Abridged version

KAWASAKI STEEL TECHNICAL REPORT
No.26 (June 1992)
Artificial Intelligence and Wire Rods and Steel Bars

Establishment of Basic Infrastructure for Expert System Development

Satoshi Fukumura, Katsuaki Sanou

Synopsis :
With a view to disseminating expert system (ES) applications within the company, Kawasaki Steel conducted a special program for strengthening fundamentals of its system development. As a central measure, ES development guide book was compiled to standardize development procedures, and a software was developed as supporting tools for ES building standards. The former summarized proper selection standards for ES applications, ES development processes, and job analysis at each process and its keypoints. The latter mainly emphasized eliminating computer environment dependency, the ease of gaining the mastery of tools, and a design for a hypothetical reasoning unction useful in solving vital planning problems in the future. Since 1989, the number of applications using these tools has increased, contributing notably to effective and efficient system development.

The body can be viewed from the next page.

Establishment of Basic Infrastructure for Expert System Development*

Satoshi Fukumura
Senior Researcher,
Systems Lab., Systems
Planning & Data
Processing Dept.

Katsuaki Sanou
Senior Researcher,
Systems Planning &
Data Processing Dept.

Synopsis:

With a view to disseminating expert system (ES) applications within the company, Kawasaki Steel conducted a special program for strengthening fundamentals of its system development. As a central measure, an ES development guide book was compiled to standardize development procedures, and a software was developed as supporting tools for ES building standards. The former summarized proper selection standards for ES applications, ES development processes, and job analysis at each process and its keypoints. The latter mainly emphasized eliminating computer environment dependency, the ease of gaining the mastery of tools, and a design for a hypothetical reasoning function useful in solving vital planning problems in the future. Since 1989, the number of applications using these tools has increased, contributing notably to effective and efficient system development.

1 Introduction

In artificial intelligence (AI) technology which has made remarkable progress in recent years, the expert system (ES) is widely recognized as the most practical to use. The applications of AI technology at Kawasaki Steel have also been advancing based on ES. The process of introducing AI at the company began with an "experiment" aimed at mastering the technology, then its "evaluation" to see how well it meets practical uses, next being "application research" to solve problems for dissemination, and currently the period of dissemination and expansion. With the seeds of an idea sown, the needs are now growing.

The company considered it essential to strengthen fundamentals for ES development in order to promote ES within the company, and since 1988 an ES development guidebook and ES building support tools have been made available. An AI Technical Forum was also set up to concentrate and co-own the know-how of ES development that were spread throughout the company, and the level of technical capability has been raised as a result.

This paper clarifies some of the problems in ES development, and outlines the ES development basis strengthening program. The ES development guide and standard ES building tools are also described, and future tasks are summarized.

* Originally published in *Kawasaki Steel Giho*, 23(1991)3, 178–184

2 Problem with ES Development

The application of ES in Kawasaki Steel started in 1982, about 30 system having already been developed, with about 20 other systems being under development or trial stage (**Fig. 1**). Some are incipient technological experiments. Some are the themes of research and development, and others in recent years are clearly identifiable as sub-systems under synchronous development with larger scale main systems.

The biggest features of ES exist in two phases: in function and mechanism. In the former, business tasks in which it was very difficult to formulate an algorithm can be incorporated into computer system coverage by utilizing expert knowledge and know-how held by experts. In the latter, knowledge can be accumulated as a kind of data, as reflected in the name 'knowledge base,' and its utilization is managed by a generalized mechanism called an inference engine in a knowledge-based system. In other words, by separating knowledge and its utilization and by describing knowledge in independent small units, software readability can be improved, and as a result, a step-by-step structuring (prototyping aproach) can be made possible, and maintenance following operations can be made easy. A big-

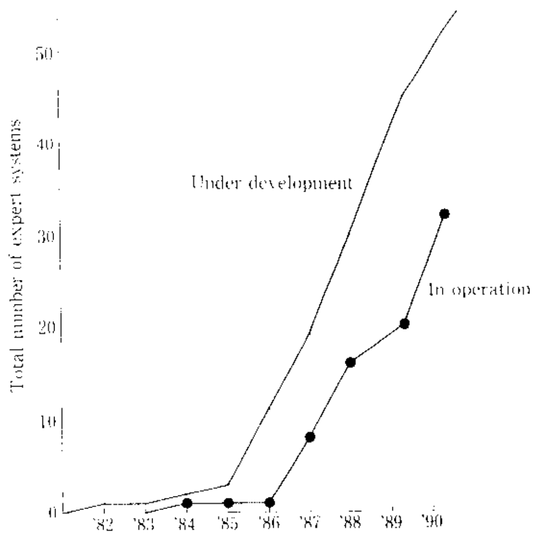

Fig. 1 Increase in total number of expert systems developed by Kawasaki Steel

gest feature keenly felt by systems engineers of conventional systems about ES development is a flexibility for specification changes.

However, not all of the 30 developed systems have been successful, less than half of these meeting the original targets. The main reason was an insufficiency in research and practical experience, which caused problems in application development.

2.1 Problems with System Development

(1) Lack of a Standard for the Development Process
Lack of a suitable standard for the development process makes it impossible to plan a schedule, so that development work was hindered, and a reliable system cannot be developed.

(2) Inadequate Identification of the Problem
It is necessary to identify problems when no technical data exists to make the most of the programming method for an expert system.

(3) Inadequate Estimation of Necessary Resources (manpower, computer time, etc.)
With ES, the detailed specifications can not be decided as early as with conventional systems. Each problem has its own time for reasoning until an answer is given, and an estimation method for necessary resources was not established.

(4) Difficulty in Verifying the System
Verification of all conditions is practically impossible, because the system specifications are inaccurate or variable, and the problem-solving process is not expressible by a flow chart.

2.2 Environmental Problems for System Development

(1) Delay in Preparation and Standardization of Tools and Languages
Although the number of ES building support tools on the market is large, it is necessary to select the most suitable tool for each problem because of its unique advantages and disadvantages. Each tool also needs its ideal working environment (computer), so it is difficult to standardize such tools, making it difficult to accumulate know-how and utilize knowledge engineers.

(2) Expensive Tools on the Market
Highly functional tools for use on work-stations are very expensive and make it difficult to ensure effectiveness on a limited ES budget.

(3) High Consumption of Computer Resources
Synthetic type problems such as for planning include combinatorial optimization problems, which can cause "a combinatorial explosion" unless solving methods are closely examined. This is especially true in the case of operating on main frame.

(4) Difficulty in Integrating with Existing Systems
Although ES needs to be run on a relatively large computer system, integration is difficult because of hardware and software incompatibility at the present time.

(5) Little Understanding of the Data Resources That Need to Be Gathered from Human Experts
The acquisition of important data which is utilized for decision making by human experts is sometimes difficult, because of insufficient sensor capacity and of the lack of a unified method for processing the data.

2.3 Problems with the Technology for Knowledge Representation

(1) Mismatching between Knowledge Representation

and the Problem

The types of knowledge representation which we can use as tools are limited, so mismatching between them and the problem sometimes occurs. The decision process which exists especially in planning problems needs to be expressed by a rule. Control rules and rules for problem solving have different characteristics and need a clear representation method.

(2) Difficulty in Extracting Experts' Knowledge

All knowledge has to be extracted through an interview with an expert and then processed by a systems engineer who is also called a knowledge engineer (KE). This knowledge acquisition process is often a very difficult task.

2.4 Problems in an Organization

(1) Difficulty in Evaluating the Effect of a System

ES is generally modeled on a method used by human experts, so that it does not exceed the capability of human experts. Although there is an advantage from standardization in business, it is difficult to relate with a quantitative evaluation.

(2) Shortage of Knowledge Eugineers

Knowledge engineers can only learn their skills by participating in practical system development, and few systems engineers have had this opportunity.

(3) Insufficient Cooperation by Human Experts

Although the participation of human experts in ES development is vital, cooperation is often insufficient.

(4) Insufficient Understanding of the Need for Maintenance

ES deals with a problem in which the environmental conditions are easy to change. Accordingly, it is necessary to maintain the system and follow it up. There was generally little understanding on these points.

Solutions to these problems one by one lead to an accumulation of applicable technology for ES, and are the key to disseminate ES application technology. The magnitude of the needs still unchanging indicates the deserving values of ES technology.

3 Establishment of a Suitable ES Development Environment

Two tools were created to establish the development environment that is most suitable for broader applications of ES.

3.1 Preparation of an ES Development Guide

3.1.1 Background and motive

As stated above, actual applications of ES have grown noticeably for these several years. In reality, however, ES systems engineers have advanced the development on a trial-and-error basis, and it is not an exaggeration to say that the development has relied on their skills. Because of this, the productivity of system development did not improve at all, and there were many doubts about what was claimed to be the feature of an "easy development" procedure for ES.

A methodology for ES development is required by general users, and various methods have been proposed by learned societies, computer manufacturers and others. However, these were not adequate for our standards because they only gave explanations of technical topics, design methods for a knowledge base, and methods for project management.

We decided to create own guide for use based on our own experience by summarizing development procedures, and keypoints at each step, so that future systems engineers can promote ES in a way more assured by making the most of our past performances.

3.1.2 Basic principles

(1) Role of ES in System Development

ES is used to complement other conventional systems. Therefore, the guide for development puts emphasis on how to coordinate with the basic system, the work to be done, and the procedure to be adopted.

(2) Developer of ES

Despite the existing popular understanding that ES is made by specialists themselves, anything practical cannot be established unless carefully designed and programmed by systems engineers deeply involved in actual experience. Therefore, the subject guide requires the hands of engineers in charge of systems design and programming.

(3) Contents of the Guidebook

The guidebook should teach how to solve actual problems based on real experience rather than teaching text-book doctrines.

3.2 Development of ES Building Support Tools

3.2.1 Background and motive

In developing ES, it is an efficient common practice to use building support tools. As part of knowledge base system elements, the tools are rather general and do not depend on applications. They consist of inference engine, working memory management, function developer interface and user inteface. Many of these tools are already available on the market from computer manufacturers and software houses, especially from third parties of the U.S.A.

At Kawasaki Steel, building support tools considered suitable have been introduced from the market depending on the type of problems and restrictions on the system operating environment. At that stage it was considered sound to select tools suitable for given problems and environment. As a result, however, various tools used proved impossible to share accumulated technology as standard method for ES development.

These tools had a wide range of functions and price, and proved expensive for large scale and complicated problem-solving requirements. The company decided to develop an original tool which could interface with existing business computer systems and process computer systems, and would be used as a standard.

3.2.2 Basic policy for development

(1) Operation Environment of Tools
Computers from various manufacturers are used for business applications and process controls at Kawasaki Steel, and it was decided that our own tool should work on UNIX to provide an open system.

(2) Language Used
Although such AI languages as LISP and Prolog were used at first, they also restricted the applications because they differ greatly from other programming languages. For this reason, C language that is similar to existing languages and is widely used was adopted as the programming language.

(3) Reasoning Function
The tool needed to have production rules and frames for knowledge representation. The former was constructed from forward and backward reasoning, and the latter from "inheritance" and "daemon". A hypothetical reasoning function was adopted in order to handle planning problems, for which there is great need.

3.3 Promotion of These Activities

The two tools introduced in Sec. 3.1 and Sec. 3.2 provide a solution to the problems of system development and organization, as well as a solution to the problem of the system development environment. The basic technology for ES was introduced steadily by testing the latest methods in the systems laboratory. These activities were publicized and the AI Technical Forum was organized to promote the use of the development guide and building support tools. This AI Technical Forum is attended by representatives from each department at Kawasaki Steel and affiliated companies to discuss technology through case studies.

4 ES Development Guide

The main points of the structuring method for ES are described by this guide.

4.1 Problem Selection

4.1.1 Types of problem for ES

If it can be premised by a rule-based system, which is the basic method for existing ES, this is suitable for solving those problems that have a complex flow for judgement that cannot be easily modeled. Planning and diagnostic problems are typical of this, and include those in which a judgement for the condition of a process is made on a trial-and-error basis.

4.1.2 Restrictions on ES

In considering the level of existing technology for ES, problems applicable to ES are unavoidably under the following restrictions:

(1) There need to be experts who can solve the problem, because ES technology only offers a sort of high-grade programming language, the basic method for solving the problem still being planned by human experts. Although it is possible to apply ES for controlling a new process without existing human expertise, great care needs to be taken with this.

(2) The problem must be on the scale that can be handled by a sub-system of the basic system.

(3) The problem must not require precise response.

4.1.3 Required condition for system operation

ES requires heavy resources and there is a strong need for a human-machine interface, so that ES has to be developed and operate on a work station linked to a network and not on a host computer. After doing that, a judgement can be made on whether there are any compatibility problems with the basic system.

4.1.4 Other conditions

The following conditions are important for development work:

(1) A system modeled on the method of human experts is advantageous.

(2) Human experts have to assign their time during system development.

(3) Both the user and system developer need to be able to maintain the system.

4.2 Development Stages

The development process is made up of 7 phases and 18 steps as working units (**Fig. 2**).

4.2.1 Phase I—Decision for ES application

Step 1—Decide to Apply ES Technology and Organize the Development Team: Approval is obtained from the project leader, and an ES development team is organized.

4.2.2 Phase II—Knowledge acquisition

Step 2—Identify the Objectives: The knowledge engineer who is in charge of system development must understand the technical terms of the problem and have a basic knowledge of the problem itself.

Step 3—Knowledge Acquisition: At the stage when an outline of the work is understood to a certain extent, knowledge needs to be drawn from experts, contradictions eliminated, and missing knowledge identified.

Step 4—Confirm the Development Schedule: Decide

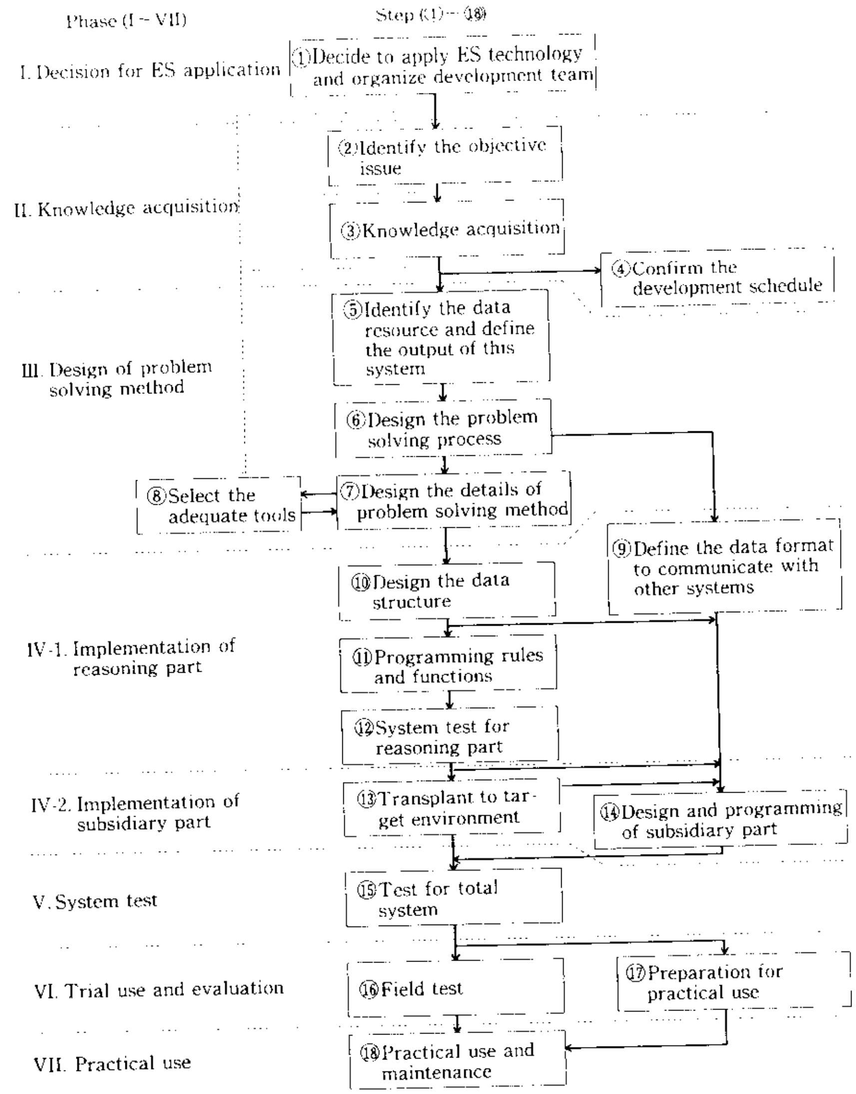

Fig. 2 Phase chart of ES development

on a development schedule, check the necessity for step prototypes, and determine each phase of the schedule.

4.2.3 Phase III—Design of the problem-solving method

Step 5—Identify the Data Resource and Define the Outline of the System: Confirm the required interface conditions with the peripheral system or work.

Step 6—Design the Problem-Solving Process: Determine the internal process for computer processing and allocate the extracted and arranged knowledge to the process.

Step 7—Design Details of the Problem-Solving Method: Design the basic problem-solving method, and specify the method by fitting it to the control mechanism and the knowledge representation of the tool.

Step 8—Select Appropriate Tools: Select suitable hardware and software, taking into account an understanding of the problem, knowledge extraction and arrangement, and the design of the problem-solving method.

4.2.4 Phase IV-1—Implementation of the reasoning section

Step 9—Define the Data Format to Communicate with Other Systems: Determine details of the interface between the reasoning section and peripheral systems.

Step 10—Design the Data Structure: Determine the data specifications to be used for knowledge processing.

Step 11—Programming Rules and Functions: Implement the reasoning section.

Step 12—Test the Reasoning Section: Test the reasoning capability from receiving data up to data transmission.

4.2.5 Phase IV-2—Implementation of the subsidiary section

Step 13—Transplant to the Target Environment: Reconstruct the prototype system to make it conform to the final objectives and operating environment.

Step 14—Design and Program the Subsidiary Section: Design the remaining parts of the system.

4.2.6 Phase V—System testing

Step 15—Test the Total System: Conduct a test by using actual operating data.

4.2.7 Phase VI—Trial operation and evaluation

Step 16—Field Testing: Run the system under actual operating conditions controlled by the user and verify its practicability.

Step 17—Preparation for Practical Use: Operate the system in a real working environment and prepare the method for maintaining the system.

4.2.8 Phase VII—Practical use

Step 18—Practical Use and Maintenance: Use and maintain the system.

This guide gives the instructions for each step, details of the major work involved, and points to check before proceeding to the next step.

4.3 Collected Cases of Development

This guide is based on a close examination of the following six applications of ES:

(1) Berth planning system for plate shipment[1)]
(2) Coal blending design system[2)]
(3) Use of the MARC structural analysis package[3)]
(4) Fault diagnosis in rotating machines[4)]
(5) Blast furnace operation control[5)]
(6) Diagnosis of strip thickness accuracy in a cold-rolling tandem mill[6)]

Applications 1, 2, and 3 are installed on a mainframe computer or work station connected with it, 4 is installed on a personal computer, and 5 and 6 are also installed on a process computer. Of the type of problem, 1 and 2 are planning applications, 4 and 6 are diagnostic applications, 3 is a consultation use, and 5 is a control use.

For each system, documented examples of the development process are included, together with the work involved, the problems incurred, and how to handle each step. The manpower involved for each step is categorized for system planner, designer, programmer, and expert.

5 ES Building Support Tool

This tool was developed by Kawasaki Steel Corp. and Kawasaki Steel Systems R&D Corp.[7)] and has been applied in a number of ES development applications.

5.1 System Environment

It was considered better to avoid developing and operating ES applications on a host computer, using instead a network environment on a workstation. With this method, it is necessary to operate with an existing system on a host computer, **Fig. 3** showing a general system configuration.

This tool employs UNIX as the operating system and is programmed in C language to allow integration with other systems. It is possible to access a relational database from the rules by an SQL interface in order to easily share data with other systems.

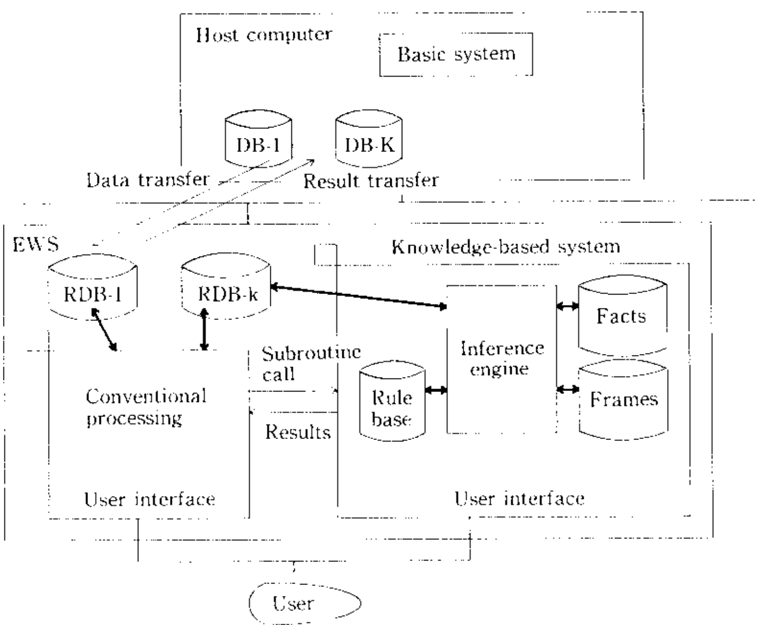

Fig. 3 Cooperative usage of basic system and knowledge-based system

5.2 Reasoning Function

5.2.1 Forward and backward reasoning

This tool controls reasoning of the data-driven mechanism to secure the independency of rules. Reasoning pattern includes forward reasoning and backward reasoning, and furthermore possible is a bilateral reasoning in which backward reasoning is initiated from forward reasoning in order to evaluate conditions. Rete algorithm[8] is adopted to achieve high-performance reasoning.

5.2.2 Rule grouping function

It is necessary to organize rules into groups, and to design control rules for each group in order to develop practical systems. Any mixing of these control rules with individual knowledge rules can greatly restrict the flexibility of a knowledge base, so that this tool adopts the rule grouping function and separates the meta-rule representation for control.

5.2.3 Hypothetical reasoning

The application which has the greatest scope for ES is planning problems. Planning essentially assigns jobs against a schedule of resources, and includes problems for optimizing from a combination of variables. This type of problem can be generally solved by the generate-and-test method, and hypothetical reasoning by the assumption-based truth maintenance system[9] is used to achieve this.

5.2.4 Frame function

Frame function fits static and structural knowledge, and is characterized by "inheritance" to reduce the representation of data and "daemon" to manage procedure as data.

5.3 Application Examples

The first version was completed in January 1990, and this tool has been used and evaluated in various ES development jobs.

5.3.1 Systems for planning

(1) Determining the Manufacturing Sequence for Hot-Rolling Seamless Steel Pipe:[10] The rolling schedule for seamless pipes is made in relation to the required quality, production setting of equipment, and production efficiency.
(2) Stowage Plan for Coastal Shipping Vessels:[11] The stowage method and shipping order of products on a ship are planned in relation to cargo stability on a voyage and working efficiency.
(3) Assembly Schedule for Small Coils: The connection schedule for small coils into larger coils is planned in relation to the quality and working restrictions.
(4) Unloading Plan for Raw Materials Vessels: The schedule for raw material unloading is planned according to the available space in the raw material yards and the available unloading and transportation machinery.

5.3.2 Systems for Diagnosis

(1) Fault Diagnosis for Rotating Machines: This system judges from experience anything unusual in the operation of a rotating machine and classifies the cause based on vibration data.

5.3.3 Systems for instruction

(1) How to use MARC: This system shows how to use the parameters of MARC by working examples.
(2) Repair Procedure for Leaking Pipelines: This system indicates the repair plan based on the position and damage for accidental leaks in water pipes.
(3) Guidance for an Image Processing System: This helps a non-expert to use the GAZOU-HAKASE image processing system that was developed by Kawasaki Steel.

These ES developments have proved these tools to be popular, and all expert systems for business applications have been developed by these tools since 1990. Our plan is to extend applications to process control.

6 Future Task

6.1 Enrichment of ES Development Guide and Improvement of Tools

This guidebook has the following tasks yet to be done:
(1) An estimation method for necessary development manpower is needed because this guide indicates only the primary factors of influence.
(2) The methodology for problem solving needs to be improved, and a better technique for knowledge acquisition is needed.

Regarding (1), it has been difficult to provide a universal standard. Because the system specification is made relatively late, there is a difference in conformity between the problem and tool, and there is a wide variation in the expression units for knowledge. However, more standardization ought to be possible at the present time because the tool has been made more standard and application examples have been accumulated. Regarding (2), planning problems are many, and an analysis of the characteristics of problems and a suitable problem-solving method has already been examined for application to the development guide.

6.2 Development of Task-Specific Tools

There are several typical problems for solution by ES that have been analyzed. Of the planning type, order allocation to semi-products and transport machinery planning have been studied. For process control, the specific dynamic characteristics of equipment has to be allowed for.

There exists a common framework for solving the problem and for the user interface in such applications. Tools for each will greatly influence the productivity of ES development, and future ES building support tools need to be diversified to accomodate specific tasks.

6.3 Incorporation of Latest Technolgies

New AI technologies are becoming available, for example, in the field of case-based reasoning, fuzzy reasoning and neural networks. Although these are said to be applicable to solve different problems from those with existing ES technology, it is necessary to integrate them for solving real problems. The methodology for systems development that can incorporate these new technologies, and the development of hybrid type of tools are important for future ES development.

7 Conclusions

Activities at Kawasaki Steel for developing necessary basis to stimulate the dissemination of expert system (ES) application techniques has been described.

(1) An ES development guidebook was prepared and ES building support tools were developed as part of the ES development basis stimulation activities, with an AI Technical Forum organized.

(2) The guidebook gave an easy-to-follow description of application selection methods, development procedures, job descriptions and keypoints at each work phase. Actual examples were attached to clarify specific working processes.

(3) The ES building support tools use UNIX/C, which is not dependent upon the computer hardware, and have high-level function such as hypothetical reasoning.

Since its first landing in the company for trial in 1982, ES has gone through many experiences, receiving many evaluations of pros and cons. Now that over-expectations or rejections affected by the sweet sounding "artificial intelligence" have now diminished, ES is finding its way as a method of actual systems development. Now time is ripe for its true effect because ES is now in a condition where its true worth is coolly accepted, thereby finding itself in a condition where it can demonstrate its true effect. The completion of ES system development guide and ES building support tool is considered worthwhile as a basis for its dissemination. The author would like to exert himself for further expansion, while reflecting users' voices in further activities.

References

1) S. Fukumura, K. Sanou, and E. Yamakawa: *Operations Research,* **33**(1988)1, 33-39
2) E. Nakata, S. Kimura, M. Miyake, and H. Fujimoto: *Fujitsu Journal,* **16**(1990)2, 22-28
3) H. Shikata, K. Morioka, H. Kobayashi, and M. Kajiwara: "Development of Consultation System for Structural Analysis Package MARC", Johoshorigakkai-Dai36kai-Zenkokutaikai (Information Processing Society of Japan No. 36 national conference), 2Q-1, (1989)
4) S. Kasai, Y. Tada, S. Hasegawa, K. Sanou, and S. Fujimoto: *Kawasaki Steel Giho,* **22**(1990)2, 74-82
5) S. Yamasaki, M. Satoh, M. Kiguchi, O. Iida, and S. Fukumura: *CAMP-ISIJ,* **2**(1989)1, 6-9
6) S. Arai: "The Outline of the Expert System for Abnormality Diagnosis in the Cold Rolling", Jinkouchinou-Gakkai-Zenkokutaikai (Artificial Intelligence Society of Japan national conference), 11-7, (1989)
7) M. Kikuchi: *Kawasaki Steel Giho,* **23**(1991)3, 261
8) C. L. Forgy: *Artificial Intelligence,* **19**(1982), 17-37
9) J. de Kleer: *Artificial Intelligence,* **28**(1986), 127-162
10) N. Fukaya and T. Katagirl: *Kawasaki Steel Giho,* **23**(1991)3, 191
11) K. Iritsuki, E. Yamakawa, S. Fukumura, K. Nogami, and J. Ikuta: *Kawasaki Steel Giho,* **23**(1991)3, 232