation of Analysis Type Problem]		
Control problem		
1. Hysteresis dependency due to time lag 2. Locality due to non-linearity 3. Responsibility for stabilization 4. Realization of control accuracy 5. Connection with real process 6. Connection with real time 7. Analytic problems in the discrete system	1. Expression of system construction 2. Expression of system's dynamic features 3. Involving tasks for diagnostic problems 4. Prediction of conditions using models 5. Priority execution of stabilizing operation 6. Energy saving on stable operation 7. Operator guidance	1. Condition diagnosis 2. Prediction using a simulator 3. Prediction by stable inference 4. Multiobjective evaluation of the control law 5. Action guidance 6. Deadlock analysis 7. Interlock avoidance
Synthesis Type Problem		
Schedule Problem		
1. Very wide area to be searched 2. Variety of evaluation attributes 3. Uncertain environmental prediction 4. Interaction between partial schedules 5. Reutilization of existing schedules 6. Cost-benefit trade-off 7. Requests for support for generating interactive schedules	1. Hierarchization of planning process 2. Combined search 3. Interaction between constraints 4. Environmental prediction 5. Intellectual regression to higher-order level 6. Retrieval and utilization of scheduled examples 7. Variety in planning evaluations	1. Top-down precision strategy 2. Constraint minimization strategy 3. Comprehensive search function 4. Intellectual search through inference of hypotheses 5. Utilization of planning examples through analogical inference 6. Multiobjective evaluation of planning 7. Decisionmaking under risks

[continued]

[Continuation of Table 1]

Feature	Basic task	Problem-solving function
[Continuation of Synthesis Type Problem]		
Design problem		
1. Large area for system construction 2. Basic synthesis through analyses 3. Necessity of optimizing components 4. Completeness of verification 5. Efficiency in verification 6. Support forms responsive to design phases 7. Request for support for interactive design	1. Expression of components and relevant items 2. Hierarchical expression of design problems 3. Automatic generation of alternatives 4. Evaluation of partial system 5. Intellectual regression to high-order levels 6. Retrieval and utilization of scheduled examples 7. Parallel problem solution	1. Top-down precision strategy 2. Constraint minimization strategy 3. Optimizing function 4. Verifying function 5. Intellectual search through inference of hypotheses 6. Utilization of design examples through analogical inference 7. Cooperative inference

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Method of In-Depth Knowledge Expression in Process Design

43063809b Tokyo DAINANAKAI CHISHIKI KOGAKU SYMPOSIUM in Japanese
22-23 Mar 88 pp 7-12

[Article by Hideo Fujimoto, Nagoya Institute of Technology, and Hidehiko Yamamoto, Toyoda Automatic Loom Works, Ltd.: "In-Depth Knowledge Expression; Process Design of Expert System Using In-Depth Knowledge"]

[Text] **1. Introduction**

When a new production line project is formulated, production engineers undertake activities preparatory to production such as production equipment design. The process design in this phase involves utilizing properly the knowledge acquired during several years of operational experience, including such features as the names of processing-equipment and machine-tool manufacturing firms (equipment makers) and processing conditions, and then deciding on the process, the equipment makers, and the machine types. A process design expert system[1] for shaft-shaped parts has been developed as an application of such process design to knowledge engineering. The knowledge expression used in this system is mainly the frame type, with the individual frames listing in a hierarchical manner in descending order the names of the process, the equipment maker, and the machine type. One disadvantage of a system based on such knowledge expression is that its problem-solving ability can be displayed only for specific problems. To solve this problem, an inference becomes necessary that is based on an in-depth system involving interference while conjecturing models of the system's construction and functions. To do this, an object model[2] is expressed, representing a type of such models based on in-depth knowledge on the machine type, and studies are carried out using this knowledge not on the processing precision of the processing equipment but on its construction, and then a comprehensive evaluation is performed of a great number of items such as equipment cost, equipment area, service setup, and the technical ability and equipment delivery performance of the equipment maker. Such research conducted in order to obtain a process design expert system for shaft-shaped parts will be discussed.

2. In-Depth Knowledge Expression

For in-depth knowledge expression, an object model is expressed using frame type knowledge expression. An object model is expressed by breaking the

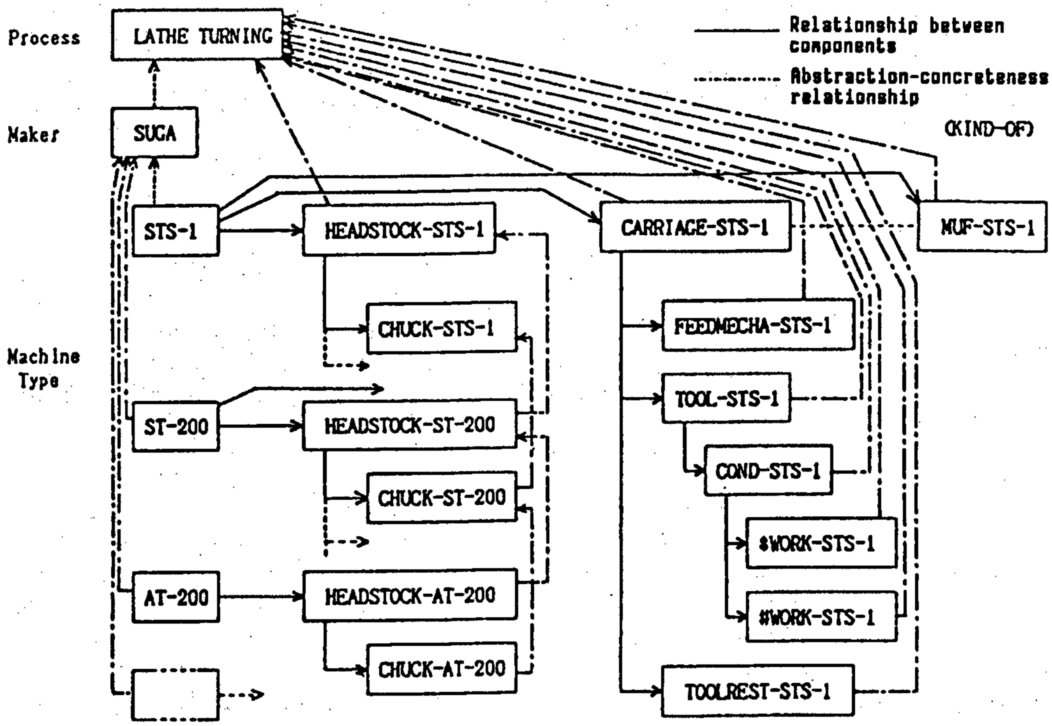

Figure 1. In-Depth Knowledge Expression

machine down into the mechanisms and functions of the machine for each machine type. The following is a description of a concrete example using a lathe, as shown in Figure 1. As is the case with a conventional process design expert system for shaft-shaped parts, the frames are constructed in a hierarchical manner in descending order of the names of the process, the equipment maker, and the machine type; the machine type that is at the bottom level of this hierarchical construction is expressed as an in-depth model obtained by breaking the machine down into mechanisms and functions. In Figure 1, solid-line arrows and broken-line arrows show the relationship between components and between abstraction and concreteness (KIND-OF). For instance, the machine type STS-1 consists of a headstock (HEADSTOCK-STS-1), carriage (CARRIAGE-STS-1), etc., and the degree of utility. Of these, the components other than the degree of utility are models obtained by breaking the machine down as to mechanisms, and the degree of utility is a model obtained by breaking it down as to functions. And the components of this mechanism can be broken down into smaller parts. The carriage, for example, is comprised of a feed mechanism (FEED-STS-1), a tool (TOOL-STS-1), and a tool rest (TOOLREST-STS-1). In addition, the tool can be described in further detail as being comprised of processing conditions (COND-STS-1) in terms of functions. In this way, knowledge description of commercial machine types ST-200 and AT-200 can be described. In Figure 1, the machine types STS-1, ST-200, AT-200, etc., are arranged in descending order, which is very important; i.e., these machine types are arranged in ascending order of newness. In other words, the basic machine that equipment maker Suga Ironworks sells is STS-1, and ST-200 and AT-200 have been developed based on it. The latter two are considered types that have been evolved from the original, and a concept of abstraction-concreteness relationship can also be applied to in-depth knowledge obtained by breaking the machine down into mechanisms and functions. Namely, the construction frames of STS-1's in-depth knowledge, including HEADSTOCK-STS-1, CARRIAGE-STS-1, etc., and the construction frames, including CHUCK-STS-1, FEEDMECHA-STS-1, TOOL-STS-1, etc., are regarded as superordinate concepts, while the construction frames of ST-200's in-depth knowledge, including CHUCK-ST-200, etc., are regarded as subordinate concepts to the above, followed by the construction frames of AT-200 which are regarded as subordinate to the latter concepts. The turning (LATHE TURNING), the process name, is ranked at the top of these concepts. The application of the abstraction-concreteness relationship to the frames obtained by breaking the machine down as to its individual mechanisms and functions permits separate descriptions of feature knowledge--feature knowledge of the up-to-date machine type AT-200 only in AT-200's construction frames and that derived from the base model in the base machine. Expressing knowledge in this way not only enables an inheritance concept of the knowledge to be used, but it shortens the length of programs, makes the complicated object of the machine tool relatively simple in terms of concept, and facilitates the grasping of knowledge.

The following is a description of a retrieval method of values for in-depth knowledge. The method involves regarding this knowledge as a cause-effect network using a tree construction, with the individual construction frames as its nodes and relationships between components (indicated by solid-line arrows in Figure 1) as its arcs, conducting cross retrieval[3] whereby after retrieving every high-level node the subsequent lower level ones are retrieved, and thus going down to in-depth knowledge until the values are retrieved. For the retrieval of a value of the machine type STS-1, for example, construction frames such as HEADSTOCK-STS-1, CARRIAGE-STS-1, etc., are retrieved first. If the value is not found in these frames, construction frames such as CHUCK-STS-1, FEEDMECHA-STS-1, TOOL-STS-1, etc., are retrieved. In this way, the retrieval is repeated on a descending basis. Of course, for retrieval within the individual component frames, additional procedure inference, which is the value retrieval method in conventional frame type knowledge expression, and retrieval inference using an inheritance concept are also conducted.

3. Process Design Expert System Using In-Depth Knowledge

3.1. Conventional Process Design Expert Systems

The process design expert system for shaft-shaped parts, whose development was described in a previous report, is aimed at deciding on the necessary process, the equipment maker capable of realizing it, and the type and number of units of the machine, while taking into consideration the processing precision and the processing time, using rule-type and frame-type knowledge expression, as shown in Figure 2. To decide on these items in reality, however, process designers study not only the process precision but also the contents of construction of the processing equipment, as well as a wide range of items including the price and area of the equipment, the service setup, and the technical ability and delivery performance of the

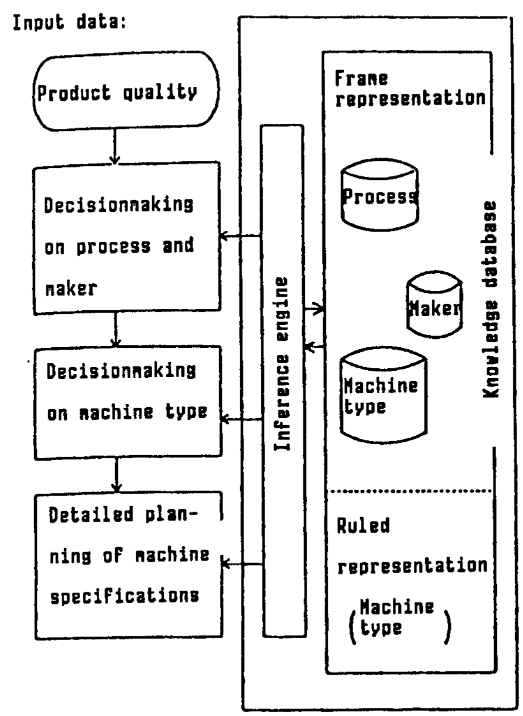

Figure 2. Process Design Expert System for Shaft-Shaped Parts

equipment maker. In such circumstances, through improving knowledge expression with in-depth knowledge expression, based on this process design expert system, an expert system permitting studies of the aforementioned wide-ranging items has been developed.

3.2. Process Design Expert System Using In-Depth Knowledge

The decision on the process based on the inference method of process design expert system using in-depth knowledge is made taking into consideration the processing precision, similar to that for a conventional process design expert system. Unlike the latter method, however, the consequent inference processing adopts the method of elimination involving setting temporary targets and eliminating them one by one when they are inappropriate through collating their processing precision and features of the machine construction. When the temporary targets are not eliminated with this method, they will be handled as multipurpose optimization problems having five items as an evaluation standard--the price and area of the equipment, the service setup, and the technical ability and delivery performance of the equipment makers--and one temporary target is decided using the multiple attribute utility theory.[4,5] The following is an example of the above using the process design of shaft-shaped parts.

As shown in Figure 3, based on the necessary product processing precision derived from user input information, the corresponding process and the equipment maker capable of realizing the process are retrieved and represented in the CRT. Next, the machine types this equipment maker sells

```
*************************************
Processes and makers have been retrieved
as follows**************************
      Process                    Maker
---------------------------------------------
      CENTERING =====>  SUGA      YACHIYODA
      SENSAKU   =====>  SUGA      SHOUN      STAR
      YAKIIRE   =====>  JEOL
      KENSAKU   =====>  KOYO      NIPPEI     MICRON
      S-KENSAKU =====>  SEIBU
---------------------------------------------
```

Figure 3. Example of Process Equipment Maker Retrieval and Representation

```
  ******************************************
  Machines being sold by above makers are
  represented below
  ******************************************
Process      Maker            Machine type
--------------------------------------------------
CENTERING =>  SUGA    => STS-1C
CENTERING =>  YACHIYODA=>*CE-70
SENSAKU   =>  SUGA    => STS-1      ST-200     AT-200
SENSAKU   =>  SHOUN   => MV-5
SENSAKU   =>  STAR    => JNC-25
YAKIIRE   =>  JEOL    => JTR-50
KENSAKU   =>  KOYO    => KC-200
***
KENSAKU   =>  NIPPEI  => CLG-2N-CNC
KENSAKU   =>  MICRON  => MD-600
S-KENSAKU =>  SEIBU   => RN-3000
--------------------------------------------------
```

Figure 4. Example of Machine Type Retrieval and Representation

are also retrieved and represented on the CRT, as shown in Figure 4. From hereon, the method of elimination is applied. Machine types STS-1C, *CE-70, and STS-1 are set as temporary targets, and the details are collated on such items as processing precision (including tolerances and surface roughness in outer diameter processing) and machine construction (including the feasibility of mounting parts judged on the basis of the machine feed mechanism and dimensions of each part), and thus inappropriate machine types are eliminated from among the temporary targets. Figure 5 is an example of this, whereby in order to ascertain the feasibility of mounting the total length of a work on machine types STS-1, ST-200, AT-200, MV-5, and JNC-25, which are the temporary targets in lathe turning, the length of the work is compared with the maximum distance between the two centers of the machine; machine type MV-5, wherein the maximum distance between the two centers is smaller than the work's total length, is thus eliminated.

```
##################################################
Machines for lathe turning
selected:----->      EVALUATE-QUALI ZEN-LNGTH-DATA
Total length of work compared with distance
between two centers of machine
##################################################
Process      Maker            Machine type
--------------------------------------------------
CENTERING =>  SUGA    => STS-1C
CENTERING =>  YACHIYODA=>*CE-70
SENSAKU   =>  SUGA    => STS-1      ST-200     AT-200
SENSAKU   =>  SHOUN   =>
SENSAKU   =>  STAR    => JNC-25
YAKIIRE   =>  JEOL    => JTR-50
KENSAKU   =>  KOYO    => KC-200
KENSAKU   =>  NIPPEI  => CLG-2N-CNC
KENSAKU   =>  MICRON  => MD-600
S-KENSAKU =>  SEIBU   => RN-3000
--------------------------------------------------
```

Figure 5. Example of Elimination Inference Result

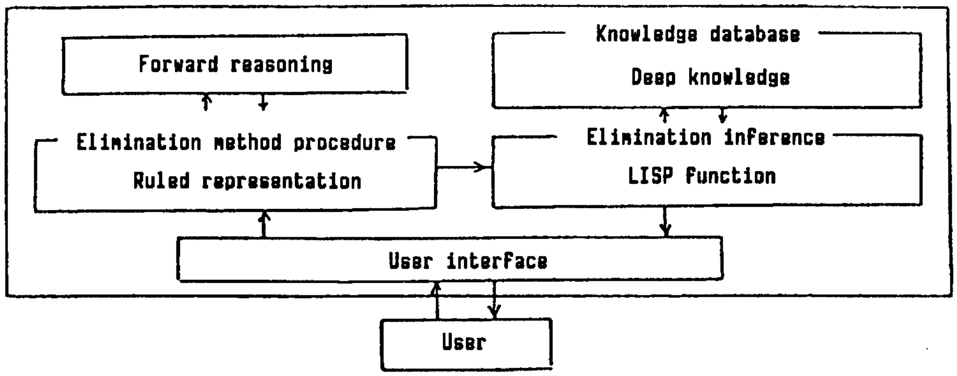

Figure 6. Drawing of Inference for Method of Elimination

```
(PROCEDURE: "Machines for lathe turning selected"
  (IF (SENSAKU))
  (THEN ((EVALUATE-QUALI SENSAKU-G-DATAS) (Lathes which satisfy outer diameter
        tolerance selected)
        ((EVALUATE-QUALI SENSAKU-A-DATAS) (Lathes which satisfy surface roughness
        selected)
        ((EVALUATE-QUALI ZEN-LNGTH-DATA)  (Total length of work compared with
        distance between two centers of the machine)

        ((MATCH-MECHA 'FEED-MECHA) (Is any feed mechanism specified?)
        "Enter desired number(s) from among 1. mechanical feed;  2. hydraulic
        feed; and  8. either 1 or 2."
        ((MATCH-MECHA 'SPOL-TYPE)  (Is headstock orientation specified?)
        "Enter desired number(s) from among  1. headstock, horizontal;
        2. headstock, vertical; and  8. either will do."
```

Figure 7. Description of Inference Procedure for Method of Elimination

Here is a description of inference by the method of elimination. In inference by this method, the inference procedure is expressed, as shown in Figure 6, in IF-THEN rule type knowledge, and concrete elimination inference described using LISP functions based on results inferred with forward reasoning is conducted. In this elimination, knowledge about the necessary machine types is invoked accordingly from the in-depth knowledge on the machine types to be processed. The result is represented for the user on the CRT, as shown in Figure 5. Figure 7 shows a concrete example of the inference procedure described with this rule type knowledge expression.

3.3. Application of Multiple Item Optimization To Deciding Machine Type

After a study of multiple items using the method of elimination, more than one temporary target of machine type remains without being eliminated. To select and decide on a single machine type from among several, let us consider evaluation objects other than machining precision and the construction of the processing equipment that are evaluated by the method of elimination. According to actual process designers, the objects to consider are the price and area of the equipment, the service setup, and the technical ability and delivery performance of the equipment maker. Each of these five items is important when processing equipment is actually purchased for productive operation in a factory. So, multipurpose optimization for the comprehensive evaluation of these five items becomes necessary. To find a solution to this multipurpose optimization problem, the multiple attribute utility theory can be applied.

Multiple attribute utility function can be formulated as (1) and (2):

$$U_\alpha) = \sum_{\alpha=1}^{m} k_\alpha \; u_\alpha(f_\alpha) \quad (\text{when } \Sigma\, k_\alpha = 1) \tag{1}$$

$$U_\alpha(f) = \{ \underset{\alpha=1}{\pi} (1 + k\; k_\alpha\; u_\alpha\; (f_\alpha)) - 1\} \;/k \quad (\text{when } \Sigma\, k_\alpha \neq \tag{2}$$

Where U_α is a utility function which takes the value (0, 10) with respect to attribute f_α and k_α is called a scale constant, permitting $0 < k_\alpha < 1$. A utility function can be formulated with expression (3)

$$U_\alpha(f_\alpha) = \frac{c_\alpha}{f_\alpha - a_\alpha} + b_\alpha \tag{3}$$

where a_α, b_α, and c_α are constants.

Here is an example of comprehensive evaluation using the utility functions of the five items--equipment price (CS), equipment area (AR), equipment maker's service setup (SR), equipment maker's technical ability (TC), and delivery performance (RC). First, with respect to the individual machine types, temporary targets, the best-level value f^*_α and the worst level value f°_α for the five items are retrieved from in-depth knowledge and calculated. In the case of equipment price, for example, the prices of the individual machine types of the temporary targets are retrieved, and f°_α, the difference between the maximum and minimum prices, and $f^*_\alpha = 0$ (because of f^*_α including the price difference ¥0) are set. With respect to those functions that cannot be quantitatively represented, such as the equipment maker's service setup, their level values have been set at f^*_α and f°_α by sorting them into several levels, as shown in Table 1. Table 2 shows the tolerance areas for each target function. When the values of f^*_α and f°_α occur at a probability of 50 percent, the system inquires of the user what value f_α is equivalent to and requests an answer, as follows:

(In the case of equipment price)

How much variation in price will you accept for its purchase?
Please enter the variation in price you will accept.

Table 1. Service Setup Levels

SR1:	Headquarters is located in K City.
SR2:	Headquarters is adjacent to K City.
SR3:	Sales office is located in K City.
SR4:	Sales office is adjacent to K City.
SR5:	Headquarters is located in a single prefecture.
SR6:	Sales office is located in a single prefecture.
SR7:	Headquarters is located in a prefecture adjacent to another.

The same inquiry is made for the other four items so as to obtain input data for each of them. Letting them be f_α and substituting f^*_α, f°_α, and $\hat{\bar{f}}_\alpha$ for expression (3) results in

$$1 = \frac{C_\alpha}{f^*_\alpha - a_\alpha} + b_\alpha \tag{4}$$

$$0 = \frac{C_\alpha}{f^\circ_\alpha - a_\alpha} + b_\alpha \tag{5}$$

$$\frac{1}{2} = \frac{C_\alpha}{\bar{f}_\alpha - a_\alpha} + b_\alpha \tag{6}$$

Table 2. Examples of Best and Worst Levels by Purpose

f_α	CS 万¥	AR %	SR	TC	RC
f^*_α	0	0	SR1	TC1	RC2
f°_α	300	40	SR5	TC6	RC5

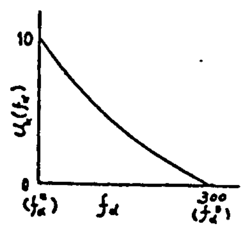

Figure 8. Utility Functions Vis-a-Vis Equipment Prices

By simultaneously solving equations (4), (5), and (6), a_α, b_α, and c_α can be obtained. Figure 8 provides an example of utility functions in relation to equipment prices. Next, scale constant k_α is to be found. Since scale constant k_α indicates the degree of importance between individual purposes, a percentage for the degree of importance is set for each of the five purposes in selecting the machine type. For this, inquiries are made of the user about the degree of importance of individual purposes. Since one hundredth of the input data is the value k_α and Σk_α equals q, a multiple attribute utility function value can be computed using expression (1) for each temporary target. Figure 9 provides an example of this. The temporary target with the greatest multiple attribute utility function value is finally selected to determine the machine type.

The above processing for each process results in a combination of the process, the equipment maker and the machine type. The number of machines is decided on the basis of machining conditions, etc., similar to a conventional process design expert system. Figure 10 provides an example of the system's final output.

```
****************************************************
Degree of importance of each machine's
evaluation value shown
****************************************************
```

Machine type	CS	AR	SR	TC	RC	Comprehensive evaluation value
*CE-70	10	3	5	12	10	+0.8966667-+01
STS-1	10	3	10	5	5	+0.8300000-+01
JTR-50	10	3	10	10	10	+0.9300000-+01
KC-200	10	2	10	5	10	+0.8950000-+01
RN-300D	10	3	10	10	10	+0.9300000-+01
STS-1C	0	3	10	10	10	+0.3350000-+01
MV-5	7	5	5	6	10	+0.7448718-+01
MD-600	5	2	0	10	0	+0.3700000-+01
ST-200	5	3	10	5	5	+0.5300000-+01
CLG-2N-CNC	0	2	0	10	10	+0.2200000-+01

Figure 9. Example of Computation of Multiple Attribute Utility Functions

```
*************************************************************
Processes, makers, machine types, and numbers of machines
are summarized as follows
*************************************************************
```

Process		Maker		Machine type		Number of machine
Centering	==>	Yachiyoda Kikai	==>	*CE-70	=>	2 Unit
Lathe turning	==>	Suga Tekko	==>	STS-1	=>	2 Unit
Quenching	==>	LEOL, Ltd.	==>	JTR-50	=>	1 Unit
Lathe turning	==>	KYC Machine Industry Co, Ltd.	==>	KC-200	=>	1 Unit
Superfinishing	==>	Seibu Automatic Equipment Co., Ltd.	==>	RN-300D	=>	1 Unit

Figure 10. Example of Final Output

4. Conclusion

It is very effective to express a complicated machine in a relatively simple but detailed manner, making use of extensive knowledge in a short program by applying the in-depth knowledge expressing models obtained by breaking down the processing equipment into its mechanisms and functions.

In addition, multipurpose items such as the prices and areas of equipment, the service setup, the technical ability and delivery performance of the equipment makers were comprehensively evaluated. This was previously conducted ambiguously in actual corporations, but the formulation of these items results in clear judgment criterion and correct evaluation of a great number of objects in a short time.

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20117/9365

FMS Just-In-Time Scheduling Using Rule-Expression Method

43063809c Tokyo DAINANAKAI CHISHIKI KOGAKU SYMPOSIUM in Japanese
22-23 Mar 88 pp 13-18

[Article by Yutaka Nakamura, Yoshiaki Obara, Keiichi Yamagata, and Tanji Tamura, Engineering Department, Osaka University: "Predicates and Priority Rules To Eliminate Conflicts; Rule Expression for Just-In-Time Environment; Rule Evaluation"]

[Text] **1. Introduction**

In the production field, a rapid shift to a flexible manufacturing system (FMS) is underway.[1,2] Production planning for FMS is undertaken for a relatively long period, on a yearly or monthly basis. For such production, it is necessary to make a concrete schedule for each task, such as when and with what machine to conduct which task--that is, production scheduling.

Scheduling by means of formulating problems so as to achieve the optimum combination results in massive computations for actual problems, so the formulation can be applied only to small-scale problems within the framework of extremely limited problem setting. And, in reality, seldom are optimum schedules obtained. The simulation approach, whereby good schedules can be obtained in a short time, has been adopted widely. In this approach, a simulation of objectives is generated, and the best one is selected from among the priority rules or dispatching rules set using a heuristic method.[1,3,4] Obtaining a schedule that has fixed priority rules, however, does not necessarily satisfy the initial purpose, as the priority rules may not be appropriate to the situation. Taking these problems into consideration, the authors[5] proposed that priority rules be selected dynamically, expressing rules whereby conflicts are eliminated, and, using the example of a production target, we demonstrated how the time required for completing machining can be minimized.

When a just-in-time environment is a production target,[6] it is necessary not only to minimize delivery delay but also to consider loss due to such factors as inventory management costs for parts finished ahead of delivery time before deciding on the optimum time to initiate machining of the parts. This means that merely expressing rules that eliminate conflicts does not necessarily lead to achieving just-in-time environment targets. To this end, this paper is concerned with newly devising the expression of rules that eliminate conflicts in order to minimize delivery delay and delivery allowance, gradually updating the rules for machining initiation time in the schedule obtained by means of these rules, and then proposing a new FMS scheduling approach for a just-in-time environment.

Section 2 of this report describes the predicates and priority rules necessary for rule expression to eliminate conflicts in order to minimize delivery delay and delivery allowance. Section 3 describes the rules to decide on machining initiation time and discusses the total formulation of rule expression for a just-in-time environment. Finally, section 4 discusses the efficiency of the rule expression constructed with numeric examples in section 3.

2. Predicates and Priority Rules for Conflict Elimination

Considering condition Pi as the predicate to check the buffer condition and progress in the machining of each part in an FMS model and result Ri as the group number for priority rules, or rules to be checked next, the authors[5] proposed to select priority rules based on if-Pi-then-Ri format rules for the elimination of conflicts. The following are descriptions based on the similar concept of predicates and p necessary for rule expression for conflict elimination aiming at a just-in-time environment.

2.1. Predicate

When a just-in-time environment is the goal, it is necessary to obtain from within FMS models not only information on the buffer condition and progress on the machining of each part, but also on the difference in the delivery date between individual parts and the time remaining until their delivery dates. This is done not only to operate each machine efficiently and to complete machining in a short time, but also to project possible delivery delay or excessively early completion of machining based on the machining time needed for each part and the number of unfinished parts. Therefore, for the dependent clauses of rules, the following must be considered:

1) True: always true.
2) Not (a): false only when a is true.
3) Time (a): true only when the current time is after a.
4) Buffer (a, b): true only when all occupancy rates of buffer a processes ahead of the current one are over b percent.
5) Progress (a): true only when some conflicting parts have remaining processes of below a.
6) Best-time 1 (a): true only when the ratio/min of remaining time until delivery for each of some conflicting parts is greater than a.
7) Best-time 2 (a): true only when the ratio/min of remaining time until delivery for every conflicting part is greater than a.
8) Conflict (a): true only when the number of conflicting parts is over a.
9) Machine: true only when conflicts occur in machine tools.
10) Beginning: true only when machining of some conflicting parts has already begun.

11) Filter (a): selects from among conflicting parts those that may be machined before time a.

In the above, I min represents the minimum time expected to be required for finishing all of the parts for which orders have been received with respect to time to verify whether a predicate is true or false. For simplification, it is supposed here that all of the processes up to the current one have been completed and that with regard to those ahead of the current one, no process, except for finished parts, has been completed yet. Therefore, the following expressions are used on the assumption that parts except for those finished exist in buffers:

I min = T + (n - 1) S
n = Number of unfinished parts
T = Total of machining time for the processes ahead of the current one
S: Maximum value of machining time for the processes ahead of the current one

In the rules, each predicate functions as follows: "Time" decides the time to discharge the first material for each part into the system, and "buffer" prevents blocking. "Progress" moves out parts for which machining has been completed on a priority basis. "Best-time 1 and 2" decide the initiation of machining. Since how to decide the initiation of machining differs depending upon the number of conflicting parts and the elimination of conflicts, the notion of a machine tool differs from that of a carrier vehicle; "conflict" and "machine" are used to classify types of conflicts. "Beginning" maintains the machining of a part once its machining has begun, while "filter" prevents it from being discharged into the line before the machining initiation time set for each part.

2.2. Priority Rules

From among a great number of priority rules suggested, the following R1-R8 have been selected for schedules with a just-in-time environment as the production target. When schedules are considered only partially, selecting parts regardless of their delivery time permits each machine to operate more efficiently and in some cases finally leads to accomplishing the production target; R9-R11 are used on an auxiliary basis.

R1: priority to jobs in order of delivery
R2: priority to the job with minimum slack time
R3: priority to the job with maximum delivery delay time
R4: priority to the job with maximum number of parts delayed in delivery
R5: priority to the job with minimum total delivery allowance time
R6: priority to the job with a minimum delivery allowance rate
R7: random job selection
R8: no loaded jobs
R9: priority to the job with a maximum buffer occupancy rate
R10: priority to the job with a minimum next-process buffer occupancy rate
R11: priority to the job with a minimum number of remaining processes

In the above, a delivery allowance rate of R6 represents the ratio/min of time remaining until delivery of a part to the part. Although this is approximative for accomplishing the production target, it is effective in that it permits parts to be selected using the delivery date and the number of unfinished parts as judgment criteria. It involves selecting parts based on their expected delivery allowance, and differs from R5 in the function wherein parts are selected based on the total delivery allowance time of finished parts.

3. Rule Expression for a Just-In-time Environment

3.1. Decision on Machining Initiation Time

Scheduling for a just-in-time environment must satisfy two requirements: the earliest possible initiation of machining when it appears that delivery delay is likely to occur, and delayed initiation of machining proportionate to delivery allowance likely to occur. Based on machining information alone, it is different to judge the possibility of occurrence of delay and allowance in delivery, and so the proper machining initiation time cannot be decided upon. When a schedule is given in advance, however, it is possible to adjust the machining initiation time so as to realize a just-in-time environment. As the simplest rules, the following can be considered.

Rule 1: A schedule result is slipped along the time axis so as to realize a just-in-time environment.

However, this rule alone does not necessarily result in a proper schedule. In this context, this paper suggests the combined use of the following two rules.

Rule 2: The machining initiation for parts for which delivery delay has occurred is hastened by their maximum delivery delay time.

Rule 3: The machining initiation for parts for which delivery delay has not occurred is delayed by their minimum delivery allowance time.

Rules 1-3 are applied as follows: First, as initial schedule and machining initiation time for each part in the schedule are obtained; then, machining initiation time is updated by Rules 2 and 3 from the above result, and a new schedule is obtained. Rule 1 is applied when, while repeating this operation, no improvement is found in delay and allowance in delivery, and a final schedule is set to accomplish a just-in-time environment. The schedule is obtained through simulation by eliminating conflicts by means of rules to be formulated in the following section, based on the predicates and priority rules provided in section 2.

3.2. Rule Expression

In order to prevent delivery delay from being concentrated on one part and to minimize delivery delay when a just-in-time environment is the goal and delivery delay occurs, a rule base has been formulated based on the following notions.

Heuristic methods (1)-(4) are used in machining each part with the machine, while (5) and (6) are used in transferring it.

(1) Machining initiation time will be set according to the number parts of types, the number of unfinished parts, the delivery date and the time remaining for machining conflicting parts, and the parts will apply no load on the machine until that time.

(2) With respect to parts for which machining has once been initiated, they will be discharged when the condition in (1) is not applicable.

(3) Load will be applied for the part that seemingly has the least allowance in its delivery when every conflicting part has delivery allowance.

(4) Load will be applied for the part with the earliest delivery date when delivery delay has already occurred for some conflicting parts.

(5) The part in the final transportation process among conflicting parts, if any, will be transferred first.

(6) When every buffer in the following process is full, no parts will be transferred. When not full, the part with the lowest occupancy rate with respect to the buffers in the following process will be transferred first.

Figure 1 provides an example of a formulation of a rule base. The rules are checked beginning with the first condition in Group 1 of Level 4. When the condition is applicable, the conditions are checked in the order of the direction indicated by the arrow. When not applicable, the next condition in the same group is checked. On the condition of true in Level 0, a part given priority according to its corresponding priority rules is selected. When there are two or more parts with the same condition, the priority rule corresponding to true next to Level 0 is applied, and this is repeated until the last one is selected.

Priority rules are originally used to select the part to be machined next from among conflicting parts. However, in order to use R8 as a priority rule, each predicate is checked when no conflicts have occurred. Semicolons in the rule base represent "or."

Each group functions as follows. With respect to selecting parts, the notion of a machine tool is different from that of a carrier vehicle, so

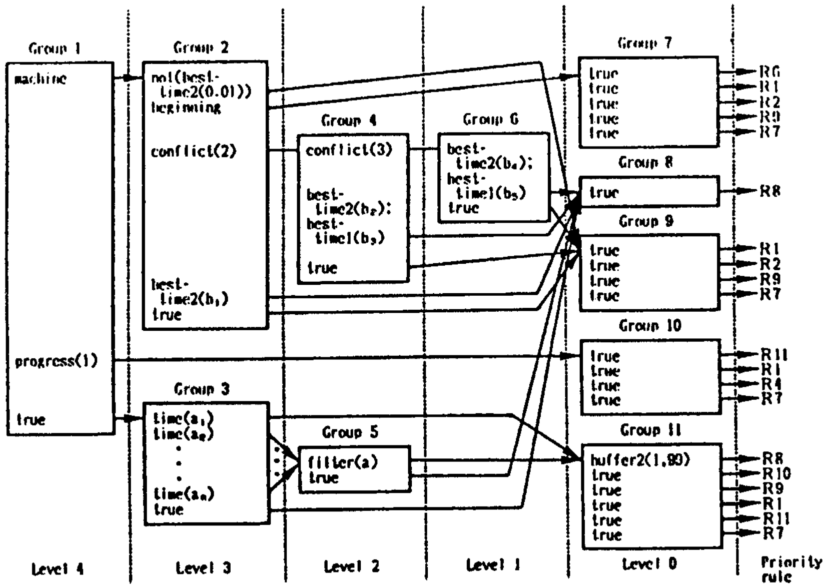

Figure 1. Example of Rule Base

in Group 1, conflicts are divided into those in machine tools and those in carrier vehicles. Also, with a carrier vehicle, (5) is distinguished from (6). In Group 2, the occurrence of delivery delay is checked and, if absent, the presence of parts on which machining has already begun is checked. In the initial schedule, when machining has not been started, whether or not machining should be started is decided on the basis of the number of parts conflicting together with Groups 4 and 6. Groups 3 and 5 prevent parts from being discharged into the line before the machining initiation time set for each part, where the parameters of time represent machining initiation time, updated for each schedule obtained. They are provided starting first with a_1, the latest in machining initiation time, and going to the earliest in sequence, their initial values being the same. In addition, when time (a_i) is true for i > 1, the parameter of filter corresponding to it will be a_{i-1}. The machining initiation time to be decided by parameter b_1 in Group 2 is set so as to be ahead of time a_n for each update of the parameters in Group 3. Group 11 prevents a carrier vehicle from being unable to transfer another part due to blocking.

4. Rule Evaluation

In this section, a comparison is made between simulation results in the cases where priority rules are fixed and where machining initiation time is changed by applying the rule base, shown in Figure 1, from the standpoint of delay and allowance in delivery and schedule efficiency.

4.1. Evaluation Scales

Various items have been suggested for schedule evaluation scales.[7] With respect to delay and allowance in delivery, this paper uses such scales as maximum delivery delay (T_{max}), number of units delayed in delivery (n_T), total delivery allowance (E) and total minimum delivery allowance (c). With regard to schedule efficiency, it uses such scales as average residence time (F), average operating ratio (R) and frequency of tooling change (S). The individual scales are defined as follows:

Maximum delivery delay:

$$T_{max} = \max_i \{c_i(n_i) - d_i, 0\}$$

Number of units delayed in delivery:

$$n_T = \sum_{i=1}^{n} |\{j : \max\{c_i(j) - d_i, 0\} > 0\}|$$

Total delivery allowance:

$$E = \sum_{i,j} \max\{d_i - c_i(j), 0\}$$

Average residence time:

$$F = \frac{\sum_{i,j} (c_i(j) - r_i(j))}{\sum_i n_i}$$

Average operating ratio:

$$R = \frac{\sum_{k,i} n_{ik} t_{ik}}{m(c_{max} - r_{min})}$$

Frequency of tooling change:

S = frequency of a machine tool's changing types of works

where:

- m : number of machine tools
- n : number of types of parts
- n_i : number of part i
- d_i : delivery date of part i
- $c_i(j)$: part i's j machining completion time
- $r_i(j)$: part i's j machining initiation time
- t_{ik} : time for part i to be machined by machine tool k
- n_{ik} : number (≥ 0) of part i to be machined by machine tool k

$$c_{max} = \max_{i,j}\{c_i(j)\}, \quad r_{min} = \min_{i,j}\{r_i(j)\}$$

4.2 Numerical Example

As a simple numerical example, the line-type FMS scheduling shown in Figure 2 is considered. An FMS consists of three machine tools: a loading and an unloading station and a carrier vehicle. Table 1 shows the machining time needed for machining each part with each machine tool. The parts are machined in the following order:

Part A: a→b
Part B: a→b→c
Part C: b→c

Table 1. Machining Information

Part types	Machines a	b	c
A	6	6	–
B	4	3	5
C	–	5	6

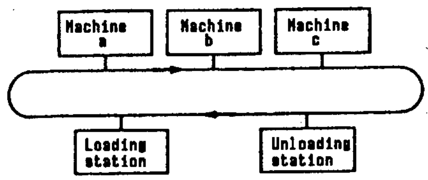

Figure 2. Line-Type FMS

It was assumed that it takes time 1 for each part to be transferred between machining tools and that a buffer with capacity of N is installed in each process. In addition, it was assumed that the delivery dates of the parts are 200, 250, and 300, respectively. As an FMS simulator, time Petri net was used.

It was decided to discharge the same number (M) of each part into the production line, and simulations were conducted with respect to the cases where the rule base shown in Figure 1 was applied and where the priority rules were fixed at R1-R6, respectively. In addition, minimum value (delivery date -1.8 x 1 min) were provided for the initial values for parameters a_1-a_n of each predicate in Figure 1, with b_1-b_5 set at 1.1, 2.0, 2.7, 3.0, and 3.7, respectively.

Table 2. Maximum Numbers of Parts To Be Discharged Which Cause No Delivery Delay

Buffer capacity	3	6	9	12	18	24	30
Rule base	18	18	18	18	18	18	18
R1	16	15	12	12	16	16	16
R2	13	13	12	12	16	16	16
R3	12	14	15	14	14	14	14
R4	12	12	14	13	14	13	14
R5	13	17	18	18	18	18	18
R6	9	11	12	13	17	17	17

Table 2 shows the maximum numbers of parts to be discharged that cause no delivery delay when buffer capacity N is changed from 3 to 30. When the rule base is used, up to 18 parts can be discharged so as not to cause delivery delay, while when priority rules are fixed, delivery delay occurs, except for R5, before 18 parts are discharged. In the case of R5, relatively large buffer capacity obtains the same result as the rule base, while N = 3 and N = 67 cause delivery delay for M = 14 and M = 18, respectively.

Figure 3 provides a comparison between t_{max} and n_T when the number of parts to be discharged is 18 or more and N = 3. The application of the priority rules not shown in Figure 3 resulted in larger values than the result shown in it. Use of the rule base permitted T_{max} and n_T to be smaller than is the case where priority rules were fixed.

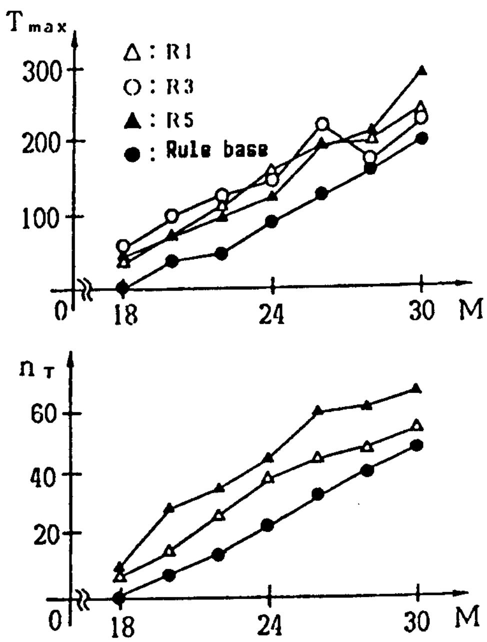

Figure 3. Comparison Between Maximum Delivery Delay and Numbers of Parts Delayed in Delivery (N = 3)

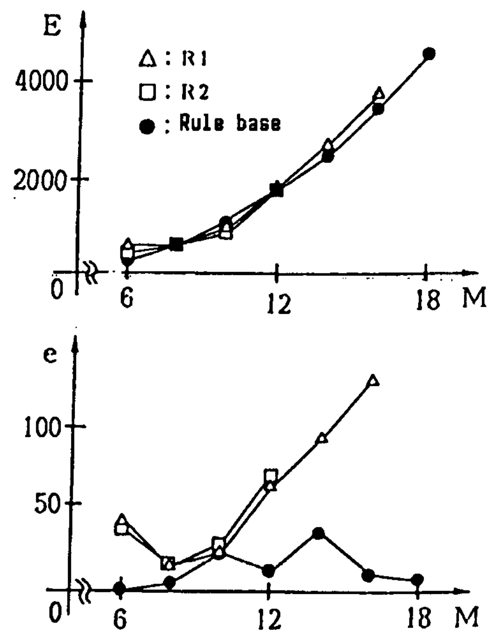

Figure 4. Comparison Between Total Delivery Allowance and Total Minimum Delivery Allowance (N = 3)

Figure 4 provides a comparison between E and e when the number of parts to be discharged (M) is below 18 and N = 3. There, Rule 1 was applied to the simulation results of R1 and R2, and machining initiation time was slipped. Use of the rule base results in smaller values of e than where priority rules are fixed, while with respect to E, R1 and R2 are slightly smaller for M = 10.

Figure 5 shows the result of a comparison between simulation results of the rule base and R1 and R2 using $\overline{F}$, $\overline{R}$, and S. With respect to the average residence time and average operating ratio, the rule base is better. However, R1 and R2 are better with regard to the frequency of tooling change, so a comparison is not necessarily appropriate in terms of schedule efficiency.

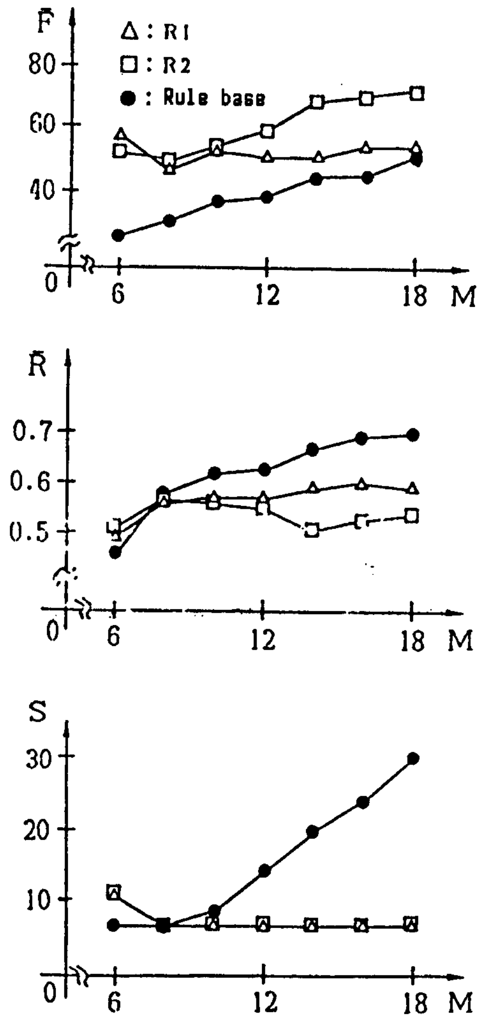

Figure 5. Comparison Using $\overline{F}$, $\overline{R}$, and S (N = 3)

Besides the above result, a similar simulation result was obtained when machining information--the number of machine tools, part types and delivery date--was changed. In addition, delivery allowance could be improved by applying Rules 1-3 instead of Rule 1 alone. In the above simulations, the schedule was updated about three times on average.

From the above results, it can be seen that an efficient schedule capable of accomplishing a just-in-time environment can be obtained through formulating a rule base and successively updating machining initiation time, rather than considering as fixed the priority rules which are selected with a simulation for each update of the schedule.

5. Conclusion

This paper has proposed the methodology to accomplish a just-in-time environment by successively updating machining initiation time. Problems to be solved in the future are:

1. Development of a method of evaluating precisely the excellence of a rule base under multipurpose circumstances.

2. Development of meta rules capable of automatically generating a rule base matching a purpose changeable according to circumstances.

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Evaluation Support System for Multiple R&D Projects

43063809d Tokyo DAINANAKAI CHISHIKI KOGAKU SYMPOSIUM in Japanese
22-23 Mar 88 pp 31-36

[Article by Yoshinori Katayama and Mitsuhiko Toda, International Information Social Science Research Institute, Fujitsu, Ltd.: "Evaluation Support System for Multiple R&D Projects; Information and Knowledge for Evaluation Support System; Engineering Impact Rules and Examples of Their Application; Final Studies"]

[Text] **1. Introduction**

The evaluation of groups of R&D projects largely depends on the experiential judgment of experts. This article proposes a method for the total evaluation by experts of groups of projects and supporting decisionmaking based on it, focusing on engineering repercussion effects of project information. The basic framework of the support method involves knowledge of rules to deduce engineering impact relationships and relevant knowledge to expand the applicability of knowledge of these rules. An evaluation support system utilizes these rules as a knowledge base and supports experts' evaluation activities for multiple R&D projects. This article cites groups of R&D projects on the saving of energy as application examples of this evaluation support system and shows the support results of their evaluation.

2. Evaluation Support System for Groups of R&D Projects

Evlauation[1,2] is conducted during research and development in order to efficiently plan and implement activities. Efficient research and development takes into consideration not only the economical aspect, but also engineering application relationships with other research and development and their direction. Therefore, in support of the evaluation of an R&D project, a broad analysis is necessary not only of information obtained through detailed analysis of the direct effects cost, internal construction, and functions of the project, but also of information on the relationship with other relevant projects (engineering impact or engineering application).

This article proposes a method involving the formation of a network of multiple R&D projects from the standpoint of engineering impact and supporting the evaluation of the efficiency of each project based on broad relationships between them. It devotes attention to support for heuristic progress in the evaluation of projects in individual technical and research fields conducted by experts.

To go into detail, as shown in Figure 1, the method evaluates relationships with respect to engineering impact using the knowledge base of the evaluation support system--knowledge of various rules to deduce engineering impact relationships and relevant knowledge to expand the applicability of the knowledge of these rules--and offers a processing mechanism for such knowledge, provides relevant information, and points out the possibility of wide-ranging engineering impact.

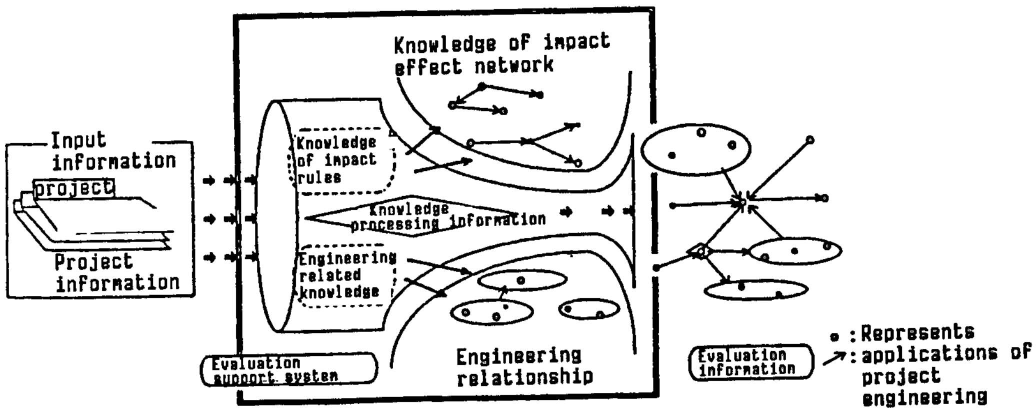

Figure 1. Processing Mechanism of Evaluation Support System

The purpose of this evaluation support system is to support experts' decisionmaking activities for research and development from the standpoint of their repercussion effects. The further development of the system's knowledge base and processing mechanism will permit heuristic thinking from a broader point of view.

3. Information and Knowledge for Evaluation Support System

In this section, the information and knowledge needed for the evaluation support system to realize a knowledge processing mechanism is sorted.

Sort item (1): Detailed information to sort and explain projects--detailed project information

Sort item (2): Engineering-related knowledge available for projects--knowledge related to engineering barriers and repercussion effects

Sort item (3): Experts' knowledge of target fields related to engineering impact and application--know-how type knowledge

Sort item (1) needs to be extracted from each R&D project by experts. Items (2) and (3) represent the knowledge base of the evaluation support system, to which experts' knowledge can be added. The evaluation support system uses the above knowledge to realize the evaluation support system function on the basis of the knowledge processing mechanism. The evaluation support system deduces the basic rules for engineering impact from sort item (2), improves them for engineering impact rules using the know-how type knowledge in sort item (3), and supports more flexible retrieval and heuristic evaluation with respect to engineering impact.

The engineering impact rules and examples of them provided in this article are those deduced for 35 projects selected from groups[5] of energy-saving technological development projects, and these rules are applicable to general R&D projects.

(a) Information Corresponding to Sort Item (1)

Detailed information on the contents of each project is represented by applicable industrial sectors, functions, purposes, technical concepts, development (research) targets and effects, developmental periods and developmental cost.[5] In addition, for the clear ranking and sorting of each project, technical subjects are sorted, which not only makes clear subject fields but also plays an important role in expanding the knowledge of the fields related to sort item (3).

As stated above, the information corresponding to sort item (1) includes diverse detailed information. However, from the standpoint of the evaluation in this article, the focus of the project information is placed in particular on a developmental target (to be referred to as technical barrier as a technical difference between the current technical level and the target), the repercussion effect (part of the effect and the possibility of engineering impact and its application to other fields), in particular, and on the sort of technical subjects. The other information is used to further develop the evaluation support system described in this article and to realize the optimum evaluating function.

(b) Knowledge Corresponding to Sort Item (2)

The technical barriers and repercussion effects in sort item (1) are used as knowledge about engineering between projects. A general form representing the relationship between a technical barrier and the repercussion effect of each R&D project can be described as follows. The mark (→) means that the repercussion effect to the right can be obtained by overcoming the technical barriers to the left.

$$Pn:\ B_{n1}, B_{n2}, \ldots, B_{nm} \rightarrow E_{n1}, E_{n2}, \ldots, E_{nt}\quad (m, 1 \geq 0)$$

(Pn: project name; B_{n1}: technical barrier; B_{nt}: repercussion effect)

From here on, the technical barrier against and repercussion effect of project Pn is represented by B_n and E_n, respectively. The project information of sort item (1) replaced by this general formula will be used as the basic pattern. The evaluation support system deduces engineering impact relationships with other projects by relating basic patterns to one another.

Relating occurs when an expert judges that the repercussion effect of project P1 and the technical barrier of project P2 are technically the same in their content ($E_1 = B_2$), and in these two projects, E_1 is engineering to be deduced and B_2 is required engineering, so $E_1 = B_2$ is a basic relationship. A direction (P1→P2) can be rendered between the two projects from this technical viewpoint. It is understood that new engineering to be developed by overcoming technical barriers in project P1 through the network will serve to overcome technical barriers in project P2 (engineering impact). This is represented by Engineering Impact Rule 1.

Engineering Impact Rule 1: Relationship of basic engineering impact between projects: In the case where $E_1 = B_2$ for P1: $B_1 \rightarrow E_1$ and P2: $B_2 \rightarrow E_2$; $B_1 \rightarrow$ repercussion effect E_1 = technical barrier $B_2 \rightarrow E_2$ is obtained, and from the engineering impact from P1 to P2, $B_1 \rightarrow E_2$ can be deduced.

This rule is the basis of the network expression for groups of projects and the engineering impact rule in the following section.

(c) Knowledge Corresponding to Sort Item (3)

This is knowledge about the wide-ranging application of engineering impact rules. A category to systematize the information to be utilized for rules (technical barriers and repercussion effect) is provided, according to which know-how type knowledge is deduced. The category is subdivided into subcategories according to objects. The category and subcategories correspond to sorted technical subjects of project information, to be further divided in detail with matrixes.

The 35 projects used as examples in this article are those falling into matrixes (data (i)-(iii)) of engineering subcategories related to thermal energy which have been selected by the author from among 120 projects described in reports.[5]

The major data divisions (i)-(iii) are categories, and the subdivided categories added to each source are subcategories. To decide which items of these data are to be placed on the axes of ordinates and abscissas, a systematic sort representing their material engineering fields/systems and equipment is placed on the axis of ordinates, while wide-ranging technical (research) subjects in the subcategories representing the entire list are placed on the axis of abscissas, by means of reference to the list and project data in the energy technology data handbook.[6]

Information on these matrixes is accumulated in the system when a user inputs the project information in the sort item into the system interactively. Hereafter, the frame of the intersection of each matrix is referred to as technical subject field S. The upper and the lower row of each technical subject field of the data represent technical barriers and repercussion effect, respectively. The numbers on technical fields denote project numbers, corresponding to pages of reports.[5] The know-how type knowledge of sort item (3) is knowledge related to engineering application in each category taken up here and to engineering impact related categories.

In each category, with respect to each systematic sort item on the axis of ordinates of the list--the same material engineering fields or the same sort of systems/equipment--there may be mutual applications of engineering between engineering subjects. A direction of engineering impact cannot be decided through this relevant knowledge alone, but it can be utilized in searching widely for relevant projects (Figure 2).

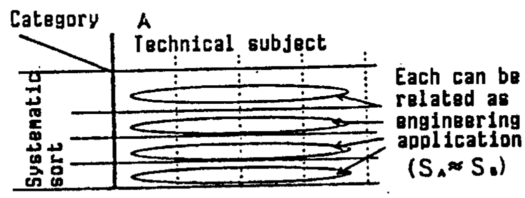

Figure 2. Engineering Applications in Categories

Knowledge related to engineering application in the same category is represented by ($\approx$).

$S_A \approx S_B$: Represents engineering subject fields S_A and S_B being divided into the same systematic sort (material engineering field or system/equipment). In this case, mutual application of engineering is possible.

A direction of engineering impact can be provided between categories from the relationship in their sort. In an energy-saving technical development project which has categories of material and equipment/system, engineering impact from material (data (i)) to equipment/system (data (III) and (iv)) can be set. It is difficult, however, to provide a direction for the relationship of engineering application between subcategories: data (ii) on natural energy in equipment/system sort and data (iii) on effective utilization of energy. With subcategories, like the relationship of applications within a category, knowledge related to engineering application with no definite direction is deduced (Figure 3).

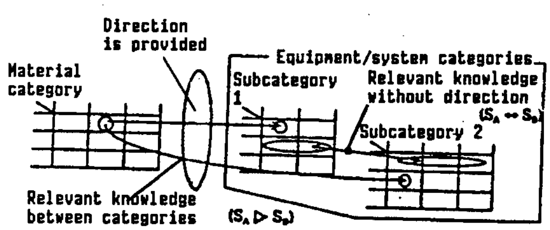

Figure 3. Engineering Impact Relationship Between Categories

The marks ($\triangleright$) and ($\leftrightarrow$) are used to decide relevant knowledge between different categories and between different subcategories.

$S_A \triangleright S_B$: Denotes that there is an engineering impact relationship from engineering subject fields S_A to S_B.

$S_A \leftrightarrow S_B$: Denotes that mutual engineering applications are possible between the engineering subject fields S_A and S_B.

The relevant knowledge between categories and subcategories basically indicates the frame of the intersection of a matrix in one category to which engineering impact is possible from an intersection of a matrix in another category. Examples of $S_A \triangleright S_B$ and $S_A \leftrightarrow S_B$ are shown on (data iv-A) and (data iv-B), respectively. These relevant bits of knowledge are judged by the author as being for experts to relate to each other by reference to information through a handbook, etc.

The engineering subjects on the axis of abscissas in each list correspond to the engineering subject sort information in sort item (1). Therefore, an increase in the number of intended R&D objects will result in increased sort information, expanded matrixes in the sort list, and an increase in the number of engineering subject field S. This will lead to increased relevant knowledge, permitting the evaluation support system to handle a wider range of engineering impact relationships.

Given a wide range for each frame (engineering subject field S) in the sort list, it is possible to provide new engineering impact relationships among engineering factors included in each engineering subject field S.[7]

The following section and section 5 provide enhanced engineering impact rules, based on the engineering impact rules wherein the basic patterns are project information and engineering impact relationships summarized in this section and the two types of relevant knowledge, and give a summary of the analysis and evaluation of subjects.

4. Engineering Impact Rules and Examples of Their Application

First, improvement of Engineering Impact Rule 1 and its application result are summarized. Next, the basic patterns are reviewed from a new standpoint, the rule is expanded, and its application result is summarized.

4.1. Relationship of Repercussion Effect of Engineering Barriers and Effects

Since the engineering barriers and repercussion effect of each R&D project are divided into matrixes in sort item (3), the project includes at least one engineering subject field S. Use of engineering subject field S permits $E_1 = B_2$, the condition of Engineering Impact Rule 1, to be replaced by the condition that it is sorted into the same engineering subject field S ($E_1 \in S_A$ and $B_2 \in S_A$). This enables the evaluation support system to judge whether or not the engineering is of the same content with respect to the basic rule which has been judged by experts, thus facilitating application of the rule.

Engineering Impact Rule 2: Engineering impact relationship between projects: In the case where $E_1 \in S_A$ and $B_2 \in S_A$ (same engineering subject field) for P1: $B_1 \rightarrow E_1$ and P2: $B_2 \rightarrow E_2$, $B_1 \rightarrow$repercussion effect $E_1 \Rightarrow$ engineering barriers $B_2 \rightarrow E_2$ is obtained, and $B_1 \rightarrow E_2$ can be deduced from the relationship of engineering impact from P1 to P2.

Subject example:

Let engineering subject field S be 302c "heat storage device for solar thermal electric conversion" in data (ii) "natural energy in equipment/system sort (1)." Note: In this rule, pairs of a numeral and an alphabetic character represent the engineering subject field S whose engineering subject in each list is a numeral and whose system sort is an alphabetic character.

With respect to projects P58 energy self-sustaining housing system, P62 heat storage system, and P210 heat accumulator for power load flattening power generation, since repercussion effect E_{210} "applicable to solar heat applied heat storage" $\in S$, engineering barriers B_{58} "comprehensive application engineering for solar heat, etc." $\in S$, and B_{62} "high efficiency heat storage tank" $\in S$ are deduced from data (ii), the application of Engineering Impact Rule 2 shows that there is engineering impact from project P210 to projects P58 and P62.

Next, the condition of Engineering Impact Rule 2 is widened and enhanced so as to have a broader range of applicability. The know-how type knowledge in sort item (3) is used for the condition in Engineering Impact Rule 2. This improvement permits engineering/application relationships to be found in a wider range than in Engineering Impact Rule 2.

Engineering Impact Rule 3: Wide-ranging relevant rule using know-how type knowledge: In cases where P1: $B_1 \rightarrow E_1$, P2: $B_2 \rightarrow E_2$, if we have (a) $E_1 \in S_A$ and $B_2 \in S_B$, and $S_A \approx S_B$, (b) $E_1 \in S_A$ and $B_2 \in S_B$, and $S_A \triangleright S_B$, and (c) $E_1 \in S_A$ and $B_2 \in S_B$, and $S_A \rightarrow S_B$; $B_1 \rightarrow$repercussion effect E_1 = engineering barrier $B_2 \rightarrow E_2$ is obtained, and from engineering impact from P1 to P2, $B_1 \rightarrow E_2$ can be deduced.

Engineering Impact Rule 3(a) holds on condition that S_A and S_B are assigned to the same material engineering field or the same system/equipment sort are the sort list in the previous section. On this condition, only the relationship of mutual engineering application and the direction of engineering impact can be decided based on the basic relationship ($E_1 \Rightarrow B_2$). With regard to Rule 3(b), there exists, in addition, a definite direction of impact relationship between the categories, so that the orientation of a result deduced is more certain than with (a). As for Rule 3(c), the orientation can be made based on the basic relationship, as with (a). Therefore, the support effect in (b) as a result of applying the rule is greater than in (a) or (c).

Subject example--the case where relevant knowledge (c) between categories is used:

From data (ii), engineering subject field S_A is regarded as c "heat storage device sort." From this sort, with respect to projects P56 "household total energy system," P58 "energy self-sustaining housing system," P62 "solar heat applied heat storage tank," and P210 "heat accumulator for power load flattening power generation," engineering barriers $B_{56} \in S_A$, $B_{58} \in S_A$, and $B_{62} \in S_A$ and repercussion effect $E_{210} \in S_A$ are obtained. From data (iii), engineering subject field S_B can be regarded as h "heat accumulator sort," and from this sort, in addition to projects P56 and P210, project P250 "heat storage system using chemical reaction," engineering barrier $B_{56} \in S_B$ and repercussion effects $E_{210} \in S_B$ and $E_{250} \in S_B$ are obtained. Data (iv)-B results in $S_B \leftrightarrow S_B$, and the direction of engineering impact can be decided by letting S_B and S_A be repercussion effect and engineering barrier, respectively. Thus, the application of Engineering Impact Rule 3 demonstrates that there is engineering impact from project 250 to projects 58 and 62.

From Engineering Impact Rule 3(a) and (b), improved versions of Rule 2 which are made flexible, newly improved Engineering Impact Rule 4 can be deduced by combining (a) and (b) for the wider applicability of the rule.

Engineering Impact Rule 4: Relevant rule combining know-how type bits of knowledge: In cases where $E_1 \in S_A$ and $B_2 \in S_B$ for Pa: $B_1 \rightarrow E_1$ and Pw: $B_2 \rightarrow E_2$, and where $S_A \triangleright S_B$ for $S_A \approx S_A$ and $S_B \approx S_B$, ($S_A \not\approx \triangleright \gtrsim S_B$) and $B_1 \rightarrow$repercussion effect E_1 $\Rightarrow$ engineering impact $B_2 \rightarrow E_2$ can be obtained, and from the relationship of engineering impact from P1 to P2, $B_1 \rightarrow E_2$ can be deduced.

No subject example of this rule can be found. From the project information in the sort list, another analogy of repercussion effect is possible.[7]

4.2. Relevant Engineering Relationship Focusing Exclusively on Engineering Barriers

Generally speaking, R&D projects are varied, ranging from those to develop totally new technologies to those to integrate or improve existing ones. With respect to some subject projects, engineering barriers are well studied, while repercussion effect is handled as convenient, with an indefinite or an abstract keyword in many cases. Therefore, it is sometimes difficult to analyze engineering barriers and repercussion effect on an equivalent basis as in the previous rules. In order to permit evaluating R&D projects even in such cases, a rule focusing on engineering barriers has been formulated. Since engineering barriers are a developmental subject of a project, they themselves can be regarded as the project's minimum repercussion effect.

A general form is represented exclusively by engineering barriers of each project:

$$Pn: B_{n1}, B_{n2}, \ldots, B_{nm} \rightarrow B_{n1}, B_{n2}, \ldots, B_{nm} \quad (m \geq 1),$$

where Pn is a project name and B_{nm} is an engineering barrier.

In this general form, each engineering barrier becomes its own repercussion effect. Therefore, an analysis using this pattern seldom deduces information that is not always appropriate, such as that which posed a problem in the previous basic pattern. This is because, as shown in Figure 4, relational structure A which was the base of Engineering Impact Rule 1-4 is replaced by relational structure B.

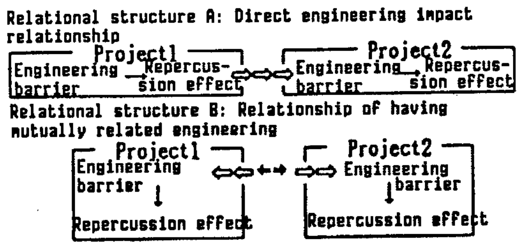

Figure 4. Basic Relational Structure for Engineering Impact Rules

In this case, as can be understood from Figure 4, repercussion effect ⇒ engineering barrier cannot be made the base for the orientation, as has been done so far. However, from the standpoint of R&D projects, the presence of other projects with mutually related engineering is known, which is important as part of the evaluation support function. In addition, if the direction of engineering impact can be regulated with respect to the relationship with this engineering by using a bit of know-how type relevant knowledge (▷), it will lead to an excellent evaluation support system.

Engineering Impact Rule 5 is a basic rule resulting in relevant engineering between R&D projects through utilization of the information in engineering subject field S in sort item (3) according to relational structure B.

Engineering Impact Rule 5: Relationship of relevant engineering between projects: In the case where engineering barriers of each project are included in the same engineering subject field for P1: $B_1 \rightarrow E_1$ and P2: $B_2 \rightarrow E_2$ ($B_1 \in S_A$ and $B_2 \in S_A$), the relevant engineering relationship is possible between P1 and P2 (P1↔P2).

Engineering Impact Rule 5 shows the relevant engineering relationship between projects whose engineering barriers are included in the same engineering subject field (responsive to Engineering Impact Rule 2).

The engineering barriers included in the same engineering subject field S are high in their common aspects, as their engineering subjects and material engineering fields or system/equipment sort are the same. With respect to these engineering barriers, therefore, it is very likely that engineering developed by overcoming barriers and the result obtained in each project can be transferred.

Subject example:

In data (ii), 301c "heat storage device utilizing solar heat" is regarded as engineering subject field S. With respect to projects P56 "household total energy system," P58 "energy self-sustaining housing system," and P62 "solar heat applied heat storage tank," engineering barriers B_{56}

"miniaturized heat storage tank and improved heat reserve ratio" $\in S_A$, B_{58} "solar heat, etc., comprehensive application technology" $\in S_A$ are obtained.

The application of Engineering Impact Rule 5 shows that projects 56, 58, and 62 are related from the standpoint of solar heat storage. Rule 5 focuses on engineering barriers sorted into the same engineering subject field S. In cases like this wherein a large number of projects which have common engineering barriers exist, study can be conducted to deduce new key projects by obtaining only those common engineering barriers. To obtain such information is one of the effects of the evaluation support.

In addition, the use of relevant knowledge within a category and between categories permits the formulation of a rule for which the condition of Rule 5 is broadened, and that is Engineering Impact Rule 6.

Engineering Impact Rule 6: Wide-ranging relationship of relevant engineering using category-related knowledge: In cases where, for P1: $B_1 \rightarrow E_1$ and P2: $B_2 \rightarrow E_2$, and if (a) $B_1 \in S_A$ and $B_2 \in S_B$ and $S_A \not\approx S_B$, (b) $B_1 \in S_A$ and $B_2 \in S_B$, and $S_A \triangleright S_B$, and (c) $B_1 \in S_A$ and $B_2 \in S_B$, and $S_A \leftrightarrow S_B$; for P1 and P2, the relationship of relevant engineering ($P1 \leftrightarrow P2$) is indicated by (a) and (c), while the relationship of impact ($P1 \Rightarrow P2$) is shown by (b).

In the relationship of relevant engineering, it is necessary to widen the applicability and to show information from diverse viewpoints. In Engineering Impact Rule 6(a), the applicability is widened from the same engineering subject field to the same material engineering field or the same system/equipment sort. As a result, it cannot indicate the direction of the application of relevant engineering and result, but it does permit a wider range of relevant engineering to be searched. The same is true with (c). Rule 6(b) is not formulated to expand applicability, but to search for relevant engineering and result. These three cases show the optimum functions necessary for the evaluation support system.

Subject example--the case of (b):

When data (i) 103c "latent heat storage material for exhaust heat application" is regarded as engineering subject field S_A and data (ii) 301c "heat storage device sort for solar heat applied air-conditioning system" as engineering subject field S_B, data (iv)-A results in $S_A \triangleright S_B$. With respect to projects P56 "household total energy system," P58 "energy self-sustaining housing system," P62 "solar heat applied heat storage tank," and P54 "local integrated air-conditioning heat storage system," data (i) results in engineering barrier B_{54} "development of latent heat storage material" $\in S_A$, while data (i) results in engineering barriers B_{56} "miniaturized heat storage tank and improved heat storage ratio" $\in S_B$, B_{58} "solar heat, etc., comprehensive application engineering" $\in S_B$, and B_{62} "high-efficiency heat storage tank" $\in S_B$.

The application of Engineering Impact Rule 6 to the above demonstrates that there is a relationship in engineering impact from project 54 to projects 56, 58, and 62. Integrating the viewpoints of Engineering Impact Rule 6 deduces another engineering impact rule. This rule widely searches for relevant engineering and decides the direction of the application of the relevant engineering and result.

Engineering Impact Rule 7: Relationship of relevant engineering impact using category related knowledge: In the cases where, for Pl: $B_1 \rightarrow E_1$ and P2: $B_2 \rightarrow E_2$, $B_1 \in S_A$ and $B_2 \in S_B$, and $S_A' \triangleright S_B'$ for S_A S_A' and S_B S_B', ($S_A \approx \triangleright \approx S_B$) can be deduced and the relevant engineering impact relationship between Pl and P2 (Pl $\Rightarrow$ P2) can be indicated.

Subject example:

When data (i) 101b "solar heat applied insulating material" and data (ii) 302c "heat storage device for solar thermal electric conversion" are regarded as S_A' and S_B', respectively, form data (iv)-A, $S_A' \triangleright S_B'$ can be obtained. Here, when data (i) 100b "insulating material as a general engineering subject" and data (ii) 301c "heat storage device for solar heat applied air-conditioning" are regarded as S_A and S_B, respectively, $S_A \approx S_A'$ and $S_B \approx S_B'$ can be deduced from each list.

With respect to projects P56 "household total energy system," P58 "energy self-sustaining housing system," P62 "solar heat applied heat storage tank," P98 "electronic control high-pressure cooking equipment," P96 "vacuum adiabatic high-temperature cooking equipment," and P82 "refrigerator-use high-performance heat insulator," engineering barriers B_{96} "development of heat-resistant materials" $\in S_A$, B_{98} "the development of heat-resistant and durable heat insulator" $\in S_A$, and B_{82} "low-temperature high-performance flat vacuum heat insulator" $\in S_A$ can be obtained, while from data (ii), engineering barriers B_{56} "miniaturized heat storage tank and improved heat reserve ratio" $\in S_B$, B_{58} "solar heat, etc., comprehensive application engineering" $\in S_B$, and B_{62} "high-efficiency heat storage tank" $\in S_B$ can be deduced. Therefore, the application of Engineering Impact Rule 7 to the above shows that there is a relationship of relevant engineering impact from projects 98, 96, and 82 to projects 56, 58, and 62.

5. Study

Figure 5 shows a network, related to heat storage, obtained by summarizing the results in the previous section. It is noteworthy that the relationship of relevant engineering viewed from the aspect of a heat storage device is made clear, as well as the fact that with project 250, not only heat storage but also its engineering impact in the form of heat transport is possible. In addition, it is indicated that there are engineering impact relationships from projects 98, 96, 82, and 54 to the groups of projects related to heat storage devices.

Results of the application of engineering impact rules presented by the evaluation support system sometimes include those so apparent that it is not necessary to apply rules by mean of an expert's standard or those beside the mark. These results largely depend on the definitiveness and precision of the relevant knowledge of sort item (3). If the relevant knowledge reflects the inference an expert draws, wide-ranging engineering-related information can be obtained as a result of applying engineering

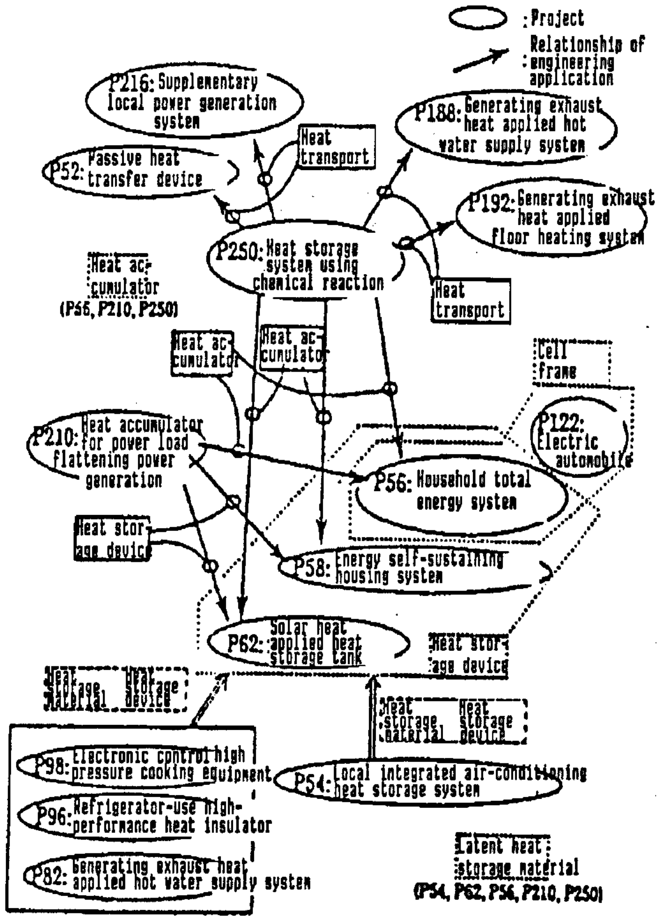

Figure 5. Engineering Related Network of Subject Examples (partial)

impact rules, and the system can effectively support the evaluation conducted by the expert. Diverse evaluation results have been obtained in the limited groups of projects presented in this article. Thus, an increased number of R&D projects and the expansion of dedicated subject areas will permit the evaluation function of this support system to be well displayed.

6. Conclusion

What an expert needs to evaluate in R&D projects is, although they may be considered from diverse viewpoints, the analysis results of each bit of information responsive to sort item (1) in general. Such information, for example, includes the difficulty of an R&D target, the degree of R&D effect, and the results of a comparison between the development period/cost and the effect. For the final evaluation, it is necessary to establish a function for the comprehensive analysis of all these items.

It has been found that, as stated in section 3, the evaluation support system presented in this article focuses on the repercussion effect, which is important for the evaluation of R&D activities, and that as shown in a few examples in sections 4 and 5, the system can obtain the information necessary for evaluation activities. Satisfactory results have been

Material sort (1): Category — Data (i)

Thermal Function: Subcategory — All engineering barriers

Mark	Engineering subject / Material engineering field	Solar heat application	Exhaust heat application	General (miscellaneous)	~
	No.	101	103	100	
a	Heat storage material	60			
a1	Latent heat	62	54	210	
b	Heat insulator			96,98,82	
...	...				

Equipment/system sort (1) — Data (ii)
Upper row: engineering barrier
Lower row: repercussion effect

Natural energy

Mark	Engineering subject / System/equipment sort No.	Solar heat applied air-conditioning system 301	Solar thermal electric conversion 302	~
...	...			
c	Heat storage device	55, 58, 62	58, 62	
		218	210	
...	...			

Equipment/system sort (2) — Data (iii)

Efficient application of energy

Mark	Engineering subject / System/equipment sort No.	~	Exhaust heat application 404	~
...	...			
b	Heat accumulator		56	
			210,250	
...	...			

Category/Subcategory Relationship

Data (iv)-A

Material data (i) Engineering subject field	Equipment/system Data (ii)(iii) Engineering subject field
101a	302c
103a	301c
101b	302b,302c
...	...

Relationship of engineering application from left to right ($S_A \triangleright S_B$)

Data (iv)-B

Equipment/system Data (ii) Natural energy Engineering field	Equipment/system Data (iii) Efficient application of energy Engineering field
c (Heat storage device)	b (heat accumulator)
...	...

Relationship of engineering application both ways ($S_A \leftrightarrow S_B$)

Relationship Between Categories and Subcategories

obtained for evaluation stressing repercussion effects. The framework of the evaluation support system described in this article, which mainly utilizes a knowledge base, is available generally and is not restricted to R&D projects. In the future, the authors will study evaluation activities based on the remaining information not taken up in the project information and further develop the evaluation support system. Incidentally, this research was conducted as part of the fifth generation computer project.

Acknowledgement:

The authors wish to express their appreciation to Ibara, Nozaki, and Koyama, Electrotechnical Laboratory's Energy Dynamics Research Office, for their enthusiastic helpful discussions and many suggestions. To Enomoto, general manager of Fujitsu, Ltd.'s, International Research Institute, we acknowledge helpful comments.

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Intelligent Mobile Robot Working in Unknown Environment

43063809e Tokyo DAINANAKAI CHISHIKI KOGAKU SYMPOSIUM in Japanese
22-23 Mar 88 pp 61-64

[Article by Norio Baba and Yasuhiro Shiraishi, Engineering Department, Tokushima University: "Basic Learning Model and Its Application to Route Selection by Mobile Robot; Learning Behavior of Probability Automaton in Nonstationary Unknown Environments"]

[Text] **1. Introduction**

In work that entails danger, robots should be used to replace human workers as much as possible. In fields such as those related to atomic energy, where direct harm to the human organism is likely to occur, in particular, the introduction of robots is indispensable. In such cases, however, robots have to work under conditions of insufficient human monitoring. Hence, it is important to provide the robot with the ability to judge the situation and act on its own--that is, with the intelligence to properly judge the circumstances. Research on the intellectualization of robots has only begun recently, and great expectations are harbored for the research results to be accumulated from now on.

This report focuses on the problem of learning unknown environments for basic research on the intellectual action of mobile robots. With respect to the problem shown in Figure 1, in particular, the research is aimed at permitting a robot to find the optimum direction to move in order to get out of a labyrinth by using its learning function, on the assumption that the number of selections a robot makes--that is, the number of moving directions that can be selected--is limited. Here, a robot successively transmits information on its success or failure in moving through the labyrinth to the "control center," which in turn commands the next route to select based on the information so far obtained. The authors have conducted research on this problem and have shown that application of the learning function of the probability automaton to a mobile robot permits the easiest route to pass to be found.[1] It was, however, conducted on the assumption that robot environments are nonstationary, and it is desired that discussions be undertaken on the basis of general environments. In other words, it is necessary for a mobile robot not to have its specific performance assumed, but for it to properly display its learning effect as it must act in unknown environments.

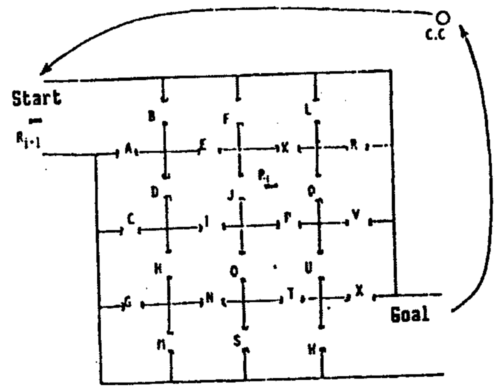

Figure 1. Mobile Robot Moving Through Labyrinth

The nonstationary environments reported so far include one often appearing in communication networks,[2,3] (nonstationary environment (A) in the following section) and one often seen in games[4,5] (nonstationary environment (B) in the following section) [as published]. It is important to find a learning algorithm that will perform appropriately in both of these nonstationary environments. Regrettably, no learning algorithms that perform as desired in both environments have so far been found.

This report will show that the use of a probability automaton with a TNP scheme, a kind of absolutely expedient scheme, for route selection by a mobile robot results in it performing as desired in both nonstationary environments.

2. Basic Learning Model and Its Application to Route Selection by Mobile Robot

Basic Learning Model:

This research utilizes the probability automaton's learning performance for route selection by a mobile robot. The following is a description of the basic model (Figure 2) of the probability automaton which performs in unknown environments.

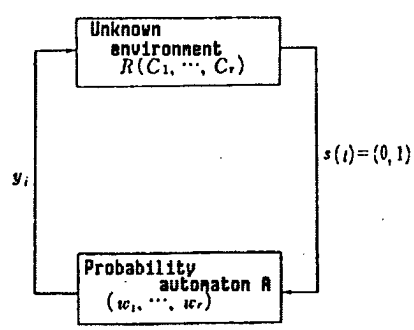

Figure 2. Basic Model of Probability Acting in Unknown Environment

Unknown environments are represented by $R(C_1,\ldots,C_r)$ and probability automaton A performing in them is defined by {S.W.Y.P.(t).g.T}, where S, W, Y, and P(t) represent the set of input data to probability automaton A, the set of A's states $(w_1,\ldots,w_r)$, the set of output from A and state probability vector at time t, respectively, while g is an output function showing that w_i and y_i $(i = 1,\ldots,r)$ correspond to each other and T represents a reinforcement method for changing state probability vector P(t) into P(t+1) through a response from unknown environment $R(C_1,\ldots,C_r)$--input into probability automaton A.

Suppose that at time t, the ith output y_i is produced. Then, environment R $(C_1,\ldots,C_r)$ returns, as a response to y_i, Penalty s(t) = 1 for probability C_i and Reward s(t) = 1 for probability $1-C_i$. The probability automaton changes the state probability vector P(t) into P(t+1) using reinforcement method T, according to the output it has produced and the response to it from the environment.

Here, it is desired for probability automaton A to select an output not resulting in a response of Penalty as much as possible from unknown environments $R(C_1,\ldots,C_r)$. However, the value of each $C_i (i = 1,\ldots,r)$ is unknown, so that A is apt to select, using reinforcement method T, the output with the least probability of receiving a response of Penalty.

Model Application to Route Selection by Mobile Robot

The following is a description of how the abovementioned basic model is used for selecting the optimum route. First, r state $(w_1,\ldots,w_r)$ is made to correspond to a possible route and the fact that the automaton produces the ith output is made to correspond to the fact that a mobile robot selects the ith route. When the robot succeeds in passing, a response of s(t) = 0 (Reward) is transmitted to the "control center," whereas when it fails, a response of s(t) = 1 (Penalty) is transmitted to the "control center." The "control center" plays the role of probability automaton A and issues a command on the next route to be selected according to the probability distribution of state probability vector P(t).

The reinforcement method T changes P(t) to P(t+1) according to s(t) information obtained at the "control center." What type of learning algorithm the reinforcement method T should select is very important, as assurance of finding the optimum route depends on T's selection (ith component $P_i(t)$ of probability vector P(t) indicates the probability of the ith route being selected at time t by the "control center."

3. Learning Behavior of Probability Automaton in Nonstationary Unknown Environments

In Figure 2, when any one of the $C_i (i = 1,\ldots,1)$ in $R(C_1,\ldots,C_r)$ fluctuates against time t and point ω in measure space, $R(C_1,\ldots,C_r)$ is called a nonstationary environment and, if not, a stationary environment. In other words, nonstationary environments are more general, and it is important to discuss the probability automaton's behavior in nonstationary environments if we are to deal with the problem of it learning in unknown environments.

The main nonstationary environments so far found include (A), an environment which often appears when games are played, and (B), one seen in a communications network.

Nonstationary environment (A)

The following inequality holds for any W_α, any $\delta > 0$, all time t and all ω ($\in\Omega$):

$$C_\alpha(t,\omega) + \delta < C_{k1}(t,\omega), \ldots, C_{kr-1}(t,\omega),$$

where $k_1, \ldots, k_{r-1} \neq \alpha$ and Ω and B represent basic space of space (Ω, B, μ) and a minimum borel aggregate including $\bigcup_{n=0}^{\infty} F_n$ (where $\bigcup_{n=0}^{\infty} F_n = \delta(P(0), \ldots, P(n),$ $C(0), \ldots, C(n))$, respectively.

Nonstationary environment (B)

(B) satisfies the following conditions (i)-(v):

(i) Each $C_i(p_1, \ldots, p_r)$ is a continuous function of p_k $(k = 1, \ldots, r)$

(ii) $\frac{\partial C_i}{\partial p_i} > 0$ for all i

(iii) $\frac{\partial C_i}{\partial p_i} \gg \frac{\partial C_i}{\partial p_j}$ for all i and j ($i \neq j$)

(iv) $C_i(\cdot)$ permits continuous differential to all its components

(v) $Ci(\cdot)$ and $\frac{\partial C_i(\cdot)}{\partial p_i}$ satisfy Lipchitz' conditions with respect to all their components

Learning algorithms (reinforcement method) that perform appropriately in either of the two nonstationary environments (A) and (B) have been found,[3,4,5,6] but no algorithm that performs as desired in both of these nonstationary environments has been found to date. When its performance related to environments is totally unknown, a learning algorithm adaptable to any nonstationary environment is desirable. Therefore, it is necessary to find a learning algorithm that performs appropriately with regard to both nonstationary environments (A) and (B).

This report shows that the TNP scheme[5] presented below permits appropriate performance in both nonstationary environments.

TNP scheme:

Let $y(t) = y_1$.

i) If $s(t) = 0$,

$$P_i(t+1) = (1-0)p_i(t) + 0$$
$$P_j(t+1) = (1-0)p_j(t) \quad (j \neq i)$$

ii) If $s(t) = 1$,

$$P_i(t+1) = P_i(t)-k0(1-P_i(t)(H/(1-H))$$
$$P_j(t+1) = P_j(t)+k0P_j(t)(H/(1-H)) \quad (j \neq i)$$
$$H = \min(p_1(t),\ldots,P_r(t)),\ 0<0<1,$$
$$o<k0<1,\ P_1(0) = \ldots = P_r(0) = 1/r$$

With respect to the TNP scheme's behavior in nonstationary environment (A), reports[5,7] show that the following properties a) and b) hold:

a) ϵ-optimality

$$\lim_{0\to 0} \lim_{t\to 0} E\{P_\alpha(t)\} = 1$$

b) Semimartingale inequality

$$E\{P_\alpha(t+1)/F_t \geqq P_\alpha(t)$$
for all t and ω.

With respect to the TNP scheme's learning behavior in nonstationary environment (B), the following theorem holds:

Theorem: If $P_i = 0$, then it is assumed that $C_i(P) = 0$ $(i = 1,\ldots,r)$, where a $P^\cdot$ which satisfies $C_1(P^\cdot) = \ldots C_r(P^\cdot)$ exists, and, from the TNP reinforcement method, $E\{(P_i(t)-P_i^\cdot)^2\} = 0\ (\theta)$ holds.

Note: $E\{(P_i(t)-P_i^\cdot)^2\} = 0\ (\theta)$ shows that $E\{(P_i(t)-P_i^\cdot)^2\}$ nears zero (0) at a speed equal to that of θ. In other words, it means that ${}^3K>0$ exists and that $E\{(P_i(t)-P_i^\cdot)^2\} \leq K\theta$.

The following is a proof when $r = 2$ (the same proof can be obtained with respect to r in general):

Proof: For the sake of space, only the outline is given here.

$$E\{\frac{\Delta P_i(n)}{o} / P(n) = P\}$$

$$= p_1(1-p_1)\ [(C_2-1)\ \{1+k(H/(1-H))\}] \qquad (1)$$

Let $f = C_2 = C_1$.

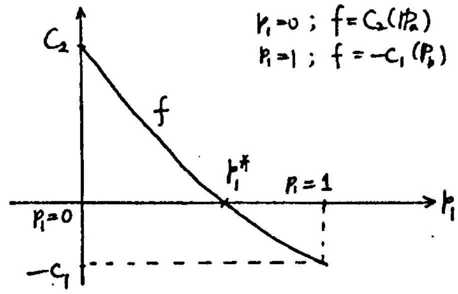

Figure 3. Function f

From assumptions (i)-(iv) in (B), $P^{\cdot}$ which satisfies $C_1(P^{\cdot}) = C_2(P^{\cdot})$ exists uniquely. Using $w(p_1)$ for the right of the expression (1), we find

$$(w(p_1) \triangleq p_1(1-p_1)[C_2-C_1)\{1+k(H/(1-H))\}]).$$

Let us consider the following function $g(P_1)$.

$$g(P_1) = \frac{w(P_1)}{P_1^* - P_1}, \quad P_1 \neq P_1^*$$

$$= -\frac{dw(P_1)}{dP_1}\bigg|_{P_1=P_1^*}, \quad P_1 = P_1^*$$

From an argument similar to that in reports[3,9], R>0 exists and satisfies

$$(p_1^{\cdot}-p_1)w(p_1) = (p_1^{\cdot}-p_1)^2 g(p_1) \geq R(p_1-p_1^{\cdot})^2$$

Following the lemmas in reports[3,9].

$$E\{(p_1(n)-p_1^{\cdot})^2\} = 0\ (\theta).$$

4. Computer Simulation

For an example of nonstationary environments (B), $C_r = P_1$ and $C_2 = 0.2P_2$ were selected and the learning effect by the TNP a method was examined with the value of parameter θ changed. Figure 4 shows the computer simulation result.

5. Conclusion

For application of the learning automaton to route selection by mobile robots, it is necessary to research thoroughly its learning behavior in nonstationary unknown environments. This report has shown that the TNP method permits excellent learning effect to be obtained in both types of nonstationary environments so far reported. It is expected that research on this subject will be further promoted and that positive efforts will be made for its practical application in the future.

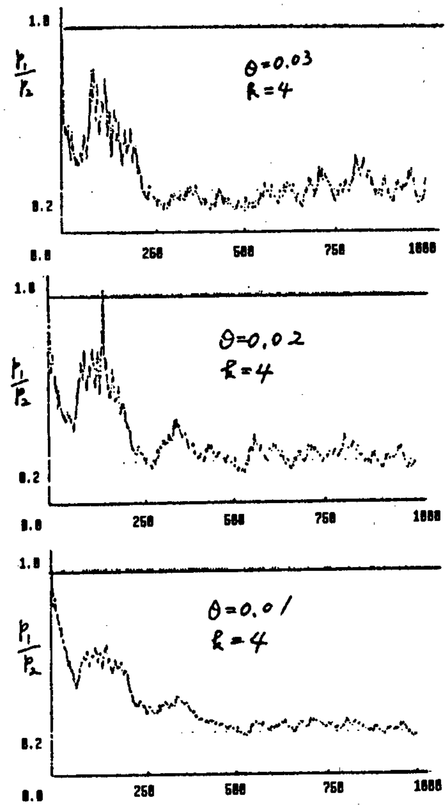

Figure 4. Simulation Result

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20117/9365

Recognition of Object Domain by Color Distribution

43063809f Tokyo DAINANAKAI CHISHIKI KOGAKU SYMPOSIUM in Japanese
22-23 Mar 88 pp 125-128

[Article by Takako Mugitani, Information Processing and Manufacturing System Division, NEC Corp.; Mitsuru Mifune, Second System Engineering Division, Chugoku NEC Software Co., Ltd.; Shigeki Nagata, Second Application System Division, NEC Software Co., Ltd.: "Setting of Surface Model of Reflected Objects; Verification of Surface Model of Reflected Objects; Recognition of Object Colors and Extraction of Object Domain"]

[Text] **1. Introduction**

For the image processing of an object in its natural image, it is necessary to extract in advance the object to be processed from its image. To accomplish this the outer shape of an object is extracted through human instructions, which requires a great deal of time and patience.

This paper describes a method involving the setting of a model of color distribution on the surface of an object, thereby automatically providing "color" recognition, a piece of knowledge to represent the properties of an object, from its natural image. In addition, it describes a method for recognizing and extracting the object in the image according to the color recognized.

2. Setting of Surface Model of Reflected Objects

In computer graphics, various methods of expressing the surface of an object have been proposed in order to obtain realistic images. The authors studied a color distribution model with the light constantly contained in natural images taken into consideration by applying a model phong, which is often used for expressing bright surfaces, etc.

A phong model is often used for plastic-like material expression. The reflected light S_p at point P on the surface can be expressed by the expression (1):

$$S_p(\lambda) = C_p(\lambda)\,\{\cos(i)\,(1 - d) + d\} + W(\lambda, i)\,\{\cos(s)\}^n \qquad (1)$$

where

- C_p: diffuse reflectance at point P on an object
- i: angle of incidence of illumination light
- w: mirror reflectivity
- s: angle between the directions of mirror reflection and the line of sight
- n: power value for mirror reflection model by each material
- d: ambient light reflection coefficient

Since S_p is a function of light wavelength λ, the three stimulus values of R, G, and B can be obtained by integrating them with sensor sensitivity;

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \int S_p(\lambda) \begin{matrix} r(\lambda) \\ g(\lambda) \\ b(\lambda) \end{matrix} d\lambda \qquad (2)$$

Since the terms dependent on wavelengths are $C_p(\lambda)$ and $W(\lambda,i)$ alone, substituting expression (1) for expression (2), we have

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} R_o \\ G_o \\ B_o \end{pmatrix} \{\cos(i)\ (1 - d) + d\} + \begin{pmatrix} R_s \\ G_s \\ B_s \end{pmatrix} W(\lambda,i)\{\cos(s)\}^n \qquad (3)$$

where

$$\begin{aligned} R_0 &= \int C_p(\lambda)r(\lambda)d\lambda & R_sW(i) &= \int W(\lambda,i)r(\lambda)d\lambda \\ G_0 &= \int C_p(\lambda)g(\lambda)d\lambda & G_sW(i) &= \int W(\lambda,i)g(\lambda)d\lambda \\ B_0 &= \int C_p(\lambda)b(\lambda)d\lambda & B_sW(i) &= \int W(\lambda,i)b(\lambda)d\lambda \end{aligned}$$

It is considered that W(i) is dependent on color term i of the light source and is separable. Setting $\alpha = \cos(i)\ (1 - d) + d$, $\beta = W(i)\ \{\cos(s)\}^n$, we find that expression (3) results in

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} R_o \\ G_o \\ B_o \end{pmatrix} \alpha + \begin{pmatrix} R_s \\ G_s \\ B_s \end{pmatrix} \beta \qquad (4)$$

$$(0 \leq \alpha \leq 1, \quad 0 \leq \beta \leq 1),$$

where $(R_o, G_o, B_o)t$ and $(R_s, G_s, B_s)t$ can be regarded as colors appearing in diffuse reflection of an object (hereafter called object color) and those of illumination light (hereafter called light source color), respectively. It is considered that the color of reflected light at each point changes according to the surface direction and illumination at each point and the positional relation between itself and the observer, and that these factors are mixed at rates of α and β.

If the expression (4) model is correct, the color of the object surface must exist in a plane passing the black, the light source color and the object color. The report by Tajima and his colleague[1] indicates that the color of an object is distributed on a plane and that the slippage between this plane and the one passing the black, the light source color and the object color is about 5 degrees, with these two planes almost according with each other.

Figure 1 shows a projection drawing in which the body color of an automobile parked on a street is projected on this distribution plane with the black-white axis from the black (0,0,0) in RGB space to the white (255,255,255) displayed at the same time. From the picture, the light source color seems to be white, while the color of the object surface is distributed not only in the plane decided by the black, light source color and object color, but also in a triangle with the black, light source color (white) and object color as its vertexes. From this, expression (5) is considered to hold:

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} R_o \\ G_o \\ B_o \end{pmatrix} \alpha + \begin{pmatrix} R_s \\ G_s \\ B_s \end{pmatrix} \beta \qquad (5)$$

$$0 \leq \alpha \leq 1, \quad 0 \leq \beta \leq 1, \quad 0 \leq \alpha \leq + \beta \leq 1$$

We will call this color distribution model a reflected object surface model.

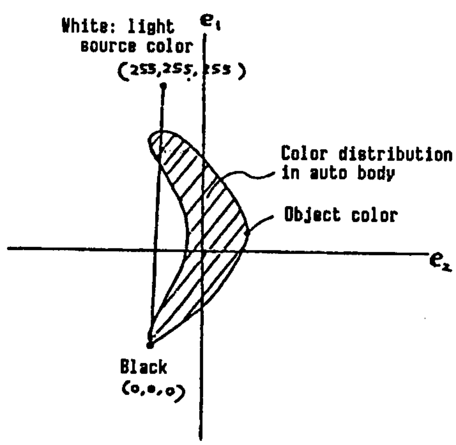

Figure 1. Color Distribution in Automobile Body

3. Verification of Reflected Object Surface Model

We decided to verify the efficiency of the reflected object surface model of the expression (5) proposed in section 2 with several natural images. The processing for the distribution drawing in Figure 1, however, was conducted by deciding a distribution plane after the dispersion was obtained, so that it required about 40 minutes with a minicomputer with processing performance of 3 mips. To facilitate the verification, we considered a method for expressing color distribution without seeking

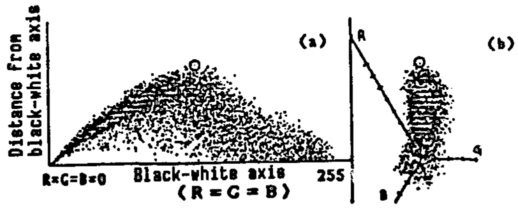

Figure 2. Color Distribution in Automobile Body

dispersion and succeeded in the processing above with a 16-bit personal computer. Figure 2(a) and (b) show the result of the above processing for the same picture of the automobile.

The axis of abscissas in Figure 2(a) is the black-white axis where factors of R, G, and B become equivalent, while its axis of ordinates represents the distance from the black-white axis. Figure 2(b) shows individual points projected on plane vertical to the black-white axis. If examination of a natural image of an object other than an automobile shows its color to be distributed as in this distribution drawing, it will demonstrate that the reflected object surface model is correct.

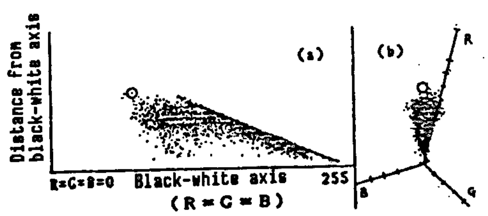

Figure 3. Color Distribution in Cleaner

Figure 3(a) and (b) show a color distribution of a natural image of a cleaner with a plastic-like surface for a phong model. Here, too, the light source color can be assumed to be white, and it can be found that as is the case with an automobile, the color is distributed in a triangle with the black, light source color and object color as its vertexes. In addition, the authors examined such objects of materials with great mirror reflection as a TV set, a telephone and a desk, and obtained a similar result, thus confirming the reflected object surface model as correct.

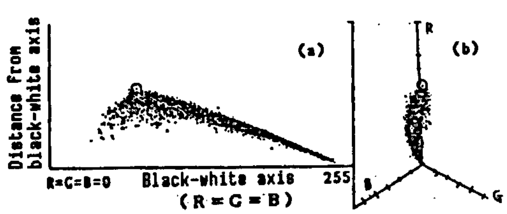

Figure 4. Color Distribution in Suit

With respect to the surface of a suit material lacking mirror reflection, a similar result to that shown in Figure 4(a) and (b) was obtained, indicating that its color is distributed in the same way. With respect to interior light equipment, which has great mirror reflection and is made of material permitting light to permeate, the result shown in Figure 5(a) and (b) was obtained, and it has been confirmed that its color is distributed as well.

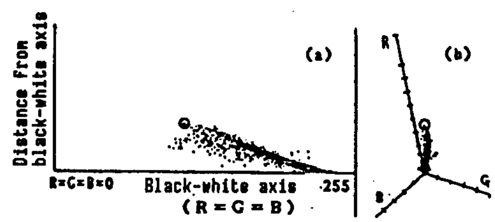

Figure 5. Color Distribution in Interior Lighting Equipment

From the above results, it has been confirmed that the color of the surface of an object, irrespective of the materials used in the object surface, is distributed in a triangle, with the black, light source color and object color as its vertexes. Therefore, the reflected object surface model the authors have proposed is applicable, irrespective of the materials used in the object surface.

4. Recognition of Object Color and Extraction of Object Domain

Since the light source color can very often be assumed as white, as is the case with sunlight the light source color is regarded as white in the following description. In a reflected object surface model, the color of the object surface exists on a plane with a black-white axis as its bottom end and the object color itself is the one farthest from the black-white axis. Therefore, if any color on an object is specified and its distribution plane is decided, the color farthest from the black-white axis on this plane can be recognized as the object color. The authors considered that by doing so, what entered the scope of a triangle with the white, black, and object color as its vertexes could be automatically extracted as a portion of the object.

However, as verified in section 3, the object color in a natural image is distributed not in a perfect plane, but in a certain width. The lightness of color changes due to the effect caused by light sources such as shadows, but the hue does not, so it can be considered that the width of color distribution extends in the direction vertical to the hue surface. When viewed in the color distribution in Figure 2, since the plane with the black-white axis as its end can be approximately regarded as the hue surface in RGB space, the water droplet type shown in Figure 2(b) can be regarded as the width of color distribution. For practical performance, the authors conducted an experiment having a water droplet type approximate to a fan type, confirming that use of a fan-type model with a given interior angle permits the object color to be recognized without posing any problem for its practical use.

Table 1. Width of Color Distribution

Object	Interior angle
Automobile	58
Cleaner	42
Suit	37
Interior lighting equipment	28

The object color could be recognized by using a fan-type model with a given interior angle; however, with respect to the automatic extraction of a portion of an object, since the width of the interior angle of one image is largely different from that of another, the unrecognizable portion of the object increases when the interior angle is too narrow, while something other than the object is also recognized by mistake when the width of the interior angle is too wide. For the automatic extraction of object domain, it is necessary to strictly set the interior angle. The authors succeeded in extracting object domain by providing the dispersion of hue in terms of parameter through visual observation.

5. Conclusion

The authors have so far conducted an experiment on the automatic recognition of object domain from its natural image, but they could not automatically recognize the width of color distribution. From the analysis result of natural images obtained so far, the width of color distribution is considered to be caused by materials of the object surface; therefore, if knowledge of materials with the width of color distribution taken into consideration can be obtained, more perfect automatic extraction of object domain together with color will be possible.

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