Advances in Methodology and Applications of Decision Support Systems

Marek Makowski, Yoshikazu Sawaragi, Editors

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Proceedings of the Workshop
held on August 20-22, 1990
at IIASA, A-2361 Laxenburg, Austria.

Preface

These Proceedings are composed of the papers that correspond to the selected presentations of the Workshop on *Advances in Methodology and Applications of Decision Support Systems*. The Workshop was organized by the System and Decision Sciences (SDS) Program at the International Institute for Applied Systems Analysis (IIASA) and the Japan Institute of Systems Research (JISR) and was held at IIASA on August 20-22, 1990.

The research on Decision Support Systems (DSS) has a long tradition at IIASA. The Institute is a forum for the common research of scientists from countries with different cultural backgrounds and different experiences with real-life applications of their results. One of the most important activities of the Methodology of Decision Analysis (MDA) Project of the SDS Program is to operate an international network of scientific institutions involved in the research related to the methodology of decision analysis and decision support systems. The JISR plays an important role in this network and one of its activities is to organize cooperation with different Japanese scientific and research institutions in Japan.

The MDA project focuses on a system-analytical approach to decision support and is devoted to developing methodology, software and applications of decision support systems concentrated primarily around interactive systems for data analysis, interpretation and multiobjective decisionmaking, including uncertainty analysis and group decision making situations in both their cooperative and noncooperative aspects. The results of the research performed by the scientists who cooperate with the MDA project are applied at IIASA and utilized by other institutions in the countries that are Members of IIASA.

In most important decisionmaking situations it is necessary to take a number of competing and contradictory factors into account; moreover, there are usually complicated links and relationships between various alternatives. One way of assisting the decision maker is to provide him with computerized tools capable of evaluating the various alternatives. These tools are known as decision support systems. On one hand, such tools consist of standard mathematical algorithms, and on the other hand, on the needs of the tools to create the necessary models. There are many considerably advanced approaches in the methodology of decision support systems; it is necessary, however, to study them comparatively, particularly in relation to real life applications.

The objectives of the research on DSS performed in cooperation with the MDA Project are to:

- compare various approaches to decision support systems;
- advance theory and methodology of decision support;
- convert existing theories and methodologies into usable (simple to use, user-friendly and robust) tools that could easily be used in solving real-life problems.

A principal characteristic of decision support systems is that they must be tuned to specific decision situations, to complex real-life characteristics of every application. Even if the theory and methodology of decision support is quite advanced, every application might provide impulses for further theoretical and methodological advances. Therefore the principle underlying this project is that theoretical and methodological research should be strongly connected to the implementation and applications of its results to sufficiently complicated, real-life examples. This approach results in obtaining really applicable working tools for decision support.

The papers for this Proceedings have been selected according to the above summarized framework of the research activities. Therefore, the papers deal both with theoretical and methodological problems and with real-life applications. However, in most cases, there is no clear distinction between theoretical and application oriented papers. Hence, the papers are arranged in alphabetical order of the names of the authors. Below is some brief information on the contents of the papers included in the Proceedings. *Y. Sawaragi and Y. Nakamori* present the Shinayakana methodology and its application for the development of a DSS for the man-environment system. *T. Fukuda and J. Baba* introduce an application of the Shinayakana approach in management of an R&D organization. *Z. Wang* presents the methodological background and experiences related to development of DSS in the P. R. of China. *J. Baba and T. Fukuda* discuss the functions of organizations aimed at promoting innovations in science and technology. *M. Nakajima and Y. Othake* review the role of DSS in different application areas. *S. Bodily* discusses influence diagrams, which are a tool for expression of relationships among the variables in a decision model and of conditional probability. *S. Opricović* compares two methods for multiple-aspect ranking of alternatives, namely the Compromise Programming and the Electre. *S. Ruuth et al.* review the Mathematical Modelling Environment MME designed for supporting mathematical modelling and algorithm design and demonstrate one of the MME application. *R. Vetschera* introduces a preference-preserving projection technique for visualizing information both on data values and preference relations and discuss the application of this technique in multicriteria decision making. *T. Nakagawa and Y. Sawaragi* demonstrate the application of a management system based on a cooperative multi-agent model for a cement making process. *M. Nagata and K. Takada* introduce an application of the Hypertext model for multimedia dental information database. *T. Takahashi et al.* present a prototype of an object-oriented multimedia database and also give an illustration of its applications. *N. Ueno et al.* review an application of the satisficing trade-off method to a scheduling problem of lot formation in steel manufacturing.

The editors of these Proceedings would like to thank IIASA for financing the Workshop and for its continuous support and encouragement for research in the field of DSS. This support and encouragement came especially from Prof. Alexander Kurzhanski, Chairman of the System and Decision Sciences Program at IIASA. Thanks are also for Mr. Tadeusz Rogowski, Institute of Automatic Control, Warsaw University of Technology, who has organized processing of the manuscripts in a professional manner.

Marek Makowski
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Kyoto, Japan and Laxenburg, Austria, July, 1991

Contents

The Center of Excellence and the Role of Stakeholders

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Abstract

The center of excellence is an important organization for promoting the innovations in science and technology. In the research networks of science and technology, the center of excellence is a core of innovation process. The stakeholders have important responsibilities for the development of the center of excellence. The roles of stakeholders are discussed from the view point of the center of excellence.

1 Center of excellence

The center of excellence (COE) is an organization which is recognized with its excellent activities in the field of science and technology. The COE is known in each field, such as the NIH in medical science, Max Planck Institute in physics and other famous national laboratories, in which the major field is the basic research.

The fundamental characteristics of the COE can be considered as the following three; Creativity, Openness and Generality. In the well known COE there are famous authorities and the large scale research facilities. For the creative research the COE has established the sufficient research environment. The well known research activities are the best characteristics to the COE. It is open in a sense of knowledge distribution which is found and integrated. It is not hard for the people to access to the institute and the large volume of information are communicated in the research field via publishings and conferences. The knowledge originated from the COE is considered to become basis for the broader application technology. So the research from this make usually general scientific fruits which can be implicated some time in the future. From these three factors the effects are great for the development of science and technology.

The research domain of science and technology can be classified into two categories; the basic science and the generic technology. The basic science seeks the pure intellectual curiosity like astronomy, quantum physics and life science. On the other hand the generic technologies, that is, common based technologies, are electronics, information technology and biotechnology. In Japan, the COE can be found in this field of generic technology which can be found in the corporate level research activities. The research in the field of generic technology is strongly connected to engineering, by which the innovation can be implicated into the new products. The management of R&D is quite important to develop the technology for the leading edge of the corporate business.

From the view point of innovation process, the COE can be assumed as a core in the innovation process. The innovation process can be considered as a cycle consisting of two phases: the differentiation and the diffusion as shown in Fig.1. (Baba et al., 1988)

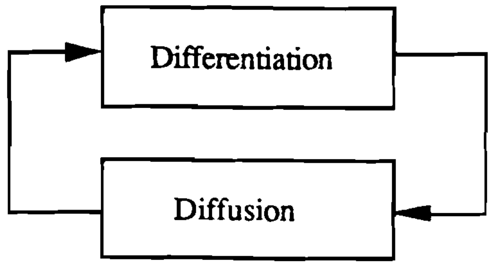

Figure 1: Two phases of Innovation Process

The differentiation is a process to create the innovation which has not been found and developed as yet. The innovation is not only the new breakthrough but also the incremental innovation (nuts and bolts) and the system innovation as pointed out by R. K. Muller, (1971). The phase of diffusion process is also important through which the innovative technology is propagated into the society with the technologies and products. The feedback from diffusion process to differentiation process is intrinsic to the innovation. It is made clear that needs from marketplace often lead the innovation as user lead innovation to be fed back to the R&D section. (Hippel, 1988), It has been said that the innovation process is linear as staring from research through development and manufacturing to distribution. Yet the innovation process is not a linear process, but a cyclic and mutually interactive process among each section of research, development, manufacturing and distribution. The two phase model consisting of differentiation and the diffusion as described above is one of such nonlinear innovation models. It is clear that the COE becomes a center of innovation and it gives the effects to the related organizations. The COE is eventually a center of research network through which the innovation is diffused. From this point of view, it is important for a corporation to have the core center of technology innovation, that is, the COE in the corporate level, and have the network for the knowledge communication of technology.

2 Stakeholders

When considering the R&D management, it is also necessary to take into account of the view point of stakeholders. The stakeholders are all the concerned people or the organization which have relationships with regard to benefits or loss in some extent, (Freeman, 1984).

The organization does not exist without relationships with the surrounding environments. Innovation process can be promoted not only by a corporation but also by many persons of stakeholders with whom it may be concerned. Many persons who are concerned to the various interests, that is, stakeholders, should be taken into account in the innovation process. In the stages of promoting the innovation process, many stakeholders are involved, such as top management, employees (researchers, designers, engineers and maketters), stockholders, labor union, customers, suppliers, local society, government, consumers and academic people. Fig.2 shows, for instance, a map of stakeholders related with a corporation. As the COE is the central core of the corporate research activities, many stakeholders are concerned with it. It can be considered that the development of the COE has a life cycle and who is the most effective at each stage of life cycle.

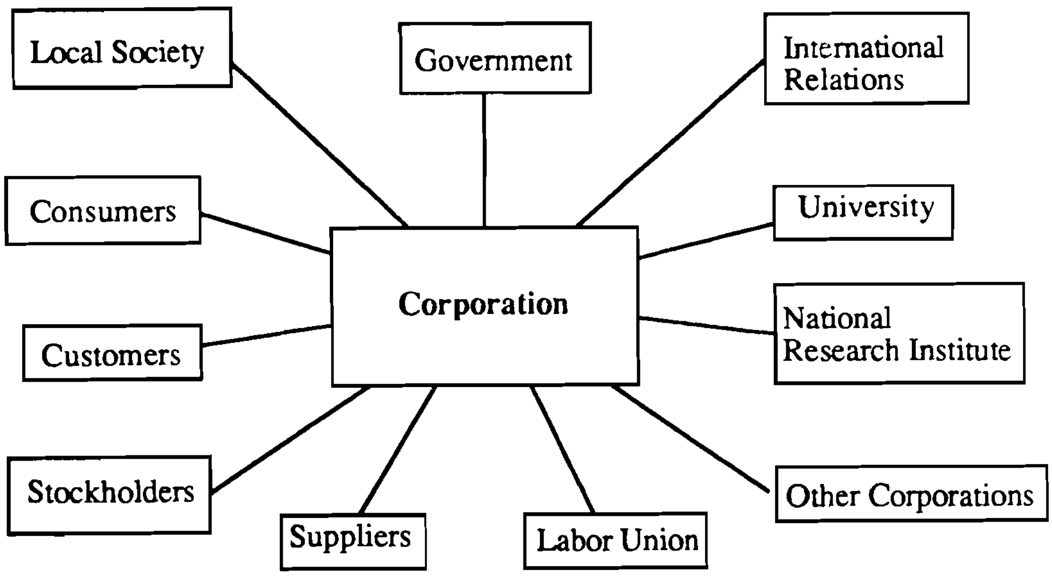

Figure 2: A Map of Stakeholders

3 Life cycle of COE

The COE has a life cycle from the birth to the growth along which the stakeholders are able to play important roles. It is not an easy way to establish a center of excellence in a corporation. Let's consider the requirements to be necessary for the development of center of excellence in a corporation. Fig. 3 shows an example of life cycle of the center of excellence. The first stage is the incubation to find and raise up it from the small scale. With the support to the hopeful research it is growing to an established center, which produces research fruits as new products based on key technologies to make it recognized as a center of excellent technologies in a corporation and other external organizations. As the research is active, the network will be made of itself. The communications are active with each other research organizations. The corporation is able to establish a new business unit to make it meta development of company by chance. New business can create new paradigm of corporate activities and also changes the corporate culture or the value system which will be a teleological drive for the company.

The origin is occasionally a small fluctuation in the organizational activities, while it is a bootleg or under the table research. The support is given by the academic field such as university professor not by the corporate decision maker. When the idea is innovative, the academic people is able to make assertion to the idea from the science and to give them the encouragements. Without the support of the academic people, it is not easy to promote the idea to the official research phase from the bootleg research. This period is call as the incubation of the COE.

As the research goes on, the corporate support becomes necessary for the investment of finance and human resource. Meanwhile it is highly risk for a decision maker to invest to such ambiguous research, the corporate executive has to make decision. It is beneficial for the executive to consider the suggestions of the stakeholders from the various aspects at the decision making.

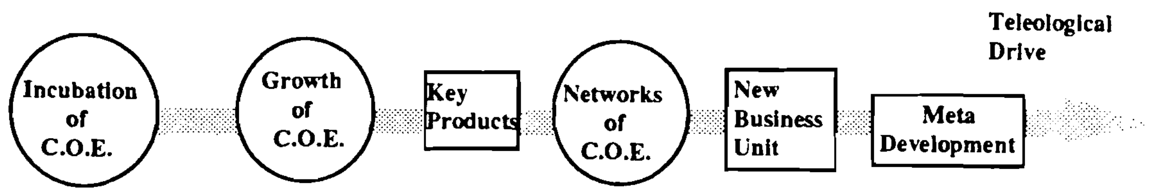

Figure 3: Life Cycle of Center of Excellence

At the stage of growth, the authorization given by the university is essentially effective for the corporate executive. The authority has usually insights into the future trends of technology. The digital electronics and the computer technology, for instance, could been predicted twenty years ago, yet at that time the major technology was analog-based electric equipment. It is also effective for the major customer to support such technological innovation to accept it in the future. The executives of electric company has supported the innovative digital electronics by carrying the cooperative research project with manufacturer. In the case that the research investment costs high for a large sale facilities such as the VLSI, the top management decision is required for the future competitiveness. At this stage, technological, financial and organizational decision makings are asked for the corporate executives.

The establishment of COE in a corporation comes from the success of key products with innovative technology. The new material, for instance, is a kind of key technology. For example the success of development of ELD (Electronic Laser Diode) makes establish the optical-semiconductor technology. These key technologies can be diffused into the other products as it is a common base technology. With the success of key technology development, the research laboratory becomes a COE in the corporate R&D level.

As the establishment of COE, the network of COE is created with each other in the common research domain. For example, the laboratory in A-company, the one in B-company and national laboratory would have the research network with cooperative project. The interdisciplinary, inter–institute and international network will be realized.

4 The role of stakeholders

As discussed above, the role of stakeholders are essentially important for the development of the COE. Three roles can be observed such as awareness, open–mindedness and risk–taking. The manager in R&D should be aware of the signs at the bootleg phase of research and the academic people is able to support with the scientific authorization. The second role, open–mindedness, is required for the top management to maintain the high risk researches. This open–mindedness also is able to make the top management see the long term management rather than the short term management. The third role, the risk taking is characteristic to the long term investment for the future business. As the recent high-technology R&D takes high cost, it is not easy to make decision of risky investment. The cooperation will be an answer in the future corporate activities. In these days as the recent R&D is strongly interconnected with each other in the scale and the scope of science and technology, it is necessary for the R&D management to obtain the supports from the various stakeholders at each stage of the development of the COE. With those stakeholders' supports, the R&D will be able to become a center of excellence in the technology–based company.

5 Concluding remarks

The center of excellence is a core of innovation process. It is noted that the center of excellence can be considered in the various fields and the scale with regard to national, academic, business, technology, or science. It is required for the corporate executives to make clear who is the stakeholder to be the most effective at each stage of development of the center of excellence. In these days that the communications are active among the people as well as the organization, networks of the center of excellence will be more important in science and technology.

From the view point of innovation process, the decision support system can be considered in the various aspects. At the differentiation process of innovation, the decision support systems for the researcher and the engineers are required, which are analysis tools, simulation tools and communication tools. On the other hand at the diffusion process, the standard data base, engineering tools and the transparent systems are required. The differentiation needs the decision support systems for the creative research activities and the integration of the acquired knowledges. The diffusion process needs the decision support systems for the transparent information and the common recognizable distribution of knowledges.

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The Influence Diagram: A Modern Graphical Tool for Decision Modeling

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Abstract

The practice of decision analysis and modeling has been greatly enhanced by influence diagrams, which aid the expression of relationships among the variables in a decision model and of conditional probability. All steps of the modeling process are improved by the influence diagram, including structuring, understanding, exercising, and explaining quantitative models. This paper describes the significance of influence diagrams in their own right as graphical tools. In addition, their importance in unifying several directions of work in modeling and relating to other natural language representations of models is discussed. Examples come from general classes of problems, including decisions under uncertainty, financial decisions, and optimization applications.

1 Introduction

In recent years, influence diagrams have had a profound influence on two fundamental activities in decision modeling:

1) the structuring of relationships among variables, including decision variables, intermediate variables, and outcome attributes

2) the expressing of conditional probability.

In either instance, the influence has gone beyond the formulation of the model, into every stage of the modeling process, including analysis (with new influence diagram software) and the presentation of results. For the non-specialist, this new tool is especially significant. Along with the desktop computer and new ubiquitous "modeling" software, it transports the less technically prepared into a, perhaps alien, new world of modeling opportunity.

Specialists who have been modeling right along may use the influence diagram for greater productivity in modeling, especially in the process of formulating problems and presenting them to others. Non-specialists may need a graphical interface such as the influence diagram (along with accessible software) in order to function at all as modelers. Neither group may appreciate fully the unifying capabilities of the influence diagram. For example, even those who have used the tool for structuring variables may not appreciate its value in expressing conditional probability.

This paper shows how the influence diagram serves in a variety of problem areas, and throughout the model's life–cycle. It shows how the influence diagram ties together recent developments in decision making under uncertainty with innovations elsewhere in structured modeling and natural language.

2 Relationships among variables

An influence diagram is a graphical display of the elements of a decision problem and their relationships. It consists of decision nodes (denoted by rectangles), intermediate variables (circles), a single value or utility node (a rounded square), and directed arcs (influences) between variables.

The influence diagram has developed in several forms. The earliest use of a related diagram was probably that of Forrester (1968) who used arcs between variables to represent causal relationships. More recently Owen (1978) and Howard and Matheson (1980) used influence diagrams for decisions under uncertainty. Shachter (1986,1987) has formalized the diagram for probabilistic inference. Geoffrion (1987) uses a device, the genus graph, for deterministic problems that has some similar features to the influence diagram. The use of influence diagrams for structuring relationships among the variables in a decision model is described in Bodily (1985, chapter 3).

Figure 1 shows an influence diagram for a new product investment decision. **Selling Price** is a decision variable that affects **Revenue**. Other cost and market-related variables affect **Revenue** and **Expenses**. The ultimate measure of value is the **Net Present Value**. For our purposes, assume that all variables are deterministic in this diagram.

The arrows coming into a node indicate what influencing variables are used to calculate the variable associated with that node. For example, **Market Size** and **Market Share** are needed to calculate **Revenue**; **Market Size, Market Share, Unit Product Cost,** and **Annual Fixed Cost** are needed to calculate **Expenses.**

Some of the most significant statements are made by the absence of an arrow in the influence diagram. For instance, the lack of an arrow between **Selling Price** and **Market Share** is a strong statement that **Market Share** is unaffected by **Selling Price**.

An arrow into a decision node indicates that the decision maker knows the information denoted by the predecessor variable at the time the decision is to be taken. Otherwise, an arrow does not imply time precedence. Arrows may exist for causal relationships but do not necessarily signify causality.

The influence diagram conveys the structure of a model. Consider a set S of model variables. More formally, we can define the structure of an influence diagram and the associated model to consist of:

1) the set S of variables and variable names for each element of S

2) a partitioning of S into the three types of variables: Decision, Intermediate, Utility

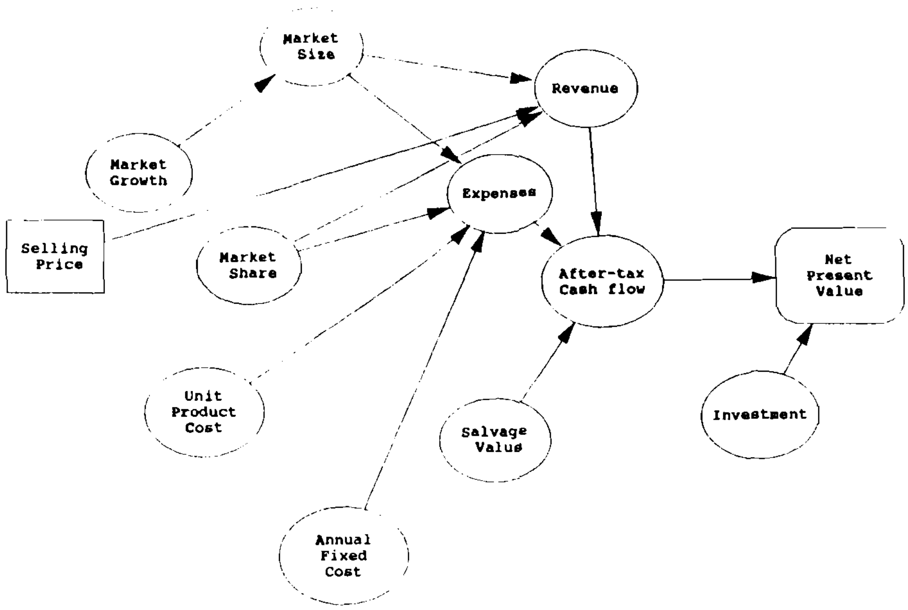

Figure 1: New Product Influence Diagram

3) an influence partial order P among the variables

4) an indication of which, if any, intermediate variables are uncertain variables

In P, a variable x precedes y if the value for x must be known in order to determine the value (or the probability distribution) for y. Thus P is a binary relation on pairs of elements drawn from S, such that for any x, y, and z in S, the P relation is irreflexive (xPx for no x), asymmetric (xPy implies not yPx), and transitive (xPy and yPz imply xPz also). It being a partial order there may exist x and y such that not xPy and not yPx.

Shachter (1986) defines requirements to make an influence diagram regular:

1) no cycles

2) the utility node, if present, has no successors, and

3) there is a directed path which contains all of the decision nodes.

Stated differently, the third condition requires a total ordering of all decision nodes. Cycles could be allowed if there were no uncertain variables in the diagram. With little loss of generality, however, assume in what follows that influence diagrams are regular. Shachter also defines a diagram to be oriented if it contains a value node, and is proper if it "represents a single decision maker's point of view" and contains decision variables.

3 Conditional probability

While it is easy enough to make any node in an influence diagram uncertain (that is, a chance node), doing so alters the meaning of arrows into that node. An arrow from one uncertain node to another is a statement about probabilistic influence. By definition, an arrow from uncertain node A to uncertain node B states that

$$\text{Prob}(B|A) \neq \text{Prob}(B).$$

The arrow is often used more as a statement of the structure of information. That is, an arrow means there is suspicion in the mind of the decision maker of probabilistic dependence of B on A; it may turn out later that the dependence is so weak that it can be assumed there is no correlation at all between B and A. Note that if A and B are uncertain, then an arrow from A to B implies that an arrow could just as well be drawn instead from B to A, since it must also be true that $\text{Prob}(A|B) \neq \text{Prob}(A)$.

Figure 2a shows an example influence diagram involving three binary variables: **Gender** (with possible outcomes M and F), **University Degree** (with possible outcomes D for Degree and D'), and **Computer User** (Y or N). These variables describe an individual selected from a given population. The arrows in that diagram suggest a dependency of **University Degree** on **Gender** and a dependence of **Computer User** on both **Gender** and **University Degree**. Thus if we wished to calculate the joint probability of M and D and Y, it would be

$$\text{Prob}(MDY) = \text{Prob}(M)\ \text{Prob}(D|M)\ \text{Prob}(Y|DM).$$

The arrow from one variable to another, **Gender** to **University Degree**, for example, does not imply causality; **Gender** does not determine **University Degree**. Again, the significant statement is the absence of an arrow, which suggests probabilistic independence.

This structure is similar to the decision (or probability) tree shown in Figure 2b. Yet the influence diagram says more than does the tree. In the tree we must know the indicated probabilities on the tree (P_1 and P_2) to know whether $\text{P}(Y|D)$ depends on **Gender**. However, it is already evident in the influence diagram that $\text{Prob}(Y|D)$ depends on M.

The structure indicated in Figure 2a may be the preferred assessment form. For example, it may be preferred to assess $\text{Prob}(D|M)$ than $\text{Prob}(M|D)$. Even though the probabilistic model is assessed in this way, other forms of probabilistic structure can be computed. The reversal of an arrow is the same as switching the order of events in the decision tree. The revised conditional probabilities are calculated in either case through the use of Bayes theorem. Software is available on personal computers to construct influence diagrams graphically that have simple commands to carry out Bayes theorem and reverse arrows.

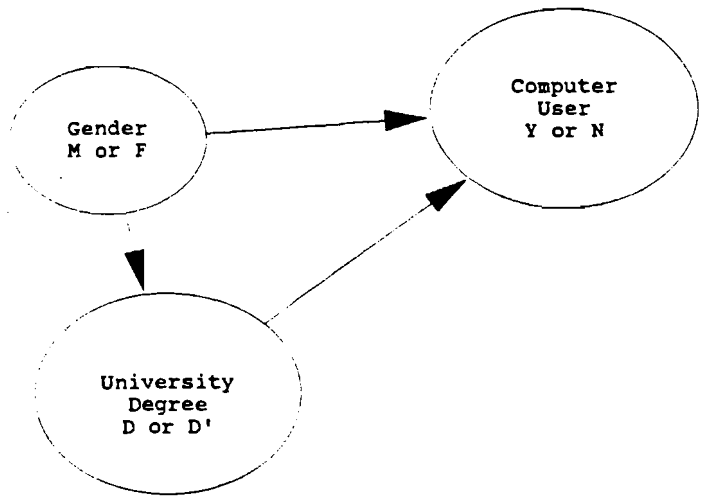

Figure 2a: Influence Diagram for Conditional Probability

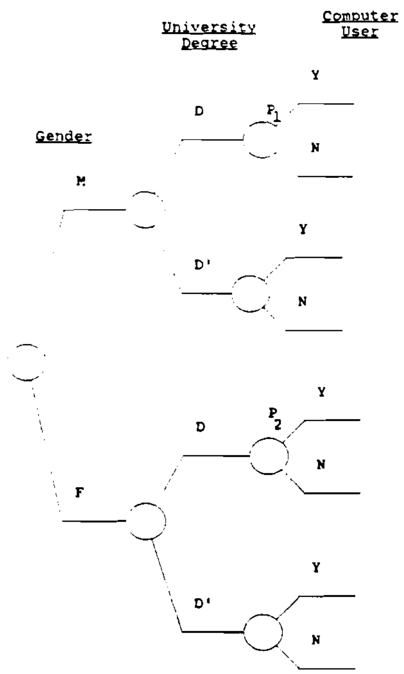

Figure 2b: Equivalent Decision or Probability Tree

Clearly, there is more to a problem, even a simple one such as these two, than is described by the influence diagram alone. Certain data elements relating to each node and each arrow must be used in solving the problem. Yet the structure of a model of the problem can be conveyed by the influence diagram and understood readily.

4 Other types of problems

The influence diagram is a portentous development, in part, because it is usable for a wide class of problem structures, including decision trees, risk analysis, optimization, multiattribute choice, dynamic programming and others. Thus it is useful for structuring problems at an early stage, before it is even clear what solution methodology may be needed.

Consider a feedmix problem as an illustrative example. The mathematical formulation might be written in algebraic terms as follows:

$$\min \quad cx + dy$$

subject to

$$ax + by \geq r$$

$$x, y \geq 0.$$

Here x and y represent the quantity of two materials that can be blended into a feedmix; they cost c and d dollars per unit respectively. There is a constraint that the nutritional level of the mix exceed r, where a and b are the nutrients per unit of the two materials.

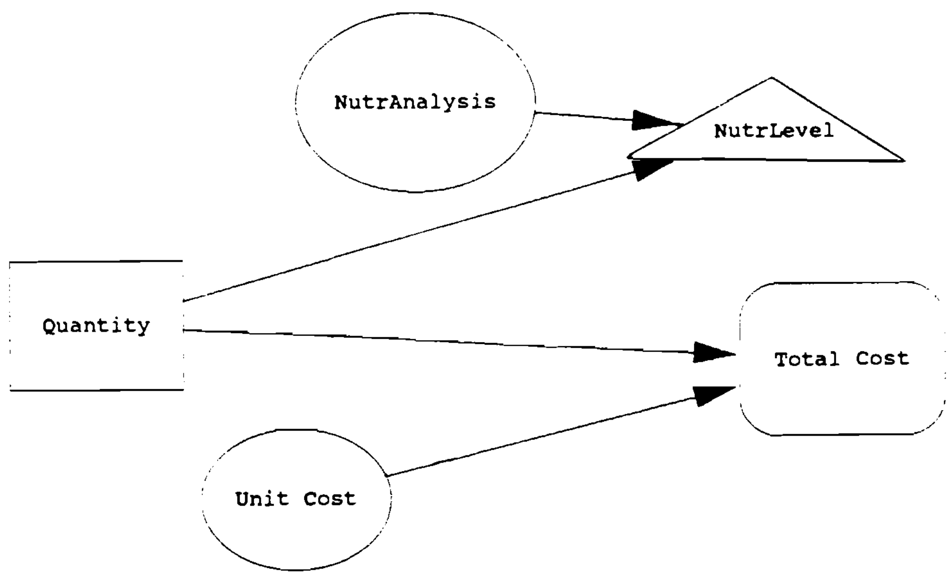

Figure 3: Influence Diagram for Feedmix Problem

Figure 3 shows an influence diagram for this problem. **NutrAnalysis** is the amount of nutrient per unit for an ingredient; **NutrLevel** is the total nutrient level for a feedmix. Both **Quantity** and **NutrAnalysis** must be known in order to calculate **NutrLevel**, hence the arrows from these variables to **NutrLevel**. **Quantity** of a particular feedmix is the decision variable; overall utility is measured by **Total Cost**, which is computed from **Unit Cost** and **Quantity**. The triangle indicates that the variable **NutrLevel** is constrained. Plane (1986) extended the influence diagram to include constraints.

Since problem-solving typically requires a computer, the problem must be rendered in a language that the computer can process. In former times, this would have been a completely different representation from the algebraic expression above. Language advancements mean that the model could be expressed in syntax that matches the algebraic expression and used directly with a linear programming solver (e.g. LINDO). In order to use a single representation, however, one must have known in the formulation stage the type of solver needed. A different representation would be needed to accommodate a different solver (e.g. a Monte Carlo simulation related to the same variables).

We cannot always expect to know in advance which analysis we wish to perform; many solvers may end up being used. The influence diagram, with its wide versatility is preferred for formulating and structuring decision models. It is independent of particular solvers that may be used with it, e.g. expected value calculation, Monte Carlo simulation, linear programming. And it can be independent of the data base that stores the supporting numbers (e.g. a, b, c, d, r in the feedmix problem). As software becomes available that integrates generic solvers and data bases with influence diagram graphics, the tool will be even more widely used.

5 Relationship to other representations

The influence diagram ties into other modern natural language expressions for modeling. Consider the very simple structure for a pricing decision given in Figure 4 to illustrate. We will briefly describe a number of alternative representations.

5.1 Indented list

In an indented list, variables that precede another variable in the influence diagram (and thus must be known to calculate the variable) are indented and placed below that variable. Variables may appear twice in the list. In no case can a variable reference a variable to its left in the indented list. The influence diagram associated with the indented list has no cycles if and only if there is some list of the nodes such that all of the successors of a node are to the left of it in an indented list. The indented list for the simple pricing decision is as follows:

Revenue
- Selling Price
- Unit Sales
  - Selling Price

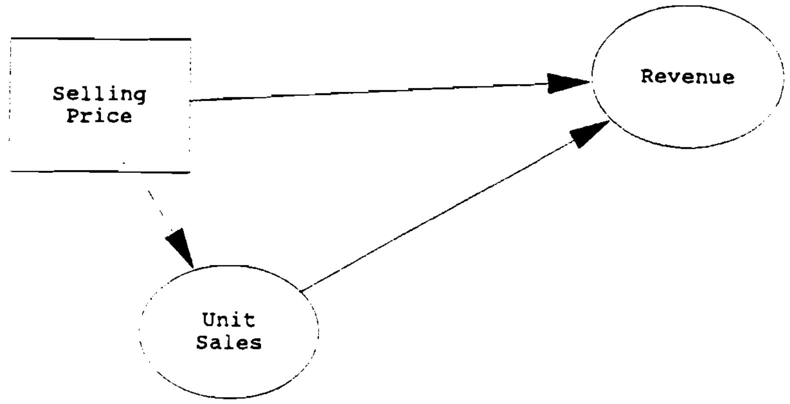

Figure 4: Simple Pricing Model

The indented list for the feedmix problem in Figure 1 would be as follows:

Total Cost
    Quantity
    Unit Cost
NutrLevel
    Quantity
    NutrAnalysis

The indented list format is often useful as a way of setting up a data base, a spreadsheet, or the model expressed in some structured programming language. In validating a model, a user may use it to quickly trace the genealogy of predecessors of any output variable. Outlining software may be used to manipulate an indented list.

5.2 Cross reference

The simple pricing model of Figure 4 can be expressed in a cross reference listing as follows:

Variable	Where Used
Selling Price	Revenue, Unit Sales
Unit Sales	Revenue

This may be a convenient way to document a model; the list is usually sorted alphabetically on the first column to afford easy lookup. It may be useful to store structure in the computer in this way. However, for a user who is building a structure or analyzing a model, position in this listing (either through arrows or indentations) has no structural meaning as it does in the above representations.

Each of the alternative representations have advantages for particular uses. For example, the cross reference listing may be useful for understanding and validating the structure of complex models, due to the alphabetical lookup capability. Each ties to the influence diagram in natural ways, which of course has a graphic impact that the others do not.

One can envision a computer modeling environment wherein the base structure is created using the influence diagram and the other representations are used to view the structure from alternative perspectives. It may be useful to look at the alternative representations for pieces of the entire model. Again, we look to the influence diagram as providing the basic tool for expressing these pieces or modules.

5.3 Structured modeling

Geoffrion (1987) has developed alternative problem representations in his excellent work on structured modeling. His *schema* has some properties of the indented list (no leftward references in any computations), but adds much more detail on the attributes of particular variables, and places the structure within modules. His *genus graph* is very much like the influence diagram; called variables are at the tail of arrows coming into a variable. The work of Geoffrion goes a long way towards developing the understanding of how to separate model, data, and generic solvers.

5.4 Other modern structuring and modeling methods

Influence diagrams relate directly to several other devices that are becoming important in the structuring, representation, and analysis of models. These methods have originated in the social sciences or in artificial intelligence, yet their application is now more widespread. For many purposes to which they are now put, the influence diagram would serve similarly and just as well.

Cognitive mapping (Axelrod, 1976) is intended to capture a mental model. In its use in business strategy, it is used to provide insights into the qualitative relationships among the features of a problem situation. Its origins are in the social sciences where it normally gets more quantitative treatment. Since it is a map, distances between factors play a more important role in its use than in the influence diagram.

Structural equation modeling (Bagozzi, 1980; Duncan, 1975) is a general approach for estimating a wide range of linear relationships. The model is generally described with a diagram that shows what are the dependent and independent variables and how they relate. This diagram resembles an influence diagram and defines the same structure. In addition it identifies the error terms that are key to the process of estimating parameters in the linear model.

Belief nets allow the combination of a system of independent belief functions over states of a network in order to draw conclusions about the whole. The methods bring together Bayesian analysis and artificial intelligence concepts of knowledge. The book edited by Oliver and Smith (1990) describes the ties between influence diagrams and belief nets.

6 A single model representation used throughout the modeling process

The conventional approach to problem–solving using management science comprises several activities: mathematical formulation, data collection, creation of computer program, analysis, and presentation of results. Each of these steps typically requires its unique representation of the problem. A paramount aim in developing tools for decision modeling is to simplify this task. The influence diagram offers promise as a single representation of a model that is useful for many or all of the stages in the modeling process. It is easily understood by generalist and specialist alike, it is intuitive, and general. It works smoothly with various existing representations of model and data, for example, spreadsheets and data bases. Consider what it offers in several stages of the modeling process.

6.1 Structuring

The influence diagram was designed as a fundamental tool for getting started on a decision model. In the structuring process, the first questions are What is the fundamental decision? and How do we measure the performance of alternatives for this decision?. Answering these gives us a decision variable on one side and a Value node on the other.

Consider, for example, how we might have structured the model in Figure 1. Answering the two questions above would have given us the decision rectangle for **Selling Price** on the left and the value node for **Net Present Value** on the right. Then we ask ourselves "What is needed to compute **Net Present Value**?" We must have **Cash Flow** and **Investment**, so we create those nodes and the arrows coming from them into **Net Present Value**. Repeating the question "What do we need to compute **Cash Flow**," we create the **Expenses** and **Revenue** nodes and arrows coming from each to **Cash Flow**.

Another question that helps structure the problem is to ask what the decision variable affects. The answer is **Revenue** and we draw the arrow from **Selling Price** to **Revenue**, giving us a connection from initial decision node to ultimate value node. Then we ask "What is missing?" to identify the other variables. Thus the model takes form in the process of moving from the sides (the decision side and the value side) towards the middle, filling in the intermediate variables as we go.

6.2 Modeling influence dependencies

In order to flesh out a decision model, we must specify the relationship for each decision variable. In the simple problem of Figure 1, for example, we must be specific about how revenues are affected by **Market Size** and **Price**, for instance. For each node with arrows coming into it, it must be established how that node is calculated using the quantities assigned to influencing variables.

For this problem, those influences can be expressed in a spreadsheet. Below, the quantities of all variables in the model are shown in spreadsheet form:

New Product Investment Model

	Initial	1992	1993	1994	1995	1996
Investment	400	0	0	0	0	0
Market Size	290	290	319	350.9	385.99	424.589
Market Growth	0.1					
Market Share	0.4					
Selling Price	3					
Unit Product Cost		1	0.95	0.93	0.91	0.9
Annual Fixed Cost	90					
Revenue		348	383	421	463	510
Expenses		206	211	221	231	243
Salvage Value						20
After-Tax Cash Flow		77	93	108	126	164
Net Present Value	15					

There is a cell here showing the numbers for each variable in the influence diagram. The influence relationships are modeled, however, by the cell–formulas which are background to these numbers. The cell for Revenue, for example, shows that it is calculated as (**Selling Price**) $\star$ (**Market Size**). Those nodes in the influence diagram with arrows coming into them would have in their cell formulas cell references to each influencing variable (at the tail of each arrow of the influence diagram).

It is possible therefore to create an influence diagram for any spreadsheet. In fact the computer must make use of this influence structure in order to know which cell to calculate first in the spreadsheet.

6.3 Exercising the model and sensitivity analysis

Once the relationships in the decision model are complete, the model is ready for analysis. The influence diagram may play a role in conducting that analysis.

An obvious form of analysis that plays such a big role in routine work is sensitivity analysis. Its archetypal form is the what if analysis that is predominant with spreadsheet models.

Sensitivity takes two major forms in the influence diagram. First is what we will call *impact* analysis. This tests the effect of many variables on a single variable. Consider the impact analysis of the new product model (from Figure 1) described in Figure 5a, where the effects of three input variables on one output variable are needed. In the original diagram there was no direct influence of these three input variables on the output variable; the impact is indirect through other intermediate variables. The intent is to identify whether there is any influence at all and to report the significance of the influence.

High and low values for each of the input values would be tried for each variable one at a time and the resultant NPV level calculated and displayed. Or a complete rendering of the response surface for the three variables may be provided by the generic solver. It may be possible to display results cleverly with graphics in the influence diagram itself, e.g. the thickness of influence paths could relate the strength of the relationship between input and output variables.

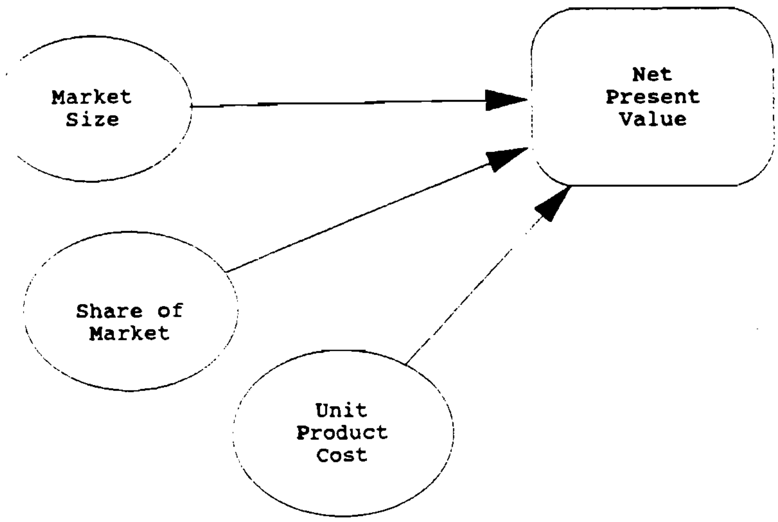

Figure 5a: Impact Sensitivity Diagram

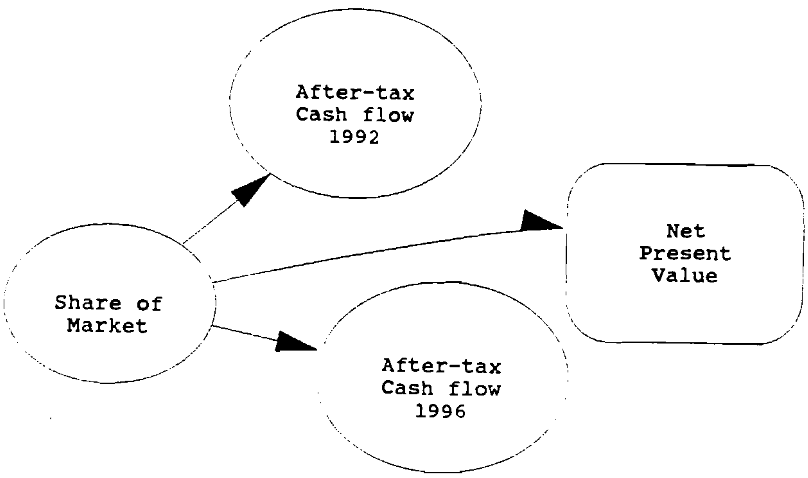

Figure 5b: Response Sensitivity Diagram

The more significant use of this analysis may be for input variables that are many steps removed from the output variable in the influence diagram. Of course if there is no path of influence from an input variable to the output variable, the impact is nil.

The other kind of sensitivity analysis, which we will call *response*, is, in some sense, an opposite of impact. It shows the effect of one variable on many. For instance, in the new product model, we may wish to know what effect **Share of Market** has on several other variables, as indicated in Figure 5b. The generic solver would solve for low and high cases of the input variable, calculate the effect on the output variables, and display it.

The influence diagram may be the only representation needed to study sensitivity in the model. It certainly can be, at the least, the graphic medium in which to direct the sensitivity analysis.

The analysis process is greatly simplified now by the availability of software that aids the development of influence diagrams and the analysis of the resultant decision model. For example, DAVID (Drawing And eValuating Influence Diagrams) has been developed by Ross Shachter for the Apple Mackintosh computer (available from Academic Computing and Computer Services, Duke University). Using a mouse, one can draw an influence diagram with DAVID on the computer screen, and add the supporting relationships and probability distributions for chance nodes. DAVID will then automatically perform expected value calculations to indicate the optimal decision for decision nodes. If it is necessary to use Bayes Theorem in the process, DAVID will do that automatically also. Using the mouse, one can add arcs from nodes into decisions and easily compute the expected value of information (EVPI) for any number of uncertain nodes. The expected value of sample information (EVSI) is also easily computed from the graph.

DPL is more recent software for IBM-compatible computers in the Windows environment that will carry out similar analysis. In addition, it will draw the decision model in either the decision tree format or the influence diagram format. This software promises fast computation of even very large decision models due to the structure of its own Decision Programming Language.

6.4 Presenting

Once the analysis is complete, the task of preparing a presentation begins. In addition to results of the analysis and recommendations, the structure and concept of the model would be presented. It is key that the representation of the model be quickly understood by the non-specialist. Unfortunately, many of the common representations of models in management science are not as useful with general audiences.

A nice feature of the influence diagram is that the same tool used to structure the problem and guide the analysis may be the most effective way to present it to others. This is particularly true with generalists not acquainted with algebraic or other mathematical representations of problems and especially when new software is available to aid the real time projection or preparation of high quality graphics.

The influence diagram is concise; the structure of very complicated models can be shown on a single sheet of paper. And the scope of the representation can be adjusted to match the level of detail desired. The diagram is modular; many decision variables might be combined into one node for purposes of presentation and blown up if requested to show the detail. In fact the nature of the structure can evolve in real time as it is communicated to others.

The influence diagram evolves in its own, separate from, but compatible with associated data and solvers. This constitutes a step forward in modeling and in computer use. Early computer implementations included all input/output functions, all data, and all solvers in one program. Then input/output functions were separated. Soon data came to be stored in separate files, and shared in common with many other applications. Now we are ready for data and model and solver to be separate. The representation of the model must be simple and flexible, yet provide transparent access to computer commands for data and solver. The influence diagram fits these needs.

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Duality of Flexibility and Consistency: Shinayaka–ness in R&D Organization

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Abstract

It is not sufficient to have a single perspective on the organization. This paper discusses how the origin of the Shinayaka–ness (flexible, pliant and active in Japanese) is generated in the systems. It is said that the the flexibility is necessary for the organization, on the other hand the consistency is necessary too. Both properties are contradictive but the management to take into account both of them is essential for the development of an organization. The duality of flexibility and consistency is considered to be the principal property for stable and evolutional systems. From this point of view, management of R&D organization is required to have both aspects of flexibility and consistency, that is the origin of the organization's development. The effects of information technology to the management is also discussed, which supports the executive decision process. The information networking would become a powerful infrastructure for management to adapt itself to the turbulent economical and technological environment.

1 Introduction

The environment surrounding a company is changing with speed and scale. The aim of industry has been in the scale of economy based on the mass productionism and the cost reductionism. Yet in these high–technology era, the mass productionism is not true in business maintenance and development, for it is concerned with the stability and the efficiency of a corporate system. As the increasing of investment into the R&D indicates, the economy of scope (Golder and Jelnik, 1983), that is to seek the varieties of products and services in trends of a shorter life cycle than before, is major concerns of the corporate management.

As well as the high–technology development, the information technology makes a great deal of changes in the management style as described in the "Informated Organization" (Zuboff, 1988). The decision system for management would become changed by the introduction of the information network based on the computer network. In these changing environments in the economical and technological fields, it would be more difficult for the top management of an organization to make the appropriate decision making. The DSS (Decision Support Systems) for the top management is required, which is especially called ESS: Executive Support Systems (Rockart and DeLong, 1988). The environment of the organization is strictly turbulent, and the top management should make policy to adapt itself to the turbulent environment. The aims of ESS can be considered to make clear the mental model of its organization and the environment based on which the effective decision making is done. The ESS is to monitor the raw information wider and deeper for the establishment of precise model. It should be noted that the perception is reality for a human decision making and that the correct perception of its status of a company in the environment is significant for his or her decision making. The purpose of ESS is to have the correct perception, that is mental model, concerning the changing environment. While it will take a few years for the ESS to be realized, for it requires the management staff and the network infrastructure, the ESS will make an important role in the corporate management. The ESS is a management system for those turbulent environment. It is considered that the ESS makes adaptability and enforces the "Shinayaka-ness (flexible, pliant, resilient or active in Japanese)" of the corporate management.

We discuss the "Shinayaka-ness" in the organization from the management discipline. The consistency and the flexibility can be seen as the origin of Shinayaka-ness.The paradigm considered with systems has been a single scope such as a stabilizing feedback control of an organization as a black box model in which the control is to aim the maintenance of a system. As seen in the development in the field of biology, it is being made clear that the brain has different functions between the right hemisphere and the left hemisphere. The maintenance of a system such as atom, gene and brain is carried out by the coordination between two functions of the internal control and the external control functions(Cook, 1980, 1986). This paradigm can be considered as a balance system rather than the single purpose system in the natural system. Although the organization in society is too complicated to describe it simply as in the natural systems, it is meaningful to investigate it from this aspect. We are studying the R&D organization from the flexibility and the consistency.

2 System's consistency and flexibility

For a system to exist in the time horizon, it is necessary to have the core to represent itself as it is. The maintenance of the core is to hold the consistency as a system which is not easily effected by the disturbances from the environment. The internal control is to maintain this consistency to decrease the effects of the turbulent environment. Yet the consistency oriented control is not effective for the development of the system. On the other hand the flexibility is required to adapt itself to the changes of the environment. These two functions of the consistency and the flexibility are clearly contradictive and the coordination of both functions is intrinsic for the existence and the development of a system. Table 1 shows examples which are observed in the natural, artificial and social systems.

Table 1. The consistency and the flexibility of systems

System	Control Center	Consistency	Flexibility
Atom *	Nucleus	Proton	Neutron
Cell *	Nucleic Acids	DNA	RNA
Family *	Parents	Mother	Father
Power system	Power Center	Infinite bus	AVR,AFC
Business company*	Management	Board of Directors	Executive Hierarchy
R&D	Management	Fundamental Res.	Development Res.

* quoted from Cook.

As shown in Table 1, the functions of systems are divided into two functions: consistency and flexibility. In the physical systems, the atom has two nucleus of proton and neutron. The proton is rather inactive and stable but the neutron is active with the another atoms in the environment. The DNA is rather stable to hold the memory of genetic information in itself, yet the RNA works to adapt itself to the change of the environment. In the case of electric power systems as an artificial system, the power flow governs the network systems with generator, transmission line and load terminals. The frequency is an index of power flow and the infinite bus can be considered as a consistent element. The AVR (Automatic Voltage Regulator) and AFC (Automatic Frequency Control) is the flexibility controller to the turbulent load changes. As observed in the physical systems, the similarity is found in the human society. The control center of a family is parents that mother is considered to be a core of family, and father is working in the outer world and flexible to the change of the world. In the case of business company, the board of directors maintains the corporate policy as the core of the company and the executive hierarchy of a company manages againts the turbulent environment.

In the R&D organization the function of consistency is carried out by the department of fundamental research of which the area is rather basic and general purpose research. On the other hand the department of development aims the direct contribution to the new products or problem solving occurred in the market. So that the management of R&D organization is required to recognize the contradictive characteristics of both functions. Yet in these high-technology times, it is becoming difficult to maintain the technological policy for the shorter life cycle of technology and the closer commitment from market than that of before. It would become hard to hold the consistency of technology. Yet the over reaction to the turbulent market makes the management lose the core technology on which the R&D division has the responsibility throughout the corporate activities. It is essential for the management in this fluctuated environment to recognize well the status of its own technologies and the trends of the environment in the needs and the seeds.

As is shown the isomorphism that a system has two functions of consistency and flexibility is found in many varieties of systems. It is clear that both function are necessary for a system. The consistency makes the system be stable, yet without the flexibility it is difficult for a system to evolve itself with the environmental changes. As like this only the flexibility makes a system severely be unstable and fluctuated. It is noted that the co-existence of two contradictive functions is significant for a system to exist and evolve in the turbulant environment.

3 Fixed point theorem's view of systems

The consistency of a system has an important role for the existence of it. This consistency can be considered as a fixed point of a system. [1] Whatever the system changes to there exists a core to be maintained, and the consistent core can be seen as a fixed point of the system. Although the system is effected by the environment, the surface of a system is modifiable. The surface can be seen as new functions in a system, organ, institute and business, or buffer. Yet the core itself is hardly changed in any case, which is the fixed point of a system.

Let us consider the fixed points of an organization. The control center of organization is the management level and the information is management policy. This policy of management is seen as the fixed point of an organization. It should be noted that in the management policy many varieties of fixed points can be found. The fixed point of sales division is to seek the profits, that of production division is cost reduction and that of R&D is the future oriented–ness. The fixed point of the executive hierarchy is today's profits and that of board of directors is in the tomorrow's investment. So it can be said that the coexistence of these contradictive fixed points emerges the forces to the turbulent environment. The simple and homogeneous policy, that is one fixed point, would make the organizational system efficient but vulnerable to the external forces.

4 Information–based company

The information is critical to the management of an organization. As an infrastructure of organization, information network is becoming available in these days by communication network technologies. The keywords of network is the accessibility to any information, at any time, at and from any place. The varieties of information are quite wide in the network, which are, for instance, telephone, facsimile, electronic mail, computer data, and TV media. Our company has been building a private use network, which we call MIND–network, accessible at any office throughout the company .

The information networking makes the impacts not only on the efficient communication but also on the effects to the management style. The network has three functions: communication, status access and analysis for the management. With these functions, managemental benefit is to know the company and its environment, that is, the stakeholders better than before. The information makes the enhancement of mental model. The deeper recognition of the managemental world is the key for the flexible and the consistent management. The network is an infrastructure for the realization of Shinayaka–ness in the management.

The purposes of ESS are in the following three (Rockart and DeLong, 1988).

(1) ESS supports the managemental effectiveness and efficiencies.

(2) ESS improves the support of planning and control process, which eventually changes the ways of management.

[1] Fixed Point Theorem: There exist a point x satisfying $x = T(x)$ in linear topological space R where $T(x)$ is closed convex set corresponding to x.

(3) ESS enhances the mental model of the environment.

Although the ESS has not yet been widely available at every company, the information network is expected to be promptly developed in the future.

The ESS is also considered to be significant to empower the Shinayaka–ness: flexibility and consistency. The flexible and consistent decision process needs the sufficient information throughout the organization. It is not only necessary that the central control center monitors the system but also that every element of organization can access to the other's status mutually. In this sense of mutual accessibility, networking is completely different from the hierarchical structure of information flow. With the information networking, each decision making can be more effective and understandable on the mutual status. Moreover it will make the better understandings of their environment.

From the view point of the flexibility and the consistency, the information networking would make the following three effects. First, it would make the fluent and the prompt information flow throughout the company. The varieties of information media and the routes would decrease the information gap among the organization. Second, it would enhance the reality of perception of each decision maker at any level. It will make the recognition in common among them although they have different values. Third, it would make the maintenance of consistency which comes from the consensus of decision making through the information network. Based on the meta–management policy, the contradictive demands from organizations would become converge to a clear and agreeable decision making.

For example, let us consider the decision process in R&D direction. The proposals are come from many varieties of fields in the organization. The selection from the proposals can be considered in the following two ways; abstractive model and human activity model. The final goal of both model is to reach the mutual agreement within the persons concerned, for instance, researcher, manager and factory in the company. The abstractive model is oriented to the mathematical or objective model excluding ambiguous human factors, yet the human activity model is to the decision process itself to the final agreement. The process of mutual agreement is most significant for the human activity model. In this case, the mutual recognition of technology, economy and stakeholders are important and it is realized by the development of information accessibility and understandings of status.

The ESS or DSS will make significant role in the future in the sense of smooth distribution of information and the reality of perception of management.

5 Conclusion

The management is considered as a realization of duality of flexibility and consistency as observed in natural, artificial and social systems. The Shinayaka–ness (flexible, pliant and active in Japanese) is emerged from this property of duality. The coordination of these contradictive functions can be considered as one of the roles of meta–management level. To the management level decision making, it is quite critical to have the correct perception about the environment from the economical, technological and life–style view points. The ESS (Executive Support System) based on the information network will make the powerful impacts on the enhancement of mental model of management on the stakeholders. The ESS provides the information to treat the turbulent environment and to empower the Shinayaka-ness as a result. It will be required for the management to build an informated organization, that is, the organization of which the intelligence can be empowered by computer and information network.

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The Hypertext Model and its Stackware for a Multimedia Dental Information Database

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Abstract

This paper studies a hypertext model and its stackware for a multimedia dental information database. Hypertext is a software tool which has the capability of storing a multimedia database with various media and/or formats into objects and connect links among objects, through which users can navigate to search for the object. First, the hypertext model is considered using an object-oriented data model. Several properties of the hypertext model are described in comparison with those of the object-oriented data model. Second, we apply the hypertext to a multimedia dental information database. Detailed characteristics of objects in a multimedia dental information database are described. Finally, the stackware of the hypertext for the multimedia dental information database is presented with an emphasis on the linkage and navigation among objects of the database for decision support and data storage in clinical orthodontics.

1 Introduction

Intelligent information management is not simply a problem of computer science but is also widely regarded as a tool for decision support systems. There has been an attempt to develop intelligent information management systems which can treat many documents that are represented in various forms in contrast to conventional relational database system which can only treat normalized tables. Two representatives of the new intelligent information management models or systems are the object-oriented model and the hypertext. In this report, we discuss the hypertext model using an object-oriented data model and its stackware.

The hypertext is a software tool which has the capabilities of storing many documents in various forms as objects and span navigation links among objects, through which users can navigate to retrieve the documents. The hypertext is a promising software tool due to the many advantages of the efficient storage of multimedia information, the possibility of various operations according to its multiple media, i.e., various formats of text, image, animation and voice. In the near future, hypertext will be found in offices, hospitals, factories and homes, as a special-purposed machine equipped with communication facility.

A brief history of the hypertext model will be surveyed. The word "hypertext" was advocated by T. H. Nelson in 1965. A. Kay presented Dynabook in 1977, a personal computer on which media systems were installed. In 1981, N. Negroponte proposed Mediaroom which was the pioneer in multimedia data management. N. Meyrowitz in 1986 presented Intermedia which is an object-oriented hypermedia system. Xerox and Apple Co. Ltd proposed NoteCards and Hypercard, respectively. And in 1989 Tanaka proposed Intelligent Pad. Since the apperance of Smalltalk-80, the hypermedia has been programmed by the object-oriented language. The development of the hypertext systems has always been motivated by new paradigms and technologies. However, theoretiocal development has been behind the advances in technologies in the hypertext.

The scheme of the hypertext is a representation about storage of data into objects and linkages between objects. The stackware is a programming of scheme of the hypertext or user interface as a programming product. The hypertext is unique in that its conceptual scheme and user-interface scheme cannot be distinguished. Since the apperance of hypertext tool, general-purposed stackwares have been developed to some extent. Yet, special purposed stackwares have not been designed and implemented for a multimedia dental information database. As a case study for designing stackware for a multimedia database, the multimedia dental information is appropriate material. Although conventional patient information in dentistry consists of a personal history, facial and oral photographs, radiographs, and dental casts, our implemented multimedia database is characterized by a time-series database that consists of an electromyographic signals including silent period data, and a spatial database that consists of a mandibular kinesiographic signal. There are two requirements for the construction of the dental information database. First, the accuracy of the database depends upon the accuracy of the clinical records and a trade-off between data accuracy and data compression must be considered. Second, consideration must be given to the design of a scheme that is capable of recording dental information based on various kinds of data.

The organization of this paper is as follows: In Section II, the hypertext model is considered from a viewpoint of the object-oriented data model. In Section III, we present a detailed description of a multimedia dental information database in clinical orthodontics. And in Secton IV, we provide a stackware of the hypertext for a multimedia dental information database.

2 Hypertext Model

The hypertext model can be approached using an object-oriented data model. Properties of the hypertext model can be summarized as follows:

Property 1 Every entity of a hypertext application is modeled as an object.

Remark 1 In a world of hypertext model, a personal history data of a dental patient can be an object. Personal history data of several patients can also be an object. Radiographs of one patient or several patients may be another object. The logically meaningful data with same media may be stored into an object.

Property 2 Every object has a unique object identifier.

Remark 2 Two objects of hypertext regarding the personal history data of one patient and several patients have different object identifiers.

Property 3 Every object has a state. The state of an object is the set of values for the attributes of the object in an object-oriented data model. On the other hand, the state of an object is the set of values for buttons of the object in the hypertext model. The button is usually identified by an icon in the object. The object of the hypertext has data besides buttons. Although the button and data are originally different, part of the data becomes buttons in some cases.

Remark 3 Consider an object of multimedia dental information in which a few buttons exist that consist of key indices about personal history data, radiographs, oral photographs etc. This object consists of only buttons. Consider another object which consists of data and buttons for displaying the data by several manners. This is an case in which buttons and data are different. Furthermore, consider an object which consists of facial photos of several patients where each portrait becomes a button. This is a case in which the data can partly be buttons.

Property 4 Every object has a special type of behavior in an object-oriented data model. The behavior of an object is the set of methods which operates on the state of the object. Some objects do not have methods in the hypertext model.

Remark 4 For an object of numerical data, a method for data processing may be provided. For the other object of image data, a method for image processing can be installed. An object consisting of only buttons does not have a method.

Property 5 The value of an attribute in an object is also another object in an object-oriented data model. On the other hand, the values of buttons in an object in the hypertext model are mapped into a set of methods in its object or a set of the other objects.

Remark 5 Consider a set of buttons in an object of a hypertext. This set is decomposed into two disjoint subsets. The value of a button in the first subset is mapped into a method operating data in its object. The value of a button in the second subset is mapped into another object, and a link is spanned from the value to the mapped object.

Property 6 In an object-oriented data model, a class includes all objects that share a common set of attributes and methods. In a hypertext model, there does not exist a concept of class.

Remark 6 The value of an attribute in an object is also another object and there is an inheritance between objects in an object-oriented data model. Therefore, the concept of class which groups objects with common attributes and methods is meaningful. However, if there should be a class including objects of the hypertext model with common buttons and methods, the class would be meaningless due to the lack of inheritance.

Property 7 In an object-oriented data model, every object belongs to one and only one class as an instance of that class. The object of the hypertext exists without belonging to any class.

Remark 7 Since the hypertext model does not have a concept of the class, every object exists as object itself.

Property 8 In an object-oriented data model, the value of an attribute of an object also belongs to a class. This class is called the domain of the attribute of the object. A new class is defined as the domain, which is a specialization of an existing class. The new class called a subclass of the existing class inherits all the attributes and methods of the existing class. However, there is no concept of the inheritance between objects in the hypertext model.

Remark 8 Between objects of the hypertext model, there is no inheritance which conveys information of the upper object to the lower object but only a link which supports the navigation from the upper object to the lower object.

Property 9 In an object-oriented data model, users may dynamically specify additional attributes and methods for the subclass. In a hypertext model, users can also dynamically span links which connect a button of an object with another object.

Remark 9 Dynamic generators of a new attributes/methods or links are equipped in an object-oriented data system and a hypertext system, respectively.

Property 10 The retrieval of the searched object is done automatically by tracing class-attribute hierarchy in an object-oriented data model. On the other hand, because of the navigation by tracing the links between objects, retrieval of the searched object is done by a man-machine interface manner in the hypertext model.

Example 10 In an object-oriented database system, the retrieval condition of a complex object is input in a command of the object manipulation language. In a hypertext system, users navigate in the network of objects without the previous assignment of retrieval condition.

Property 11 The conceptual scheme and user-interface scheme cannot be distinguished in the object-oriented data model and the hypertext model.

Remark 11 For the traditional relational data model, the conceptual scheme which represents the data structure of a database is one thing, and the user-interface scheme of database is another. Therefore, two kinds of programming language are provided for the implementation of the conceptual scheme and the user-interface scheme. However, once a scheme of the hypertext is designed for representing the storage of a database into objects and linkages among objects, this scheme plays the role of both a conceptual scheme and a user-interface scheme.

The class hierarchy in the object-oriented data model is illustrated in Figure 1. The object-button linkage mechanism is also illustrated in Figure 2.

3 Multimedia Dental Information Database

This section presents a detailed description of a multimedia dental information database in clinical orthodontics.

The objects of the dental information database are as follows:

- electromyographic signal
- bite–force signal
- lip/tongue pressure signal
- silent period data
- mandibular kinesiographic signal
- dentition of study casts
- oral photographs
- facial photographs
- radiographs
- personal history data

In the following paragraphs, a multimedia dental information database is described in detail.

3.1 Electromyographic Signal

The biosignal data consist of an electromyographic signal, a jaw displacement signal, a bite-force signal, and a lip/tongue pressure signal. They are, however, classified into three objects, i.e., a chewing data, clench and rest data, and a silent period by virtue of the oral function.

3.1.1 Raw Data Collection

A more detailed description of the recording, sampling and analyzing methods of the biosignals needed to characterize the objects has been reported elsewhere (Takada et al. 1988a, b). Briefly, the data recording system can provide an eight–channel simultaneous recording of muscle activity and jaw movement in three dimensions associated with 30 unilateral chewing strokes on the right and left sides. Muscle activity, bite force and tongue/lip pressures during voluntary clench tasks and/or at the mandibular rest position, are also sampled in a form of a 2-s bin data to a maximum of ten bins for each task.

The jaw displacement is recorded by a mandibular kinesiograph. It consists of a light head-frame which supports a set of magnetometers and is fixed on the patient's head by means of a spectacle-like device. The magnetometers are aligned to sense the linear movement of a magnet transducer referenced to the Frankfort horizontal plane and the midsaggital plane. The magnet transducer is attached to the labial surface of the lower central incisors, and the three reference planes are aligned to meet in the center of the magnet at the habitual intercuspal position, i.e., to which the apparatus is zeroed.

A measurement is made within a framework of -15 to +15 mm in the x direction (lateral), -10 to +20 mm in the y direction (anteroposterior), and 0 to -40 mm in the z direction (vertical). The origin is defined as the midpoint between two lateral sensors which correspond to the intercuspal position of the mandibular incisor point. The distorted measurement of the mandibular kinesiographic signal is corrected by the GMDH correction method, which estimates the mean error of 0.101 mm (s.d. 0.125 mm) for all of the coordinates tested (Nagata, 1986b). Figure 3 shows mean chewing patterns of the masticatory muscles recorded by a mandibular kinesiograph.

Biosignals are sampled by the computer through the A/D converter every 0.5 msec. Data obtained in the RAM for transient storage is absolute-valued, and running averages with a moving interval of 1 msec are computed over 5 msec, and stored in the hard disc. The possible maximum capacity required for a standard examination of a patient is approximately 13MB. The entire records of a patient are stored in a cassette tape with a high speed streamer.

3.1.2 Chewing Data

The normalization of chewing data is performed automatically: each stroke is divided into equal time intervals of open, close and intercaspal phases. The opening phase corresponds to the time periods between the onset of jaw-opening and the maximum jaw-opened position. The closing phase is between the MOP(1) and the COin(2), while the time course between the COin(2) and the COout(2) represents the intercuspal phase. It is possible to compare chewing strokes with different durations in the same individual and/or between different individuals by dividing one chewing stroke into three equal phases. Each phase is divided further into 24 equal time segments, and the main biological voltages are calculated for a set of data points in each segment. Normalized mean voltages, and their standard deviations, are calculated for each of the 73 segmented data points with respect to the maximum peak voltage of the whole strokes and the maximum mean voltages of the clenching task for each channel. Figure 4 shows a sample of the digitized electromyography of the masticatory muscles.

3.1.3 Clench and Rest Data

The mean voltages of mid-500 msec data points are computed for each 2-s bin of rest and clench tasks for each channel and then the means and standard deviations of the biosignal voltages for each task in each channel are calculated. Each of the electromyographic signal, bite force signal, and tongue/pressure signal are normalized to the maximum mean voltage of all the tasks performed in each channel.

3.2 Silent Period Data

The silent periods (SPs) are transient stops or a decrease in muscle activity that are induced by tooth contact during tapping movement or chewing, mechanical chin or tooth tapping or electrical stimuli applied to the oral tissues. The algorithm in a previous report (Takada et al., 1991) provides effective detection of SPs because of the simultaneous detection on many channels and also because it can be parallel with measurements from the kinesiographic signal during the chewing performances. The algorithm for the automatic detection of SPs is based on the following knowledges:

1. Silent periods occur between the final stage of a jaw-closing phase and the midway into an intercuspal phase.

2. A silent period is characterized by an abrupt decrease in muscle activity at its onset followed by a transitory inactive phase and an immediate remarkable return of activity. The inactive phase lasts about 8ms to 40 ms.

3. The EMG amplitudes during an SP are almost equal to or lower than the mean muscle amplitude determined during a jaw-opening phase when the jaw-closing muscles reveal minimum activity.

4. A weak but identifiable EMG discharge may be observed during an SP.

5. Multiple SPs may be observed in an EMG record of one chewing stroke, or they may not occur during the chewing strokes of a single subject.

Figure 5 shows a sample of the silent period (SP) occurred in an EMG of the masseter muscle during a chewing effort.

3.3 Dentition of Study Casts

Dentition of study casts were traditionally stored in a plaster cast. However, a plaster cast has many disadvantages as a method of storage because of the difficulty of quantification, fragility and occupation of much storage space. Information extracted from the study cast is required for a database. Information recorded from the study casts consists of two-dimensional structural data and distance/angle data of the tooth arrangement.

3.4 Oral and Facial Photographs, Radiographs and Personal History Data

Information from photographs, radiographs and personal history data can be stored in the videographic images. Besides objects of these videographic images, some key words in the personal history data are stored as buttons of an object for navigation to another object through links.

4 Stackware of Multimedia Dental Information Database

We present a stackware of the hypertext for a multimedia dental information database, which is a scheme of the hypertext representing data storage into objects and linkage between objects. The conceptual and user-interface schemes cannot be distinguished in the hypertext system. An outline of our implemented stackware is shown in Figure 6. We implemented this reported scheme using a hypertext tool, Supercard (Appleton, 1989).

When the computer is turned on, a home card is displayed, and the OWL, i.e., Orthodontists' Wisdom Laboratory, button of the home card is activated using the mouse (Fig. 6 (1)). When a patient button is selected in the home card, a new card offering two buttons is displayed: one button is related to the single patient information and the other to the group information (Fig. 6 (2)). For retrieval of the single patient information, when a button of the patient information is selected, a new card with the name and age of patient is displayed (Fig. 6 (3)).

To retrieve information by name, users select the "Name" button of a card of name/age of patients (Fig. 6 (3)), and a pictorial file (Fig. 6 (4)) is displayed for searching for the patient's name. By assigning the first character of a patient's name in a card of the pictorial file, a searched name can be retrieved by scrolling the files and selecting the patient's name in a card of scrolling names (Fig. 6 (5)). When a patient's name is input, a card of patient's individual database is accessed (Fig 6 (8)). A card of the pictorial file is illustrated in Figure 7. Users can alternatively approach a card of individual database by tracing other links. When users select the "Age" button of a card of name/age of patients (Fig. 6 (3)), a card of a cluster of ages (Fig. 6 (6)) is accessed. By assigning a cluster of ages, for example, 7-9 years old, then a card of patients' facial photographs (Fig. 6 (7)) with the corresponding clustered ages is accessed. Every facial photo is not only a data but also a button for accessing a card of an individual database. Figure 8 exemplifies a card of patients' facial photographs.

In an identified card of patient's individual database (Fig. 6 (8)), a menu of buttons relating to patient's chart, radiograph, electromyographic signal, SP, mandibular kinesiographic pattern, bite force and tongue/lip pressures, dentition of study cast, oral photograph, and personal history data is displayed (Fig. 6 (9)). When a user selects a button corresponding to a particular type of dental information, one of the cards of a patient's information (Fig. 6 (10)) can be accessed. Figure 9 illustrates a card of patient's chart as one type of cards of the patient information. All cards of patient information not only display accessed patient information, but they also produce a multi-windowed display of combined patient information. Users can interactively display any necessary multiple information by assigning information by using buttons of a patient information card. The patient's ID and facial photograph are always displayed. Furthermore, a bird's-eye view of the digitized time-series biosignal database can be displayed (Fig. 10).

Biosignal data on a group of patients can also be retrieved (Fig. 6 (11)). When a user selects the "Group" button in a home card, the name of the worksheet for a patient group is requested. When users input a name, a worksheet of an assigned group is accessed. In every worksheet, a list of patients' names and ID numbers, together with basic attributes, such as a gender, an age, a type of food tested, and types of special treatment for chewing and clenching performances, is displayed. Users can make several statistical processings in an accessed worksheet. We used a software tool (Wingz, 1989) for implementing the worksheet.

Figure 11 exemplifies a patient information that consists of a dentition of study cast, a radiograph and facial photographs. Figure 12 also exemplifies a patient information that consists of an EMG, a radiograph and facial photographs. Each card offers a button consisting of a patient's facial appearance and his/her name. This button is used not only to return to the menu but also to identify to which patient this record belongs.

5 Conclusions

This presentation addresses an alternative option not only for the intelligent information management in clinical orthodontics but also for that in decision support. We explored modelling of the hypertext and its application to a multimedia dental information database in clinical orthodontics. A modelling of the hypertext was considered using the object-oriented database model. A multimedia dental information database, with an emphasis on a biosignal database and a time-series/spatial database was reported. Finally, our implemented stackware of the hypertext for the multimedia dental information database was described to show a scheme of storing a database into objects and spanning links among the objects for navigation in a hypertext world.

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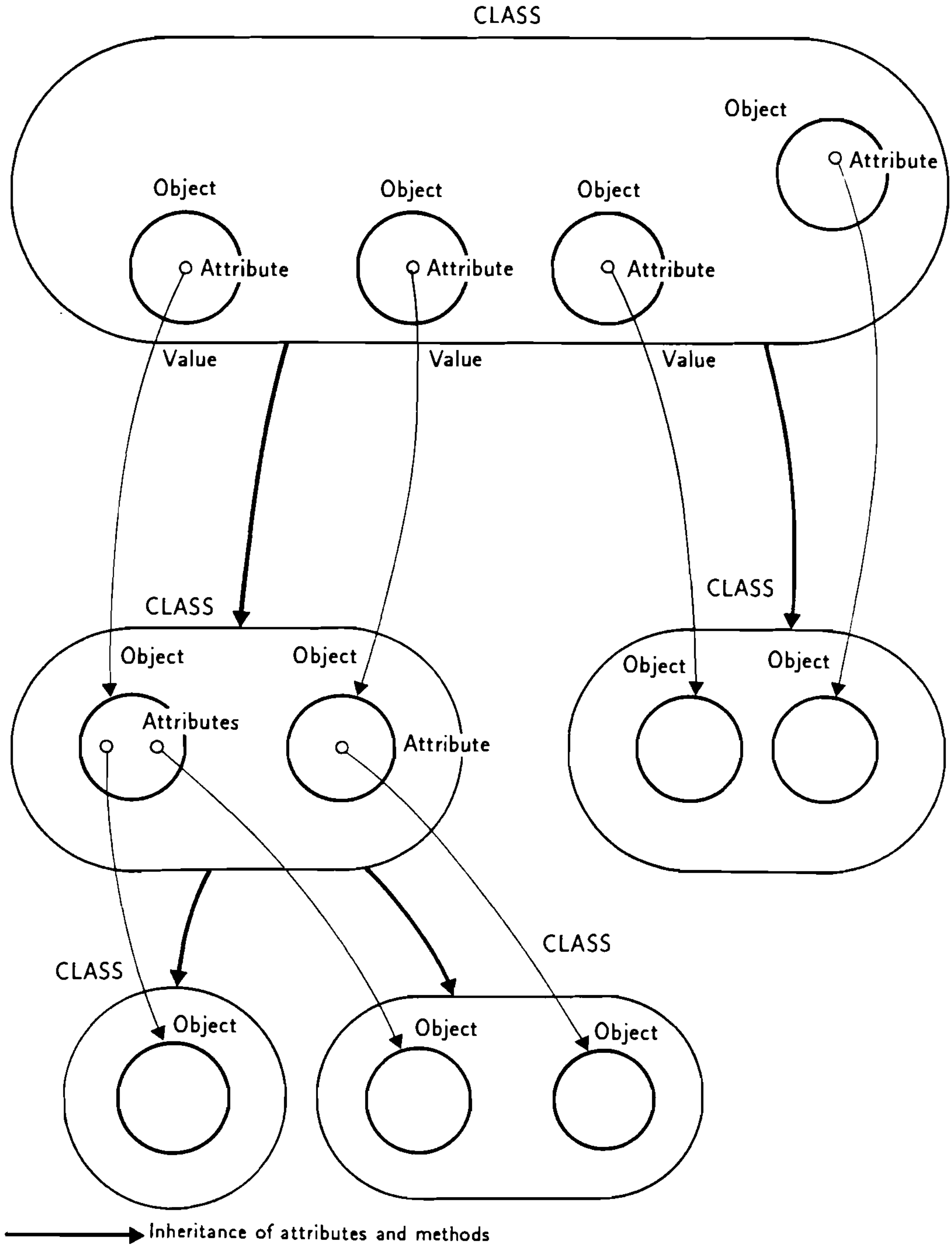

Figure 1: Class hierarchy in the object-oriented data model

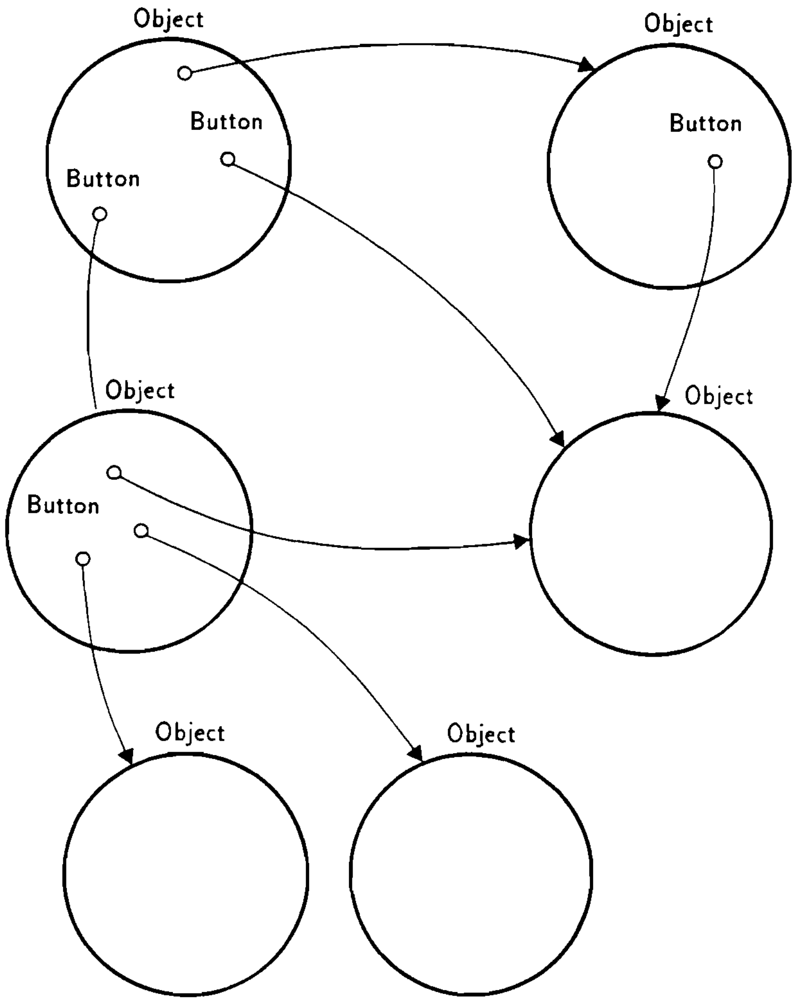

Figure 2: Object-button linkage in the hypertext model

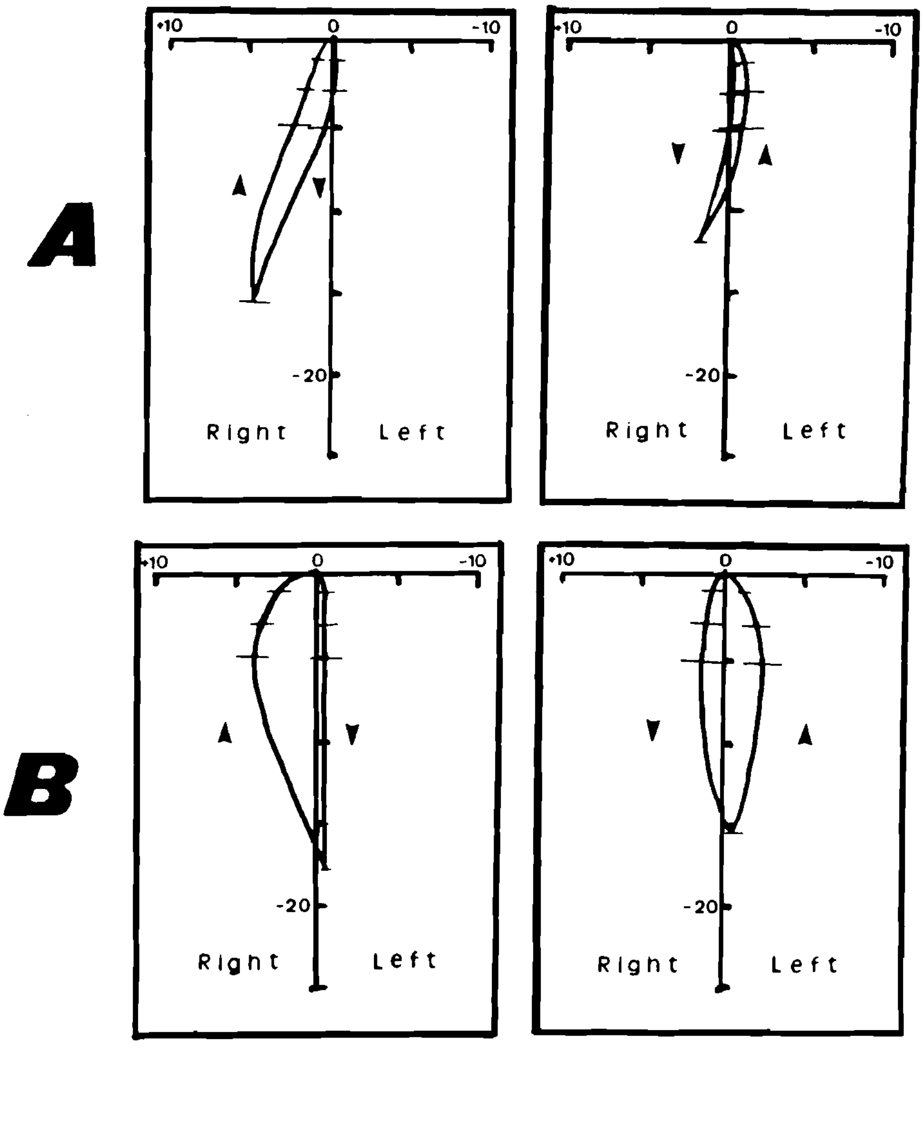

Figure 3: Mean chewing patterns of the masticatory muscles recorded by a mandibular kinesiograph recorded for a patient, A, pretreatment; B, posttreatment

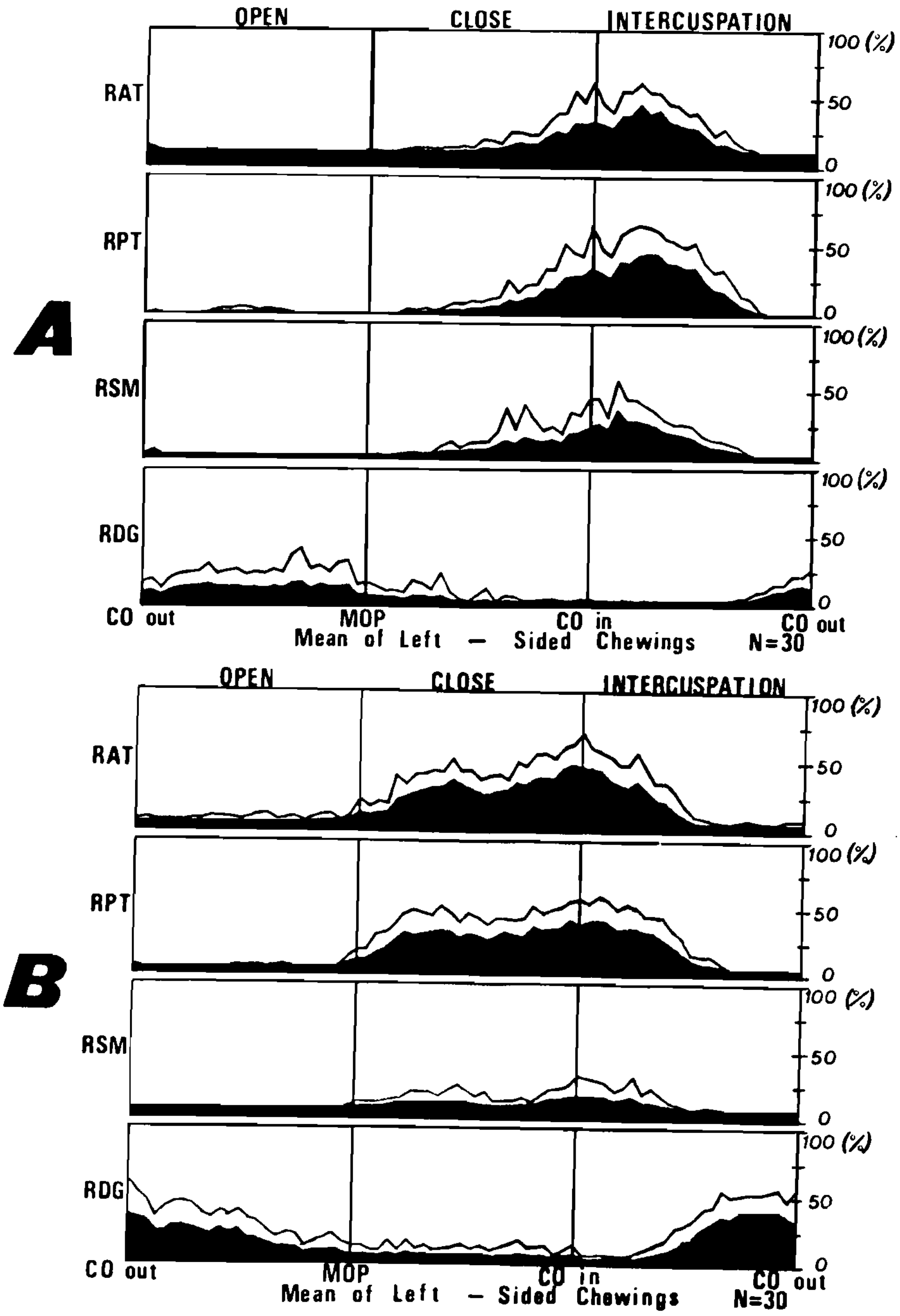

Figure 4: Digitized electromyography of masticatory muscles during left-sided gum chewings recorded for the patient shown in Figure 3. *A*, pretreatment; *B*, posttreatment. RAT: right anterior temporalis, RPT: right posterior temporalis, RSM: right superficial masseter, RDG: right anterior belly of digastric. COin: time when the mandible goes across the trigger level from downward to upward, COout: time when the mandible goes across the trigger level from upward to downward, MOP: maximum opened jaw position

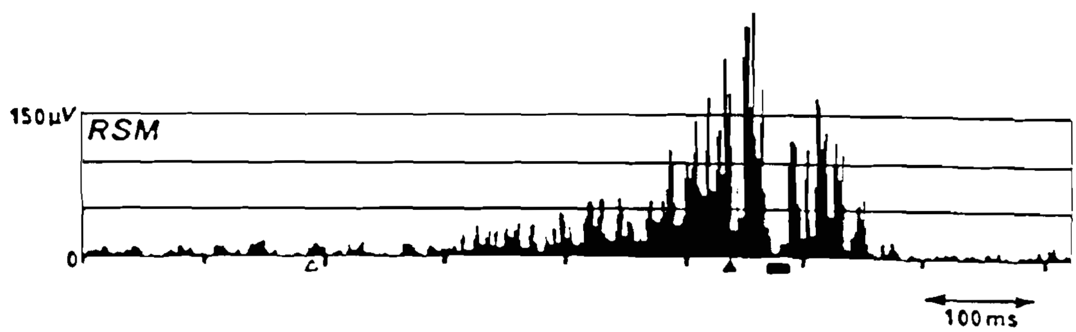

Figure 5: Silent period (SP) occurred in EMG of masseter muscle during chewing effort. The SP is detected automatically and indicated by a horizontal bar

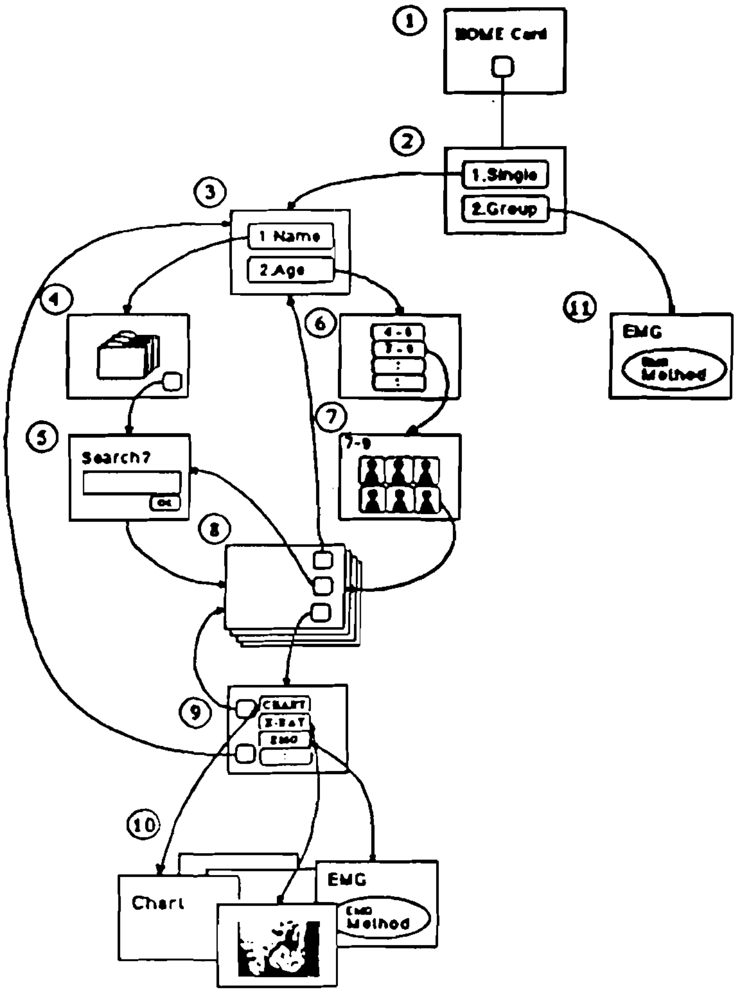

Figure 6: Stackware for multimedia dental information database. (1): home card, (2): card of single patient/patients group, (3): card of name/age of patients, (4): card of pictorial file by patient's name, (5): card of scrolling names, (6): card of cluster of ages, (7): card of patients' facial photographs, (8): card of patient's individual database, (9): card of selecting particular kind of dental information, (10): cards of patient information: patient's chart/radiograph/electromyographic signal/SP/mandibular kinesiographic pattern/bite force and tongue-lip pressures/dentition of study cast/oral photograph/personal history data, (11): card of selecting biosignal data of patients' group for accessing worksheet

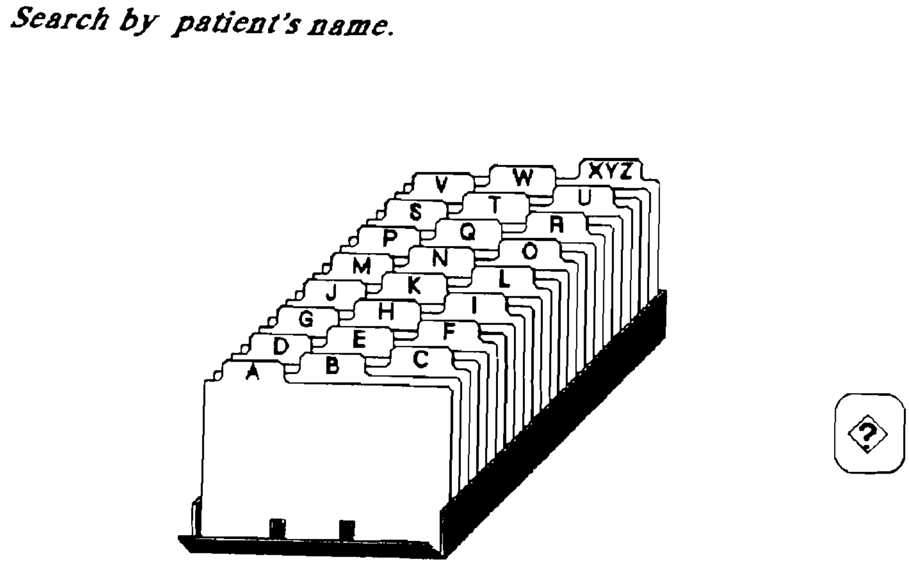

Figure 7: Card of pictorial files

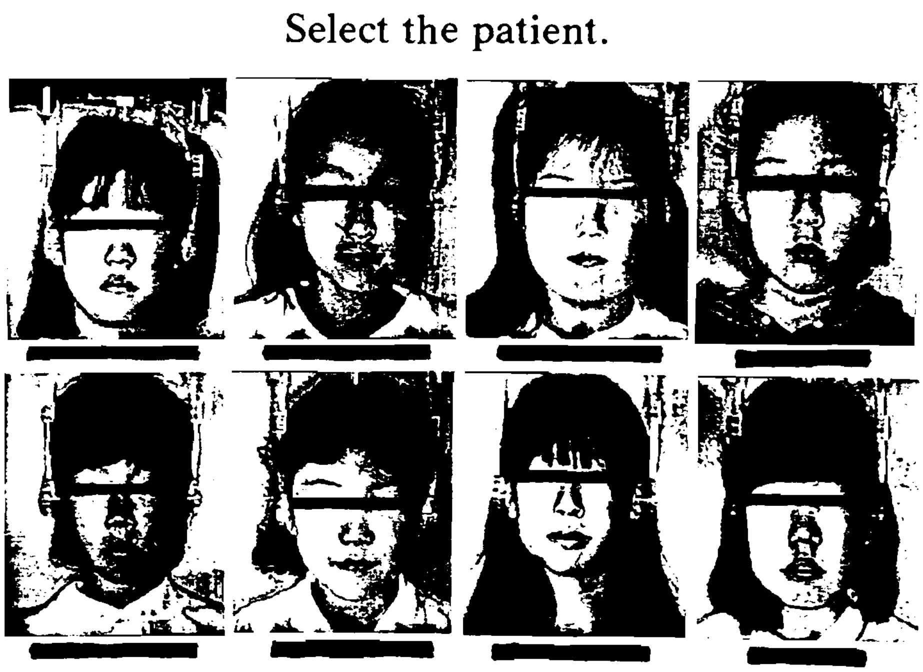

Figure 8: Card of patients' facial photographs

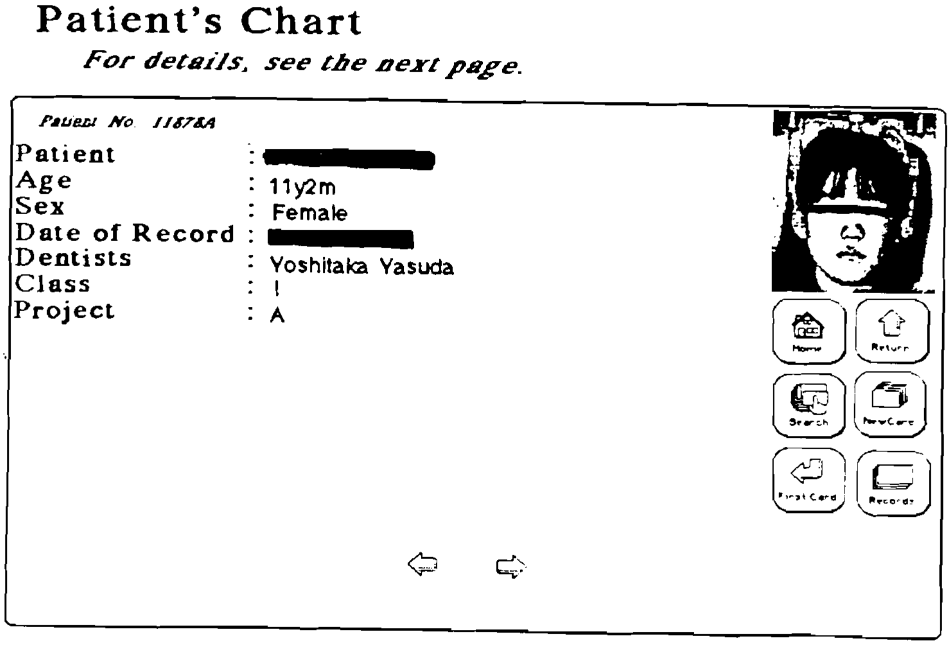

Figure 9: Card of patient's chart as one type of cards of patient information

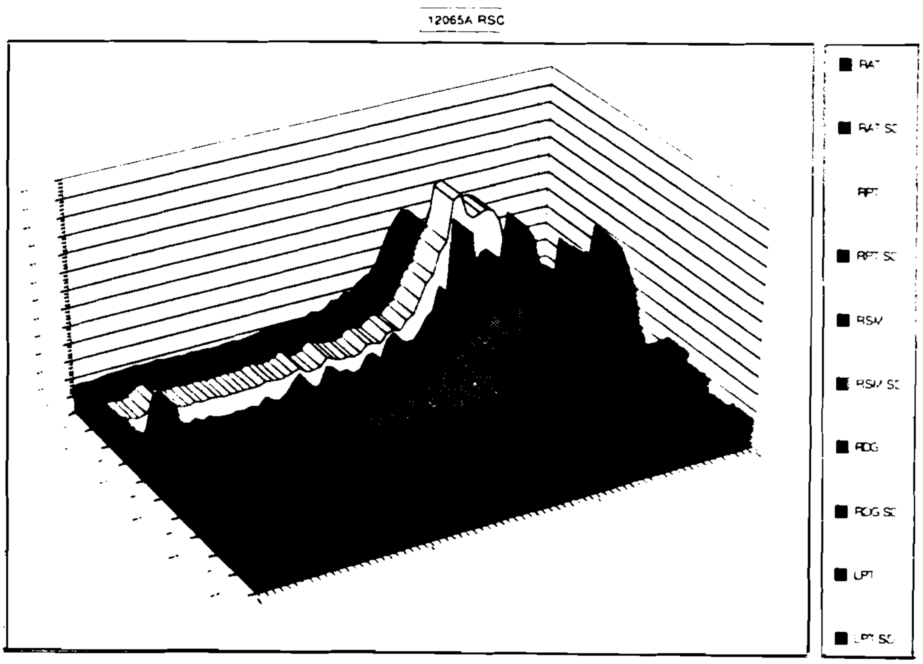

Figure 10: Bird's-eye view of the digitized time-series biosignal database

Figure 11: Patient information that consists of dentition of study casts, radiographs and facial photographs

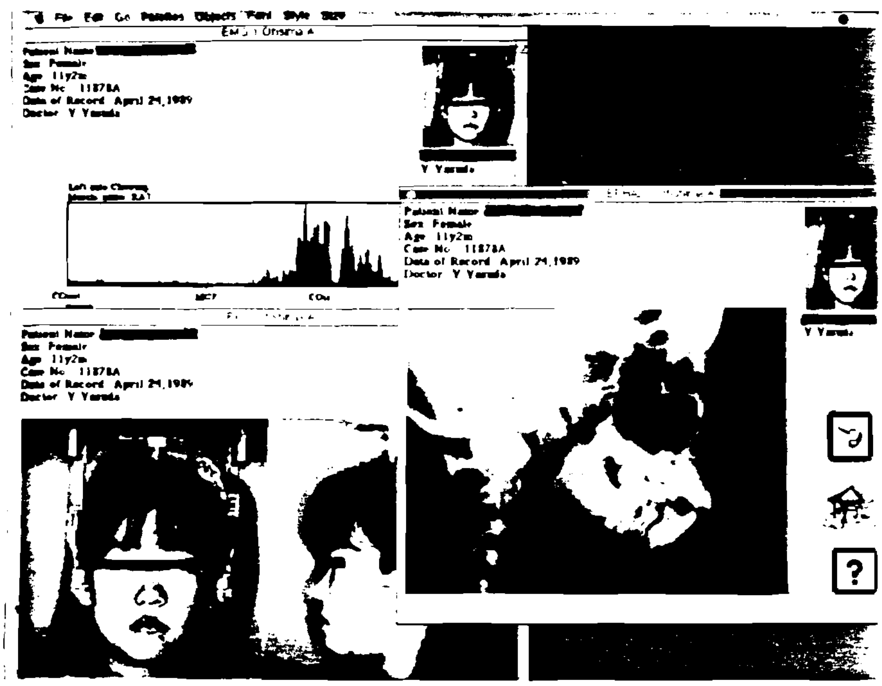

Figure 12: Patient information that consists of EMG, radiographs and facial photographs

Computer Aided Knowledge-based System in Process Supervision and Control

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Abstract

This paper describes a management system based upon a cooperative multi-agent model and computer aided knowledge based system. The science of management for decision support is depended upon a body of distributed domain knowledge which is concerned with methodologies for analysis and synthesis. The art of management is regarded as the human skill such as expert system through artificial intelligence. Both are complemental each other. Therefore, a soft system approach is based on cooperation of knowledge base human and computational computer systems by which both well and ill-defined systems can be controlled and human cognitive and decision making activities can be implemented in the complex environment of the manufacturing process. The examples presented in this paper are concerned with cooperative work relating to the cement making process. Finally, it is concluded that multi-phase cooperative systems with distributed knowledge constitute a very effective means for promotion of activities in realistic situations.

1 Introduction

This paper is concerned with a management system based on a cooperative multi-agent through mathematical or behavioral approaches and expert systems. As shown in Fig.1, the process is surrounded by various approaches such as mathematical, time series, qualitative, AI, neural network, optimum control, and expert system. In analyzing the performance of a plant, a process control engineer and a process operator use different kinds of knowledge. The process control engineer uses static and dynamic mathematical models, while the operator works at a more heuristic level. The process chosen as demonstration for the system is a cement making process.

2 Cement making process

An outline of the cement making process (Nakagawa, 1964; Akaike and Nakagawa, 1988) is shown in Fig.2. Here, a brief explanation of the kiln process is given. The raw materials such as limestone, clay and pyrite cinder, which have been ground in a mill, are fed into the upper end of the kiln and move downwords through the kiln's rotating action. During its travel through the kiln, the raw material is first dried, then calcined and further heated to a reaction temperature to form clinker after several phases of phisicochemical reactions. The clinker is then quenched and cooled in the clinker cooler. The heat required for the reactions within the kiln is supplied by burning fuel at the lower end of the kiln.

Two types of mathematical models for the cement making process, which have their own characteristics are very briefly described in the appendices of the present paper.

3 Mathematical model

Roughly speaking, two types of mathematical models for rotaly kiln are popular. One is the mathematical model presented by partial differential equation (Stillman, 1964; Johnson, 1969; Nakagawa, 1968), and the other is so called time series behavior model (Akaike, 1968; Otomo et al., 1972; Akaike and Nakagawa, 1972; Wong et al., 1968). The merits and demerits of both mathematical model are shown briefly in Table 1.

Table 1:

Partial differential equation	Time series model (AR model)
(merits) Simulation and indicial response Acquision of deep knowledge Quantitative and qualitative reasoning Reformation process of chemical composition is viewed as profile form.	(merits) With colored noise Reasoning by relative power contribution Characteristics of process noise Optimum control (on line use)
(demerits) Not in real time use A lot of parameter(measurability) Parameter sensitibity White noise (noiseless) Computational time	(demarits) only use for linear and stational process Limitation of measurerable variables

Fig.3 shows a heat and mass flow diagram of the rotaly kiln process. In case of cement rotaly kiln, the partial differential equations are hyperbolic type. Then the characteristics method is applicable for simulation. The results of indicial response through computational simulation are very instructive for the acquision of deep knowledge, but this type of model is not applicable for practical use, in stead of so called Autoregressive model etc. Fig.4 shows the profile of calculated value of variables for long wet kiln (characteristic method), at the Kumagaya plant of Chichibu Cement Co., Ltd.. As shown in Fig.4, it is very difficult to tune up various parameters, because the parameter sensitivity to process is very nervous.

4 Monitor with artificial intelligence

In the cement kiln process, relatively few measurements are available directly, and most process data are not always primary but secondary variables. Viewing from the long term, it is very important to decide whether the process situation is good or not, as a whole. For example, the power consumed by the kiln driving motor naturally depends on the load. Moreover the state of the coating on the inside of the kiln is irregular and rough, and the travelling speed of the raw material passing through the kiln is strongly correlated with uneven phase of the coating. Then heat transfer efficiency, in turn, depends strongly upon this shape.

Therefore, spectral analysis of the power distribution within the range of one revolution is regarded as affording valuable insight into the kiln process situation (Nakagawa, 1988). When process is under normal and good conditions, the spectral value at a certain specified frequency is rather high, and conversely, under bad conditions, the spectral value is comparatively low. Example of this is shown in Fig. 5(a). Time series spectral value of the pressure in the combustion chamber is shown Fig. 5(b). This spectral intensity seems to provide valuable information about the state of combustion. This is, when combustion conditions are satisfactory, the spectral value is comparatively high and under poor conditions, the spectral value is lower at the specified frequency. When burning zone temperature decreases, then atmosphere of kiln inside become milky sky, because suspension of flying powder of clinker incleases. Then amplitude of the record become narrow as shown in Fig. 5(c) and it looks like stable apparently, but this is no good conditions.

Samely as shown in Fig. 5(d) the amplitude of record concerning driving power of quenching grate cooler becomes too narrow, then the quality of clinker is poor, because the grain of clinker is dusty state something like sand. Generally, operators know something about these situation but can not explain in clearly how to connect these hidden information to computer. These examples illustrate the existence of implicit information underlying the process. These measures with intelligence are regarded as useful for expert system. By picking up these hidden information in the process, we can recognize the present process situation, in stead of skilled operator. In these thinking process, a neural network model is also used. This example has two inputs and one output. The relation between kiln speed and burning zone temperature is strongly non-linearly and therefore, a neural network model is appropriate. We have experimented with Back-Propagation neuro-network(BPN) (Rumelhart, 1986) with a view of learning by self-organization based on example data sets. An example is shown in Fig. 6. Samely the relation between the efficiency of fuel consumption (oil-ℓ/cl'-ton) and kiln driving power by BPN is given in Fig. 7.

As above mentioned, multi-phase approach is necessary. In this meaning, the intelligent controller designed for multi-use and distributed knowledge and function is needed. Recently this type of intelligent controller is developed by our group which is implemented on a board computer in order to be embedded within various controller units (Inabayashi et al., 1991). Fig. 8 shows the conventional link of knowledge base and Fig. 9 shows the distributed link of knowledge base. In complex process, each local function such as monitoring, detection and control and so on need their own distributed knowledge, because expert knowledge is distributed to each local domain and various specialists have partial expertise in each field. This type of knowledge linkage is also corresponding with individual alternative thinking process of one person for operational and managerial point of view.

5 Production management and control system

Control system in a broad sense including production management generally process a hierarchical structure. The control problem for production processes generally signifies the stabilizing control of process variables. However, in general, optimal production level and setting of the levels of the corresponding process variables have not been regulated at all, or have been controlled empirically on the bases of static heat and mass balance considerations without existence of colored noise. Moreover, the criteria for operation are generally subjective rather than objective. The behavior of production systems is dynamic in actual operation, and it is not valid to determine optimal production levels only from static specifications of equipments. In other words, static control is only aposteriori passive management like the so called conventional quality control, and does not solve the problem of how and what to manage. A hierarchical system of production and control management, including determination of optimal production levels, pursuit control aimed at this level and stabilizing control are necessary. Energy saving and high quality are important factors in determining the production level. Therefore, if the object function signifies "manufacturing high quality products with the least energy", then direct determination is possible by maximizing or minimizing this object function. In order to realize optimum production, pursuit control using many variables is indispensable for smooth transition from the current state of the process to the new production level. The mathematical model is briefly referred as follows, by which optimal production can be planned. Autoregressive model (AR model) of discrete type is built through the identification of behavior. Output variables of the process (Controlled variables) are expressed as dimensional vector $x(n)$, and input variables to the process (manipulated variables) as I dimensioned vector $y(n)$, then the model is expressed as the following equation (Nakagawa and Yagihara, 1985; Nakagawa and Yagihara, 1985):

$$x(n) - \bar{x} = \sum_{m=1}^{M} A_m[x(n-m) - \bar{x}] + \sum_{m=1}^{M} B_m[y(n-m) - \bar{y}] + \sum \varepsilon(n) \tag{1}$$

where
$\bar{x}$: mean value of actual data $x(n)$
$\bar{y}$: mean value of actual data $y(n)$
A_m: $r \times r$ dimensional coefficient matrix to each m where $m = 1, \ldots, M$
B_m: $r \times I$ dimentional coefficient matrix to each m where $m = 1, \ldots, M$
$\sum \varepsilon(n)$: r dimentional white noise vector of 0 average.

When the sampling interval Δt is smaller than the time constant of the process, equation (1) represents process model for stabilization control, and expresses dynamic characteristics of relatively high frequency zone. On the other hand, when Δt is large

($\Delta t >$ time const.), a model only extracted low frequency zone is obtained by taking an average of running data during Δt's, because high frequency characteristics is filtered out.

As the problem of production level is started from the problem of determining the set points, the model is expected to be expressed by equation (1) only with low frequency characteristics. Set points are originally determined by theoretical physical or chemical models, but in the practical control cases, they mostly manage unobservable variables which can not be treated by theoretical models. Therefore, models of equation(1) obtained from actual running data of daily oparation are needed as more practical use. The above-mentioned method has been applied to the problem of optimum production level for a rotaly kiln process. Optimum production is performed under a set of set points of each variable to manufactur high quality products with the least fuel original unit (liter/ton) within the given constraints. Fig. 10 and Fig. 11 present the ralative contribution of power spectra density between noise and power of variable at frequency f (Akaike and Nakagawa, 1988; Nakagawa, 1989).

These graphs show that variable of fuel/clinker (liter/ton) effected by fuel used in tower of furnace is bigger than the one effected by fuel used in burning zone of furnace. This knowledge is very instructive for fundamental kiln design and operational controllability. These optimal sets point make the fuel original unit decrease by about 1.47 liter/ton from the conventional average level. This result is not actual but simulation value. But this is very exciting and give us the expectation of fuel saving still remained for further study.

6 Meeting Simulator

Next, the so called meeting simulator (Plaza et al. 1986; Darzentas, 1986; Gregory, 1986; Niwa, 1986; Sawaragi and Nakagawa, 1988) is explained. The aims of the meeting simulator are to solicit the shared utilization of domain oriented knowledge and to induce abduction from within such knowledge. It quips plant management with operational functions over short term, and planning, policy decision making and other functions over the long term.

The meeting simulation system has been developed on an expert shell called ESPARON. We have combined this new neural network association with ESPARON. The association part in the structure of each participating agent is implemented by neural computing facility. The ANZA board, which is neural computing board developed by HNC Inc., can be utilized by linking this board with ESPARON. We have provided a software interface between ESPARON and ANZA. Hence, we can combine both of these functions on a single personal computer using MS-DOS. An overview of the implementation is shown in Fig. 12. This simulator handles the collaborative intellectual tasks performed by several agents, where each agent has its own role. And we can touch the world concerning the multidiciplinary nature through the shared and distributed intelligence and the elaboration of model about process and human behavior.

A mechanism for conceptual learning and association is referred. In general, the BPN learning process can be adjusted by means of the learning factor and the momentum factor.

We have realized a mechanism for generation of unexpected concepts from the deep structure which is not learned directly in the BPN learning process. One example is presented as follows.

Example:

Input	Learning	Association
Symbolic No. and concept	Symbolic No. of output	Symbolic No. of output
25 Work at night	26,27,29	26,27,29,55,80
27 Labor problem	25,28,29,31,32	25,28,29,31,32,55
33 Holiday system	29	29,55
60 Genaration gap(Employees)	29,55	29,55
63 Labor market	29,64,65	29,55,64,65
64 High educational level	29,46,51	29,46,51,55,59
73 Sense of values	29,79	29,55,73,79

This example shows that output 55 is frequently associated with inputs related to output 29, because when input 60 was entered, both 29 and 55 were taught as concurrent outputs. This suggests the existence of same abstract concept in the hidden layer relating to both 29 and 55. In fact, we verified that these inputs generate output 55 with considerably greater frequency than other inputs. This is explained by the schematic illustration shown in Fig. 13. Fig. 14 shows the display image on the CRT during the simulation of association.

The unexpected outputs described by association is very instructive for us. Viewing from another point, we can select any agents in the meeting simulator tentatively and intuitively according to the topic to be discussed. For example, human agents such as manager, engineer and operator, functional agents such as mathematical, behaviour model, artificial intelligence, neural network model and other methods may be selected as tentative and intuitive agents.

The association map for neural network model by learning is usually dealt intuitively. These fuzzy structure is depended upon the combination value of P and λ, which are threshold value of each element and parameter of structure, concerning with menbership function respectively. The pattern of change around the fuzzy cognitive map stimulates the abduction in the mental world. These relaxation extends the flexibility for association. Recently an idea of reflecting mental world into topological space is reported, because it is easy to look at the world from different views in the topological representation (Hori and Ohsuga, 1990). We are trying to connect this program with the meeting simulator and expand the mapping of the problem space under the environment of virtual reality.

7 Summary

By combining these various methods and distributed representation, familiar scenarios and partial process concepts arise naturally. Complex processes are always fuzzy in nature, and the estimation of the overall situation from knowledge of the constituent parts under noisy conditions constitutes a vital problem. Finally, it is to be emphasized that the partial combination of sort systems with conventional hard systems is apparently very important with respect to the promotion of activities in realistic situations.

The essential points of the presented paper may be summerized as follows.

1) A combination of several different thought processes is necessary in order to assess real situations.

2) The present system is by a multiplicity of interconnected methods, and the state of the system is determined by many different factors and conditions. Hence, the system permits a flexible choice of alternative methods appropriate for various situations.

3) The basic functions of the present system are shared by a number of distributed information process, models and methods, which work together.

4) Integration of partial information works well in the face of ambiguity and incompleteness.

5) Multi-phase cooperative systems with distributed knowledge constitute a very effective means for promotion of activities and production of ideas by a groupe of people and methods.

8 Appendices

(1) AR model

A basic model of stationary stochastic processes is proposed for the analysis of linear feedback systems. Here we consider a set of observation points ($i = 0, 1, 2, \ldots, k$). The model of the system is given by the relation (Akaike, 1968; Otomo et al., 1972; Akaike and Nakagawa, 1972; SILTAC Operation Manual, 1986; Akaike and Nakagawa, 1988; Nakagawa, 1989). $i = 0, 1, ., k, \quad n = 0, 1, 2, \ldots$

$$X_i(n) = \sum_{j=0}^{k} \sum_{m=0}^{m} |\gamma_{ij}|\, a_{ijm} X_j(n-m) + U_i(n) \tag{1}$$

where $(u_i(n); i = 0, 1, 2, \ldots)$ is the driving input at i and $(x_i(n); i = 0, 1, \ldots k, \quad n = 0, 1, \ldots)$ is the response of the system and the initial condition of the system is given by $(x_i(n); i = 0, 1, \ldots, \quad n = -1, \ldots, -M)$

The controller design follows the general line described in based on a state space representation of the system.

$$Z_N = \phi Z_{n-1} + \Gamma y_{n-1} + W_n \tag{2}$$

The controller is designed so as to give the minimum of the quadratic criterion with positive semidefinite Q and positive definite R.

$$J_H = E\left\{\sum_{n=1}^{H} \left(Z_n' Q Z_n + Y_{n-1}' R Y_{n-1}\right)\right\} \tag{3}$$

where H is a predetermined positive integer and E denotes expectation. For practical use of the identification and control, the software program called SILTAC (Self-Instructive, Learning and Tutorial systems for statistical Analysis and Control of dynamic systems) is already published (SILTAC Operation Manual, 1986; Nakagawa, 1989).

(2) Mathematical model
The otherhand, we refer briefly to other type of mathematical model. In qualitative sense, we can use this type of model for qualitative inference, which is used as supplementary method for the autoregressive model. The analysis of the problem by derivation of a set of mathematical equations to describe the grate cooler process and kiln process are referred. The characteristics of these models are calculated and also simulated by a set of mathematical equation (Nakagawa, 1964; Stillman, 1964; Johnson, 1969).
The equations for the solids phase and the gas phase of the cooler are

$$\frac{\partial T_s}{\partial x} + \frac{1}{V_s}\frac{\partial T_s}{\partial t} = \left[\frac{1}{\beta C_{p_\beta}}\right]\left\{U_w\left(T_i - T_s\right) + h_1 c_1\left(t_{ws} - T_s\right) + h_7 w\left(T_g - T_s\right)\right\} \tag{1}$$

$$\begin{aligned} -\frac{\partial T_g}{\partial x} + \frac{1}{V_g}\frac{\partial T_g}{\partial t} = \left[\frac{1}{\Psi_T C_{p\Psi_T}}\right]&\left[W V_i p_i \int_{T_g}^{T_i} C_{p\Psi_T} dt\right. \\ &\left. + U_w\left(T_s - T_i\right) + h_2 c_2\left(T_{wg} - T_g\right) + h_7 w\left(T_s - T_g\right)\right] \end{aligned} \tag{2}$$

The equations for the solids phase and the gas phase of rotary cement kiln are

$$\begin{aligned} \frac{\partial T_s}{\partial x} + \frac{1}{V_s}\frac{\partial T_s}{\partial t} = \left[\frac{1}{\sum_{i=4}^{16} s\left(m_i C_{p_i}\right)}\right]&\left[\frac{h_3 c_3}{\beta}\left(t_{ws} - T_s\right) + \frac{h_4 c_4}{\beta}\left(T_g - T_s\right)\right. \\ &\left. -\frac{1}{V_s}\left\{\sum_{i=4}^{5} g\left(R_i \int_{T_r}^{T_s} Cp_i dt\right) + \sum_{i=4}^{16} s\left(R_j \int_{T_r}^{T_s} C_{p_i} dt\right) + \sum_j \Delta H_{R_j} R_j\right\}\right] \end{aligned} \tag{3}$$

and the final gas energy equation is

$$\begin{aligned} \frac{\partial T_g}{\partial x} - \frac{1}{V_g}\frac{\partial T_g}{\partial t} = \left[\frac{1}{\sum_{i=1}^{5} g\left(n_i C_{p_i}\right)}\right]&\left[\sum_{i=1}^{5} g\left(\left\{\frac{R'}{V_g} + \frac{\beta}{V_s \Psi} R_i\right\} \int_{T_r}^{T_g} C_{p_i} dt\right)\right. \\ &- \left(\frac{\beta}{\Psi V_s}\right)\left\{\sum_{i=4}^{5} g\left(R_i \int_{T_r}^{T_s} C_{p_i} dt\right)\right\} + \frac{h_5 c_5}{\Psi}\left(T_g - T_{wg}\right) \\ &\left. + \frac{h_4 c_4}{\Psi}\left(T_g - T_s\right) + \sum_j \Delta H_{R_j} \frac{R'_J}{V_g}\right] \end{aligned} \tag{4}$$

(Main nomenclature is follows)

V_g velocity of gas, m/min
V_s velocity of clinkerable mass
V_i velocity of air through bed in cooler
T_g temperature of gas
T_i temperature of incoming gas in cooler
T_s temperature of solids
T_{wg} temperature of the wall in contact with the gas
T_{ws} temperature of the wall in contact with the solids
Ψ flow rate of nitorogen through the kiln
Ψ_T total gas flow rate
R_i rate of production by reaction of component i in solid phase, kg i produced/kg clinkerable mass
H_{R_j} heat or reaction based on component j
R_i rate of production by reaction of component i in gas
R_j rate of production by reaction of component j in gas

$\sum g$ sum of all components in gas phase i

$\sum s$ sum of all components in gas phase j

This type of model is not available viewing from inaccurate parameters and large amount of computing time, but qualitative knowledge acquisition for dynamic behavior from these models are more or less useful for common sense behind behavior. The indicial responses by simulation are used for convenience of qualitative inference for common sense of structure (Stillman, 1964; Johnson, 1969). How to use the transfer function which is fitted to the indicial response is appropriate in case by case.

(3) Design of optimum production level

This process model in low frequency region is shown as equ. 1

$$y(n) - \bar{y} = \sum_{m=1}^{M} A_m (y(n-m) - \bar{y}) + \sum_{m=1}^{M} B_m (u(n-m) - \bar{u}) \tag{1}$$

$\bar{y}$ and $\bar{u}$ are average value of running data.
y_s and u_s are value of equilibrium vector in out and input.
Then equ. 2 is derived from equ. 1.

$$y_s - \bar{y} = \left[I - \sum_{m=1}^{M} A_m \right]^{-1} \left(\sum_{m=1}^{M} B_m \right) (u_s - \bar{u}) \tag{2}$$

K_p is defined by stational gain of process, as equ. 3.

$$K_p = \left[I - \sum_{m=1}^{M} A_m \right]^{-1} \left(\sum_{m=1}^{M} B_m \right) \tag{3}$$

Then equ. 2 is expressed as equ. 4

$$y_s - \bar{y} = K_p(u_s - \bar{u}) \tag{4}$$

J is performance index for considering of cost and quality, as shown equ. 5, then equ. 6 is introduced by Taylor expansion.

$$J = f(y_s, u_s) \tag{5}$$

$$J = \sum_{i=1}^{r} \alpha_i (y_{s_i} - \bar{y}_i) + \sum_{j=1}^{i} \beta_j \left(u_{s_j} - \bar{u}_j\right) \tag{6}$$

Optimization of equ. 6 is formulated by L.P. problem.
(4) The relative power contribution

The system is a feedback system within which $x_j(s)$ is connected to $x_i(s)$ by an element having the frequency response function $a_{ij}(f)$ and each $x_i(s)$ has its own noise source $u_i(s)$. Thus, $x_i(s)$ can be expressed as a sum of the influences of $u_j(s)$'s. Under the assumption that $u_j(s)$'s are mutually uncorrelated, the power spectral density function $p_{ii}(f)$ of $x_i(s)$ can be expressed as a spectral density function of $u_j(s)$, by $p(u_j)(f)$, then, as the influence of $x_j(s)$ on $x_j(s)$ is generated by the frequency response function $b_{ij}(f)$ of $x_j(s)$ to the input$x_j(s)$ within the closed loop system, we get

$$p_{ii}(f) = \sum_{J=1}^{k} |b_{ij}(f)|^2 \, p(u_j)(f), \tag{1}$$

If we define $q_{ij}(f)$ by

$$q_{ij}(f) = |b_{ij}(f)|^2 p(u_j)(f) \tag{2}$$

this represents the contribution of $u_j(s)$ to the power spectral density of $x_i(s)$ at the frequency f. Accordingly the relative power contribution is given by

$$r_{ij}(f) = \frac{q_{ij}(f)}{p_{ii}(f)} \tag{3}$$

and the commulative relative power contribution is given by

$$R_{ij}(f) = \sum_{k=1}^{j} r_{jk}(f) \qquad (j = 1, 2, \ldots, k). \tag{4}$$

When, these quantities are graphically represented, the pattern of the contributions of the noise sources to the system behavior becomes quite clear.

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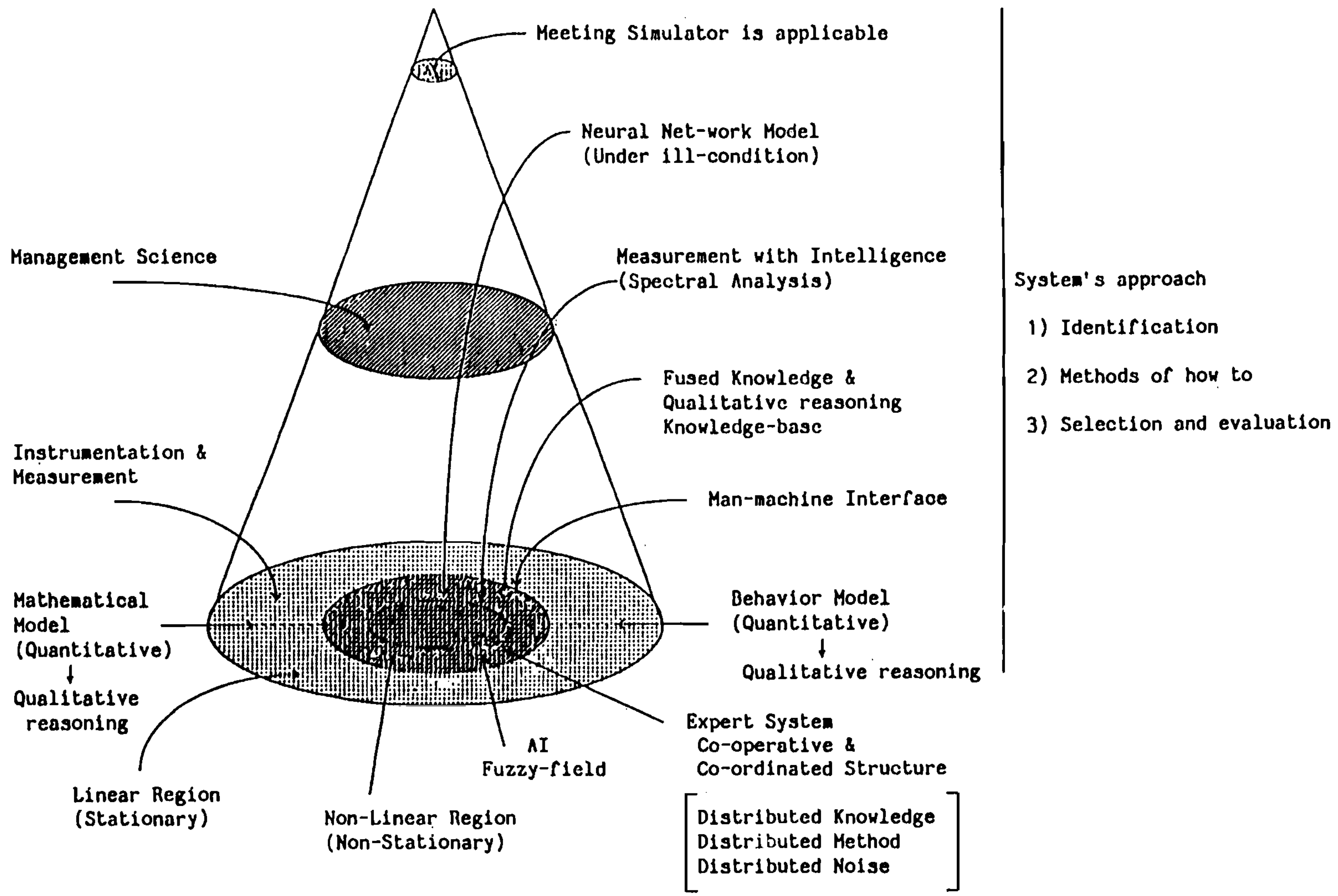

Meeting Simulator is applicable
Neural Net-work Model
(Under ill-condition)
Management Science
Measurement with Intelligence
(Spectral Analysis)
Fused Knowledge &
Qualitative reasoning
Knowledge-base
Instrumentation &
Measurement
Man-machine Interface
Mathematical
Model
(Quantitative)
↓
Qualitative
reasoning
Behavior Model
(Quantitative)
↓
Qualitative reasoning
Expert System
Co-operative &
Co-ordinated Structure
AI
Fuzzy-field
Linear Region
(Stationary)
Non-Linear Region
(Non-Stationary)
Distributed Knowledge
Distributed Method
Distributed Noise
System's approach
1) Identification
2) Methods of how to
3) Selection and evaluation

Fig. 1

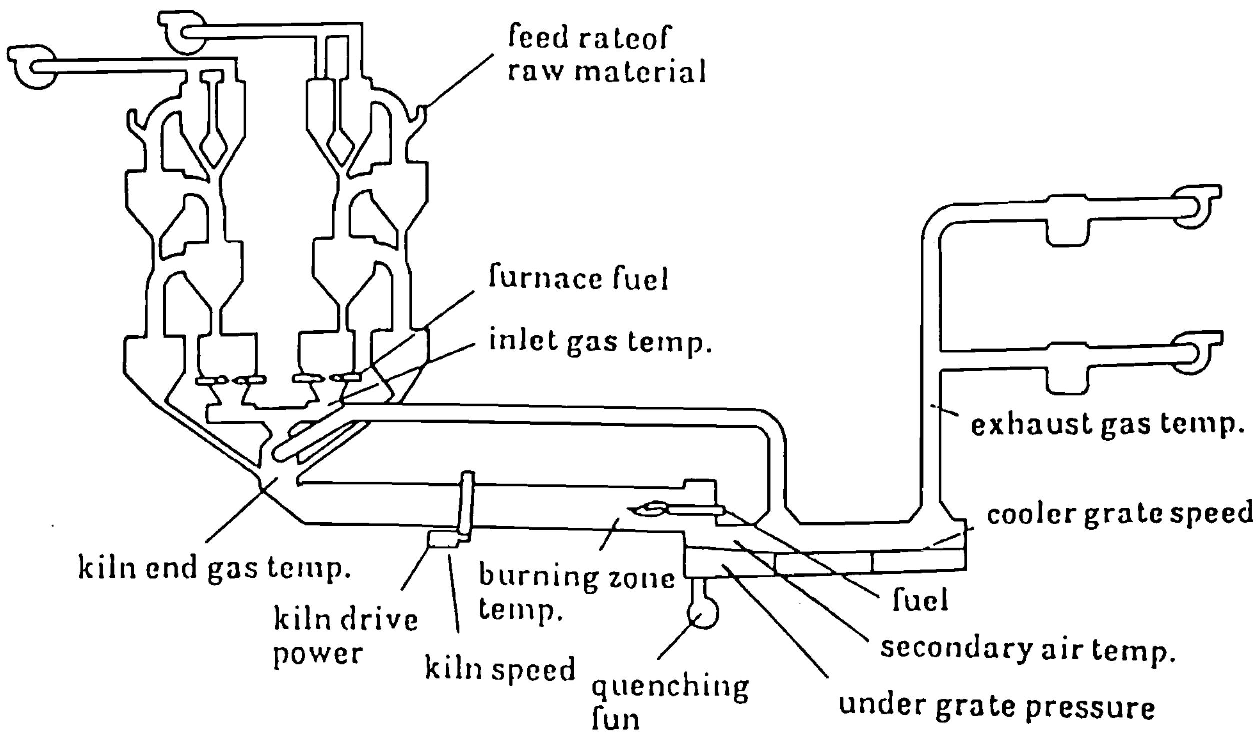

feed rateof
raw material
furnace fuel
inlet gas temp.
exhaust gas temp.
cooler grate speed
kiln end gas temp.
kiln drive
power
kiln speed
burning zone
temp.
quenching
fun
fuel
secondary air temp.
under grate pressure

Fig. 2

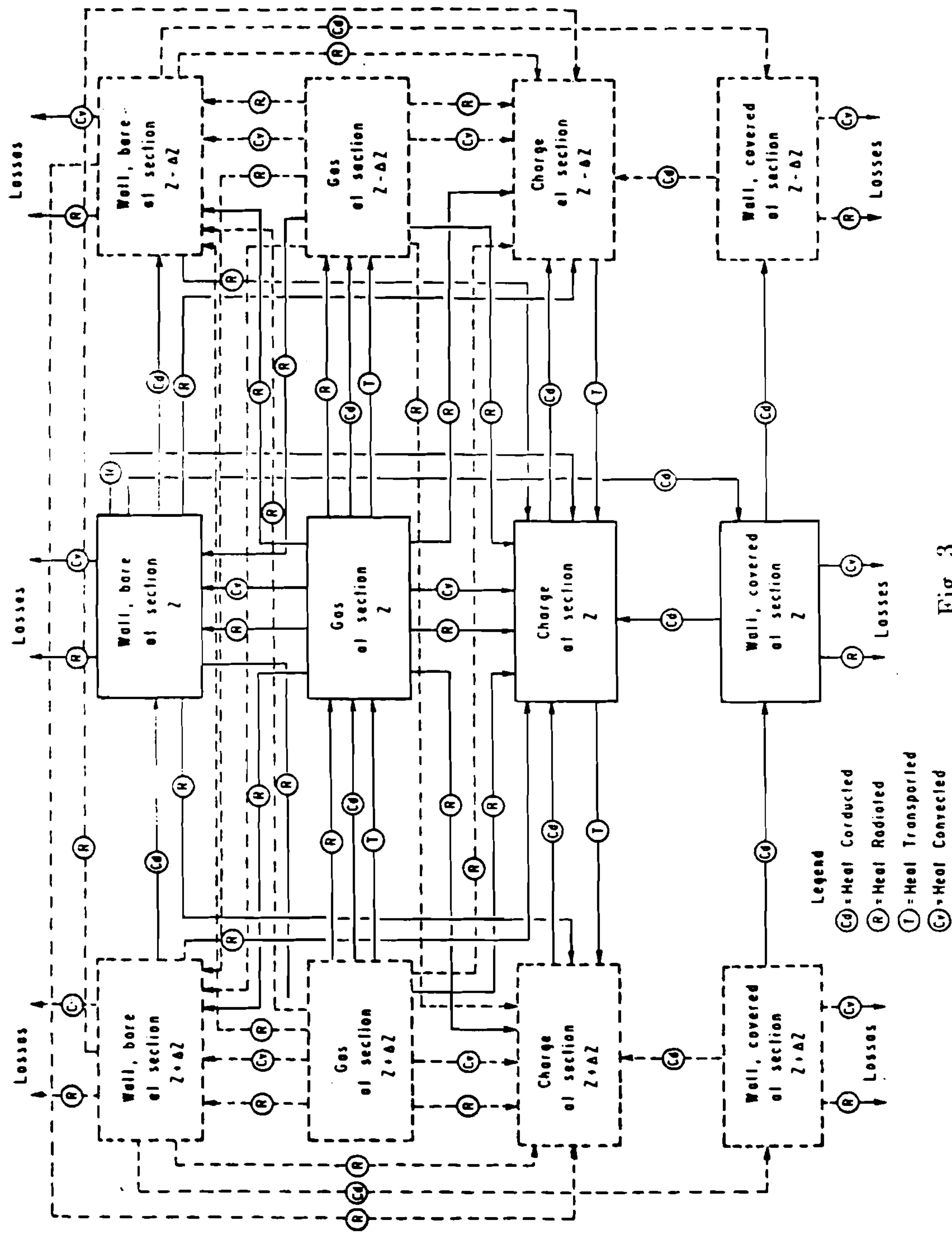

Wall, bare at section Z - ΔZ
Gas at section Z - ΔZ
Charge at section Z - ΔZ
Wall, covered at section Z - ΔZ
Wall, bare at section Z
Gas at section Z
Charge at section Z
Wall, covered at section Z
Wall, bare at section Z + ΔZ
Gas at section Z + ΔZ
Charge at section Z + ΔZ
Wall, covered at section Z + ΔZ
Losses
Losses
Losses
Losses
Losses
Losses
Legend
Cd = Heat Conducted
R = Heat Radiated
T = Heat Transported
Cv = Heat Convected

Fig. 3

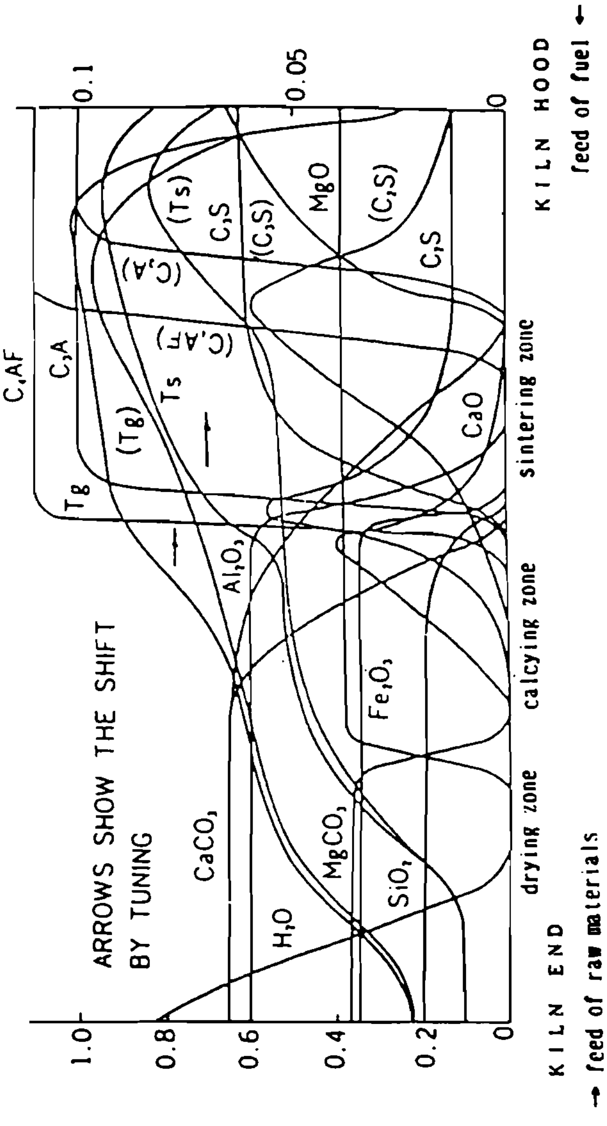

ARROWS SHOW THE SHIFT
BY TUNING
C4AF
C3A
Tg
(Tg)
Ts
(Ts)
(C3A)
(C4AF)
C3S
(C3S)
MgO
(C2S)
C2S
CaO
Al2O3
Fe2O3
CaCO3
MgCO3
SiO2
H2O
1.0
0.8
0.6
0.4
0.2
0
0.1
0.05
0
K I L N E N D
→ feed of raw materials
drying zone
calcying zone
sintering zone
K I L N H O O D
feed of fuel ←

Fig. 4

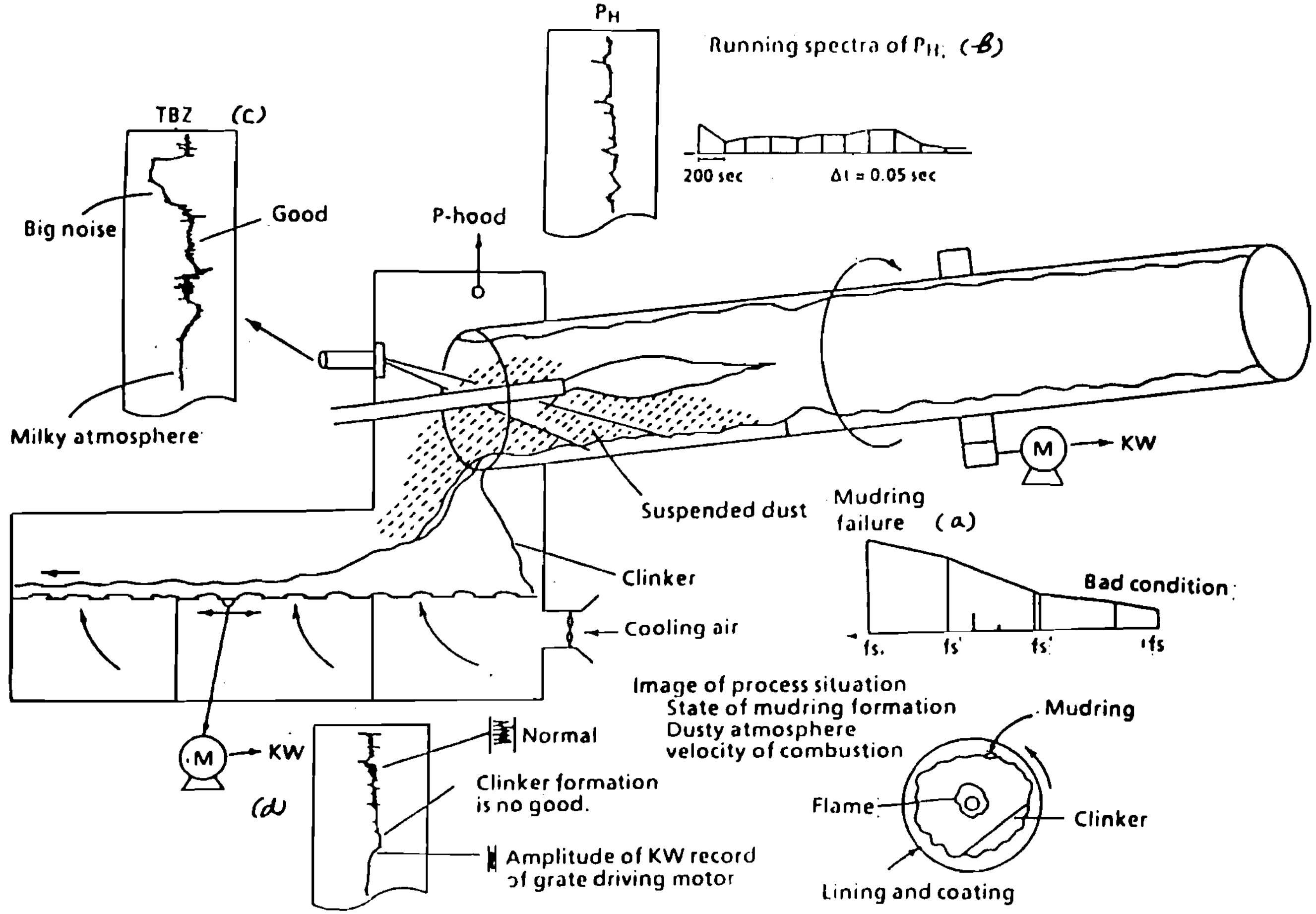

TBZ (c)
Big noise
Good
Milky atmosphere
P-hood
P_H
Running spectra of P_H; (b)
200 sec
Δt = 0.05 sec
M
KW
Suspended dust
Mudring failure (a)
Bad condition
fs.
fs'
fs'
fs
Clinker
Cooling air
Image of process situation
State of mudring formation
Dusty atmosphere
velocity of combustion
Mudring
Flame
Clinker
Lining and coating
M
KW
(d)
Normal
Clinker formation is no good.
Amplitude of KW record of grate driving motor

Fig. 5

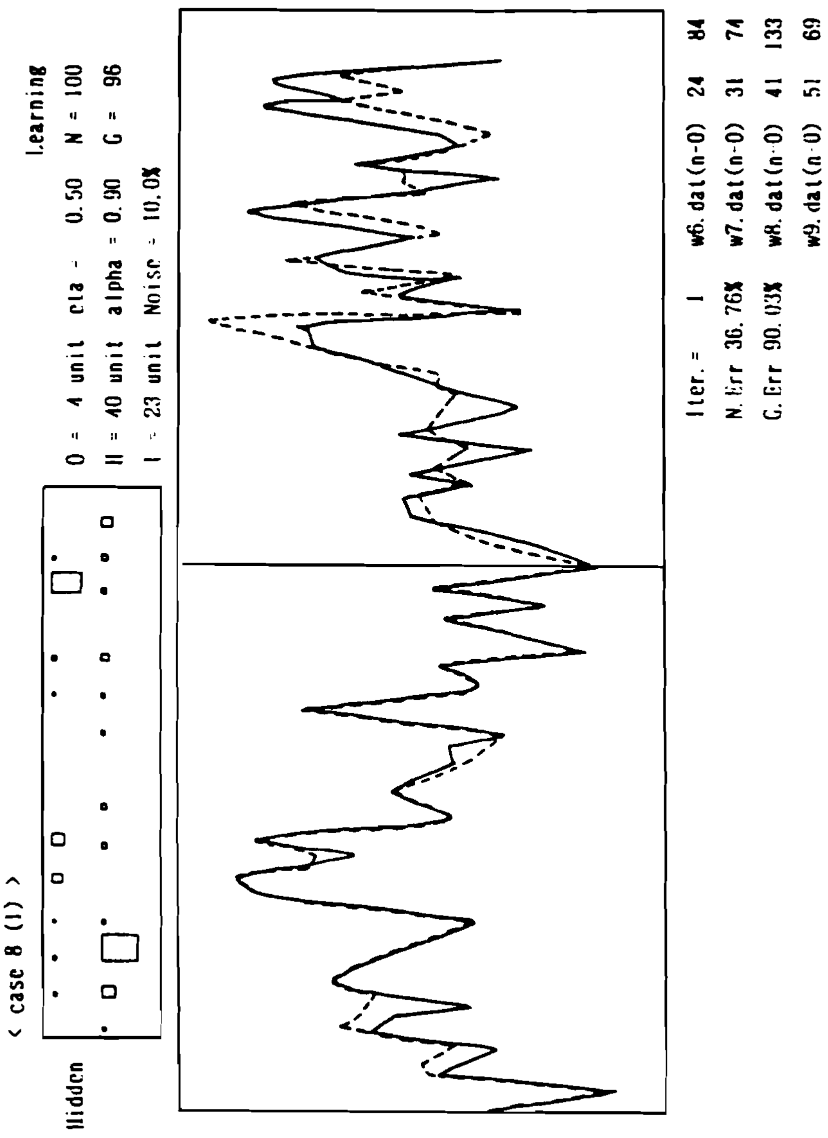

Hidden
< case 8 (1) >
Learning
O = 4 unit eta = 0.50 N = 100
H = 40 unit alpha = 0.90 G = 96
I = 23 unit Noise = 10.0%
Iter. = 1
N.Err 36.76%
G.Err 90.03%
w6.dat(n-0) 24 84
w7.dat(n-0) 31 74
w8.dat(n-0) 41 133
w9.dat(n-0) 51 69

Fig. 6

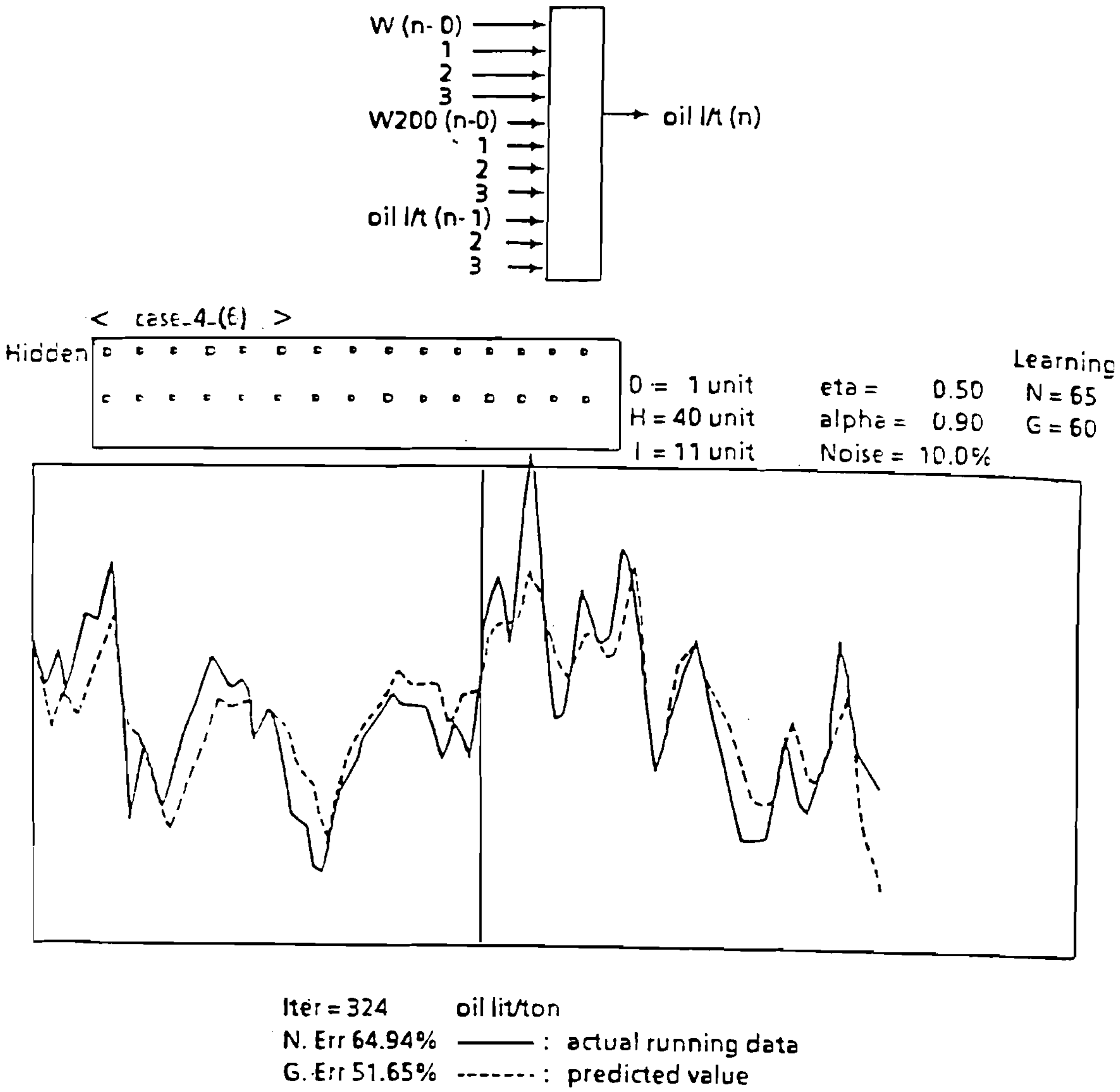

W (n- 0)
1
2
3
W200 (n-0)
1
2
3
oil l/t (n- 1)
2
3
oil l/t (n)
< case_4_(6) >
Hidden
O = 1 unit
H = 40 unit
I = 11 unit
eta = 0.50
alpha = 0.90
Noise = 10.0%
Learning
N = 65
G = 60
Iter = 324
oil lit/ton
N. Err 64.94%
: actual running data
G. Err 51.65%
: predicted value

Fig. 7

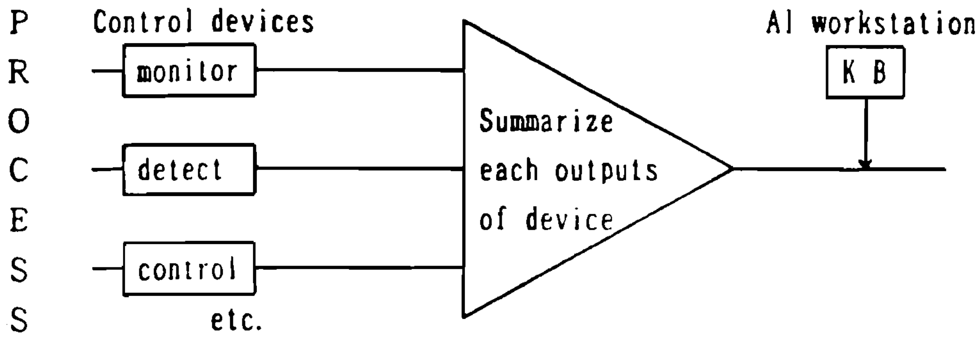

P
R
O
C
E
S
S
Control devices
monitor
detect
control
etc.
Summarize
each outputs
of device
AI workstation
K B

Fig. 8

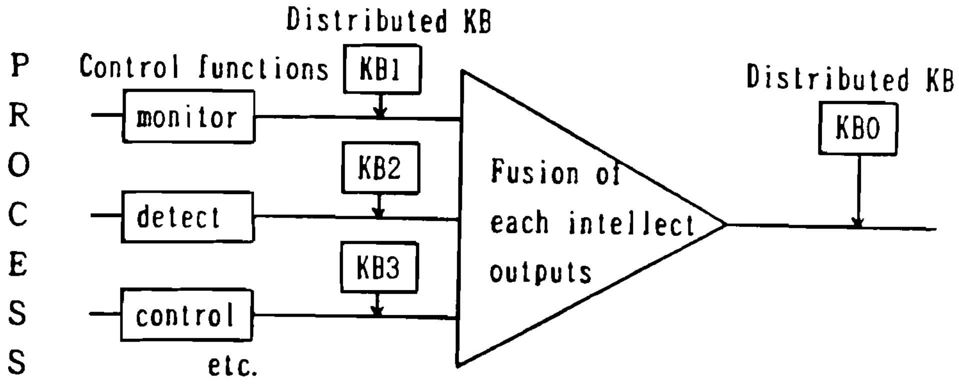
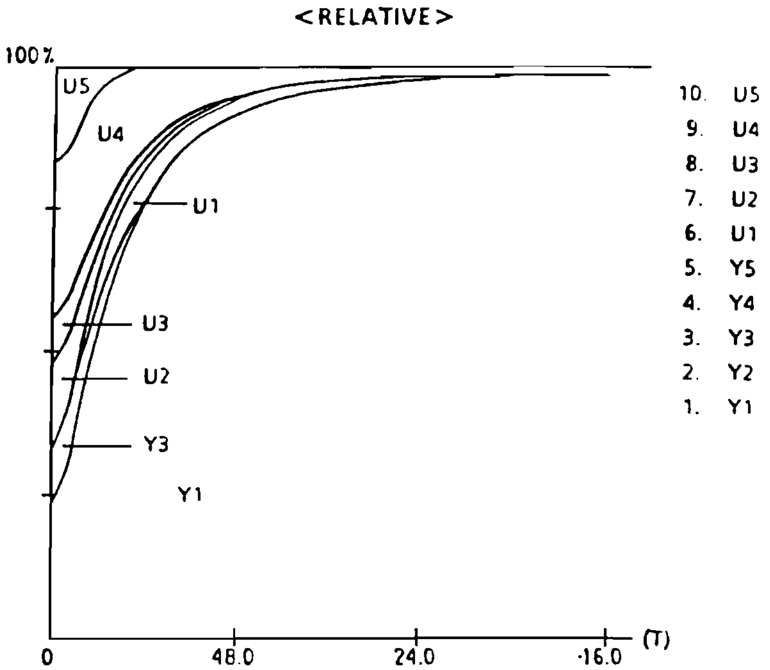
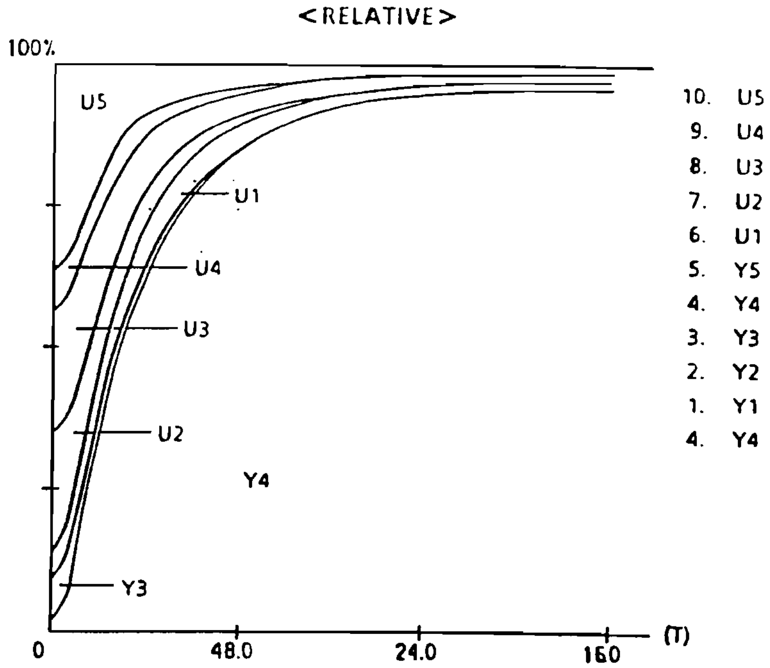

P
R
O
C
E
S
S
Distributed KB
Control functions
KB1
KB2
KB3
monitor
detect
control
etc.
Fusion of
each intellect
outputs
Distributed KB
KB0

Fig. 9



<RELATIVE>
100%
U5
U4
U1
U3
U2
Y3
Y1
0
48.0
24.0
·16.0
(T)
10. U5
9. U4
8. U3
7. U2
6. U1
5. Y5
4. Y4
3. Y3
2. Y2
1. Y1

Fig. 10



<RELATIVE>
100%
U5
U1
U4
U3
U2
Y4
Y3
0
48.0
24.0
160
(T)
10. U5
9. U4
8. U3
7. U2
6. U1
5. Y5
4. Y4
3. Y3
2. Y2
1. Y1
4. Y4

Fig. 11

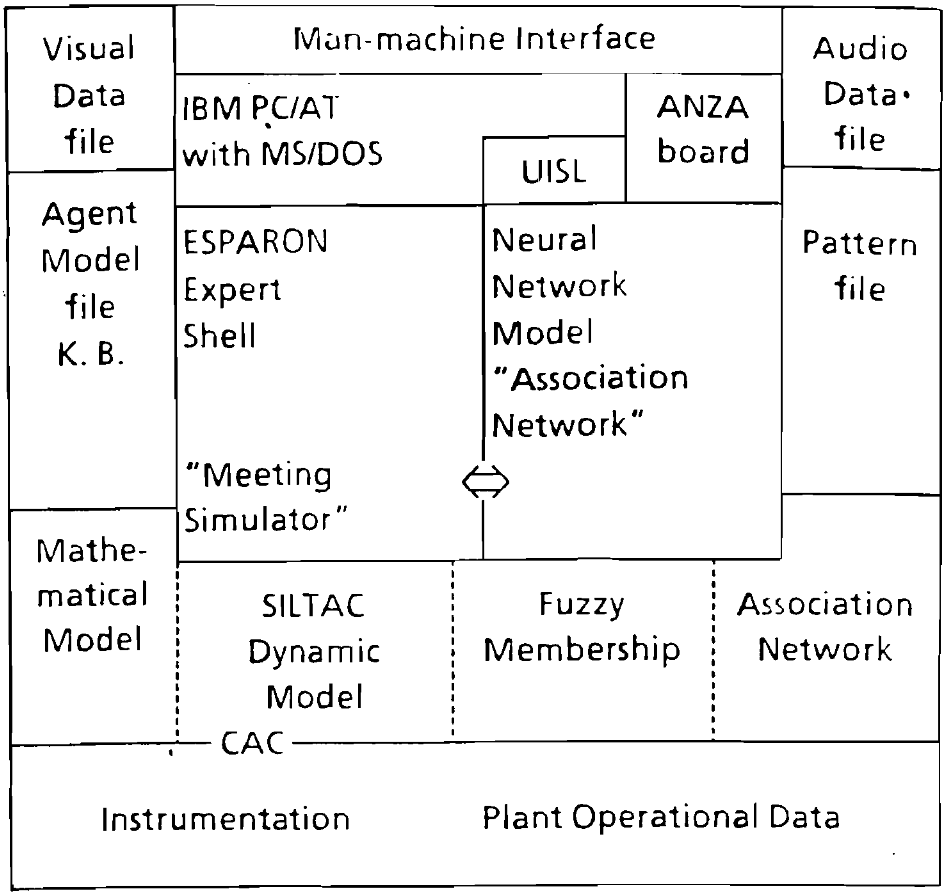

Visual Data file
Man-machine Interface
Audio Data file
IBM PC/AT with MS/DOS
UISL
ANZA board
Agent Model file K. B.
ESPARON Expert Shell
"Meeting Simulator"
Neural Network Model "Association Network"
Pattern file
Mathe-matical Model
SILTAC Dynamic Model
Fuzzy Membership
Association Network
CAC
Instrumentation
Plant Operational Data

Fig. 12

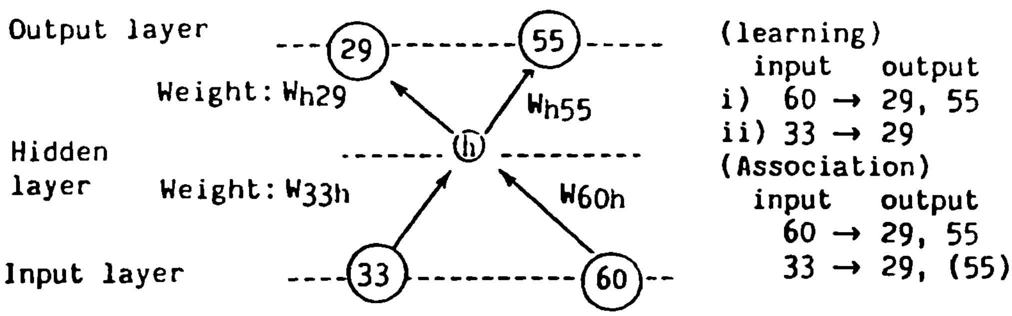
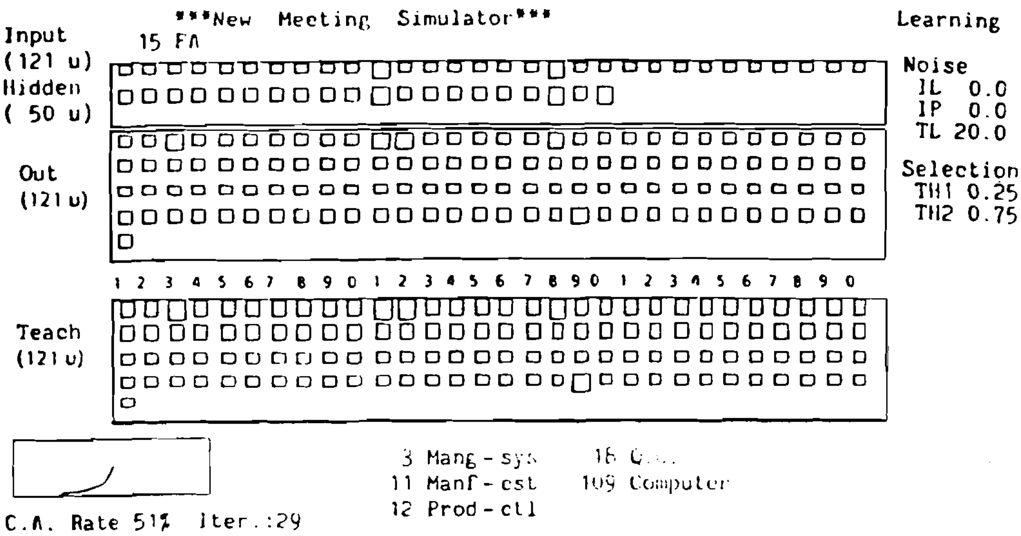

Output layer
29
55
Weight: Wh29
Wh55
Hidden layer
h
Weight: W33h
W60h
Input layer
33
60
(learning)
input output
i) 60 → 29, 55
ii) 33 → 29
(Association)
input output
60 → 29, 55
33 → 29, (55)

Fig. 13



The activation status of each PE is represented by a white square, with the area of the square proportional to the activation value.

Fig. 14

Role of DSS on Business Activities

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Abstract

In this paper we review the role of decision support system (DSS) from the standpoint of application areas, DSS package tools, and its relation to the management information system. Sometime DSS is considered to be a simple presentation tool of management information to the top management. But DSS has to deal with all of the business activities from the operational level to the corporate planning level. Recent advances of computer and software technologies makes it possible to construct DSS covering all of the business processes easily and economically. Finally we discuss the functionality of DSS required from users standpoint. Key factors to improve such requirement are network technology, man-machine-interface and multi-media processing.

1 Introduction

Rapid advances in information technology and cheaper hardware cost permit us to use computers more easily and to apply them for more widely business areas. Application of Decision Support System for practical business activities in most of Japanese companies are:

1) Decision Support for Capital Investment.

2) Decision Model by Statistical Analysis.

3) Management Information System for Corporate Decision Support.

The first two subjects are single and rather ad-hoc applications, but the last one is structured applications where standard operating procedures, decision rules, and information flows can be pre-defined. Now let's see each case.

2 DSS for capital investment

1st case of DSS application is to determine capital investment policy for a company. These applications come to us in such situations that we propose some project of plant construction to our customer. Some cases, they are private company or national enterprises. For them we do the economic evaluation, marketing analysis, production cost analysis of the proposed project for them to decide whether they should invest to the proposed construction project or not. We analyze ROI (Return on Investment) based on estimated cash flow through the plant life. The reason why we apply DSS for these fields are:

1) Financial conditions are different from company to company, from country to country. For example, tax calculation, depreciation method etc.

2) Data levels are quite different, some time very sparse, some too detailed.

3) Many IF–PLAN's are required.

Fig. 1 shows the general flow chart of applying DSS tool for the feasibility analysis of capital investment. We have to study what happens if investment cost is changed, or if tax rate, interest rate, sales price etc. are changed. For these application , procedural language, FORTRAN for example, are not suitable to solve these problems. Procedural languages has a limit on expression to follow model changes. IBM's "AS", EXECUCOM's IFPS, are very flexible, easy to use, and very excellent from the view point of modeling function.

3 DSS for statistical analysis

2nd cases of DSS are analysis of economic time series. I want to show two case studies for this application.

1st one is "Chemical Diffusion Index", which we developed for a chemical company to help them determine sales or inventory policy. Diffusion Index are a kind of economic indicators whether current economic status are upward or downward tendency. It also counts leading indicators and lagging indicators. By leading indicators, for example, production manager can get an information that he should increase or decrease inventory level for coming sales activities. For this application we have to select many economic time series which are coinciding, leading, and lagging to the current economic situation. For example. GNP, stock price index, production index of industry, YEN exchange rate etc. All of these economic time series are candidates for determining Diffusion Index, and must be checked their relations to the economic cycle. Usually these time series are raw data which is observed from actual economy. To analyze these data we have to decompose the original time series into seasonal, irregular or cyclic factors as shown in Fig. 2 .

2nd application are economic models. To solve the econometric model we need much statistical analysis , for example, least squares, and solving method of simultaneous equations.

Fig. 3 is a model of Personal Consumption Equation. It include a data manipulation such as "Divide", taking "Lag" of original time series. "Least Square" is also processed for this equation and finally parameters are determined. To automatically process above two examples, We have developed a packaging system called "STAMPS" (STAtistical Method Package System). It is aggregation of subroutine packages of simple data manipulation such as ADD, SUBTRACT, MULTIPLY, DIVIDE, and statistical solvers like LEAST SQUARE, MOVING AVERAGE, EXPONENTIAL SMOOTHING etc. Users of this system only write English like statements according to his or her requirement of how to modify the original time series.

Fig. 4 shows input data to extract trend–cycle from the original time series. Users of STAMPS write only the original series number, type of analysis or manipulations, and some argument. In this case we used EPA Method for extracting seasonal factor and used Moving Average or Repetitive Moving Average to extract trend and cycles.

Fig. 5 shows the case of estimate of consumption function. It include many simple data manipulations before setting up data series for analyzing Ordinary Least Squares. As shown in these figures modeling are very simple understandable to user , then it is very easy to re–calculate "What If" case studies.

4 Management information system for corporate decision support

3rd case of DSS is Management Information System (MIS). MIS is an integrated system which combines data processing and existing tools. The managers can use languages and data management systems which he is already familiar. The main purpose of this system is to improve efficiency of business work by reducing cost and manhours, turn–around time, and by replacing clerical personnel. The relevance for managers' decision making is indirect, for example, by providing reports and access to data base.

Fig. 6 shows a simulation model of a chemical company. It consists from three blocks. Marketing analysis, Investment, Profit & Loss blocks. In marketing analysis many statistical DSS applications are used to forecast product demand and market share. If estimated volume of a product exceeds the capacity, new investment plan are come into consideration. In Investment block, financial DSS application are used to test feasibility of capital investment. Once new product are added to the existing capacity, optimum production scheme of each factory are determined by, for example, LP (Linear Programming). Then balance of each product is calculated by some modification of Input–Output Analysis method. Profit & Loss calculation system is typical financial accounting system by which profit is available for a certain rate of dividend to the share holders. By combining DSS tools and existing EDP system we can construct easily Management Information System for the corporate decision

Fig. 7 shows a general framework of typical engineering company's MIS. MIS covers all the business processes of engineering, procurement, and construction, as well as processing of all available resources like manhours, materials, cost. Computer Aided Engineering (CAE) is also an integrated system which assist engineering work such as, document, drawing/drafting, calculation by using, for example, CAD (Computer Aided Design), database, and process simulation tools.

Project Management System (PMS) is another most important system in a engineering company which controls time schedule, cost, and performance of a project. Project managers uses this system for their decision making, such as, whether cost is too much consumed compared with the progress, and so on. Role of DSS in the corporate management information system means reporting to both top and divisional managers, as well as, to project managers. In our company annual and semi–annual performance of the company profit and loss and its related financial statement are required to report from this system.

Fig. 8 shows management information flow in our EDP management information system. The figure shows the data-flow between each sub-system. For example, the manhour data from TECMAN that is based on employers' daily time sheets, (that is daily work record sheet) and the direct cost data from PURCS/PCCS that is based on actual price of purchase orders, finally reach to PMIS that is the control system of the project profit and loss by integrating all the income, cost, and manhours incurred by the project works. Each system satisfies not only the function of project control, but also that of supporting operational execution of business activities, such as purchasing, accounting, payroll, personnel, manhour control, and so on. Finally all summary of project performance and accounting and financial information are aggregated and reported to the top management.

5 Necessary conditions of MIS for constructing DSS

When we try to construct DSS, it is not always successful even if we purchase packages. In the case of using data of MIS, there are many points we must take into consideration about the design of business process and activities. Now, let me explain the necessary conditions of MIS for constructing DSS.

(1) MIS must be a system in which the transaction data are entered into Database not only precisely but also immediately. If the Database of MIS is not satisfied with such condition, the data in MIS are not suitable for DSS data, because the solution of DSS may be misjudged. The famous saying, "garbage in, garbage out" is a such example.

(2) Those functions are required that a DSS user can easily select or summarize the transaction data in any levels as he likes. At first, the decision maker selects the summarized data of MIS database to understand the problem clearly. As he repeats the hypothesizing and verification again and again, he will understand the point of the problem, and he gradually wants more detail data. To support them, those functions are required that a user can select and summarize data from MIS to DSS easily and immediately. When the database is a relational database, it is relatively easy to make the function. Recently many of DSS packages run under the personal computer, the technique of Micro-Mainframe-Link is one of the important key points.

(3) It is a very important necessary point whether the database structure in MIS is expressed as user-friendly structure or not. Such structure of the database is desired like a same data structure of real-world from the decision maker's point of view. When the MIS does not have such database, a decision maker can't select data which he wants, even if the MIS is satisfied with the former conditions. Up to now, the data expression of database was not much concerned with users, it was important only to system engineers and programmers of the EDP department. So, they were sometimes far from the real-world, because the structure was often designed thinking only access time to the database. In addition, the local used data items and the definition of data items that a user can't understand were often used in the database of MIS. One of considerable solution for them is using the Data Dictionary and building a database defined by corporate common data items.

6 An example of MIS DATA download to DSS

To execute projects efficiently, our company has a matrix organization system in which there exists both the command from a project manager and the command from each department managers such as engineering, construction, procurement and so on. In these cases , when a new project started many assigned engineers are selected from functional departments , then they have to report their work information to their department head as well as to their project manager. Actual and predicted manhours are indispensable for the optimal manpower assignment, future business planning and eventually it affects the project schedule. The manpower predictions are based on not only necessary manhours of the project which have already received orders (called "JOB"), but also that of the project which will receive orders (called "PROPOSAL"). Specially, regarding the PROPOSAL project, there are many kinds of uncertain factors. For example, we can't receive the project after all, or start time of the project may be postponed, or the scope of project will be widely changed. According to the change of contracts with customers, we must revise manpower planning as soon as possible.

When we get into contract of a large project, manpower need is enlarged. We have developed a DSS that can support flexibly such a manpower planning. This DSS is based on LOTUS 123. The data source of JOB project is stored in the database of TECMAN, and that of PROPOSAL project is in the sales information database. DSS supports the simulation for resource planning, especially with respect to the uncertain parts of PROPOSAL project, subject to the type and the scale of the plant. We are able to estimate the manpower allocation of each department's engineers from our past experience. The decision makers, mainly each department managers, can do many case studies by changing the distribution ratio of manpower using the model of LOTUS 123. For examples, (1) if this PROPOSAL runs into an order, how many engineers will be shortened ? Or, (2) when will the shortage occur ? Or, (3) if this PROPOSAL becomes in effect earlier than the original plan, what will happen ? Owing to this DSS, we can make a plan of personnel relocation or the employment of temporary manpower in early stages. In addition, it makes possible to maintain the balance of work load between engineers.

7 Required functionality to DSS

7.1 Types of DSS tool

DSS tool is classified, as I have mentioned above, into 5 types according to their application areas. These are (1) Modeling (2) Planning analysis (3) Financial analysis (4) Statistical analysis (5) Data handling.

Modeling is a kind of easy language which end users of EDP system can easily express their structure of work. Recently so called 4th Generation Language has been widely used for that purpose. I know many of these tools even replace COBOL, FORTRAN language and reduce much time of programming. Planning analysis uses many of operations research methodology. One of most used one is Linear Programming. In the above example we have used LP for the allocation of production for each factory.

For financial and statistical analysis, there are many DSS tools available. Typical application on these areas are the economic feasibility study as mentioned in chapter 2. Data handling function is a kind of integrated DSS tool. Some DSS tool is called prototyping tool for system development. Prototyping is such system as, before making structured system, by using DSS tool, we can build a pilot model system to be reviewed by end users. If they have some comment, change or add request, we can modify it instantly, and if necessary, we can develop a full-scale system based upon the prototyping.

Fig. 9 shows the relation between the system development process and available DSS tools. In the field of information technology, DSS can be considered to be classified into a category of the system development tool by which high productivity of system design or programming would be gained. 4GL, SQL, and even CASE (Computer Aided System Engineering) are new trend on DSS tools. Recently many AI (Artificial Intelligence) or EXPERT systems are enlarging their application areas. In near future we can expect the emerge of Intelligent DSS.

7.2 MIS and DSS

We have been talking about MIS that is imaged as a typical structured operational system, which handles transaction such as accounting payable/receivable, time charge and payroll.

Fig. 10 shows an idea of the classification of MIS and DSS. If we define MIS as a management information system in the wide sense, MIS is composed of both the transaction system in the narrow sense, and DSS, that is, the Decision Support System. DSS is divided into the specified DSS and the DSS software package that is a DSS GENERATOR. The specified DSS is the user developed system for specified problem. If we can't use DSS GENERATOR, we must develop a specified DSS. However, it needs much efforts and manhours to develop it, even if using 4GL or some expert system tools. In addition, the improvement and modification of the system are not able to be carried out without EDP department staff. It is difficult to make the specified DSS successful for practical use even through the prototyping systems have been developed successfully. As to DSS GENERATOR, it is divided into two types. One is data operational type, and the other is model based type. Recently, some DSS Generators which include both types have been developed. Regarding the data operational type of DSS, it is mainly used when a decision maker analyzes the data from many view points. At the conceptual phase and the design phase, it supports what a decision maker can do by trial and error approach and by watching computer display. The data operational type of DSS is indispensable to interfacing with database of transaction systems. Typical tool in this category is LOTUS 123 which is the best-seller of personal computer's software, and in mainframe base, AS, ACTIVE-DSS, SYSTEM-W, SAS, and SPSS. SAS and SPSS are superior with respect to the functionality of statical analysis. On the other hand, the model based type of DSS is a tool mainly used for solving the estimation and planning problem by modeling and simulation. If a decision maker can build the model precisely, the system can support the design phase and the choice phase of decision making process very well. However, it is so difficult for a decision maker to build the model precisely that it can assist a very limited problems such as profit planning and investment planning.

7.3 Required capability of DSS tool

In order DSS tool to be more and more used, following capability must be satisfied.

(1) Try & error, sensitivity analysis. At the planning phase we will confront many different cases, then we have to prepare many conditions, many answers.

(2) DBMS (Data Base Management System) Because of tremendous progress of Relational Database, especially in a personal or mini computer fields, this function is now almost satisfied.

(3) Report generation and Graphic output capability. Report generation is generic need of DSS, because good presentation is one of the most important key factors of decision for top management. Recently graphic, even color graphic, or visualization by computer graphics, are becoming a must to DSS.

(4) MML (Main Micro Link) One requirement is that data interface between main frame and work stations must be flexible and easily handled. Another requirement is that DSS must be used both in main frame host computer and in small computers in a same mode. If data base function or strong calculation engine is required, use host computers. But in a distributed environment many end users want to use their own personal computers. If user's interfaces are the same, it is most desirable as DSS tool.

8 Conclusion

Because of rapid progress of computer and communication technology, DSS application are also changing. The key factors which affects advances of DSS are non–procedural, man–machine interface, and multi–media. Non procedural language is important for the users in a sense that they can express their model or program as if using natural language. Man machine interface has been tremendously progressed by technique of multi–task, multi–window type of software in a personal computers. Those tool in which word processing, calculation, graphic, and editing function are fully equipped and freely integrated each other is considered to be one of the ideal DSS systems. Multi media processing means that not only data processing but also image filing and retrieval, document processing, and many other devices like voice mail and facsimile mail, are processed in a same operating system. By using multi media, decision maker can check his decision data with some other visible evidence, for example, illustration or images. Visualization is a key point in a sense that good presentation rather than content often becomes determining factors to the decision makers. Computer Graphics, Computer Aided Design technology support their availability.

Hardware and software environment also make a great influence to DSS advances. Small size portable computers make many decision makers easily access any time, any where to data. Then computers are becoming indispensable for businessman. If everybody carries personal computer , electronic–mail or data transfer between users are required. If everybody can access from any where, any time to any data, concept of DSS will be changed. It will become such an intelligent robot which has a knowledge data base and strong multi–media capability.

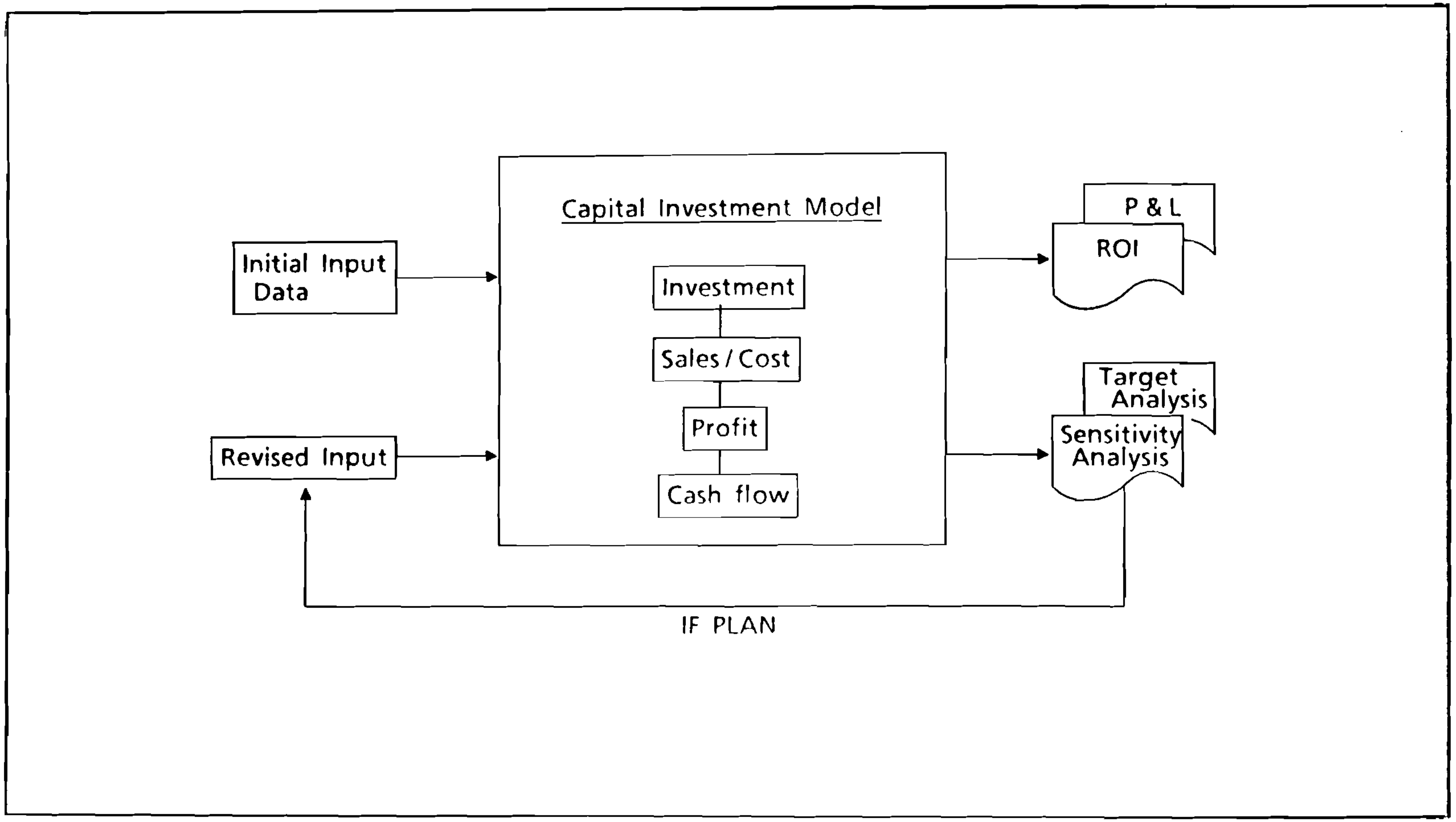

Fig.1 Decision Support for Capital Investment

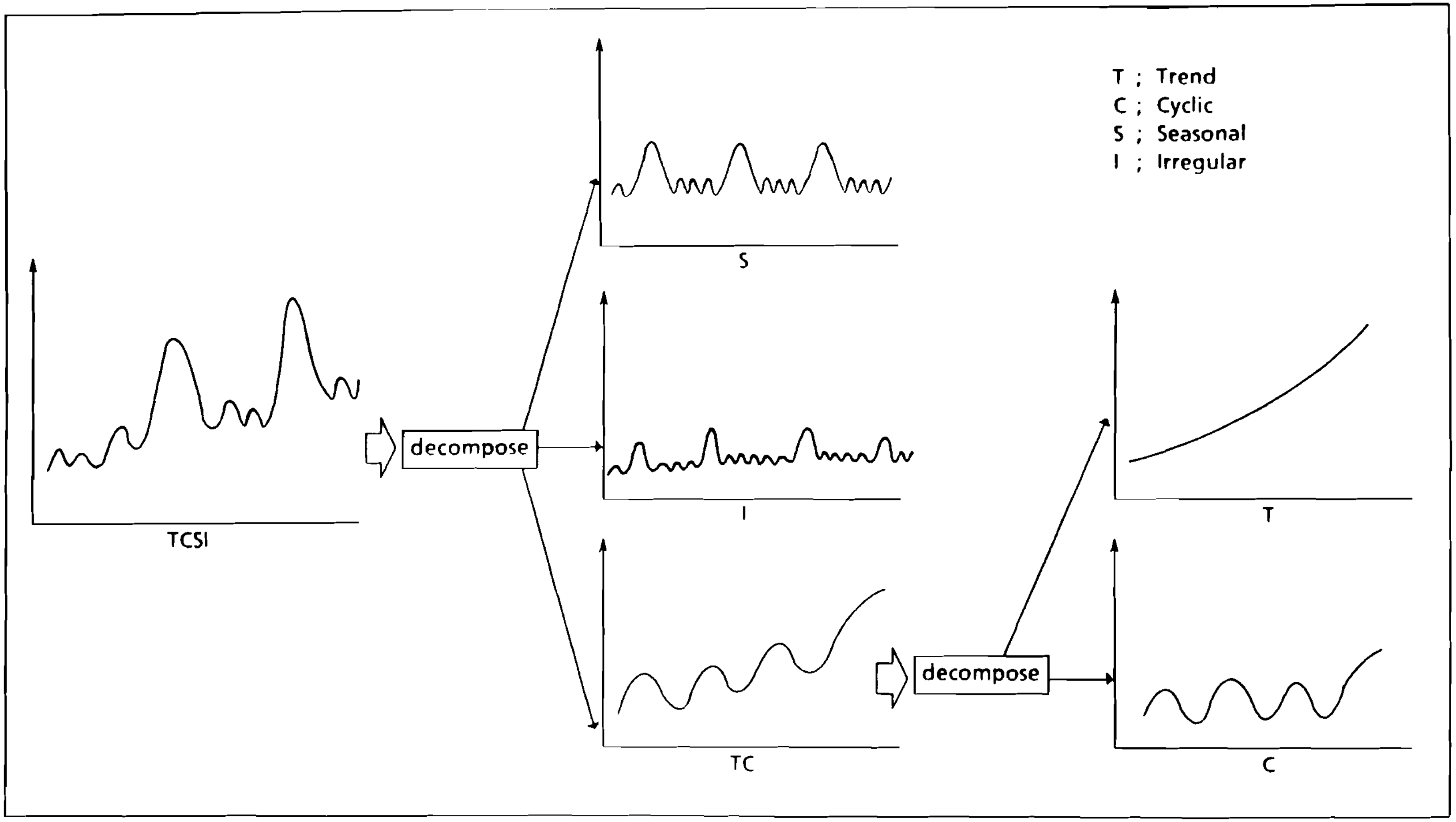

Fig.2 TREND CICLE ANALYSIS

$$\log\left(\frac{C}{PC}\right) = \alpha + \beta\log\left(\frac{PD}{PC}\right) + \sigma\log\left(\frac{C}{PC}\right)_{-1}$$

where C ; Personal Consumption

PC ; Personal Consumption Defrator

YD ; Personal Income (Nominal)

Fig.3 REGRESSION ANALYSIS MODEL

(Input Model)	(Explanation)
MOVE (***)	Move file (***) from Data Base
Y (1) = EPAM (***, pl = 12, c = tci)	Take Seasonal Factor by EPA Method
Y (2) = MANN (1, pl = 5)	Take Irregular by Repetitive M.A.
Y (3) = MAN (2, pl = 40)	Take Trend by Moving Average (M.A.)
Y (4) = DIV (2, 3)	Take Cycle by Dividing Y(2) by Y(3)
Y (5) = MANN (4, pl = 5)	Smooth Y(4) by R.M.A. Method
GRAPH (4, 5)	Graph Y(4) and Y(5)

Fig.4 EXTRACTION OF TREND CYCLE

(Input Model)	(Explanation)
MOVE (*1, *2, *3)	Move file from Data Base
T (1) = DIV (*1, *3)	Take "Real" from "Nominal"
T (2) = DIV (*2, *3)	- DO -
T (3) = LAG (T(1), pl = 1)	Take "Lag" by 1 month
Y (1) = LOGE (T(1))	Take Logarithm of each Time Series
Y (2) = LOGE (T(2))	- DO -
Y (3) = LOGE (T(3))	- DO -
Y (4) = OLS (2, 3, 1)	Execute Ordinary Least Squares
GRAPH (1, 4)	Graph Original vs. Predicted

Fig.5 ESTIMATE COMSUMPTION FUNCTION

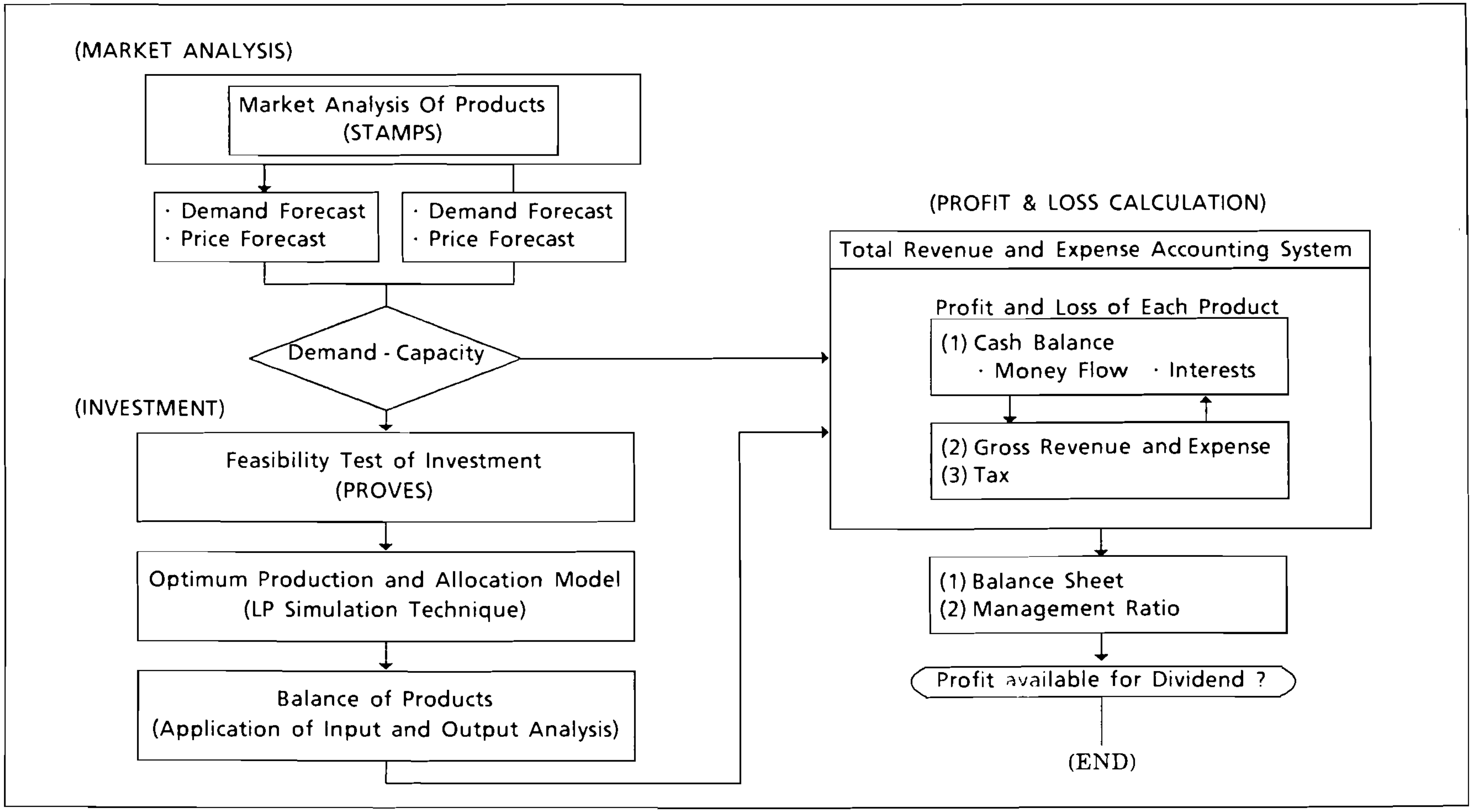

Fig.6 PLANNING SIMULATION MODEL OF CHEMICAL COMPANY

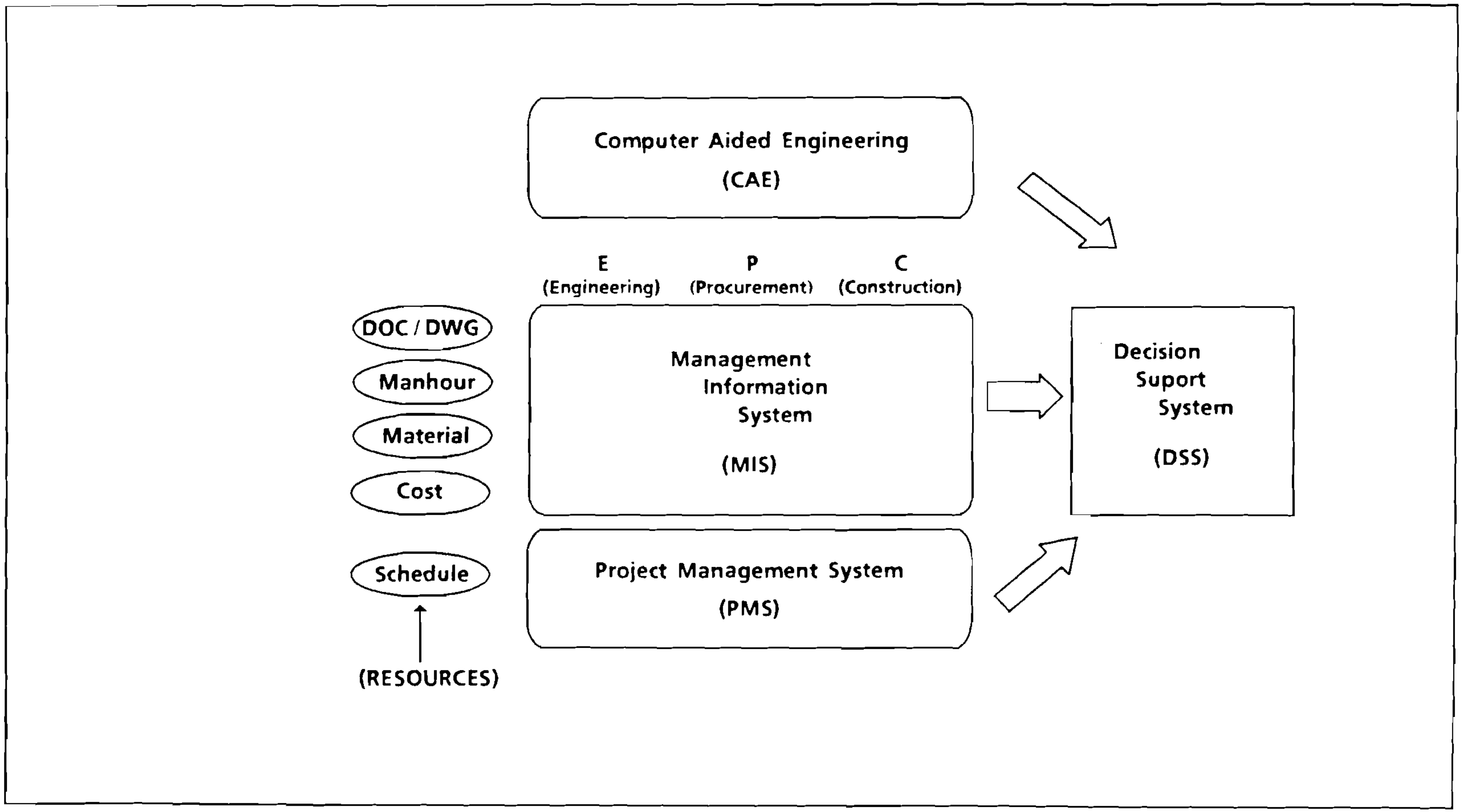

Fig.7 ENGINEERING COMPANY'S MIS

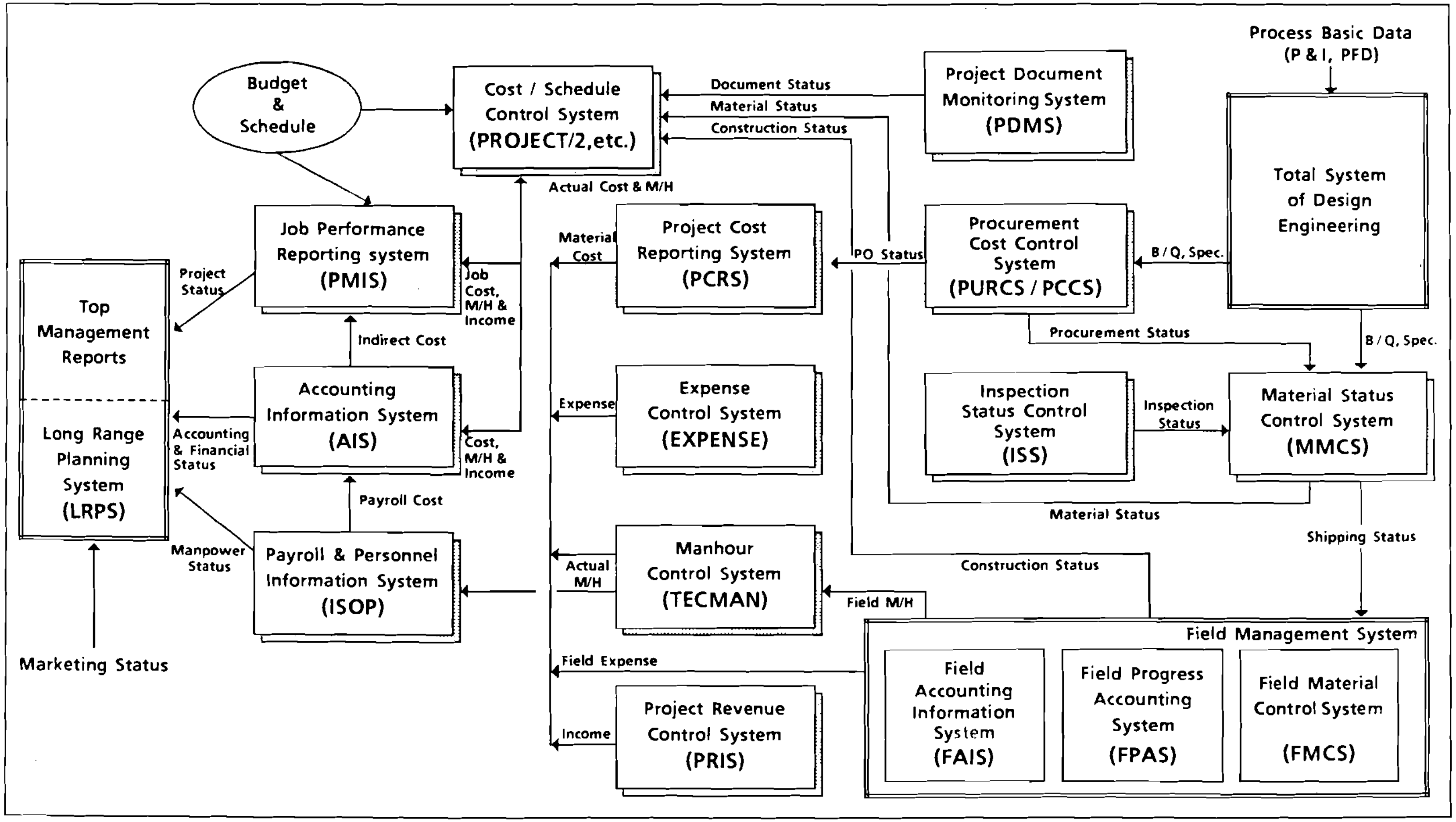

Fig.8 MANAGEMENT INFORMATION SYSTEM

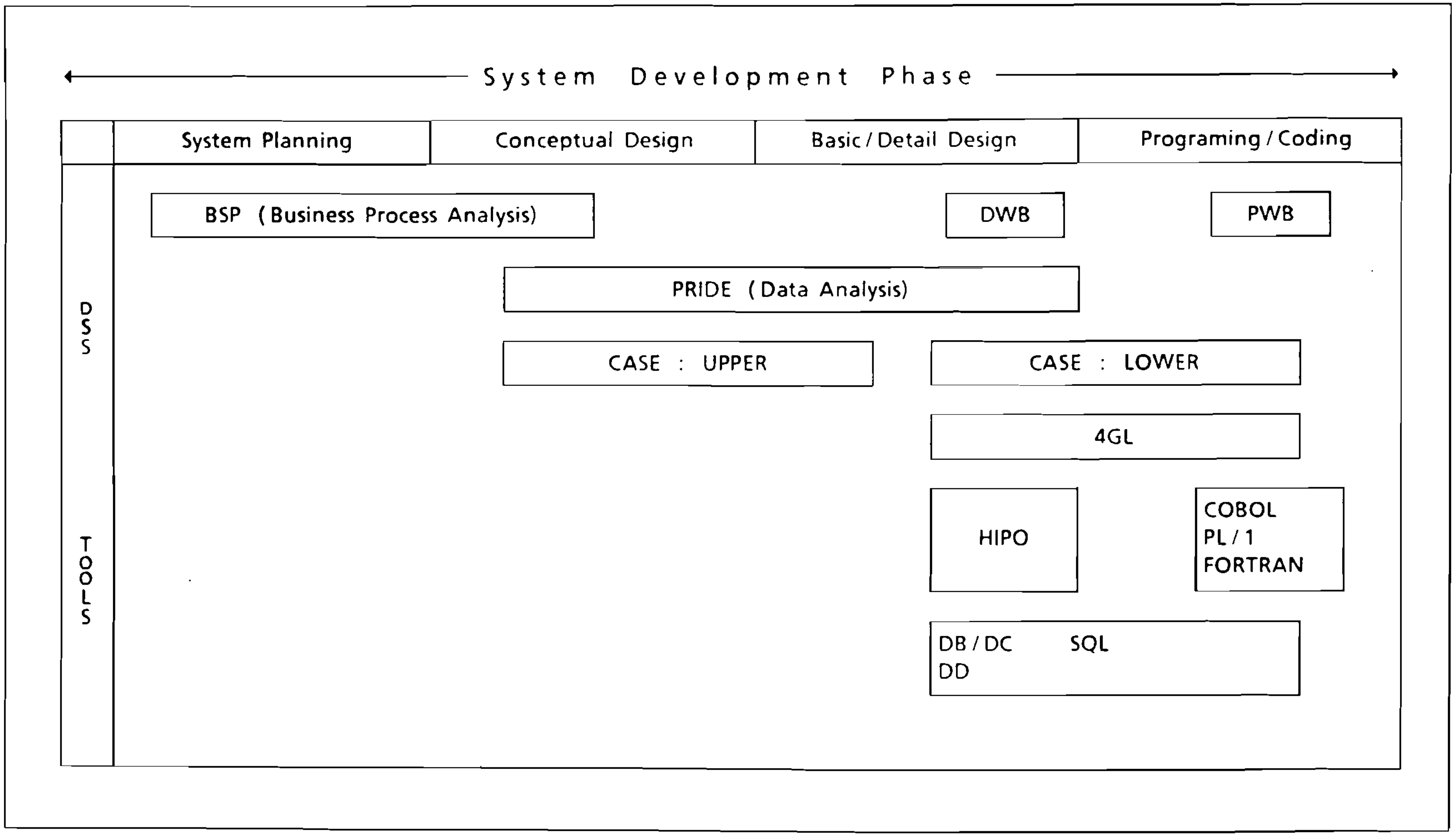

Fig.9 SYSTEM DEVELOPMENT PROCESS AND DSS TOOL

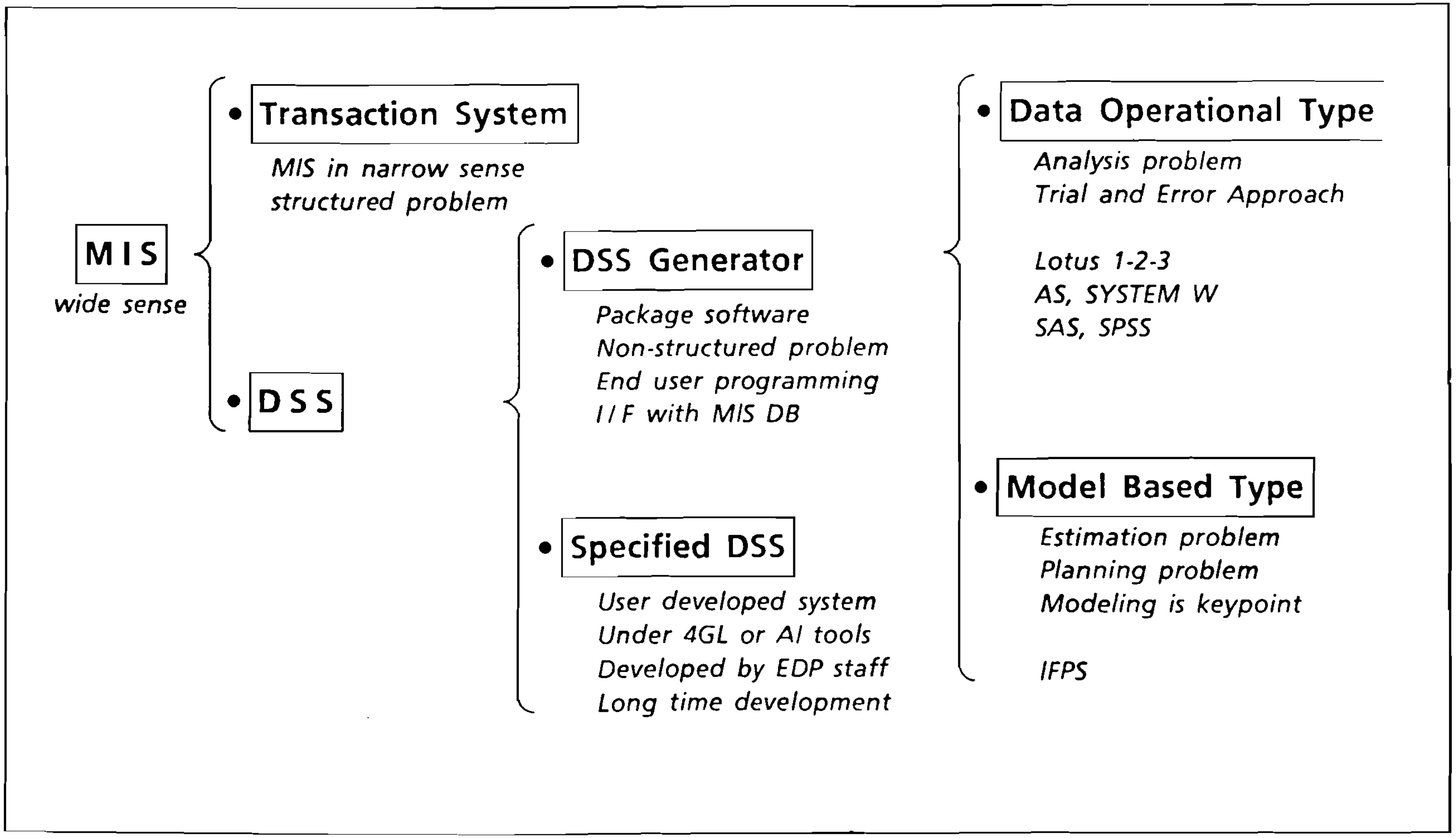

Fig.10 MIS and DSS

Compromise Ranking Method

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Abstract

The multiple–aspect alternatives ranking is considered. The methods Compromise Programming and ELECTRE are compared. The certain similarity is found out. Relying to ideas of compromise programming the new multicriteria merit is derived. This merit is the basis of compromise ranking method.

1 Introduction

Multiobjective decision making may considered as complex and dynamic process in which one managerial level and one engineering level can be distinguished (Duckstein and Opricović, 1980). The managerial level defines the goals, and chooses the final "optimal" alternative; the multiobjective nature of decisions is very much emphasized at this level, at which public officials called "decision makers" have the power to reject or accept and implement plans provided by the other level. The engineering level defines alternatives and points out consequences of choosing any one of them from the viewpoint of various criteria. This level performs the multicriteria ranking of alternatives.

Multicriteria analysis makes use of the following steps:

1. Define the desired goals, objectives, or purpose that the system is to fulfill.
2. Identity the set of engineering specifications essential for the attainment of the desired goals.
3. Establish system evaluation criteria that relate system capabilities to specifications and hence to goals.
4. Develop alternative systems for attaining the goals and determine their capabilities in terms of evaluation criteria.
5. Generate alternatives versus criteria array.
6. Perform multicriteria ranking of alternatives.
7. Accept an alternative as the optimal one.

Very, often, the foregoing steps constitute only an iteration in the decision-making process; namely, in cases when no final solution is chosen in step 7, then an additional step is necessary.

8. If the final solution is not accepted, gather new information and go into the next iteration starting at step 2.

Steps 1, 7 and 8 are performed at the highest policy level in which decision makers have a central role. Other steps are mostly engineering tasks.

In this paper problem of multiple-aspect alternatives ranking is considered. It is assumed that each alternative a_j is evaluated according to each criterion function f_i $(i = 1, \ldots, n)$.

There are two approaches in multicriteria ranking. The first approach is based on an "aggregated" function $U(f_1, \ldots, f_n)$ representing total utility, or $D(f_1, \ldots, f_n)$ as "dis-satisfaction" (like L_p metric in compromise programming (Zeleny, 1973)). The second approach is based on preference relation B (like ELECTRE method (Roy and Bertier, 1973)). If preference relation $a_j B a_k$ is confirmed, then the alternative a_j is better than a_k in multicriteria sense.

It seems that these two approaches are very different, but comparing the compromise programming and ELECTRE method (as representatives) the similarity is found out.

2 Compromise programming and ELECTRE method

The various alternatives will be denoted as $a_1, a_2, \ldots, a_J$. For a given alternative a_j the merit of i-th aspect is denoted by f_{ij}, i.e. f_{ij} is the value of i-th criterion function for the alternative a_j, $(i = 1, \ldots, n)$.

The alternative a_j is better than a_k according to i-th criterion if

$$f_{ij} > f_{ik} \quad \text{i.e.,}$$

$$a_j \succ a_k \quad \leftrightarrow \quad f_{ij} > f_{ik}$$

The ideal alternative a^+ has the following merits

$$f_i^+ = \max_j f_{ij}, \quad i = 1, \ldots, n.$$

Usually, the alternative a^+ is not in the given set $\{a_j\}$, i.e. it is not feasible.

Compromise programming introduces the measure of closeness to the ideal alternative. One of the used measure of closeness is the L_p- metric, defined as follows:

$$L_p(j) = [\sum_{i=1}^{n}(w_i(f_i^+ - f_{ij})/(f_i^+ - f_i^-))^p)]^{1/p}, \quad 1 \leq p \leq \infty$$

Freimer and Yu, 1976, and Yu and Leitmann, 1974, showed that: parameter p plays the role of the "balancing factor" between the "group utility" and maximum of the individual regret; and as p increases, the group utility decreases, however individual regret reduces too. From the decision-making point of view, the compromise solution for $p = 1$ is based on "majority rule", and for $p = \infty$ on the minimax strategy.

For $p = 1$ the measure for multicriteria ranking is

$$S_j = \sum_{i=1}^{n} w_i(f_i^+ - f_{ij})/(f_i^+ - f_i^-) \tag{1}$$

and for $p = \infty$ the measure is

$$R_j = \max_i w_i(f_i^+ - f_{ij})/(f_i^+ - f_i^-) \tag{2}$$

where $f_i^- = \min_j f_{ij}$, $i = 1, \ldots, n$, w_i are the weights of criteria.

The alternative a_j is better than a_k according to the measure S iff $S_j < S_k$, i.e.

$$\sum_{i=1}^{n}(f_i^+ - f_{ij})/D_i < \sum_{i=1}^{n}(f_i^+ - f_{ik}/D_i$$

or

$$\sum_{i=1}^{n} f_{ij}/D_i > \sum_{i=1}^{n} f_{ik}/D_i \tag{3}$$

where $D_i = f_i^+ - f_i^-$

The alternative a_j is better than a_k according to the measure R iff $R_j < R_k$, i.e.,

$$\max_{i \in n}(f_i^+ - f_{ij})/D_i < \max_{i \in n}(f_i^+ - f_{ik}/D_i \tag{4}$$

The method ELECTRE introduces the "concordance" and "discordance". The concordance condition for a_j and a_k is formulated as

$$\sum_{i \in N^+, N^=} w_i / \sum_{i \in N} w_i \geq q \quad \text{and} \quad \sum_{i \in N^+} w_i > \sum_{i \in N^-} w_i \tag{5}$$

where w_i are the weights of criteria, N is the index set.

$$N^o(a_j, a_k) = (i \in N : \; f_i(a_j) \; O \; f_i(a_k))$$

o denotes one of the symbols $+ \;\; = \;\; -$ and

O is instead of $> \;\; = \;\; <$ respectively.

The parameter q is the minimal level for concordance that alternative a_j is better than a_k.

The discordance condition for a_j and a_k is formulated as

$$(1/S) \times \max_{i \in N^-}(s_i(a_k) - s_i(a_j)) \leq r \tag{6}$$

where $s_i(a)$ represents "the surrogate" of the criterion function, S is the scale interval. The parameter r is the level of discordance that the alternative a_j is better than a_k. Let

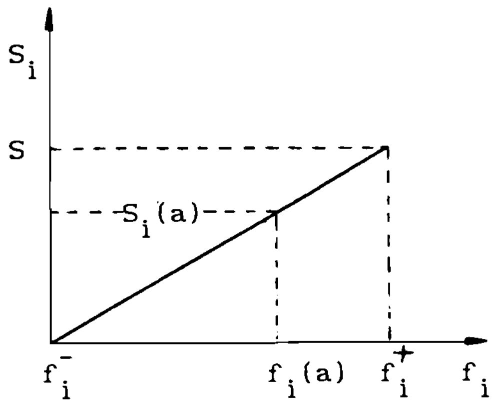

Figure 1:

us compare the relation (4) and (6). The function $s_i(a)$ is the result of scaling (Fig. 1). Supposing the linear relation between s_i and f_i, the function $s_i(a)$ has the following form:

$$s_i(a) = S \times (f_i(a) - f_i^-)/D_i$$

If this is introduced in (6), the following relation is obtained

$$\max_{i \in N^-} ((f_i(a_k) - f_i(a_j))/D_i) \leq r \tag{7}$$

Let us introduce the relation

$$\max_i b_i - \max_i c_i \leq \max_i (b_i - c_i) \tag{8}$$

and by parameter r' the inequality (8) may be presented as equality

$$\max_i b_i - \max_i c_i = \max_i (b_i - c_i) - r' \tag{9}$$

According to (9), the relation(4) may be transformed in the following form

$$\max_{i \in N} ((f_i^+ - f_{ij})/D_i - (f_i^+ - f_{ik})/D_i) - r' \leq 0$$

or

$$\max_{i \in N} ((f_{ik} - f_{ij})/D_i) \leq r' \tag{10}$$

By definition it is $f_{ik} = f_i(a_k)$, and for the subset N^- it is $f_i(a_k) > f_i(a_j)$, so the left side of inequality (10) is equal to the left side of (7).

The discordance condition (in ELECTRE) and the minimax strategy in compromise programming are based on similar relation (7) and (10). Which one is much stronger depends on r/r' $(r, r' \in (0,1))$. The conclusion is: if the alternative a_j is better than a_k according to the discordance condition, the same will be if the alternatives are ranked by R in compromise programming (rel. (2))

The conclusion of comparing the concordance condition (5) and "majority rule" by S in compromise programming is not explicit. However, the same ranking results, according to (3) and (5), may be expected when the number of criteria in subset N^+ is "sufficiently" greater than that in N^-.

The ELECTRE IV method introduces the strong outrankings $a_j B a_k$, which holds iff: For none of the criteria it is

$$f_i(a_k) > f_i(a_j) + P_i, \quad \text{i.e.}$$

$$f_i(a_j) \geq f_i(a_k) - P_i, \quad i = 1, \ldots, n \tag{11}$$

and if there is

$$f_i(a_k) \geq f_i(a_j) + p_i \quad \text{for } n' \text{ criteria.}$$

$$\text{it has to be } n' \leq n/2 \tag{12}$$

P is the threshold for strict preference (p for weak).
Let $i = L$ be index for which maximum in (10) is obtained, than it is

$$f_L(a_j) \geq f_L(a_k) - P'_L \tag{13}$$

where $P'_L = r' \times D_L$
So, if the condition (11) holds, the condition (13) in compromise programming holds too.

Let us consider the condition (12), which may by presented in the following form

$$f_i(a_j) \geq f_i(a_k) + p_i, \quad i \in n", \quad \text{where } n" = n - n'.$$

Dividing by D_i and summing it is obtained

$$\sum_{i \in n"} f_i(a_j)/D_i \geq \sum_{i \in n"} (f_i(a_k) + p_i)/D_i$$

and by additional transformation

$$\sum_{i \in n} f_i(a_j)/D_i \geq \sum_{i \in n} f_i(a_k)/D_i + \sum_{i \in n"} p_i/D_i + \sum_{i \in n'} (f_i(a_j) - f_i(a_k))/D_i.$$

By the last inequality the following condition is derived:

$$\sum_{i \in n"} p_i/D_i \geq \sum_{i \in n'} (f_i(a_k) - f_i(a_j))/D_i$$

what depends on p_i, $i \in n"$, but it could be expected in many cases since $n" \geq n'$. If the last condition holds, the condition (3) in compromise programming holds too. So, the same ranking results may be expected applying compromise programming or ELECTRE methods.

3 Compromise Ranking Method and Algorithm

Applying compromise programming with merits S in (1) and R in (2), two ranking lists are obtained. Defining the ranking measure on S and R, the two–criteria problem may be solved by compromise programming.

In the new two–criteria problem the ideal alternative has the following merits

$$S^+ = \min_j S_j \text{ and } R^+ = \min_j R_j.$$

The multicriteria merit for compromise ranking is derived (by (1)) as

$$Q_j = v(S_j - S^+)/(S^- - S^+) + (1 - v)(R_j - R^+)/(R^- - R^+) \tag{14}$$

where $S^- = \max_j S_j$ and $R^- = \max_j R_j$.

The value of v is introduced as weight of the strategy of "the majority of criteria" (or "the maximum group utility").

The best alternative, ranking by Q, is one with the minimum of merit Q.

The compromise ranking algorithm has the following steps:

1. Determination of the best f_i^+ and worst f_i^- values of all criterion functions $(i = 1, \ldots, n)$.
2. Compute the value S_j $j = 1, \ldots, J$, by relation (1), and R_j, $j = 1, \ldots, J$, by (2); (J is the number of alternatives).
3. Compute the values Q_j, $j = 1, \ldots, J$, by relation (14).
4. Rank the alternatives, sorting by the values Q_j, $j = 1, \ldots, J$.

The first compromise ranking is performed (or it is suggested to be) with following values of weights: $w_i = 1$, $i = 1, \ldots, n$ and $v = 0.6$.

Varying the values of criteria weights w_i, $i = 1, \ldots, n$, the influence of criterion importance on ranking list may be studied.

Increasing the value v of strategy weight ($v = 0.8$ or $v = 0.9$) the alternative which is very good according to many criteria ("majority rule"),but it could be the worst, according to one (or very few), it will be ranked on the top of ranking list. But, such alternative could not be "the top" if the value of v is decreased ($v = 0.2$ or $v = 0.1$). Decreasing the value of v, we are looking for the alternative which is not the worst according any of the criteria, and the ranking is based on minimax strategy. Ranking with the value $v = 0.6$ is based on "compromise" strategy (the value of v for compromise strategy is determined only "empirically").

Iterative procedure may be introduced as the following: Performing the ranking (the first run), the best and worst alternative have the rank 1 and J (the position on the ranking list). The ranking is performed as the second run without the best and the worst alternative from previous run. In the second run the best and the worst alternative will have 2 and $J - 1$ position on the ranking list. So, the iterative procedure is performed until all alternative are ranked. By such iterative procedure it is avoided the influence of the best and worst alternative on the ranks of the others. Iterative procedure is not suggested if the number of alternatives is not much greater than the number of criteria.

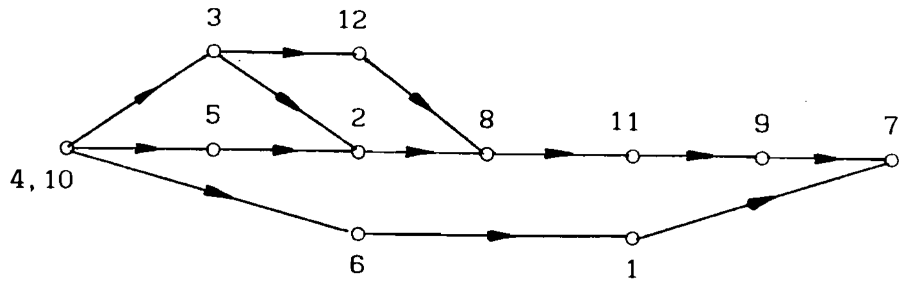

Figure 2:

4 An illustrative example

The example is chosen from the paper by Roy and Hugonnard, 1982. They considered the extension of the Paris metro system. Twelve extension projects were investigated (the extension of suburban lines). In order to evaluate the greater or lesser priority of a project, six criteria were considered. The data are presented in that paper.

The ELECTRE IV multicriteria method was applied. The results are presented as the graph (Fig. 2), showing final partial ranking.

The orientation of the links refers to the direction of decreasing priorities. The knot numbers represent the projects or alternatives (the order number of projects from the original input list). "Ahead of the ranking are found, first, projects 4 and 10, of equal merit; next two incomparable projects: 3 and 5 (both with higher priority than 2). On December 6, 1973, Governmental Select Committee assigned highest priority to four of the 12 projects, namely 3, 4, 5 and 10. They have all been initiated to date. As against this, none of the three lowest priority projects (7, 9 and 11) have been scheduled to date. Projects 1 and 6 must be set aside, as they are not comparable with the others." (This was written as a conclusion by Roy and Hugonnard, 1982).

Applying the compromise ranking method the following ranking list is obtained (with $v = 0.6$ and $w_i = 1, \;\; i = 1, \ldots, n$): 10, 4, 5, 1, 6, 3, 12, 11, 2, 7, 8, 9.

The input data for compromise ranking were only the values of criterion functions. In this case the decision maker preference is not included (it could be done by weights).

By ELECTRE IV partial ranking was obtained, but by compromise ranking method the ranking is complete.

5 Conclusion

Comparing the Compromise Ranking Method and ELECTRE one may conclude that the complete ranking could be obtained by compromise ranking.

Compromise ranking may be performed only with the values of criterion functions. Sometimes, the decision maker is not able, or he does not know to express his preference at the beginning of design.

The Compromise Ranking Method introduces the multicriteria merit based on the particular measure of "closeness" to the "ideal" solution. The decision-maker's preference could be involved by criteria weights and ranking strategy weight (v).

The Compromise Ranking Method may be applied with the following assumptions:

- The values of all criterion functions are given for all alternatives.
- It is not necessary for all alternatives to be noninferior.
- The relation between the utility and criterion function is linear (utility in general sense).

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MME - a Rapid Modelling and Algorithm Prototyping Environment

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Abstract

The Mathematical Modelling Environment (MME) is an experimental evironment, designed to support mathematical modelling and algorithm design. MME provides an interpretable functional, object-oriented language suitable for defining and generating models and implementing algorithms. The LP2 linear and mixed integer programming package is also integrated to the system.

We demonstrate the use of MME first by generating a multi-period energy management model. Then we implement Benders' decomposition algorithm and use it for solving the model.

1 MME - A mathematical modelling environment

The Mathematical Modelling Environment MME is an experimental environment that is designed to support mathematical modelling and algorithm design. The user interacts with MME using MPL (Mathematical Programming Language). MPL is an interpretable, functional, object- oriented language, that can be used both for specifying models and for implementing algorithms.

The LP2 linear and mixed integer programming package (Lahdelma, 1985; Lahdelma, 1986; Nurminen, 1986; Ruuth et al., 1985) is tightly integrated to MME. LP2 can either be used as such for solving LP/MIP models, or as a subroutine package in more complex algorithms implemented in MPL.

MME does also provide a rule interpreter that can be used for symbolic processing of mathematical formulas. This is useful eg. in model generation from a high level specification.

The memory management in MME is automatic and transparent to the user. All data structures are dynamically allocated from a common pool. When some data is not anymore needed (the last reference to it is destroyed), the automatic garbage collector reclaims the allocated memory. The structure of MME is illustrated in Fig 2. (Lahdelma, 1988; Lahdelma, 1990).

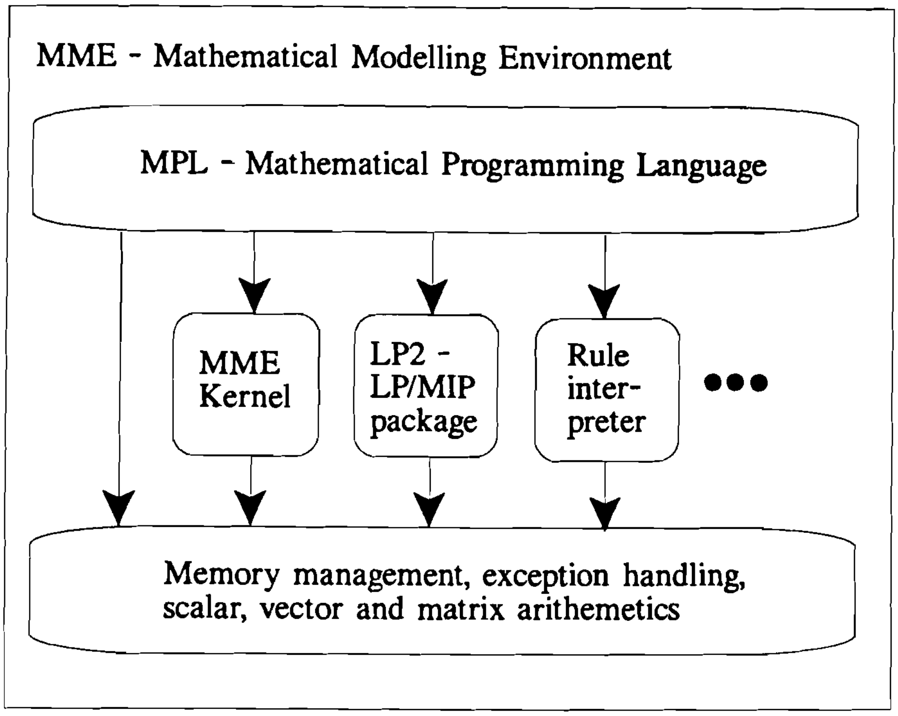

Fig. 1 The Mathematical Modelling Environment MME

1.1 The mathematical programming language MPL

MPL is a functional, internally Lisp-like language, which externally resembles most programming languages, eg. Pascal or C. MPL is both a programming language and the language that is used for modelling. MPL supports mathematical programming by providing:

- mathematical functions
- data structures for representing packed and unpacked vectors, matrices, LP- and MIP-models
- control structures and exception handling facilities
- automatic support for manipulating expressions symbolically

The syntax of MPL is very simple resembling the normal mathematical notation. The operators +, -, *, / and ^denote the five basic arithmetic operations with their natural precedence rules. Function calls are written as the function name immediately followed by the argument list in parenthesis. An example of a valid MPL expression is

```
1+x*4/max(a+5,0)
```

Arithmetics is generic, ie. the variable x of the previous example could be a scalar, a vector or a matrix. New data structures are introduced to MME in an object- oriented manner. For example complex number arithmetic could be implemented by specifying complex numbers as a class, and by defining the generic arithmetic operations as methods for that class.

1.2 MME in algorithm design

Prototyping with MME is very rapid, because it is an interpreted environment. An algorithm can manually typed in to the interpreter statement by statement. The interpreter will immediately evaluate and return the value of each statement (or rather each expression), and the user can verify that the intermediate results are correct. After this he can collect the statements into a new function, which can be immediately tested.

Test data can be typed in by hand, it may be stored in variables, or it may be accessed from the disk or a data base by a suitable function.

After prototyping and testing a new algorithm in MPL it should be evaluated, whether the performance is sufficient for a real implementation. If the performance must be improved, it is easy to reimplement only the time-critical functions using Pascal or some other compiled language. This requires modifying and recompiling parts of the MME sources in order to make the new routines and data structures visible as built- in functions and objects of MPL. MME has been designed so that this task is very easy and straightforward.

1.3 MME in modelling

MME provides two means for specifying and generating models. The MPL-language can be used as a declarative model specification language, from which a model is automatically generated. Models can also be manipulated in the MME work space by using scalar and vector expressions. It is eg. possible to decompose models into submodels, to merge models together or to modify existing models.

The integrated LP/MIP package (LP2) makes it unnecessary to generate a model on the disk and to start an auxiliar optimizer. LP/MIP models can be at any time optimized with a single function call. All optimization results are stored into the model-object and can be accessed from the environment.

2 Modelling a unit commitment problem in MME

2.1 A multi–period unit commitment problem

As a case we consider the power plant of a pulp and paper factory. Figure 2 shows the flow diagram of a simplified power plant with two boilers, a turbine, a generator and a high-and a low pressure steam header. The second boiler is assumed to operate on constant power. The Thermo Mechanical Pulping process (TMP) is also included to the diagram.

The multi-period unit commitment model of the power plant is based on the static models for successive time intervals. The decision variables are fuel flows of the boilers, steam flows, pulp mass flow (TMP) and electrical power generated by the turbine. Zero-one integer variables are used for representing the on-off states of the devices. The multi-period model is formed by combining the static models of different periods together with recursive equations for cumulating the level of the pulp container.

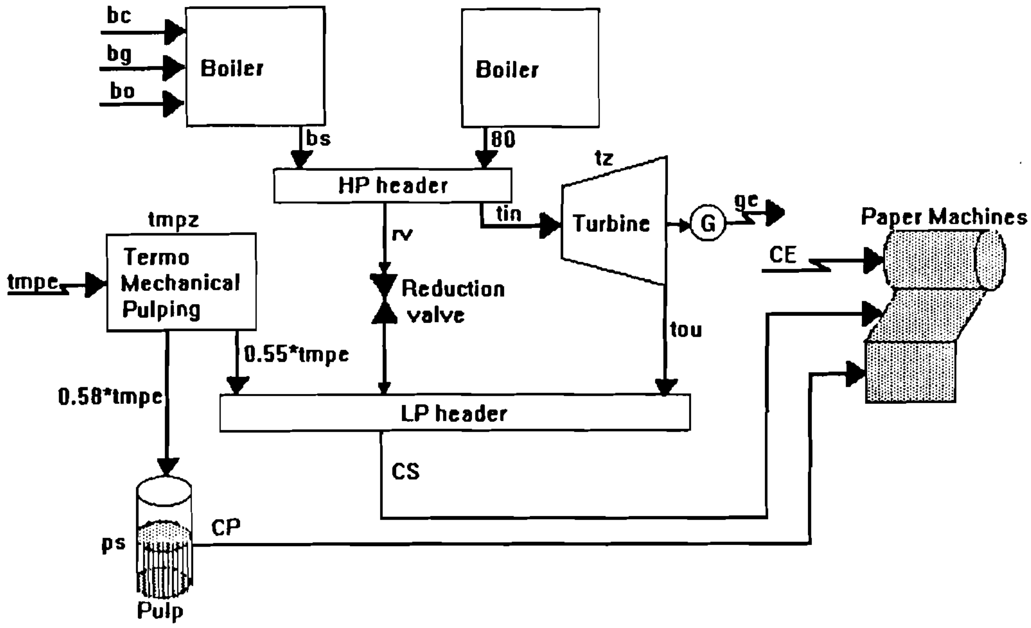

Fig. 2 Power plant with TMP

The cost of thermal and power generation is determined by the fuel costs and the efficiency of the boilers and turbines. Several kinds of fuel such as oil, natural gas and coal are used. The fluctuating electricity tariffs and power demand make it important to optimize when to operate the TMP and when to use the turbine and the other boiler.

The static model for one time period can be written as a mixed integer model as follows:

$$\min cx + dz$$

subject to

$$Ax + Bz \leq b \tag{1}$$
$$x \geq 0$$
$$z = \text{zero-one vector}$$

where

$c = (c_1, ..., c_n)$ cost coefficients for purchased fuel and power

$d = (d_1, ..., d_k)$ cost coefficients for status changes

$x = (x_1, ..., x_n)$ continuous decision variables (fuel and steam flows, power)

$z = (z_1, ..., z_k)$ zero-one variables representing the on-off states of devices

k number of devices = number of zero-one variables

m number of constraints

n number of continuous variables

A $m * n$ parameter matrix of model constraints due to mass and energy balances, boiler, turbine and valve characteristics, physical limits of devices and needs for thermal generation and electrical power.

B $m * k$ parameter matrix of model constraints due to the physical limits of devices.

b right hand side of the equation system including thermal and power requirements for the period considered.

When the static models for each period are connected together using the pulp stock equations, the resulting multi-period model is also a mixed integer model similar to (1).

2.2 MME – implementation of the model

In the following we give a detailed and complete example of how to specify and generate a multi-period unit commitment model with MME.

2.2.1 Parameters

Symbolic constants can be used for parametrizing the model. These may be either scalar or array constants. The multi-period unit commitment model requires the following parameters:

PERIODS The number of periods to generate.

CS[i] Consumption of 1.5 bar steam during each period (i= 1,...,PERIODS).

CE[i] Consumption of electricity at plant during each period.

CP[i] Consumption of pulp during each period.

PB[i] The price of bottom-tariff electricity during each period.

PM[i] The price of middle-tariff electricity during each period.

PP[i] The price of peak-tariff electricity during each period.

An assignment is used in MME to define a parameter. The number of periods is defined as:

```
PERIODS:= 4;            // number of periods
```

The steam and electricity consumption may be different during each period, therefore these quantities are defined as arrays of parameters:

```
CS[1]:= 120.7;          // consumption of 1.5 bar steam
CS[2]:= 105.5;
CS[3]:= 106.1;
CS[4]:= 105.7;
CS[5]:= 103.2;
CS[6]:= 114.6;

CE[1]:= 91.1;           // consumption of electricity
CE[2]:= 69.4;
CE[3]:= 69.7;
CE[4]:= 72.3;
CE[5]:= 73.8;
CE[6]:= 71.9;
```

The pulp consumption and electricity tariffs may also vary with time. Therefore these parameters are also arrays. However, in our sample model we use constant values for all periods. The for-loop of MME can be used for initializing the pulp consumption and electricity tariffs:

```
// consumption of pulp
for i:= 1 to PERIODS do
  CP[i]:= 10.0;
```

```
// electricity tariffs
for i:= 1 to PERIODS do
{
  PB[i]:= 65.0;          // bottom tariff
  PM[i]:= 126.0;         // medium tariff
  PP[i]:= 512.0;         // peak tariff
};
```

2.2.2 Decision variables

The decision variables of the multiperiod model are arrays over the periods i= 1,..,PERIODS. As a naming convention each variable is prefixed with an abbreviation of the device with which it is associated: t for turbine, b for boiler, e for external (purchased) electricity and tmp for thermo mechanical pulping.
Associated with some devices is a 0/1-variable representing the on/off-status of the device. The 0/1- variables are suffixed with the letter z.
By convention, all decision variables are written in lowercase. The decision variables are:

eb[i] Purchased bottom-tariff electricity.

em[i] Purchased middle-tariff electricity.

ep[i] Purchased peak-tariff electricity.

ps[i] The stock of pulp at the beginning of period i.

bz[i] Boiler status (0-1 variable).

bs[i] Steam power produced by the boiler.

bc[i] Consumption of coal in the boiler.

bg[i] Consumption of gas in the boiler.

bo[i] Consumption of oil in the boiler.

tz[i] Turbine status (0-1 variable).

tin[i] Input steam power for the turbine.

tou[i] Output steam power from the turbine.

ge[i] Electric power generated by the turbine.

tmpe[i] Electricity consumed in the TMP.

tmpz[i] TMP status (0-1 variable).

rv[i] Steam power injected through the reduction valve.

2.2.3 Objective function

In MME the symbol min or max precedes the linear object function to minimize or maximize. The sum-function of MME is used to form the object function as a sum of all the electricity and fuel costs over all periods:

```
// minimize fuel and electricity costs
min sum(i:= 1 to PERIODS,
        648.0*bc[i] + 1116.0*bg[i] + 1929.0*bo[i] + eb[i]*PB[i] +
        em[i]*PM[i] + ep[i]*PP[i]);
```

2.2.4 Boiler model

The boiler produces steam to the 100 bar header from three different fuels: coal, gas and oil. The fuel flows have upper limits and the output steam power is limited between 20 and 165 MW, when the boiler is on. The 0/1-variable bz is used to force the output to zero when the boiler is off. The for-loop is used for repeating the static boiler model for each period:

```
for i:= 1 to PERIODS do
{
  // minimum and maximum steam from boiler (when on)
  integer bz[i];
  bz[i]*20.0 <= bs[i];
  bs[i] <= bz[i]*165.0;
  bs[i] + bz[i]*2.5 = 22.84*bc[i] + 33.02*bg[i] + 36.95*bo[i];
  // Rawmaterial constraints in periods
  bc[i] <= 2.0;
  bg[i] <= 2.0;
  bo[i] <= 4.0;
};
```

2.2.5 Turbine & generator model

The backpressure turbine and generator are modelled as a unit. When the turbine is on, the generated power must be between 2 and 13 MW. The 0/1-variable tz is used for forcing the generated power to zero, when the turbine is off. The amount of generated electricity (ge) plus some constant loss (20.0) depends linearly on the amount of input steam (tin). The second equation states that energy is neither created nor destroyed.

```
for i:= 1 to PERIODS do
{
  integer tz[i];
  tz[i]*2.0 <= ge[i];
  ge[i] <= tz[i]*13.0;
  3.4*ge[i] + tz[i]*20.0 = tou[i];
```

```
  tou[i] + 1.008*ge[i] + tz[i]*1.2 = tin[i];
};
```

2.2.6 TMP model

The thermo mechanical pulping process consumes electricity and produces pulp mass and steam. Similarly to the boiler and turbine, the power of the TMP is limited between 10 and 28 MW when the system is on.
In addition, the level of the pulp stock must be accumulated from period to period by subtracting the consumption (parameter CP) and by adding the production. The level of the pulp stock must be maintained between 30 and 130 units.

```
ps[1]:= 100.0;              // the original stock of pulp
ps[PERIODS+1]:= 100.0;      // the final stock of pulp
for i:= 1 to PERIODS do
{
  // the balance of the pulp stock
  ps[i+1] = ps[i] + (1/1.7)*tmpe[i] - CP[i];
  // minimum and maximum levels of pulp stock
  30.0 <= ps[i];
  ps[i] <= 130.0;
  // minimum and maximun TMP power (when TMP is on)
  integer tmpz[i];
  10.0*tmpz[i] <= tmpe[i];
  tmpe[i] <= 28.0*tmpz[i];
};
```

2.2.7 Steam and electricity balances

The steam balances in the two headers state simply that the input steam must equal the output steam. Steam can be transferred from the high pressure header to the low pressure header through the reduction valve (rv).

```
for i:= 1 to PERIODS do
{
  bs[i] + 80 = tin[i] + rv[i];             // 100 bar steam balance
  tou[i] + rv[i] + 0.55*tmpe[i] = CS[i]; // 1.5 bar steam balance
};
```

The electricity balance of the factory states that the generated plus the purchased electricity must equal the consumption at the TMP and elsewere. The purchased electricity is modelled as a sum of the three different tariffs.

```
for i:= 1 to PERIODS do
{
  // electricity balance
  ge[i] + eb[i] + em[i] + ep[i] = tmpe[i] + CE[i];
```

```
  eb[i] <= 60.0;         // maximum bottom-tariff electricity
  em[i] <= 20.0;         // maximum medium-tariff electricity
  ep[i] <= 32.5;         // maximum peak-tariff electricity
};
```

3 Implementation of Benders' algorithm in MME

3.1 Benders' decomposition algorithm

J.F.Benders presented in 1962 an important decomposition algorithm (Taha, 1975), which can be used for solving problems of the following form:

$$\max z = cx + f(y)$$

subject to

$$\begin{aligned} Ax + G(y) &\leq b \\ x, y &\geq 0, \end{aligned} \tag{2}$$

where c is an n-vector, A an $m * n$-matrix and b an m-vector. The functions f and G may be non-linear. x and y are vectors formed by the decision variables. Benders' algorithm solves the problem by partitioning the model so that problems containing either x or y are solved in turn.

Applied to the multi-period unit commitment problem (1) f and G are linear i.e. f is a vector and G is a matrix. x consists all the continuous decision variables and y all the zero-one integer variables. The problem can then be written as

$$\max z = cx + fy$$

subject to

$$\begin{gathered} Ax + Gy \leq b \\ x \geq 0, \quad y = \text{zero-one vector} \end{gathered} \tag{3}$$

If y is fixed at given values, the problem reduces to the form

$$\max z(y) = fy + \max cx$$

subject to

$$\begin{gathered} Ax \leq b - Gy \\ x \geq 0, \quad y = \text{zero-one vector} \end{gathered} \tag{4}$$

Let $z^*(y)$ be the optimal objective value for the given y. The original problem can now be written as

$$\max z^*(y) \tag{5}$$

subject to

$$y = \text{ zero-one vector}$$

The dual of the lp-problem in (4) is

$$\min w(y) = u(b - Gy)$$

subject to

$$uA \geq c \tag{6}$$

$$u \geq 0,$$

where u is the dual vector.

Let $w^*(y)$ be the optimal objective value of (6) for the given y. It holds

$$z^*(y) = fy + w^*(y) \tag{7}$$

It is important that the feasible region of the dual problem (6) is independent of the choice of y. Let $u^k, k = 1, ..., K$, be the extreme points of the feasible region (need not to be known explicitly). Then the dual problem can be replaced by

$$w^*(y) = \min_k u^k(b - Gy) \tag{8}$$

Using (7) and (8) we can express the original problem (3) as

$$\max z = fy + \min_k u^k(b - Gy) \tag{9}$$

subject to

$$y \geq 0, \quad y = \text{zero-one vector}$$

Now consider the problem

$$\max z$$

subject to

$$z \leq fy + u^k(b - Gy), \quad k = 1, ..., r, \quad 1 \leq r \leq K \tag{10}$$

$$y \geq 0, \quad y = \text{zero-one vector}$$

When $r = K$ then (10) is the same as (9) and hence solves (3). The optimal objective values z^r to (10) form a non-increasing sequence $\overline{z}$ of upper bounds on the true optimum value z^*

$$z^* \leq \overline{z} \tag{11}$$

In turn, using the optimal solution y^r to (10) and solving the dual problem (6) we obtain a sequence of lower bounds $\underline{z}$ on z^*

$$\underline{z} \leq z^* \tag{12}$$

The termination of the procedure occurs when $\underline{z} = \overline{z}$.

The steps of the algorithm can be summarized as follows:

Step 0 Determine u^1, any feasible solution to the dual problem (6). If u^1 does not exist, stop; (3) has no feasible solution. Otherwise, set $r = 1$ and go to step 1.

Step 1 Solve (10) in z and y; that is

$$\max z$$

subject to

$$z \leq fy + u^k(b - Gy), \quad k = 1, ..., r \tag{13}$$

$$y \geq 0, \quad y = \text{zero-one vector.}$$

Let (z^r, y^r) be the optimum solution. Then set $\overline{z} = z^r$. Go to step 2.

Step 2 Solve the linear program (6) given $y = y^r$, that is

$$\min w = u(b - Gy^r)$$

subject to

$$uA \geq c \tag{14}$$

$$u \geq 0$$

Let u^{r+1} be the optimal solution. Then

$$\underline{z} = fy^r + u^{r+1}(b - gy^r) \tag{15}$$

Go to step 3

Step 3 If $\underline{z} = \overline{z}$, y^r is optimum; go to step 4 to determine optimum x. Otherwise, set $r = r + 1$ and go to the step 1.

Step 4 Let $y^* = y^r$. Then solve (4) given by

$$\max z(y^*) = fy^* + \max cx$$

subject to

$$fAx \leq b - Gy^* \tag{16}$$

$$x \geq 0$$

Let x^* be its optimum solution; then (x^*, y^*) gives the optimum solution to (3).

3.2 Implementation in MME

3.2.1 Data structures

The implementation of Benders' decomposition algorithm is based on the built-in data structures and subroutines of MME. In particular, MME provides data structures for representing linear- and mixed integer models as objects. Such an LP-object has the following accessible fields:

```
LP == class {
       m, n  :  INTEGER;              // Number of rows/columns
       a     :  MATRIX[ m,n ];        // Coefficient matrix
       b     :  VECTOR[ m ];          // Right hand side
       c     :  VECTOR[ n ];          // Object function coefficients
       intorg(j):  BOOLEAN;           // True when variable j is integer
       x,                             // Decision variables and slacks
       lbound,                        // Lower and upper bounds
       ubound:  VECTOR[ 1:n ];        // of variables and slacks
     };
```

LP-objects can be optimized as linear or mixed integer models using the built-in routines simplex(lp) and mip(lp), correspondingly. Sparse matrix techniques are used in storing the coefficient matrix and in the optimization algorithms.

3.2.2 Main routine of Benders' algorithm

The implementation of the Benders' algorithm uses the following three symbolic constants:

```
BIGM == 1.0E6;                        // A big number
EPSILON == 1.0E-6;                    // A small number
INFIN == 1.0E30;                      // Infinity
```

The main function of the Benders' algorithm receives a mixed integer model as parameter:

```
benders(model) ==                     // Solve a mip-model using
{                                     // Benders' decomposition.
//
//     Extract the components of the original MIP-model:
//     max c*x + f*y
//         a*x + g*y <= b
//
  b:= model.b;                        // Extract right hand side..
  a:= linear_a(model);                // Extract linear part of a.
  c:= linear_c(model);                // Extract linear part of c.
  f:= integer_c(model);               // Extract integer part of a.
  g:= integer_a(model);               // Extract integer part of c.

  dual:= make_dual(a, b, c);          // Form dual of linear part.
  simplex(dual);                      // Find a feasible solution.
  u:= dual.x;                         // Extract solution of dual.

  imodel:= make_imodel(g.n);          // Make initial integer model.

  z_lo:= -INFIN;                      // Initialize lower and
  z_up:= INFIN;                       // upper bounds of z.
```

```
//      Iterate by solving the integer and linear
//      models until the algorithm converges.
  while z_up-z_lo > EPSILON do
  {
    add_row(imodel,                  // Add new constraint to imodel:
            add_element(u*g-f, 1.0),  // z <= (f-u*g)*y + u*b
            inprod(u, b));
    mip(imodel);                     // Optimize integer model.
    y:= imodel.x;
    z_up:= imodel.z;                 // Update upper bound.
    dual.c:= g*y-b;                  // Set dual object function.
    simplex(dual);                   // Optimize linear model.
    u:= dual.x;                      // Extract solution of dual.
    z_lo:= max(z_lo,                 // Set new lower bound.
              inprod(f, y)-dual.z);
  };
  fix_integers(model, y);            // Fix integer variables and
  simplex(model);                    // solve original model.
};
```

3.2.3 Subroutines used by Benders' algorithm

The function make_dual forms and returns the dual problem for the linear part of the original model. An additional constraint is added to guarantee that the dual solution space is bounded.

```
make_dual(a, b, c) ==                 // Form dual model of
{                                     //      max c*x
  dual:= make_lp(transp(a), c, b);    //          a*x <= b
  for i:= 1 to dual.m do
    set_ge_constraint(dual, i);       // Make constraints >=.
  add_row(dual, vector_of(1, dual.n), BIGM);
  dual;                               // Return the model.
};
```

The function make_intmodel forms and returns the initially empty integer model. In fact this model contains one free continuous variable, the object function z.

```
make_imodel(n) ==                     // Form the initially empty
{                                     // integer model.
  imodel:= make_lp(make_matrix(0, n), // 0*n matrix.
               make_vector(0),        // Null right hand side.
               vector_of(0, n));      // Object function coefficients.
  for j:= 1 to imodel.n do
    imodel.intorg(j, true);           // Declare all variables integers.
  add_col(imodel, vector(1));         // Add z-variable with
  imodel.c[ imodel.n ]:= 1.0;         // 1.0 object function coeff.
```

```
  imodel.lbound[ cut.n ]:= -INFIN;        // No lower bound for z in model.
  imodel;                                 // Return the model.
};
```

The function linear_a extracts the linear part of the coefficient matrix. This means collecting all those columns j, for which intorg(j) is false into a matrix and then transponing the result. Similarly integer_a collects the integer part of the coefficient matrix:

```
linear_a(model) ==
  transp(collect_vector(j:= 1 to model.n when not model.intorg(j),
                        getcol(model, j)));
integer_a(model) ==
  transp(collect_vector(j:= 1 to model.n when model.intorg(j),
                        getcol(model, j)));
```

The functions linear_c and integer_c collect and return the object function coefficients of continuous and integer variables, respectively:

```
linear_c(model) ==
  collect_vector(j:= 1 to model.n when not model.intorg(j), model.c[ j ]);
integer_c(model) ==
  collect_vector(j:= 1 to model.n when model.intorg(j), model.c[ j ]);
```

The procedure set_ge_constraint changes the constraint type to 'greater than or equal' (>=) of the specified constraint. This is a built-in function not shown here.

The function vector_of forms and returns a vector of length n initialized with x:

```
vector_of(x, n) ==                      // Form a vector of length
  collect_vector(i:= 1 to n, x);        // n filled with x.
```

The procedure fix_integers fixes the integer decision variables by adjusting the lower and upper bounds:

```
fix_integers(model, y) ==               // Fix integer variables of
{                                       // original MIP-model to y.
  k:= 0;
  for j:= 1 to model.n do
    if model.intorg(j) then
    {
      k:= k+1;
      model.lbound[ j ]:= y[ k ];       // Modify lower and
      model.ubound[ j ]:= y[ k ];       // upper bounds of integers.
    };
};
```

4 Conclusions

We have demonstrated the use of the MME Mathematical Modelling Environment in modelling and algorithm design. MME provides a powerful modelling language, an automatic model generator, an interactive interpretable language for rapid prototyping and a fully integrated high performance LP/MIP optimization package (LP2).

MME is a very powerful tool in prototyping algorithms. The size of the MME implementation is comparable with a description of the algorithm in a textbook. It is also straight forward to upgrade the prototype into a more efficient one by reimplementing the most time-critical subroutines and data structures as built-in features in MME.

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An Interactive System for Modeling and Decision Support
- Shinayakana Systems Approach -

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Abstract

We have developed a decision support system for the systematic support to analysis and control of the man-environmental system. Although our main concern is the environmental problem, the support system has a universal application in data analysis, system structuring, statistical modeling and simulation. Besides the techniques for storage and retrieval of knowledge or numerical data, we have developed human-computer interfaces to acquire knowledge or judgment of the domain experts. After storing knowledge and numerical data, one can easily carry out the tasks from systems analysis to policy analysis which are usually quite difficult without the support system.

1 Introduction

We emphasize a soft systems approach which harmonizes the human judgment and the ability of computer. The main feature of this approach is the intervention of human beings at every phase of the problem solving. We name this approach *Shinayakana Systems Approach.* Shinayakana is an adjective in Japanese; it does not correspond to any English word. Its meaning is something between hard and soft, or it contains the meanings of both hard and soft. The main point is how to use methods or tools developed for well-defined systems when we have to manage ill-defined systems.

As a realization of Shinayakana Systems Approach, we will introduce a big experiment of developing a support system to predict environmental problems in the early 21st century in Japan and to find effective policy alternatives. This problem is obviously far beyond the capabilities of individual disciplines as well as individual researchers. To cope with such a problem, we should develop a computer system; its main feature is integrated utilization of the knowledge and judgment of experts in relevant fields.

Coupled with progress in systems science and methodology, advances in digital computer technology have produced great progress in the fields of decision support systems (Gruver et al., 1984; Sage, 1981; Wang and Courtney, 1984). Artificial intelligence technology has also had a great influence in this field (Fedorowicz and Williams, 1986; Sage and White, 1984; Sutherland, 1986; Zadeh, 1973). User-friendly man-machine interfaces and heuristic modeling techniques are useful tools for modeling large-scale and complex systems (Nakamori, 1989; Stanciulescu, 1986).

Tools to elicit (experience-based) intuitive or inner, personal knowledge or ideas are surveyed in (Lendaris, 1979). Elicited knowledge or ideas are combined to develop a group product of higher quality than otherwise usually available. A number of tools have been developed to assist in building and analyzing structural models (Lendaris, 1980; Norberg and Johnson, 1979; Warfield, 1974). Techniques applicable to machine construction of digraph maps are given in (Sugiyama et al., 1981; Warfield, 1977).

The purpose of developing the integrated decision support system is the systematic support of a series of tasks from systems analysis to policy analysis by the aid of these methodologies of systems science and by an integrated utilization of knowledge or judgment of experts together with the available numerical data. The system is designed to assist in model building interactively and intensively by the use of computer graphics and fuzzy set theory. Fuzzy set theory is used to express experts' knowledge and to incorporate it in model building. The system is used recursively to build environmental models for predicting future environmental conditions.

2 Varieties of systems approach

The role of systems science is to describe the relation between a system structure and its total attribute. It is the principle of scientific approach to decompose the object into elements and analize them. Systems science is therefore one of the disciplines of modern science. But unlike other analytical approaches, it puts the emphasis on the relationships between elements rather than elements themselves. Analysis and synthesis for the object with a small number of elements and weak relationships between them have been done in other disciplines as well. The objects of systems science are those which are complex and systemic. But, great difficulties are always encountered in treating complex objects. *Any scientific approach is very weak for complexity!*

Sharp criticisms to the traditional operations research or systems analysis are expressed nowadays by not a little number of researchers and practitioners. Their main argument is the following. The traditional operations research seeks for an objective explanation of an object by the mathematical language to obtain an optimal solution to the problem. But it is usually impossible to reduce the complexity to the one which can be modeled. In many cases, the difference between the reality and its model is unavoidable. *Any optimal solution is in danger of being born dead!*

Checkland (1981, 1983) points out the common paradigm between traditional operations research, systems engineering and systems analysis, and calls them *hard systems approaches.* According to him, the common paradigm is in the assumption of possibilities that we can recognize or identify the reality by observation and analyze it by the methods in natural science. Under this assumption, he continues, the subjectivity or perception of the observer cannot be treated, and there are limitations in treating the complexity. He then proposed the *soft systems thinking* which emphasizes the cycle of modification or learning of the relevant people's perception.

There are other criticisms to the traditional systems approaches and proposals of soft systems approaches. Ackoff (1979a, 1979b) expects that the death of operational research is unavoidable unless it gives up the *paradigm of predicting and preparing.* Beer (1979, 1981, 1985) advocates the organizational cybernetics to build viable systems models which can adapt themselves to new environments. In the case of Ulrich (1981, 1983), it is more severe; he criticizes that even those soft systems thinking and organizational cybernetics evade the essence of the problem. He insists that the concept of system should be used in the context of supporting *what to do* while, so far, it has been used for *how to do.*

It is a matter of common sense that no methodology is applicable to any situation and all methodologies including traditional ones are mutually complementary. Jackson and Key (1984) propose the complementary use of various kinds of systems approaches, classifying them from the points of view of systems and decision makers. After all, we arrive at a common conclusion that soft systems approaches can be used in structuring the problem situations and then traditional approaches can be used in solving the structured problems.

Mathematical systems theory and control theory are of course the members of systems approach. But they seem to be free from the above-mentioned criticism. The main reason is that their objects are engineering systems which have definite objectives and can be modeled. Is this true? Lewandowski and Wierzbicki (1988) observe that though the initial practical motivation underlying any part of mathematical systems theory is responsible for the basic concepts, the theory still remains a branch of applied mathematics, where the fundamental questions are those of syntactical correctness and completeness of mathematical language; questions of semantic importance are considered valid only in the sense of motivation.

It should be emphasized that the theories should not stop at mathematical idealizations because systems or control theory has physical objects in the real world. But we often face the gaps between theory and applications in testing our assumptions and methods on applications. We should recognize that systems theory and control theory are also facing a crisis. The rise of new types of control methods using fuzzy sets theory or intelligent engineering can be recognized as a critical demonstration toward the traditional control theory. Practitioners surely welcome these soft approaches as long as control theory remains at a mathematical idealization.

3 Shinayakana systems approach

Every real problem surrounding us has many factors which are interrelated with each other. The problem solving has been greatly indebted to the experts, so far, and this will be true in the future, too. However, the rapid development of computers and communication devices brings light and shade impacts on the problem solving. The increase of information enlarges or complicates the problems, and then makes the problem solving more difficult. This is rather a cynical view. But, in fact, a problem solving in the real world is far beyond individual competence. On the other hand, the clever utilization of information processing techniques greatly helps the problem solving. Every systems approach can play an active part in this direction.

The systems analyst provides problem solving tools to the users by analyzing, modeling or optimizing the problem. Here, the most important point is that the systems analyst should be a *coordinator* between tools and users. From this point of view, we would like to emphasize a soft approach which harmonizes the human judgment and the ability of the computer. The main feature of this approach lies in the *intervention* of human beings in every phase of the problem solving.

We name this approach the *Shinayakana Systems Approach.* Shinayakana is an adjective in Japanese; it may not correspond to any English word. The meaning is something between hard and soft, or it contains the meanings of both hard and soft. The main point is how to use methods or tools developed for well-defined systems when we have to manage ill-defined systems. The Shinayakana Systems Approach is something more than just a mathematical approach. It is an important attitude when we treat real problems. Let us imagine the tree of a willow; *better to bend than to break!*

The Shinayakana Systems Approach never makes light of mathematical methods and models, but limits them to playing the role of problem solving support only. We should always keep it in mind that any precise models of reality will never incorporate all human concerns. Therefore, an essential part of problem solving are issues of human-computer *interaction.*

Models should be built interactively, involving not only analysts but also domain experts and decision makers. Their perceptions of the problem, the relevant data and the model validity should be taken into account in model building so that the model can express their goals and preferences definitely and correctly. The interaction is essential at the decision stage as well, and it should be dynamical. We quote its reason from Lewandowski and Wierzbicki (1988) that human decision makers typically learn when using a decision support system, and we cannot assume that a decision maker comes to the system with fixed preferences.

In order to make good use of interaction, the support system must be *intelligent.* A problem solving support system should have a working area in a knowledge-based subsystem. Frameworks of dynamical knowledge utilization should be designed so that we can not only retrieve data or knowledge, but also acquire or modify them interactively. The mechanism of knowledge aquisition has two aspects: one is knowledge recognition from the knowledge base or decision support environment; the second is knowledge association by the communication with knowledge-based systems.

At the modeling stage, a model is identified partly and stepwise associated with mental models for the object and the knowledge in the support system. The registered knowledge for modeling support can be improved both in quality and quantity by the results of data analysis or by the users' perceptions. At the decision stage, the knowledge-based system should suggest the objective of optimization or the order of priority in constraints. New knowledge can be obtained by considering the gaps between the target and actual plan, or the feasibility and effects of the plan.

The third assertion of the Shinayakana Systems Approach is that the problem solving should be carried out in an *interdisciplinary* fashion. Here again we can quote the opinion in Lewandowski and Wierzbicki (1988) that the new factor in contemporary systems analysis is the realization that certain methodological principles and mathematical tools can be applied to systems in a multidisciplinary fashion.

In short, the features of the Shinayakana Systems Approach are three I's, that is, *Interactive, Intelligent* and *Interdisciplinary.* These are quite natural manners in solving modern problems. But we hardly fulfill natural things. How can we realize the three I's? The Shinayakana Systems Approach has references to the reseachers' attitude. They are summarized by three H's: *honesty* in modeling the reality, *humanity* in designing support systems, and *harmony* of the research group.

4 Integrated decision support system

We have developed an integrated knowledge-based support system for analysis, modeling and simulation of environmental systems. In this paper we will describe the support system as if it is oriented to environmental problems. But it is a problem-independent shell and therefore it has a universal application in data analysis, system structuring, statistical modeling and simulation. Numerical and knowledge data and developed models are stored in respective areas in the computer memory, and commonly accessible from any parts of the support system.

The analysis support part manages both knowledge and numerical data systematically, retrieves and displays these data immediately on request in an understandable form. It can carry out fuzzy inferences and simulate qualitative socio-economical trends. Prior to a detailed examination of the problem under study, this qualitative forecast can extract impotant factors and analyze behaviors and interactions of these factors. The basis of this part was developed at the National Institute for Environmental Studies, the Environment Agency of Japan, as a data base management system (Nishioka and Naito, 1984), and has been expanded its functions to manage knowledge data.

The modeling support part assists model building by using numerical data and mental images. It consists of several modern modeling techniques with highly interactive human-computer interfaces, and determines model structures and objectives of large, complex systems interactively and convincingly (Nakamori, 1989). The data analysis facility gives understandable graphical expressions of measurement data so that one can think of model structures before statistical modeling. The structural analysis facility is helpful for organizing one's thinking with respect to the system under study. The statistical analysis facility includes the stepwise linear modeling, hypothesis testing, residual analysis, partial and total tests to evaluate the model from the statistical points of view. This system has been improved to carry out fuzzy modeling based on both knowledge and numerical data.

The simulation support part predicts future environment by use of the models and knowledge data based on some assumed scenarios. Using qualitative fuzzy inference models, quantitative pattern models and statistical models appropriately, one can predict future environment with prescribed confidence, and examine new policy alternatives of a special problem. Many experts can participate in long-term simulation, looking at the outputs of computer which are displayed on a large screen.

Since our concern is environmental problems, the numerical data stored in the present data base are related to the socio-economical and environmental domains. The time series data of the last 20 years are classified into about 200 series of international data and more than 800 series of national data. The latter is further classified into 570 series of prefectural data and 250 series of municipal data. This data can be easily retrieved and displayed in the form of graphs such as maps or scatter diagrams. The numerical data base is also accessible from the modeling support part when developing statistical models.

The knowledge data base is a collection of expert knowledge and judgment, and a knowledge data consists of a proposition, its inference processes, evaluations, key words and information sources. A cause-effect relationship between a socio-economical change and an environmental effect is described briefly in a proposition. Relations such as the same, similar, inverse or cause-effect are used to obtain interconnections between propositions. Other information such as captions, indicators, trends, present values or certainty factors can be used to assist understanding of model structures.

In order to manage different types of models together, we have developed a framework of the model-based system which is a distributed cooperative type. We can add up-to-date submodels to the system whenever we develop them. Each submodel consists of three parts: the control, model and data parts. The control part contains information about interconnections with other submodels and controls inference or data processing. The model part consists of production rules expressed in the *if-then* form of the mathematical models or policy alternatives. The data part is the blackboard in which the temporary information or inferred results are stored.

We sometimes encounter the case where it is very difficult to obtain a global linear model for a nonlinear system such as an environmental system. To cope with such a case, we divide the data space into several fuzzy subspaces and in each fuzzy subspace we find a set of local input-output relations describing a complex system. The visual clustering supporter is designed to divide the data space with stepwise clustering. The fuzzy simulator is designed to set values of explanatory variables and to represent the model behavior.

5 Identification of environmental systems

The purpose of this section is to explain identification processes for environmental problems in Japan in the early part of the 21st century. Using the Delphi method, we have collected scenarios of future environmental trends and stored in the system. Then we have identified relations between socio-economic activities and environmental problems in the form of graghs by using such knowledge and the visual structuring supporter. To investigate the problem structure, we have simulated interaction among important factors by the linguistic fuzzy simulator.

5.1 How to collect experts' knowledge?

There are many complicated relations between socio-economic trends and environmental problems. There are socio-economic trends such as the coming of information intensive society, aging population, international trade and Tokyo Bay development. There are environmental problems such as traffic nuisance, water pollution, solid waste problem and city amenities. We expressed such complicated relations by an 80-to 200-word scenario. More than 200 such scenarios were prepared. To check the validity of the scenarios, we used the Delphi method which has been widely used in various fields to elicit experts' knowledge (Gordon and Helmer, 1964).

We asked experts to check whether each scenario was reasonable or not and to add a new scenario, if neccessary. We asked them again, showing the previous result. Nearly one hundred scenarios were approved and translated into knowkedge data.

5.2 What is the knowledge data?

To explain knowledge data, we take the scenario that describes how the increase in personal income par capita will affect traffic nuisance. We call the essence of the scenario the *proposition.* An example of a proposition is the following: *as income per capita increases, traffic nuisance will become worse.* Then we analyze the scenario and extract several events and their relations as follows: *increase in income* → *needs for a variety of goods* → *change of traffic service* → *increase in traffic volume* → *worsening of traffic nuisance.* Besides such relations, other items of information such as information sources and related data base numbers are stored as knowledge data.

5.3 How to identify system structures?

Several events and their relations are written in knowledge data. There are some other relations between events stored in different knowledge data. These events are linked together by the visual structuring supporter. The supporter can display these relations in the form of digraphs where vertices correspond to events and edges correspond to relations among these events. It is recognized empirically that drawings of the digraphs are useful as a visual aid to understand overall images of the structures of the complex systems. Sugiyama and others (1981) has developed a method for generating a visually understandable drawing of a hierarchy automatically by computer. We adopted their method and modified it so as to express *similar* and *inverse* relations.

The visual structuring supporter has several other functions besides drawing such a structure. We can open an *event* subwindow to find a detailed explanation of an event. Cause and effect of an event can be examined by the functions of the *upper* and *lower* search. The *layout* function draws the structure in a more compact form to look at the whole structure in one frame.

5.4 How to analyze system dynamics?

Though the process of simulating interaction between events is important in understanding the system structure, it is usually difficult to obtain sufficient numerical data to build statistical models. The linguistic fuzzy simulator has been developed to build prediction models using experts' knowledge and the method of fuzzy reasoning. The concet of fuzzy set theory was introduced by Zadeh (1973) to serve as a means of approximate characterization of phenomena that are too complex or too ill-defined to be described in precise terms. An approximate calculus of linguistic variables has been developed that could be used in a wide variety of practical applications (Kickert, 1979; Zadeh, 1975).

A linguistic model consists of several fuzzy rules such as

$$\begin{aligned} &\textit{rule } R^i: \quad \textit{if } x_1 \textit{ is } A_1^i,\ x_2 \textit{ is } A_2^i, \ldots, x_r \textit{ is } A_r^i, \\ &\qquad\qquad\quad \textit{then } x_j \textit{ is } A_j^k,\ j = r+1, r+2, \cdots, m, \end{aligned} \tag{1}$$

where $x_i (i = 1, 2, \cdots, r)$ and $x_j (j = r+1, r+2, \cdots, m)$ are input and output variables, respectively. $A_i^k (i = 1, 2, \cdots, m; k = 1, 2, \cdots, p)$ are fuzzy sets such as low, medium or high, and p is the number of rules. The linguistic fuzzy simulator performs fuzzy reasoning by referring to knowledge data or querying a user about fuzzy relations.

We can choose several important events from among those displayed on the computer. Such items of information as indicators, initial values and relations are assumed initially to be those stored in the knowledge base. These data are displayed in the *setting* subwindow. We can add, modify or delete these data interactively. We can assign a control function to each variable. We prepared four functions, a step, unit, linear and logarithmic function for control functions. When we point to a panel of each function, a subwindow is opened to set parameters. We can also change relations interactively with the aid of the *relation* subwindow. The result of fuzzy reasoning is shown in the *prediction* subwindow.

As an example, we simulated interaction among indicators such as information industry, fuel price and traffic nuisance. When fuel price rises steeply, traffic nuisance is improved slightly. As time goes on, it gets worse again with urbanization and an increase in service industries. We can analyze the environmental problelms by illustrating such interaction with the linguistic fuzzy simulator.

6 Development of prediction models

The inputs to the modeling support system (Nakamori, 1989) are a set of variables, measurement data and a binary relation, and the outputs are structural and statistical models. The data analysis part gives understandable graphical expressions of measurement data so that one can think of model structures before statistical modeling. We are continuously elaborating this part, referring to the exploratory data analysis.

The structural analysis part is helpful for organizing one's thinking with respect to the system under study. It also enables rapid access to the set of relationships in the statistical model. This part has been developed by implementing the interpretive structural modeling (Warfield, 1974). The statistical analysis part includes the stepwise linear modeling, hypothesis testing, residual analysis, partial and total tests to evaluate the model from statistical points of view.

6.1 How to build linear models?

Starting with the mental model, one can finally obtain a convincing model structure and a well-verified linear model. Let us denote the mental model by

$$M_m = (S_m, R_m) \tag{2}$$

where S_m is a set of variables considered as elements of the model, and R_m an initial version of cause-effect (binary) relation on $S_m \times S_m$. Note that the set S_m includes all input, state and output variables, and the relation R_m indicates their interconnections roughly. The set S_m can include time-delayed or nonlinear transformed variables to express dynamic or nonlinear relationships.

It is often difficult to make a clear-cut distinction between input, state and output variables for a large, complex system. This is the reason why we consider pairwise cause-effect relationships first. However, introduction of a cause-effect relation on the set of variables requires a craft work. We therefore ask domain experts the pairs of variables which are definitely irrelevant to obtain an initial version of cause-effect relation. We gradually validate the total model structure throughout the modeling sessions with the modeling support system.

The facility for structural modeling shows a graphical expression of the mental model M_m, a directed graph G_m denoted by

$$G_m = (S_m^*, R_m^*) \tag{3}$$

where the elements of S_m^* are identified as vertices and those of R_m^* arcs. Here, mutually dependent elements in S_m are condensed to one element, and the relation R_m^* is minimal in the sense that removal of any arc from G_m destroys the reachability present in the relation R_m. Actually we can see three types of directed graphs which represent the adjacency, reachability and skeleton relationships, respectively. We call the directed graph written in the above equation a structural model that represents the skeleton relationship.

In developing a structural model from the mental model, facilities for data analysis and structural analysis help one's thinking to confirm the model structure, which include: (a) graphical expressions of measurement data, (b) linearity checking by data statistics, (c) data screening and transformation, (d) the transitive embedding method (Warfield, 1976), and (e) graphical expressions of the relation. By the transitive embedding method, one can enter the relation into the computer with less confusion, assuming that the cause-effect relation considered is transitive. All the facilities are highly interactive so that one can easily modify the set of variables S_m, the relation R_m and the table of measurement data.

The next stage is linear modeling. Using the measurement data and referring to the transitive closure of the relation $\bar{R}_m$, which is called the reachability relation, one can develop a linear model consisting of a set of linear equations denoted by

$$M_l = (S_l, C_l) \tag{4}$$

where S_l is the set of variables selected to be included in the model, and C_l the set of coefficients of the linear model. The number of equations corresponds to that of vertices with incoming arcs in the directed graph representing the reachability relation. The relationships present in the reachability relation $\bar{R}_m$ are examined by the stepwise regression method.

Corresponding to non-zero coefficients of the linear model, a relation R_l is obtained and used for building a structural model denoted by

$$G_l = (S_l^*, R_l^*) \tag{5}$$

which is a visual version of the linear model. One can modify the directed graph G_l referring to model statistics and thinking of the model use. If any modification is done, the stage of linear modeling is repeated again. The statistical analysis part prepares useful methods from the classical regression analysis to evaluate the linear model.

There are two important facilities in the modeling support system to validate the linear model. One is scenario analysis and the other is linear programming. The aim of scenario analysis is the total test of the obtained model by predicting future behaviors of explained variables based on future scenarios of explanatory variables. The linear programming is regarded here as one of the simulators, by which one can see the model from the other side considered in scenario analysis.

6.2 How to build nonlinear models?

In model building of environmental systems, we often encounter the difficulty to obtain linear models. One can employ nonlinear transformations of measurement data such as the logarithm one before building linear models. However, that is also a very hard task because one cannot say exactly which variable affects which one in the environmental system. We adopt the fuzzy modeling (Sugeno and Kang, 1988) to express nonlinear relationships, by which we divide the data space into several fuzzy subspaces and in each fuzzy subspace we build a linear model using the modeling support system.

According to its original definition (Sugeno and Kang, 1988), a fuzzy model is described as follows. Consider a system with multi-inputs, say $x_1, x_2, \cdots, x_q$, and one-output, say y. A fuzzy model consists of several fuzzy rules such as

$$\begin{aligned} &\textit{rule } R^i: \quad \textit{if } x_1 \textit{ is } A_1^i, \ x_2 \textit{ is } A_2^i, \ \ldots, \ x_q \textit{ is } A_q^i, \\ &\qquad\qquad \textit{then } y^i = c_0^i + c_1^i x_1 + c_2^i x_2 + \cdots + c_q^i x_q, \end{aligned} \tag{6}$$

where A_j^i's are fuzzy sets, y^i the output of the rule R^i, and c_j^i's are coefficients of the linear model.

Given input values x_{1*}, x_{2*}, ..., x_{q*}, the prediction of output y_* is calculated by

$$y_* = \frac{\sum_{i=1}^p w^i y_*^i}{\sum_{i=1}^p w^i}, \qquad w^i = \prod_{j=1}^q A_j^i(x_{j*}), \tag{7}$$

where p denotes the number of rules, $A_j^i(x_{j*})$ the membership grade of x_{j*} to the fuzzy set A_j^i, and y_*^i the prediction by the rule R^i.

The most important feature of a fuzzy model is that it behaves as a nonlinear model though it consists of a set of linear equations. The main tasks in the fuzzy modeling are: (i) division of the data space into fuzzy subspaces, (ii) identification of membership functions, and (iii) statistical modeling with selection of explanatory variables. Here, the data space can be identified with the $(q+1)$-dimensional Euclidean space $\boldsymbol{R}^{q+1}$ in the present case. We use the subset of input-output measurement data corresponding to the subspace to build the linear model in a rule.

A fuzzy subspace corresponds to the product set defined by, for example, $A_1^i \times A_2^i \times \cdots \times A_q^i \times A_y^i$, where A_y^i is the fuzzy set related to the output y. Hence, the number of fuzzy subspaces is the same as that of rules. Note that every fuzzy set A_j^i should not be empty, but can be identical to its support set; which means that some variables can disappear from premises of some rules. Needless to say, some coefficients in the linear model can be zero. We omit to explain these points in this paper, (see Nakamori and Sawaragi, 1989).

The above mentioned tasks are mutually dependent, and very difficult if we would follow the traditional analytical approach. One can introduce some criteria in carrying out those tasks. But, the final result heavily depends on the capability and experience of the individual modeler. This is the reason why we have developed an interactive and intelligent environment in model building.

The fuzzy modeling is a nice idea to obtain nonlinear relationships by acquiring knowledge and judgment of domain experts. However, we sometimes find fuzzy subspaces in which we can hardly obtain linear models because of the nature of data. To cope with such a case, we propose a hybrid fuzzy modeling which develops a pattern model or linear model for each explained variable in each subspace. Moreover, we build pattern models in the subspaces with no data, which may occur in the future.

7 Conclusion

We proposed the *Shinayakana Systems Approach* in systems analysis. In designing and implementing the systems for modeling and decision support, it requires three I's, that is, the support system should be designed in an *interactive*, *intelligent* and *interdisciplinary* fashion. As a realization of the Shinayakana Systems Approach, we introduced a big experiment of developing an integrated support system for environmental planning. The developed system has user-friendly human-computer interfaces to elicit intuitive or inner, personal knowledge or idears about the problem under study.

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Multimedia Database for Decision Support Based on the Hypertext Concept

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Abstract

Multimedia database is investigated as effective technology in decision support. First an object-oriented hypertext system is considered for modeling multimedia database, and a prototype called Dennou-Zukue which runs on a personal computer is introduced. Then problems of the hypertext system are considered, and a new approach utilizing relational database besides hypertext is proposed. Some application systems developed in the proposed way are also introduced.

1 Introduction

Great advancement in computer hardware performance has made it possible to develop more user-friendly computer software. In particular, conventional computers are primarily intended to handle text information, but now multimedia systems which support more familiar media like images, graphics and sound are becoming the mainstream area of development in the computer field. Especially in the field of decision support it is very effective to utilize such multimedia systems, because the first step of decision making to get some solution is collecting varieties of data which is not necessarily in the form of text.

But there are some serious problems to be solved. The first involves what type of data structure to employ. That is, text can be represented as strings of characters, but multimedia data composed of varieties of data such as images and sounds are too complex in structure to be modeled in such a simple way. Further, when attempting to compile a database, the tubular scheme used in the conventional relational database is not suitable with such complex data.

Another problem involves design of the human interface. How users access a database having such a complicated structure is a crucial concern, as is how the system provides users with information containing completely different forms of data, such as characters, images and sounds.

As one approach to these problems, an attempt was made to utilize a hypertext system modeled with an object-oriented scheme. A prototype hypertext system named "Dennou-Zukue" which runs on a personal computer was developed, and investigation was made to reinforce the database functions to construct practical application systems.

2 Modeling in Hypertext

2.1 Concept of Hypertext

The idea of hypertext was introduced by Ted Nelson as early as the 1960s (Nelson, 1968). With the recent advances in computer technology, practical systems have been made available such as "Intermedia" by Brown University and "HyperCard" by Apple Computer (Conklin, 1987; Fiderio et al. 1988).

Hypertext has a network structure consisting of nodes and links. The nodes are actual pieces of information to which users have direct access, and the links connect the nodes representing the referential relationship of the information. When a person considers something or carries out a specific task, he often refers to related information. Hypertext has a structure similar to this human thinking process and is suitable for modeling systems which support human intellectual activities.

Figure 1 shows a simple example of hypertext. The information under the "contents" is displayed in several headings. When a person refers to the contents, he will also immediately refer to any associated information. For example, in design, he may frequently refer to information in "manual" or "proceedings". The hypertext system controls such links as shown in Figure 1 with arrows, allowing the user to trace the links and easily retrieve information for reference.

In Figure 2 the data management schemes conventionally used in computers are compared with hypertext system. It shows that the hypertext system achieves a more complex and flexible structure.

2.2 Object–oriented Data Model

An object–oriented data model was studied as a model on which to base hypertext. The formulation in Smalltalk–80 (Xerox, 1981) developed by Xerox is well–known as an object oriented data model. In Smalltalk–80 all data are handled as objects belonging to "classes" of the proper data types, and operations on objects are executed by sending messages to the objects. It is believed that an object–oriented database using this approach is suitable for handling multimedia data, and many studies have been made in the fields of computer–aided design and office automation.

In this paper a model is introduced in which the hypertext links are handled as objects as well as the pieces of multimedia information such as text, graphics, images and sounds. Figure 3 shows a simple hypertext data model. In this example, classes such as document, text, image, sound and link are defined, and "aDocument" and "anImage" denoted in the figure are individual objects which belong to the respective classes.

A document object has a set of objects including text, image and sound as components in its data structure. It also possesses link objects connecting documents.

The advantages described below result from handling a link as an object.

(1) The links in the database can be controlled as a set of objects belonging to one class.

(2) Various attributes can be given to the link for future expansion of functions.

For example, in Figure 3, each link is designed to permit the groups of users to make references. This attribute means the link setting can be varied according to the user, or security functions can be provided.

3 Actual Examples Implemented by "Dennou–Zukue"

A hypertext system named "Dennou-Zukue" was developed on the personal computer, (Takahashi, 1990) and supports multimedia nodes consisting of text, images, graphics and sounds. An outline of this system is described below.

The first system prototype was developed using Smalltalk on a personal computer. Consequently, in the computer it was possible to apply the data model as shown in the previous section. Later, the system was revised and remade in the C language to boost its operating speed, but in principle it had the same design.

In this system, a link is affixed to an area in the document just as are the document components such as graphics and images. Pointing to an area with a mouse, a user can retrieve and display the linked document. The system can indicate each object in the document by giving it a common name of message, "draw" for example, which is defined for classes like text and image. However, because sounds cannot be identified visually in the document, the system has been designed so that sounds can be generated by pointing to an area with the mouse, just as with the links. Figure 4 shows an example of the image displayed by this system.

4 Expansion of Database Functions

4.1 Structural Links and Referential links

The hypertext system described in the previous sections is, in principle, designed so that all links are manually set by the users. Such a system has the following advantages:

(1) The structure is flexible, permitting construction of the system best suited to a specific user.

(2) The system can support tasks which do not have standardized procedures.

However, trial run and evaluation also revealed that the system has the following disadvantages:

(1) The system is not necessarily effective for tasks with routine procedures.

(2) The system is less effective at retrieval operations than conventional databases.

For example, when a standardized procedure is performed, documents with a specific format are often prepared, and such documents are often linked with fixed information. With the basic hypertext function alone, the user must modify the fixed link for himself every time he conducts his business. In actual working, however, information is updated frequently, and the user must replace the link himself in order to have continual access to up-to-date information.

To make the system practical, the system must be able to execute standardized routines and must eliminate troublesome procedures.

One possible solution is to divide the links into two types: structural links and referential links. Structural links are links which occur in routine tasks and are set automatically by the system, whereas referential links are conventional links which the user can set optionally.

4.2 Utilization of relational database

Thus when developing practical application systems, we combined hypertext with a conventional relational database having powerful retrieval functions.

For standardized tasks, one node in the hypertext contains certain specified items only. Consequently, a row in the relational data table can be associated with one node and the links serve to connect these rows. Figure 5 shows an example of hypertext executing a routine task in a customer support system.

Structural links of this type can be set when the system is designed, determining which node conditions should be connected with which links. When the user traces a link, the nodes that meet the conditions are retrieved for the user. In the example shown in Figure 5, the routine format to manage delivered products is linked with the drawing and with the formats which record the adjustment history. In this case, structural link conditions such as "link the delivered product management format to the adjustment record format with the same serial number" should be set.

In this way of system design, we have developed the actual application systems as listed below.

(1) Contract Document Database in Research and Development Division (Morita et al. 1990)

(2) Customer Support System for Weldind Equipment and Robot (Takahashi et al. 1990)

(3) Company Guidance System (Araya et al. 1990)

(4) Prototype of Decision Support Network in Research and Development Division

We hope many other systems will also start operating in the future.

5 Conclusion

In this paper a multimedia hypertext system based on the object-oriented model has been proposed for a database for decision support, and a prototype hypertext system called "Dennou-Zukue" has been introduced. And it has been also shown that hypertext systems enhanced with the functions of relational database are available for the development of practical application systems.

Thus it is expected that multimedia processing technology will make a significant contribution to advancing the highly information–oriented society and can provide some solution to the many problems in the field of decision support systems.

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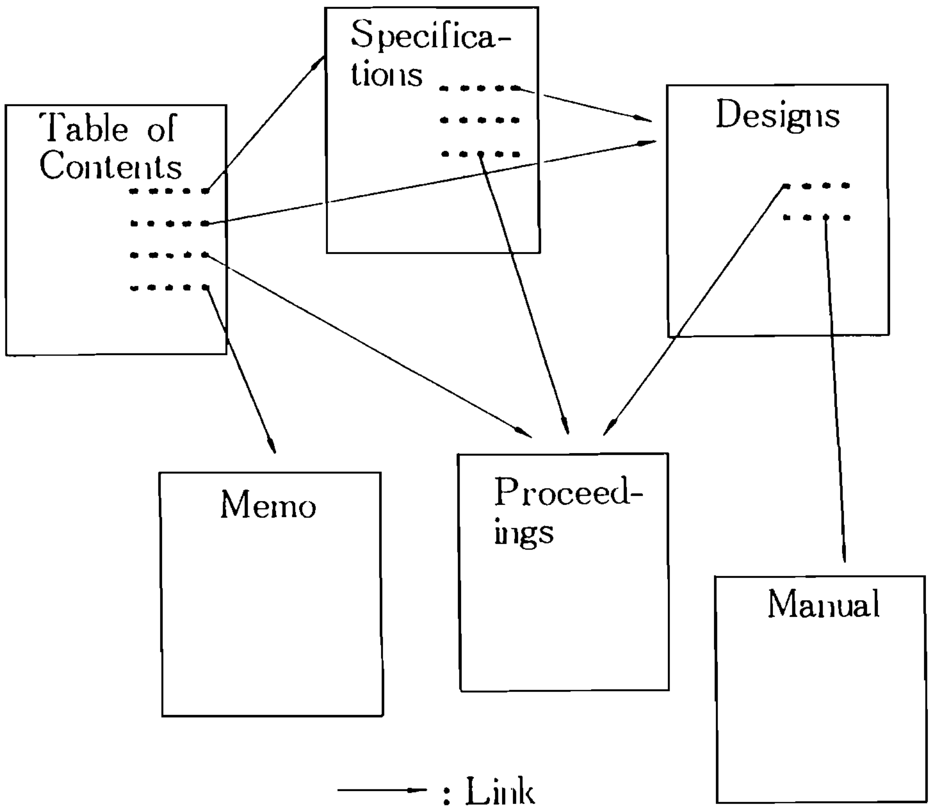
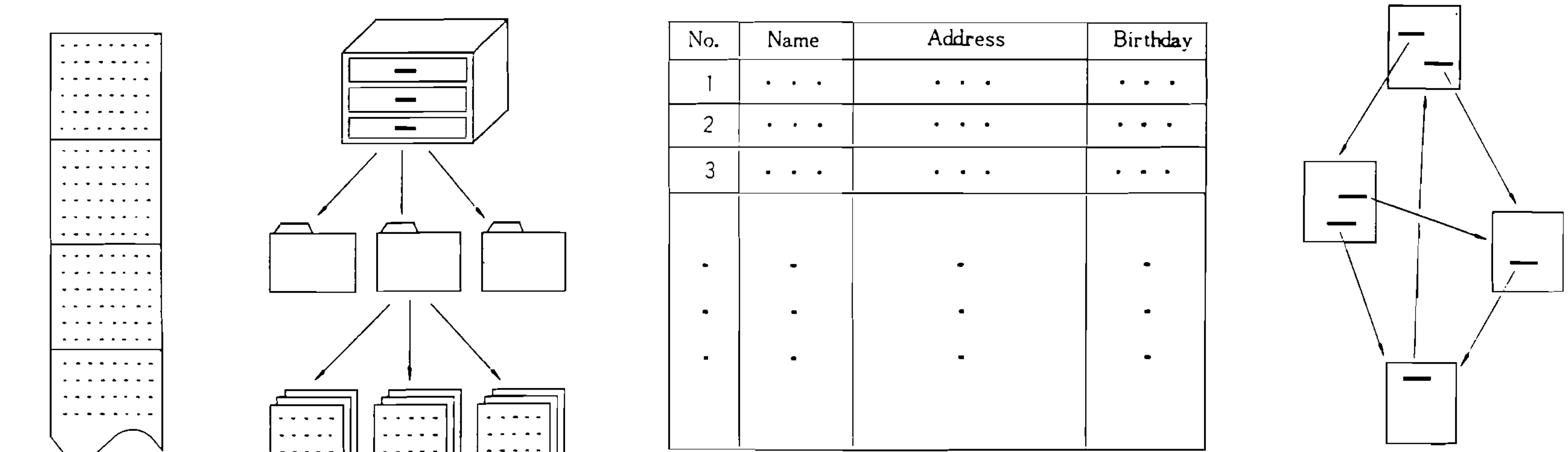


Fig. 1 Example of Hypertext



(a) Linear data such as word processor documents

(b) Hierarchical file system

(c) Conventional database system (Relational database)

(d) Hypertext system

Fig. 2 Comparison of Information Management Schemes

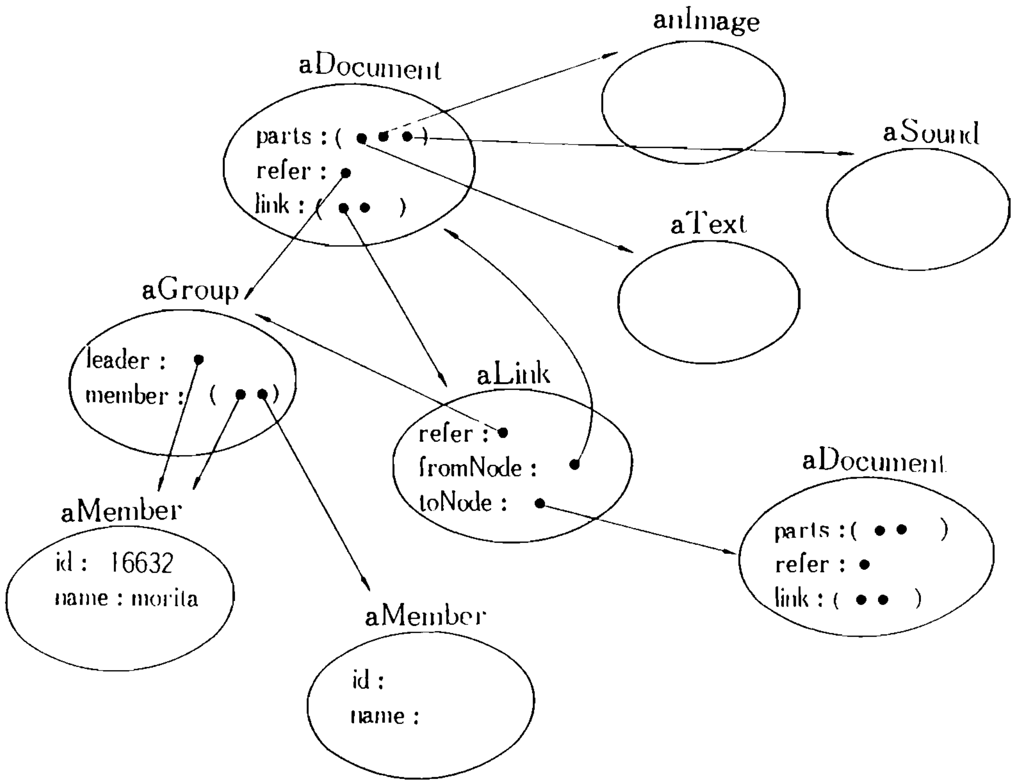


Fig. 3 Hypertext Data Model

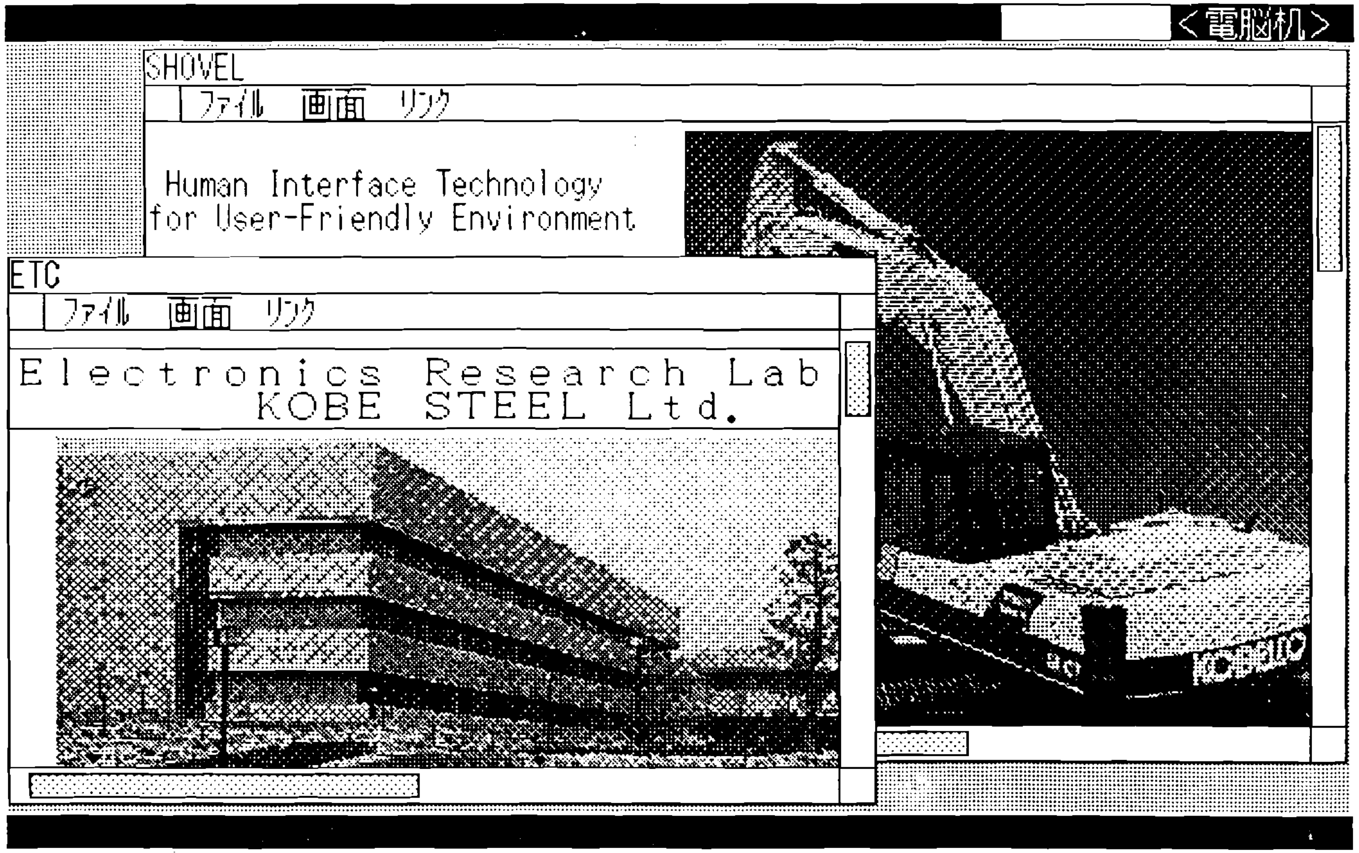


Fig. 4 Example of Displayed Image

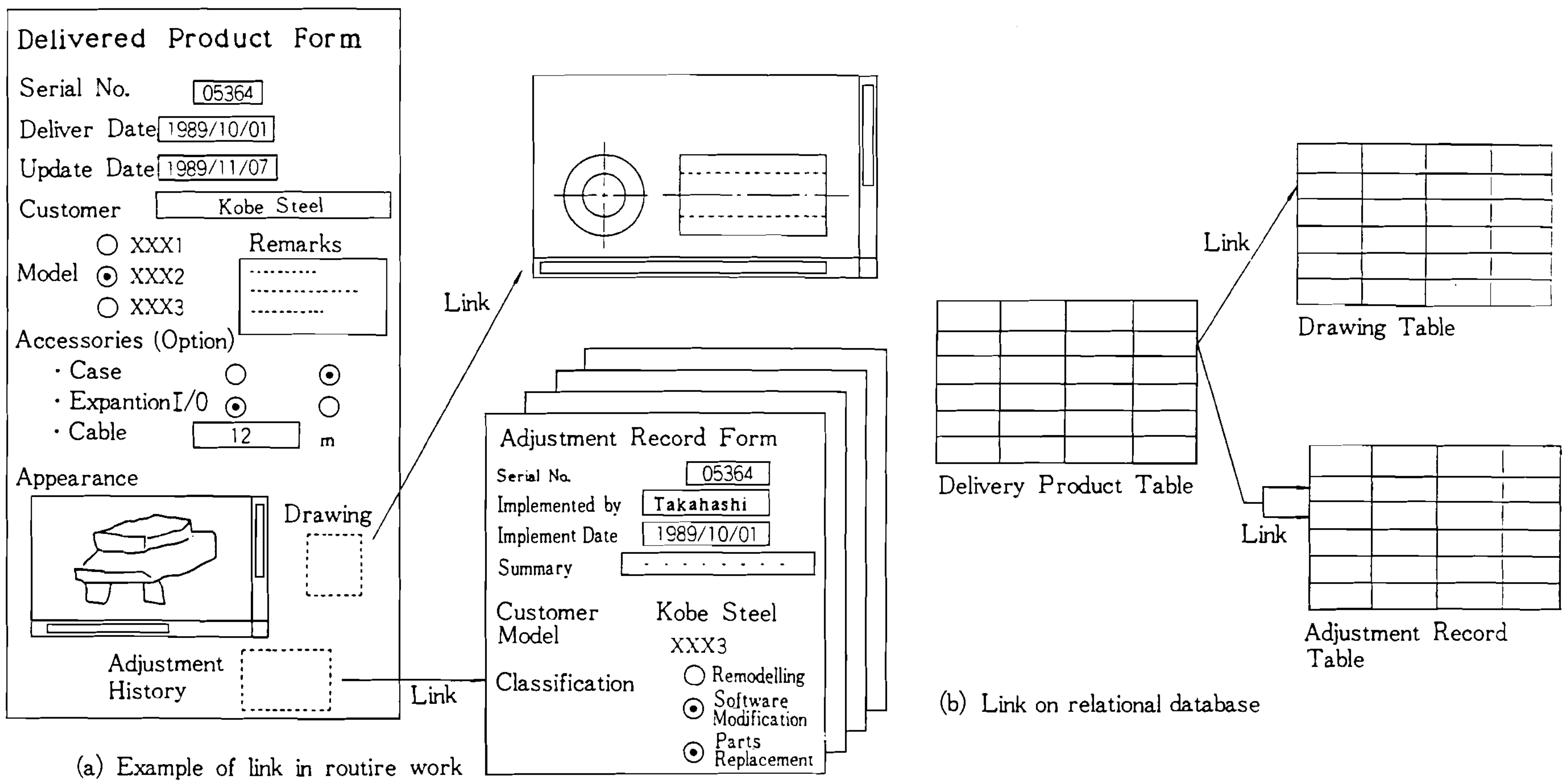


Fig. 5 Structural Links

An Application of Satisficing Trade-off Method to a String Selection Problem in Steel Manufacturing

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Abstract

For the last decade, the methodology for multiple criteria decision making has been sophisticated from a view point of practical applications as well as theoretical aspects. Now, it seems to be the time to apply the methods to real problems. In this paper, we shall report a trial of applying the satisficing trade-off method, developed by one of the authors, to a scheduling problem of lot formation in steel manufacturing.

1 Introduction

Among many kinds of interactive multiobjective programming methods, the aspiration level techniques seem most promising from a practical viewpoint, because their process is very simple and they are very easy to understand for decision makers. Above all, it is the most prominent feature that those methods do not require the consistency of judgment for decision makers, because the judgment of decision makers usually varies throughout the decision process due to the change of available information. However, the effectiveness of the methods can be proved only by application to real fields. In this paper, we report our trial of application of the satisficing trade-off method, which was developed by one of the authors (Nakayama, 1984), to a certain string selection problem, which is the most important scheduling problem in steel manufacturing process. To begin with, we review the satisficing trade-off method briefly. Our multi-objective programming problem can be formulated as follows:

$$\text{(P)} \qquad \text{Maximize} \quad f(x) = (f_1(x), f_2(x), \ldots, f_r(x)) \quad \text{over } x \in X.$$

The constraint set X may be represented by

$$g_j(x) \leq 0, \quad j = 1, \ldots, m,$$

and/or a subset of R^n itself. The algorithm of the satisficing trade-off method is summarized as follows:

Step 1. (setting the ideal point) The ideal point $f^* = (f_1^*, \ldots, f_r^*)$ is set, where f_i^* is large enough, for example, $f_i^* = \max\{f_i(x) | x \in X\}$. This value is fixed throughout the following process.

Step 2. (setting the aspiration level) The level $\bar{f}_i^k$ of each objective function f_i at the k-th iteration as asked to the decision maker. Here $\bar{f}_i^k$ should be set in such a way that $\bar{f}_i^k < f_i^*$. Set $k = 1$ for the first iteration.

Step 3. (weighting and finding a Pareto solution by the Min-Max method)

Set

$$w_i^k = \frac{1}{f_i^* - \bar{f}_i^k} \tag{1.1}$$

and solve the Min-Max problem

$$\min_{x \in X} \max_{1 \leq i \leq r} w_i^k |f_i^* - f_i(x)| \tag{1.2}$$

or equivalently

$$\begin{aligned} &\text{Minimize } z \\ &\text{subject to} \quad w_i^k(f_i^* - f_i(x)) \leq z, \quad i = 1, \ldots, r, \quad x \in X \end{aligned} \tag{1.3}$$

Let x^k be a solution of (1.3).

Step 4. (trade-off) Based on the value of $f(x^k)$, the decision maker classifies the criteria into three groups, namely,

(i) the class of criteria which he wants to improve more,

(ii) the class of criteria which he may agree to relaxing,

(iii) the class of criteria which he accepts as they are.

The index set of each class is represented by I_I^k, I_R^k, I_A^k, respectively. If $I_I^k = \emptyset$, then stop the procedure. Otherwise, the decision maker is asked his new acceptable level of criteria $\bar{f}_i^{k+1} = \bar{f}_i^k + \Delta f_i$ for the class of I_I^k and I_R^k. For $i \in I_A^k$, set $\bar{f}_i^k = f_i(x^k)$. At this stage, we can use the assignment of sacrifice for f_j $(j \in I_R)$ which is automatically set in the equal proportion to $\tilde{\lambda}_i w_i$, namely, by

$$\Delta f_j = \frac{-1}{N\tilde{\lambda}_j w_j} \sum_{i \in I_i} \tilde{\lambda}_i w_i \Delta f_i$$

where N is the number of elements of the set I_R. By doing this, in cases that there are a large number of criteria, the burden of the decision maker can be decreased so much. Of course, if the decision maker does not agree with this quota Δf_j laid down automatically, he can modify them in a manual way. Go back to Step 3.

2 String selection problem in steel manufacturing processes

Steel products are manufactured through the following processes: Firstly pig iron is made from iron ores in blast furnaces. Blast furnaces perform two main functions; reduction (removing oxygen from iron ore) and smelting (releasing the iron from its ores). Next, pure oxygen is blown onto pig iron in the basic oxygen furnace which is called a converter; the oxygen combines with impurities, converting the iron to steel. The characteristics of this steel making process is a batch type process. Certain amount of pig iron, therefore, is poured into a converter, of which capacity is about 250–300 metric tons, and it is made into steel at one time. Then slabs or billets are made from molten steel through continuous casting machines. And finally at rolling mills, slabs or billets are formed into final steel products; sheets, pipes, plates, wire rods, bars, wheel and so on.

A string selection problem relates to steel making and casting processes among above steel manufacturing processes. The main feature of steel industry is make–to-order manufacturing. A steel company receives various kinds of orders from customers. Customers' specification (size, strength, toughness etc.) and the delivery due date are different order by order. In steel companies, manufacturing specifications, that is, chemical ingredients ratio, process temperature and so on, are determined according to customers' specification. In addition, the amount of each order has been being smaller and smaller recently. Under the above circumstances, orders with the same (or almost the same) manufacturing specification are gathered, and then manufacturing lots are formed so as to match with the capacity of batch type process (steel making). One unit which matches with one batch process is called a 'heat'. In case there exist only a few orders with the same manufacturing specification, a heat may consist of both orders and non–orders. Non–order part in a heat will be assigned to other orders in a few days. It is, therefore, very important to cast heats with high order ratio in terms of daily production cost.

From the view point of quality and production efficiency, furthermore, it is most desirable to cast consecutively as many heats with the same manufacturing specification as possible. This casting sequence is called a 'string', and the index of heat sequence is defined as the number of heats in a string.

Heat formation and string formation planning are main parts of lot formation operations in manufacturing, and these formation plannings are conducted at the process planning section. A string selection planning is to select the most appropriate strings among many alternatives for a week production schedule under consideration of order ratio, delivery due date and the number of heats in a string.

3 Problem formulation

In lot–formation–operations in manufacturing, customer orders with the same specification are combined into a heat, then several heats with the same or almost the same manufacturing specification are combined into a string. The i-th string, therefore, has the following items;

C_i = the number of heats contained within the i-th string,

W_i^S = the weight of the i-th string,

W_i^O = the total weight of customers' orders included in the i-th string,

W_i^Y = the total weight of non–customers' orders included in the i-th string,

W_i^K = the total weight of imminent customers' orders included in the i-th string,

a_i = imminent degree for casting the i-th string,

$H_i(or\ R_i, S_i, T_i, F_i)$ = the number of heats with special specification $H(or\ R, S, T, F)$ included in the i-th string.

The important criteria of the string selection problem are the order ratio, the casting ratio of imminent orders and the index of heat sequence. The order ratio of a string is defined as the proportion of orders' weight per unit weight of the string. The casting ratio of imminent orders is defined as the proportion of imminent orders' weight per unit weight of the string. A string consists of several heats which are minimum units of casting. The index of heat sequence is defined as the number of heats in a string. Let Z_i be $0-1$ integer variable for selection of the i-th string;

$$Z_i = \begin{cases} 1 & \text{the i-th string selected} \\ 0 & \text{the i-th string not selected} \end{cases}$$

Objective functions are denoted as follows;

(1) Total order ratio:

$$f_1(z) = \frac{\sum W_i^O Z_i}{\sum W_i^S Z_i} \quad \rightarrow \text{ max},$$

(2) Total casting ratio of imminent orders:

$$f_2(z) = \frac{\sum a_i W_i^K Z_i}{\sum W_i^S Z_i} \quad \rightarrow \text{ max},$$

(3) Total index of heat sequence:

$$f_3(z) = \frac{\sum C_i Z_i}{\sum Z_i} \quad \rightarrow \text{ max},$$

The followings are imposed as constraints:

(4) Constraint on the total number of heats which are cast in a week:

$$|\sum C_i Z_i - C| \leq \epsilon$$

where C ($>$ 0) is the target number of heats to be cast in a week, and ϵ ($\geq$ 0) is an allowance of C.

(5) Constraints on the total number of heats with special manufacturing specification to be cast in a week:

$$\begin{aligned} HH_l \leq & \sum H_i Z_i & \leq HH_u, \\ RR_l \leq & \sum R_i Z_i & \leq RR_u, \\ SS_l \leq & \sum S_i Z_i & \leq SS_u, \\ TT_l \leq & \sum T_i Z_i & \leq TT_u, \\ FF_l \leq & \sum F_i Z_i & \leq FF_u, \end{aligned}$$

where HH_l, RR_l, SS_l, TT_l and FF_l are lower limits of total number of heats with special manufacturing specification to be cast in a week, and HH_u, RR_u, SS_u, TT_u and FF_u are upper limits of them respectively.

4 An experimental result

The satisficing trade-off method is applied to an actual string selection problem in steel manufacturing factory. Since the auxiliary Min-Max problem is of a linear 0-1 mixed integer programming, we used the interior path method based on linear programming solution (Hillier, 1969; Ibaraki et al., 1974). One of experimental results is shown in Table 1. This table shows the aspiration level and the corresponding computational results of three evaluation items (order ratio, casting index of imminent orders and index of heat sequence) at each computational iteration. The greater the values of these evaluation items, the more desirable it is. In actual string selection problem, it is easy to set the order of importance among three evaluation items previous to the string selection although it is difficult to decide the degree of importance among them. The aspiration levels are, therefore, set as the following. At the first iteration step, the aspiration level of one evaluation item (i.e., index of heat sequence) is set according to the order of importance among evaluation items. Then the aspiration level of new evaluation item is added and that of the old one is modified under consideration of the iteration result. The third setting of aspiration level is conducted in the same manner with the second setting.

Table 1. Computational Results in Each Iteration

Iteration	Total Order Ratio		Total Casting Index of Imminent Orders		Total Index of Heat Sequence	
	A. L. (%)	Results (%)	A. L. $\times 10^5$	Results $\times 10^5$	A. L. (–)	Results (–)
1	—	82.5	—	7.9	3.0	3.0
2	—	75.6	8.5	8.9	2.9	2.9
3	85.0	90.9	8.0	8.0	2.9	2.9
4	85.0	87.4	8.1	8.1	2.9	2.9

A.L.: Aspiration Level

In the iteration step 1, only the aspiration level for the index of heat sequence is set. In this case, the value of the index of heat sequence is the upper limit of this problem. In the iteration step 2, the aspiration level of casting index of imminent orders is added and that of heat sequence is relaxed from 3.0 to 2.9. In the iteration step 3, the aspiration level of order ratio is added and that of casting ratio of imminent orders is relaxed from 8.5×10^5 to 8.0×10^5 because the value of order ratio in the iteration step 2 is too small. The results of iteration step 3 is acceptable for decision maker. In the iteration step 4, however, the aspiration level of casting index of imminent orders is raised from 8.0×10^5 to 8.1×10^5. But the result of iteration step 4 is not acceptable because the value of order ratio decreases too much in compensation for the increase of casting index of imminent orders. Hence, the results of iteration step 3 is adopted.

5 Concluding remarks

The satisficing trade-off method was applied to an actual string selection problem in a steel making process, although it was an experimental trial. As a result, It has been observed that the method can be applied effectively to such a kind of scheduling problem.

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A Preference-Preserving Projection Technique for MCDM

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1 Introduction

In decision support for multicriteria problems, a considerable amount of information available on decision alternatives must be conveyed to the user. The simultaneous confrontation with several outcome dimensions, especially in numerical form, easily leads to information overload and thus reduces decision quality.

It has been frequently suggested in the literature that graphical representations of information will facilitate holistic interpretation of the data available. Although the use of graphics in general is sometimes over-valued and their effect has to be studied in more detail (DeSanctis, 1984), graphical interfaces for MCDM techniques have gained considerable popularity (e.g. Korhonen and Laakso, 1986).

Graphical methods for displaying multicriterial data can roughly be classified into two groups. The first consists of approaches that intend to provide a holistic, but detailed image of all criteria for single or few alternatives. In many MCDM software packages, standard graphical displays like bar graphs are used to represent discrete alternatives or current solutions to multiobjective problems (e.g. in VIG: Korhonen, 1987). When several alternatives are to be compared, more comprehensive visualizations like 'Chernoff faces' (Chernoff, 1973) or Korhonen's 'Harmonious Houses' (Korhonen, 1989) are used. Since these techniques provide a detailed representation of all criteria, their use is limited to a few decision alternatives.

In contrast, the second group is aimed at the representation of a larger set of alternatives. This means that information cannot be displayed in full detail for all criteria, but information has to be condensed. This can be achieved by projecting the data points from high dimensional criteria space to some lower dimensional (usually 2- or 3-dimensional) projection space. Several researchers have suggested to use techniques from statistical principal component analysis (PCA) for this purpose. Lehert and de Wasch (1983) used graphical displays from principal component analysis to match different types of alternatives (products) to different types of decision makers (consumers). In the GAIA software package (Mareschal and Brans, 1988), principal component analysis is used to represent different flows of the PROMETHEE multicriteria method. A similar approach for comparing discrete alternatives generated through reference point optimization is taken in the BIPLOT technique (Lewandowski and Granat, 1989).

All these approaches generate a projection matrix via principal component analysis directly from the data matrix or, as in the case of GAIA, intermediate results which have the same dimension. The resulting graphical representation of alternatives provides only information about data values of alternatives, but gives no indication of preference or indifference relations that might hold between alternatives. For example, it is not possible to represent indifference curves, even for very simple preference structures, in projection space.

In this paper, we discuss extensions to these projection techniques which visualize information both on data values and preference relations. The paper proceeds as follows: In section two, we extend the standard principal component analysis approach to incorporate preference information on simple linear utility functions. Section three combines this approach and standard PCA and section four illustrates the technique by a numerical example. In section five, we outline possible extensions to the case of nonlinear utility functions and identify other topics for further work.

2 A Preference-Representing Projection

2.1 A Review of Basic Principal Component Analysis

In this section, we give only a brief summary to principal component analysis (PCA). The reader is referred to standard textbooks on multivariate statistics (e.g. Bamberg and Baur, 1984) for further reference.

The goal of PCA is to provide a compact representation of multidimensional data through a small number of so-called 'factors'. Let us consider a data matrix $\mathbf{Z}$ of N observations (alternatives) in K attributes (criteria). $\mathbf{Z}$ is assumed to be standardized so that the mean of each attribute (column) is zero and its variance one. We can represent the entire matrix $\mathbf{Z}$ by M general and K specific factors as

$$z_{nk} = \sum_{m=1}^{M} a_{km} f_{nm} + d_k u_n \tag{1}$$

where z_{nk} is the value of alternative n in attribute k, the a_{km} are the *factor weights* for factor m and attribute k, the f_{nm} are the *factor values* for alternative n in factor m and d_k and u_n are the weight and value for a specific factor for attribute k. A compact representation is obtained by keeping M small.

In matrix notation, we can rewrite equation (1) as

$$\mathbf{Z} = \mathbf{F}\mathbf{A}' + \mathbf{U}\mathbf{D}' \tag{2}$$

The goal of principal component analysis is to explain as much of the variance in each attribute of $\mathbf{Z}$ as possible through the factors. Ideally, we would like to obtain

$$\mathbf{Z} = \mathbf{F}\mathbf{A}' \tag{3}$$

Ignoring the specific factors, the fundamental theorem of principal component analysis states that the correlation matrix $\mathbf{R}$ of data $\mathbf{Z}$ can be represented as:

$$\mathbf{R} = \mathbf{A}\mathbf{A}' \tag{4}$$

and that matrix **A** is composed of the M largest eigenvectors of **R**.

For the purpose of this paper, we are interested in obtaining the representation of **Z** in lower dimensional projection spaces provided by matrix **F** of factor values. Once we have determined **A**, we can obtain **F** as follows:

$$\begin{aligned} \mathbf{Z} &= \mathbf{F}\mathbf{A}' \\ \mathbf{Z}\mathbf{A} &= \mathbf{F}\mathbf{A}'\mathbf{A} \\ \mathbf{Z}\mathbf{A}(\mathbf{A}'\mathbf{A})^{-1} &= \mathbf{F} \end{aligned} \tag{5}$$

We thus define a projection matrix **P** as:

$$\mathbf{P} = \mathbf{A}(\mathbf{A}'\mathbf{A})^{-1} \tag{6}$$

The criteria can also be represented in projection space by projecting the unit vectors. This makes it possible to provide the user a comprehensive representation of how well each alternative performs in each criterion. Examples of such representations are given in section four.

2.2 Preference-Preserving Projection

When a two-dimensional graphical representation of problem data is intended to support the user's decision process, basic concepts of the user's preference structure should also have an easily observable, intuitive graphical representation. For example, indifference could be represented by a set of indifference curves where all points between which the user is indifferent lie on one curve.

For simplicity, we will assume in this section that the user's preference system can be represented by a linear utility function of the form

$$U(\mathbf{x}_n) = \sum_{k=1}^{K} w_k x_{nk} \tag{7}$$

where $\mathbf{x}_n$ is a suitably scaled attribute vector describing decision alternative n, w_k is the decision weight given to attribute k and x_{nk} is the k-th component of $\mathbf{x}_n$. Vector $\mathbf{x}_n$ will also be interpreted as the n-th row of a decision matrix **X**.

Alternatives between which the user is indifferent, i.e. for which $U(\mathbf{x}_n)$ is equal to some constant c, lie on a hyperplane in K-dimensional space. However, for arbitrary projection matrices **P**, these points can be projected anywhere in the graphical representation.

The indifference hyperplanes of K-dimensional space will, however, be projected onto straight indifference lines in two-dimensional space if the projection is orthogonal to the hyperplanes. This is the case, for example, if the weight vector is used as one column in **P**.

2.2.1 Non-Standardized Data in PCA

The usual approach of PCA as outlined above is based on standardized data, while weights refer to a specific scaling of the data. We therefore have to extend the PCA approach to non-standardized data. The indifference relation implied by (7) is preserved when a constant term is added to any column of the decision matrix **X**. We can therefore still assume that **X** is normalized to zero mean in all columns. But (7) is not invariant to the multiplication of columns by a constant term, so the column variances will be different from one. We denote the standard deviation of attribute k by σ_k and define the matrix S as:

$$\mathbf{S} = \begin{bmatrix} \sigma_1 & & 0 \\ & \ddots & \\ 0 & & \sigma_K \end{bmatrix} \tag{8}$$

Assuming that the factor values have a standard deviation of one, we obtain the following general model:

$$\mathbf{X} = \mathbf{FA'S} + \mathbf{UD'S} \tag{9}$$

It can easily be shown that matrix **A** still consists of the eigenvectors of **R**. But the factor values and the projection matrix are now determined differently from above:

$$\begin{aligned} \mathbf{Z} &= \mathbf{FA'S} \\ \mathbf{ZS^{-1}A} &= \mathbf{FA'A} \\ \mathbf{F} &= \mathbf{ZS^{-1}A(A'A)^{-1}} \\ \mathbf{P} &= \mathbf{S^{-1}A(A'A)^{-1}} \end{aligned} \tag{10}$$

The interpretation of equation (10) is obvious: instead of first standardizing the data matrix to $\mathbf{ZS}^{-1}$ and then obtaining the projection matrix through post-multiplying by $\mathbf{P} = \mathbf{A}(\mathbf{A}'\mathbf{A})^{-1}$, the standardizing process is now incorporated into the projection matrix **P**.

2.2.2 Weights and Residual Data

From now on, we will only consider projections into two dimensional space, which are all we need for representing data on a computer screen. Since we project into R^2, the projection matrix is a $k \times 2$ matrix. Our goal is to represent the preference relation implied by (7) by straight indifference lines. We will indicate a projection matrix generating indifference lines in R^2 by **Q**.

A direct way to generate indifference lines is to incorporate the weights themselves as one column of **Q**. We therefore obtain the following structure for **Q**:

$$\mathbf{Q} = \begin{bmatrix} w_1 & q_{12} \\ \vdots & \vdots \\ w_K & q_{K2} \end{bmatrix} \tag{11}$$

To determine the second column of Q, we note that the factorial representation of **Z** as **FA'** can be decomposed for the two-dimensional case as follows:

$$\mathbf{FA}' = \begin{bmatrix} f_{11} & f_{12} \\ \vdots & \vdots \\ f_{N1} & f_{N2} \end{bmatrix} \cdot \begin{bmatrix} a_{11} & \dots & a_{1K} \\ a_{21} & \dots & a_{2K} \end{bmatrix} =$$

$$= \begin{bmatrix} f_{11} \\ \vdots \\ f_{N1} \end{bmatrix} \cdot [a_{11} \dots a_{1K}] + \begin{bmatrix} f_{12} \\ \vdots \\ f_{N2} \end{bmatrix} \cdot [a_{21} \dots a_{2K}] = \tag{12}$$

$$= \mathbf{F}_{(1)}\mathbf{A}'_{(1)} + \mathbf{F}_{(2)}\mathbf{A}'_{(2)}$$

Therefore, we can obtain the *residual data matrix* $\mathbf{Z}_{(1)}$ containing the data not explained by the first column of $\mathbf{Q}$ as:

$$\begin{aligned} \mathbf{Z} &= \mathbf{FA'S} \\ \mathbf{Z} &= \mathbf{F}_{(1)}\mathbf{A}'_{(1)} + \mathbf{F}_{(2)}\mathbf{A}'_{(2)} \\ \mathbf{Z} - \mathbf{F}_{(1)}\mathbf{A}'_{(1)} &= \mathbf{F}_{(2)}\mathbf{A}'_{(2)} \\ \mathbf{Z}_{(1)} &= \mathbf{F}_{(2)}\mathbf{A}'_{(2)} \end{aligned} \tag{13}$$

All columns of $\mathbf{Z}_{(1)}$ have zero mean, but a variance different from one. We therefore have to apply equation (10) and obtain for the second column of $\mathbf{Q}$:

$$\mathbf{Q}_{(2)} = \mathbf{S}_{(2)}^{-1}\mathbf{A}_{(2)}(\mathbf{A}_{(2)}'\mathbf{A}_{(2)})^{-1} \tag{14}$$

where $\mathbf{A}_{(2)}$ is determined from the correlation matrix of $\mathbf{Z}_{(1)}$ as above.

In order to calculate $\mathbf{Z}_{(1)}$, we need both the factor values $\mathbf{F}_{(1)}$ and the factor loads $\mathbf{A}_{(1)}$. The factor values are the projections of the data points and therefore correspond to the utility scores of alternatives. But the factor loads need to be determined. This problem is exactly the opposite of the usual problem of PCA: while one is usually mainly interested in factor loads and, after computing factor loads, computes factor values according to equation (5), we now want to determine factor loads from given factor values.

Assuming that the first factor provides a sufficient approximation of the data, we can directly derive $\mathbf{A}_{(1)}$ from $\mathbf{F}_{(1)}$ as:

$$\begin{aligned} \mathbf{Z} &\approx \mathbf{F}_{(1)}\mathbf{A}'_{(1)}\mathbf{S} \\ \mathbf{ZS}^{-1} &= \mathbf{F}_{(1)}\mathbf{A}'_{(1)} \\ \mathbf{F}_{(1)}'\mathbf{ZS}^{-1} &= \mathbf{F}'_{(1)}\mathbf{F}_{(1)}\mathbf{A}'_{(1)} \\ \mathbf{A}'_{(1)} &= (\mathbf{F}'_{(1)}\mathbf{F}_{(1)})^{-1}\mathbf{F}_{(1)}'\mathbf{ZS}^{-1} \end{aligned} \tag{15}$$

Alternatively, we could try to find an "optimal" $\mathbf{A}_{(1)}$ which provides a best approximation to $\mathbf{Z}_{(1)}$ in least squares sense by minimizing a residual matrix $\mathbf{E}$. Solving the regression problem

$$\mathbf{ZS}^{-1} = \mathbf{F}_{(1)}\mathbf{A}'_{(1)} + \mathbf{E} \tag{16}$$

leads to normal equations of the form

$$\mathbf{A}'_{(1)} = (\mathbf{F}'\mathbf{F})^{-1}\mathbf{F}'\mathbf{ZS}^{-1} \tag{17}$$

and thus exactly to the same result as above.

Limited experience with an experimental system under development indicates that factor loads $\mathbf{A}_{(2)}$, obtained through this process, are very close to the largest eigenvector of the original correlation matrix and thus to the first column of $\mathbf{P}$. To utilize this fact in combined graphical representations as developed in the next section, the weights can be used as second column and the residual factor projection coefficients as the first column of $\mathbf{Q}$.

3 Combined Projection

Both representations, the one using $\mathbf{P}$ based on the standard PCA approach and the one incorporating the weights and using matrix $\mathbf{Q}$, have certain advantages and disadvantages. The projection with $\mathbf{Q}$ allows the user to visualize indifference and preference relations between alternatives along one axis. Furthermore, it can easily be seen that the projection of unit vectors will represent the corresponding criteria weights on the same axis as the scores.

On the other hand, providing utility values on one axis leaves only one dimension to represent all other aspects of the data and experience so far shows that the utility scores used in matrix $\mathbf{Q}$ will explain only a small amount of data variance. As can be seen from figures 4 and 4 in section four, the projection onto the two principal factors provides a more powerful representation of criteria values of alternatives than the preference preserving projection.

It is, however, possible to generate a combined representation by forming a linear combination of both projection matrices as:

$$\mathbf{T} = \lambda\mathbf{P} + (1-\lambda)\mathbf{Q} \tag{18}$$

By changing the weight λ in this linear combination, the user can move freely between the two forms of projection. For example, the user may start with $\lambda = 0$ and progressively 'untangle' the data values by increasing λ until a sufficiently clear picture of criteria values appears without completely destroying the preference information from the $\mathbf{Q}$-projection.

As soon as λ is increased above 0, the projection is no longer strictly orthogonal to the indifference hyperplanes. Theoretically, each indifference hyperplane is therefore projected onto the entire R^2-space. Since the data range in practical applications is finite, the projection of possible data values onto R^2 will form a finite indifference region, which can be calculated and plotted for each alternative.

We assume that data values in attribute k fall within a lower bound $\underline{x_k}$ and an upper bound $\overline{x_k}$. The boundaries of a region in R^2 containing all possible points of indifference to an alternative x_n can be determined by solving the following two parametric linear programs:

$$\begin{aligned}&\text{maximize}\, \mathbf{T}^{(1)}\mathbf{y} + \theta\mathbf{T}^{(2)}\mathbf{y}\\ &\text{s.t.}\\ &\mathbf{y}\mathbf{w} = \mathbf{x}_n\mathbf{w}\\ &\underline{x_k} \leq y_k \leq \overline{x_k}\end{aligned} \tag{19}$$

and

$$\begin{aligned}&\text{minimize}\, \mathbf{T}^{(1)}\mathbf{y} + \theta\mathbf{T}^{(2)}\mathbf{y}\\ &\text{s.t.}\\ &\mathbf{y}\mathbf{w} = \mathbf{x}_n\mathbf{w}\\ &\underline{x_k} \leq y_k \leq \overline{x_k}\end{aligned} \tag{20}$$

where $\mathbf{T}^{(1)}$ and $\mathbf{T}^{(2)}$ are the first and second column of $\mathbf{T}$. The first constraint of these linear programs considers only attribute vectors indifferent to $\mathbf{x}_n$, the remaining constraints take into account the possible data range. By parametric variation of θ from $-\infty$ to $+\infty$, the first program generates the upper half and the second program the lower half of the boundary.

4 Numerical Example

Data for the following numerical example is taken from the literature (Mareschal and Brans, 1988) to allow for easy comparison with existing approaches. Table 1 contains data on 20 different cars used in this example.

Normalizing and taking into account the optimization direction of criteria leads to the partial utility values. The correlation between the utility values of the six criteria is shown in table 2.

Figures 4 and 4 show the resulting projections for values of $\lambda = 0.1$ and $\lambda = 0.9$ respectively. These figures also indicate the indifference regions determined for one alternative, the Polo 1100. This alternative is marked in the graph by a box, while the other alternatives are indicated by x's. Figure 4 clearly shows that in the standard PCA approach, indifferent alternatives can be projected onto a widely dispersed area, while in figure 4, the indifference region is reduced to a small band. For $\lambda = 0$, the region would be reduced to a straight line.

In interpreting the values on the x-axes of these graphs, one should note that utility scores for alternatives are normalized to zero mean in each criterion, so some alternatives have negative scores. As all alternatives are shifted to the left by the same constant amount, their relative positions still give a full representation of preferences in the orthogonal projection. Furthermore, since criteria are projected using unit vectors, their values on the x-axis reflect the original weights.

Car	Price	Power	Tax	Speed	Consumption 1	Consumption 2
2 CV	28.3	29.0	3.00	115.	6.80	5.40
Visa 11	44.3	50.0	5.00	140.	6.30	4.80
205 GR	44.8	50.0	4.00	142.	5.80	4.30
R4	29.8	34.0	4.00	110.	6.30	5.60
R5 GTL	44.9	45.0	4.00	137.	6.30	4.50
Samba GL	43.0	50.0	4.00	143.	5.80	4.60
Fiesta 1.1	33.3	53.0	4.00	145.	8.80	6.00
Corsa 1.25	38.0	55.0	5.00	152.	8.70	5.10
Polo 1100	43.4	50.0	4.00	146.	9.20	6.10
MG Metro	47.5	73.0	6.00	163.	9.00	5.50
Fiat 126	21.6	24.0	3.00	105.	7.30	6.10
Fiat Panda	34.3	45.0	4.00	140.	7.10	4.80
A112 Elite	37.8	48.0	5.00	137.	7.80	5.80
Innocenti	36.4	53.0	5.00	145.	7.20	5.50
Honda Civic	44.6	60.0	5.00	145.	8.00	5.20
Mazda 323	44.9	55.0	5.00	160.	8.40	5.60
Colt	46.3	70.0	6.00	165.	7.60	5.90
Tercel	45.3	65.0	6.00	155.	8.80	5.60
Skoda 120	26.2	58.0	7.00	139.	8.30	6.40
Lada 2105	30.6	65.0	7.00	147.	9.50	7.50

Table 1: Criteria values of alternatives

	Price	Power	Tax	Speed	Cons. 1	Cons. 2
Price	1.000	-0.597	0.191	-0.735	-0.011	-0.480
Power	-0.597	1.000	-0.829	0.917	-0.546	-0.203
Tax	0.191	-0.829	1.000	-0.626	0.549	0.488
Speed	-0.735	0.917	-0.626	1.000	-0.478	-0.006
Cons. 1	-0.011	-0.546	0.549	-0.478	1.000	0.709
Cons. 2	-0.480	-0.203	0.488	-0.006	0.709	1.000

Table 2: Correlation matrix

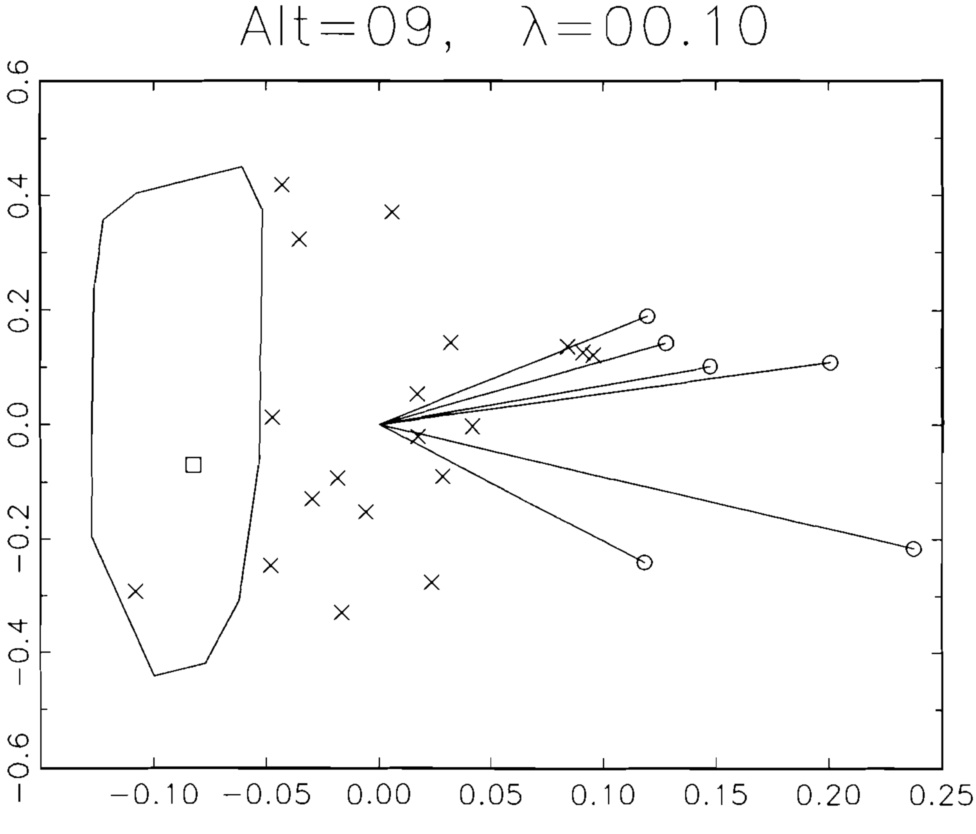

Figure 1: Projection with high weight for orthogonal matrix

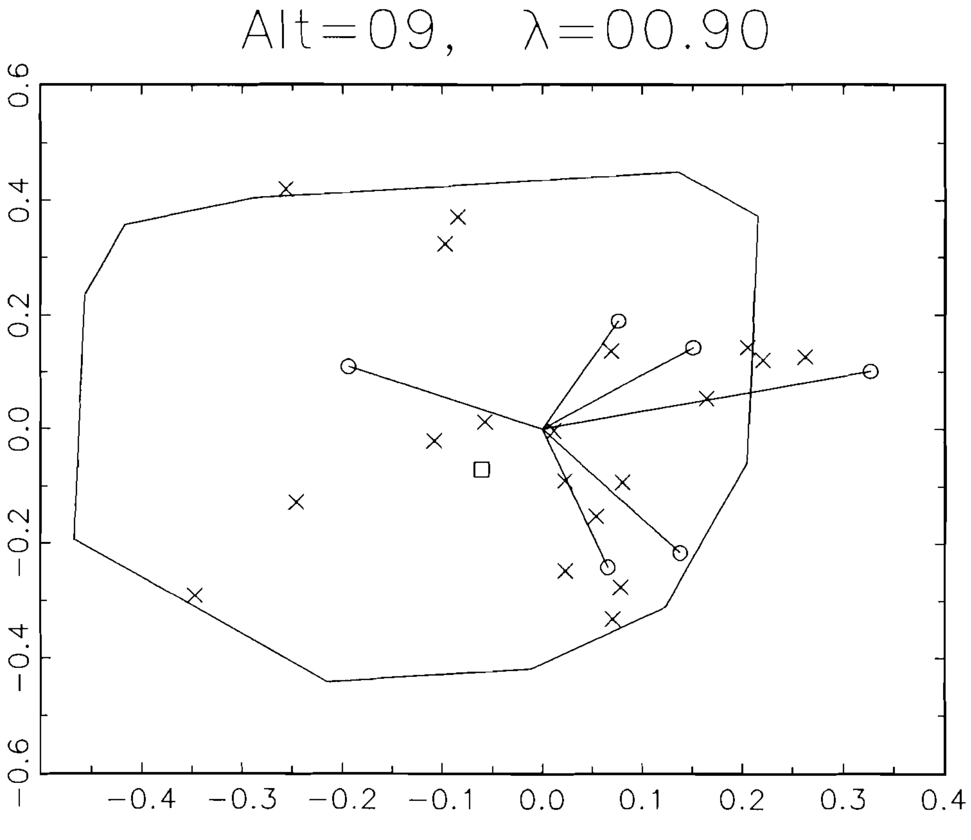

Figure 2: Projection with high weight for standard PCA matrix

5 Extensions, Conclusions and Topics for Further Research

In the above analysis, we considered the simple case of a linear preference structure. One topic of this section will be the generalization to more complex preference structures, specifically additive and completely nonlinear utility functions. Another topic concerns possible applications of the approach here in the framework of comprehensive multiattribute decision support.

5.1 Complex Preference Structures

5.1.1 Additive Utility Functions

Under rather general conditions (Keeney and Raiffa, 1976), multi-attribute utility functions take the additive form

$$\sum w_k u_k(x_k) \tag{21}$$

where w_k is the criterion weight and $u_k()$ is the partial utility function of criterion k.

Formally, this case can be treated similar to the case of a linear utility function discussed above, when partial utility values $u_k(x_k)$ are used instead of the criteria values x_k themselves. But the question arises whether graphs generated by this formal substitution can be meaningfully interpreted and thus are a useful decision aid.

Graphs as those shown in figures 4 and 4 serve three purposes: they provide information about

1) the ranking of alternatives;

2) the importance of criteria;

3) the performance of alternatives in criteria.

Functions 1) and 2) are not affected at all by projecting partial utility values instead of actual criteria values. Function 3) is changed: a projection does no longer indicate how well alternatives perform in different criteria but rather how the performance is valued according to the partial utility function. But this information is also an important decision aid, so the third function is also maintained. Graphs based on partial utility values rather than criteria values are therefore meaningful decision aids and the methodology presented above can be extended to the case of additive utility functions.

5.1.2 Nonlinear Preference Structures [1]

Completely nonlinear preference structures cause more serious problems. One basic feature of the projection technique developed above is its orthogonality to indifference hyperplanes generated by the linear utility function. In case of nonlinear indifference surfaces, orthogonality can only be defined locally, but not globally as in the linear case. It is therefore no longer possible to generate projection matrices that are orthogonal to indifference surfaces.

[1] I am indebted to Erich Neuwirth, University of Vienna, for discussing these topics

5.2 Projections in Integrated Decision Support

Another important topic is the integration of this concept into a general, graphic-oriented decision support environment. It has been shown in this paper that projections using a linear combination of the standard PCA projection matrix and a matrix orthogonal to criteria weights can be used to represent performance of alternatives in criteria, rankings of alternatives and criteria weights in one single graph. Such a graphical representation can thus be used as the central "metaphor" incorporating all important aspects of the problem and providing a consistent user interface for multi-criteria decision support.

Currently, an experimental system is under development which will use this graphical representation as its main interaction tool. This system will not only use the graphical representation for communication from the system to the user, but will also allow the user to directly manipulate elements of the problem through their graphical representation. For example, additional information on alternatives can be obtained by clicking a mouse at their graphical representation or the weights of criteria can be changed by moving their representation.

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Intelligent, Interactive and Integrated Decision Support System (I^3DSS): An Application– Oriented Approach

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Abstract

This paper introduces the experiences of research and development of a new kind of Decision Support System – Intelligent, Interactive and Integrated Decision Support System (I^3DSS) in P. R. China. The decision–process orientation and meta–decision–making guidance are two fundamental principles for the realization of such system. Some features of application of knowledge–based approach, guidance of decision support process and system integration are described.

1 Introduction

In the past two decades, people had witnessed the growing demand of computer assistance for decision making of various organizations (industry, government, military, etc.). To meet the demand, Decision Support System (DSS) had been developed and used to aid the decision makers of different levels. For the higher level decision support, especially for unstructured and semi–structured problems, a competent DSS must have the following features:

- Supporting different levels of decision
- Supporting all the phases of decision process
- Supporting the solving of semi–structured, unstructured as well as structured problems
- Flexibility, adaptability and fast responsibility
- User–friendly (especially for non-computer-scientist users), Man-machine interactive
- Emphasis both on internal and external information
- Emphasis on effectiveness rather than efficiency

- Respond to user's ad hoc requests, not only recurring
- Support and enhance rather than replace decision maker's judgment
- Improvement of user's insight not only from the results but also (even mainly) from the decision support process.

Traditional data-based and model-based *DSS* cannot possess all these features. System researchers and developers had made great efforts to find some useful tools from arsenals of Artificial Intelligence (*AI*) and Computer Technology for improvement of the system performance.

At the year 1986, when a collaborative project of State Science and Technology Committee of China (*SSTCC*) and International Institute for Applied Systems Analysis (*IIASA*) to research and develop an Integrated DSS for regional development study was set up (and after two years, a prototype had been completed), in China there were also two systems (one for petroleum refinery and one for the regional socio-economic development study of a county) under developing. We put forward a task of developing a kind of Intelligent, Interactive and Integrated DSS (briefly, I^3DSS) to probe the way of strengthening the power of such systems. The system is intelligent because we introduce some knowledge-based (as a primary step toward intelligent) to guide the decision support process, to implement qualitative analysis (coupled with model-based quantitative analysis) and to explain the support procedures. The system is interactive not only because there is a user-friendly man-machine interface for input and output of data and information for data-based and model-based modules, but also by using of dialog for synergistic interaction between decision maker and computer to enhance the effectiveness of system. Moreover, some optimization methods, especially in multiple objective case, interactive approach is very often adopted. Finally, system integration is absolutely necessary because we must organize different types of modules together to work consistently and harmoniously.

The three "*I*" can not be treated separately, they penetrate each other to form a comprehensive systems approach.

The following paragraphs describe some our preliminary experiences.

2 Decision process orientation

The *DSS* must support the decision making through the whole process. The decision maker will benefit not only by the results of the system running, but also get the insight of the problem from the decision-aid process. The majority of current *DSS* have concentrated the attention on results or solution rather than the full range of problem-solving. For semistructured and unstructured problems, there are needs to provide support for earlier stages of the decision making process. The problem finding and problem recognition are much more important than the next steps. Abraham Lincoln had pointed out: "If we could first know where we are and whither we are tending, we could better judge what to do and how to do it". The main reason of failures of some *DSS* is they cannot help the *DM* to clarify the problem at the earlier stage, although they possess great enough ability to solve well-formulated problem.

The problem finding and problem recognition in management differ from problem finding and recognition in other domains because for the managerial problems, people cannot get so many well-formulated relationships. In this case, creative thinking of decision maker and decision analyst are necessary. As described by Evans (1989), it includes the mess finding, fact finding, problem finding, idea finding, solution finding and acceptance finding. The *DSS* must offer the necessary information to initiate such process. A competent *DSS* must possess comprehensive information support to the decision maker although not much in detail, but may be helpful to the user's association.

The system must guide the decision support process by mapping a decision situation (which can be defined by a set of situation variables) to a decision-making method (as defined by an ordered set of technology and decision aids). This mapping is the kernel of the meta-decision-making. According to Kotteman (1986), this step is the whole contents of meta-decision-making, and problem-recognition is excluded. In our opinion (Wang, 1990), meta-decision-making is the task of decision of "how to make decision" throughout the whole process. It must consist the selection of each step of decision making, including the problem finding and recognition. The system may accept the user's decision approach and work to support them, but moreover the system may have the ability to restructure the decision maker's thought process toward a scientific and realistic direction. All these tasks must be completed in man-machine interactive manner. Fig. 1 shows a proposed flowchart of above process.

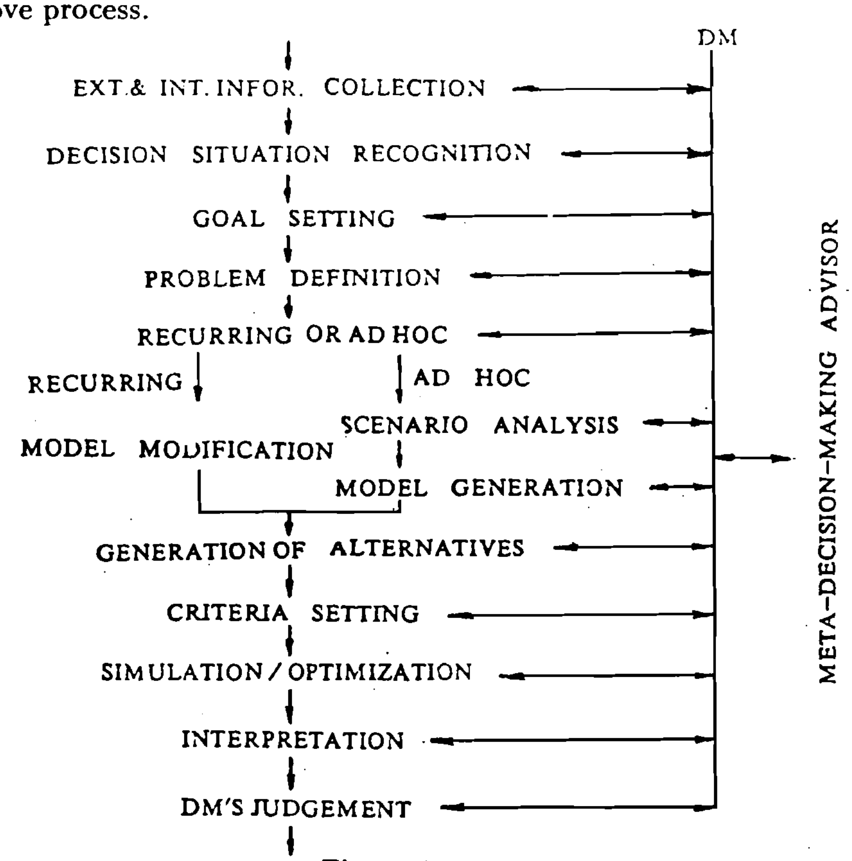

Figure 1:

At present days, we have got an ever increasing number and diversity of modelling, simulation and optimization methods and techniques. Most of these tools are applicable only respect to specific problem domains and under certain restrictions. Novice users of various professionals, when they contact the system for the first time, urgently need some support to enhance the goal-directed and problem-adapted selection and effective application. The system may list a lot of tools for experienced users for their choice, additionally may offer some advises about the selection to less-experienced users, (they are specialists in their own domain, but not skillful in *DSS* application). These advises come from the knowledge and experiences of decision analysts and systems analyst. The knowledge based subsystem of such *DSS* differs from the expert systems of other domain just at that, besides the domain knowledge, there is a need for Decision Analyst's and System Analyst's knowledge. This knowledge constitutes a guideline of meta-decision-making.

3 System architecture and components

The basic architecture of the proposed system is shown in Fig. 2. It includes the following components:

- A graphical user interface GUI
- A meta-decision-making subsystem MDM
- A problem processor PP
- A control and scheduling subsystem CS
- Data base DB and its management system DBMS
- Model base MB and its management system MBMS
- Distributed knowledge base DKB and its manager DKBM

The overall architecture is not different from many intelligent DSS reported. Here we would explain some special features of several modules.
The meta-decision-making subsystem has the advisory functions in the following aspects:

- Recognition of decision situation
- Goal setting
- Specification of the actual problem with respect to the goal (usually from the dissatisfaction of recent situation or from opportunities)
- Selection of rational modelling methods and critical cause-effect relationships
- A guide line for model-generation
- Interpretation of "what-if" or optimization results
- Find some way to get out of the stuck of process

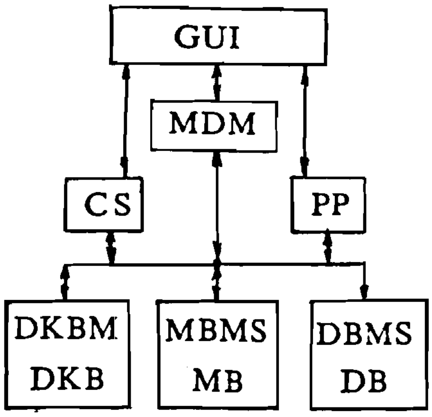

Figure 2:

Parallel to the main stream of decision support process there exists a meta-decision-making advisory process shown on the screen to assist the user, to let him (or her) know where he (or she) is and where he should go.

The meta-decision-making advisory subsystem has its most parts of rule-based. But there are some fuzzy operations used.

Suppose I——space of decision situation
P——space of decision problem
S——space of solution

The structured problem $p \in P$ may be solved by creation of mapping g:

$$g: \quad P \rightarrow S$$

For the semistructured and unstructured problems, $P \in P$ cannot be given directly and immediately, only $i \in I$ is know. The decision corresponds to create a mapping h:

$$h: \quad I \rightarrow S$$

But in real cases, h also cannot be given immediately. We must firstly construct the mapping relation f:

$$f: \quad I \rightarrow P$$

then we have

$$h = g \star f$$

and f is just the problem-generation process. The construction of f is as follows. Firstly, we construct

$$f_1: \quad I \rightarrow A$$

A is space spanned by m critical factors, characterizing the situation. Then another mapping

$$f_3: \quad E \rightarrow P$$

is also constructed. E is space of attributes of a given problem. According to experiences, f_1 and f_3 may be created without too much difficulties.

The most crucial task is to create f_2

$$f_2: \quad A \rightarrow E$$

So as

$$f = f_1 \star f_2 \star f_3$$

f_2 may be ruled-based, but in most cases we may construct a fuzzy map according to domain knowledge and experiences of decision analysis.

Recently, we have found artificial neural network is also powerful for this purpose.

The knowledge base is distributed because we apply the knowledge engineering approach at three levels:

- The upper level for guidance of decision process
- The intermediate level for model-generation and "what if" analysis
- The lower level for interpretation of interim and final results

For the convinience of calling the rules and reasoning, rule-based modules are distributed in several subsystems.
Blackboard method is adopted for the scheduling
In the model base, problem-specific models can be generated on the base of user's specification and in an Entity-Relation-problem framework. Besides the generated model sets. There are also some standard solvers (For LP, ILP, GP, etc) and analytic modules (AHP, etc).

User-friendly graphical interface is an important part of the whole system. Especially for those decision makers who are not computer-specialist, they can get more information from charts, diagrams, curves and maps than ordinary tables and texts. Top leaders have no much time to watch the data line by line, but the colorful graphs especially the sharp-contrasted diagrams draw their attention at once and they can find the key issues immediately. In China, the screen display must be in Chinese mostly for the convinience of users who do not understand English. But the display of Chinese characters is a time-consuming task and the number of lines is also quite restricted. The graphical display may partly remedy it.

4 System integration

The system integration must be realized at different levels. At conceptional level, we must has a comprehensive system approach. In our system the decision-process orientation and meta-decision-making guidance are the main principles. At the logic level, the

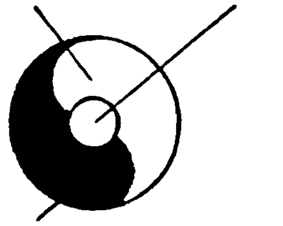

Figure 3:

quantitative models and rule sets for qualitative analysis must be able to couple together according to a problem-specific sequence. The most crucial problems are happened at implementation level. Firstly a consistent data base must be built up for different modules. At the prototyping stage, redundancy may be unavoidable, but the consistency of data is most important first of all. Data must be easily transmitted between different kinds of modules. The style of man-machine dialog must also be consistent and suitable for user's appetite. The software organization must fulfill the requirement of dynamic scheduling according to the demand of decision process. In order to overcome the difficulties of the coupling of different programming languages, we use the language C as the unique host language.

In order to overcome the restriction of area of screen display (especially for Chinese character display), we use the window technique at different levels and procedures.

Our experiences of implementation of I^3DSS on microcomputers over three years show there are bright perspectives for the application of these system to organizations of different levels, especially to medium and small corporations.

The synergistic operation of "soft technology" (including the human intuition, experience as well inspiration and their implementation such as knowledge engineering approach, fuzzy reasoning, etc) with "hard technology" (including numerical and logical analysis in its strict sense) recall to us the ancient Chinese Philosophical principle "In-Yang" in the classical book "I-Ching". "In" means flexibility, mildness and adaptability. "Yang" means strength, rigidity and exactness. The whole decision process, like the world, is a harmonious complexity of "In-Yang". Moreover we have mentioned in the principle of "I-Ching", there is a further expression of the holistic system as Fig. 3. In the center between "In" and "Yang", there is a "superior". In our understanding, it is a ruling part of whole system. For the I^3DSS, this part is just the meta-decision-making module.

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