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Development of Expert System Building-Tool for Real-Time Control System - FAIN

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Abstract:

Nippon Steel will soon have 100 expert systems (ES) which constitute a representative application field of artificial intelligence (AI). The expert systems are positively utilized in automating the information processing and judgment tasks that have hitherto been performed on the basis of human knowledge and experience. Basic software for efficiently building expert systems is called the AI shell. This paper gives an overview, application examples, and future prospects of the process control AI shell FAIN (Fast AI shell of Nippon Steel) developed by Nippon Steel. In the development of ES which is the operational know-how, the prototyping method in which the system is developed by adding or revising the specifications in a spiral-up manner is employed. the FAIN is the software in which the general-purpose, tabular format design document specification suited for the prototyping method is specified and the program is automatically generated from the specification. FAIN was the first tool to allow field operators to build expert systems by themselves.

1. Introduction

As a computer user, Nippon Steel has long had a clear vision of the need for systematizing and automating the iron and steel-production processes in both the operation and equipment control spectra. The company developed in-house such application software as mathematical models of process computers, and built large-scale control systems with advanced functions. In recent years, information processing and judgment tasks relying on human knowledge and experience have gained importance with the progress of process integration, manpower saving, multi-product small-lot operation, and product grade and quality sophistication. In this connection, great expectations are entertained in the artificial intelligence (AI) technology that incorporates such intelligent information processing into the conventional control system (see **Fig. 1**). Expert systems (ES) are a typical field of AI application, and are widely spreading today. They will soon come to number 100 within Nippon Steel alone, as shown in **Fig. 2**.

Basic software that can be commonly used as nuclei of expert systems is called the AI shell. The AI shell is a tool that is designed for building and executing an expert system and packages the functions of storing rules such as operational know-how and making inference from the rules. Nippon Steel developed a variety of AI shells, applied them to actual projects, and commercialized them. Among these AI shells are FAIN (abbreviated from Fast AI shell of Nippon Steel and tradenamed NSRAIS) for process control and ESTO (abbreviated from Expert System for Trace Origin and tradenamed Cerebro) for analytical diagnosis.

This paper describes the characteristics, in-house application examples, and future prospects of the FAIN shell, the develop-

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ment of which was completed in March 1990.

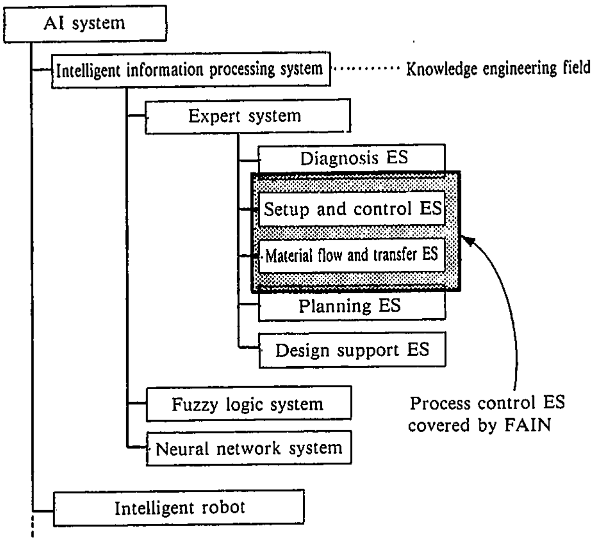

Fig. 1 Classification of AI systems

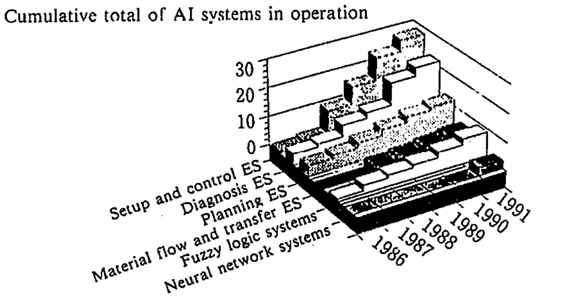

Fig. 2 Cumulative total of AI systems applied at Nippon Steel

2. Overview of FAIN

2.1 Aim of development

As expert systems were applied to blast furnaces and various other iron and steel manufacturing processes in the late 1980s, commercial general-purpose AI shells were found to have the following problems awaiting solutions:

(1) As expert systems have operational know-how systematized to a greater degree than conventional mathematical models, they continue to grow with operational changes and improvements. Under the software crisis in which systems engineers are in tight supply, it is ideal that field operators closely familiar with operational know-how should be capable of directly entering their operational know-how into expert systems. Commercial AI shells, however, need advanced programming techniques using dedicated AI languages.

(2) Commercial AI shells are aimed at versatility and are so low in reasoning speed that they cannot be applied to rolling and other high-speed processing lines in the steel industry.

(3) Expert systems cannot solve all problems, and it is difficult for commercial AI shells to combine with advanced control systems of the conventional type to form an integrated entity.

On the basis of its ample experience in expert sytem application to a variety of processes, Nippon Steel developed the AI shell

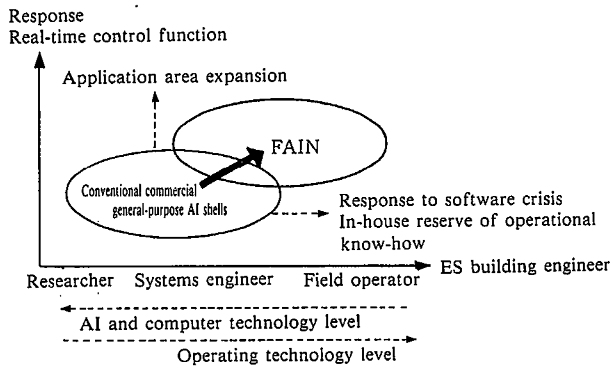

Fig. 3 Aims of FAIN

Table 1 Functions of FAIN

(1) User-friendly man-machine interface function	(3) Integration with conventional control system
• Entry of Japanese messages in tabular format • Japanese operation guide messages • Multiwindow and mouse operation • Color graphics	• Activation and halt of AI process (rule) execution • Handling the process data • Description of the numerical formula and subroutines call in the rule
(2) High-speed, high-performance reasoning function	**(4) Rich inference verification function**
• Application of high-speed inference engine OPS83 • Selection of conflict resolution strategy • Handling the process data at high speed • Separation of inference engine in on-line system and debugging system • Fuzzy control function • Asynchronized interruption procedure • Multitasking per knowledge base • Inference timeout procedure	• Inference tracing • Display and correction of frame and fact values during interruption of inference • Execution step by step • Executable rule display and forcible knowledge group switchover (forcible execution) • Rule matching status display • Graphic display Fuzzy reasoning result display and frame hierarchy map display • Separate compilation per knowledge group • Multiuser development support under the network environment

FAIN to solve the above-mentioned problems, as shown in **Fig. 3**. In the background of the FAIN development was the conviction that each expert system is an assemblage of operational know-how and that AI is a leading-edge seeds technology. From among commercial AI languages, the high-speed OPS83 (Official System 83) and high-function ART (Automated Reasoning Tool) were selected as inference engines from the considerations of development cost and time, and applied to develop two FAIN systems. OPS83 FAIN works on the VAX minicomputers in widespread use abroad and on the NS-SUN workstations, while ART FAIN works on Nippon Steel's MC series factory automation and process control computers where the high-speed dedicated AI microprocessor IVORY is installed.

2.2 Features and functional of FAIN

The FAIN has the following features (see **Table 1**, and **Figs. 4** and **5**):

(1) Automatic generation of expert system programs from tabular-format design documents

The specification and filling procedure of general-purpose tabular-format design documents to define the specification of an expert system were devised after studying various application examples. The field operator can enter and edit his knowledge by filling a design document of tabular format with his everyday words as if working with a word processor.

(2) High reasoning speed

Rules are grouped, and five conflict resolution strategies can be selected to meet specific rule groups (knowledge groups). The adoption of the high-speed OPS83 language, the high-speed dedicated AI microprocessor, and the improvement of inference engine allow a reasoning speed at least 10 times as high as possible

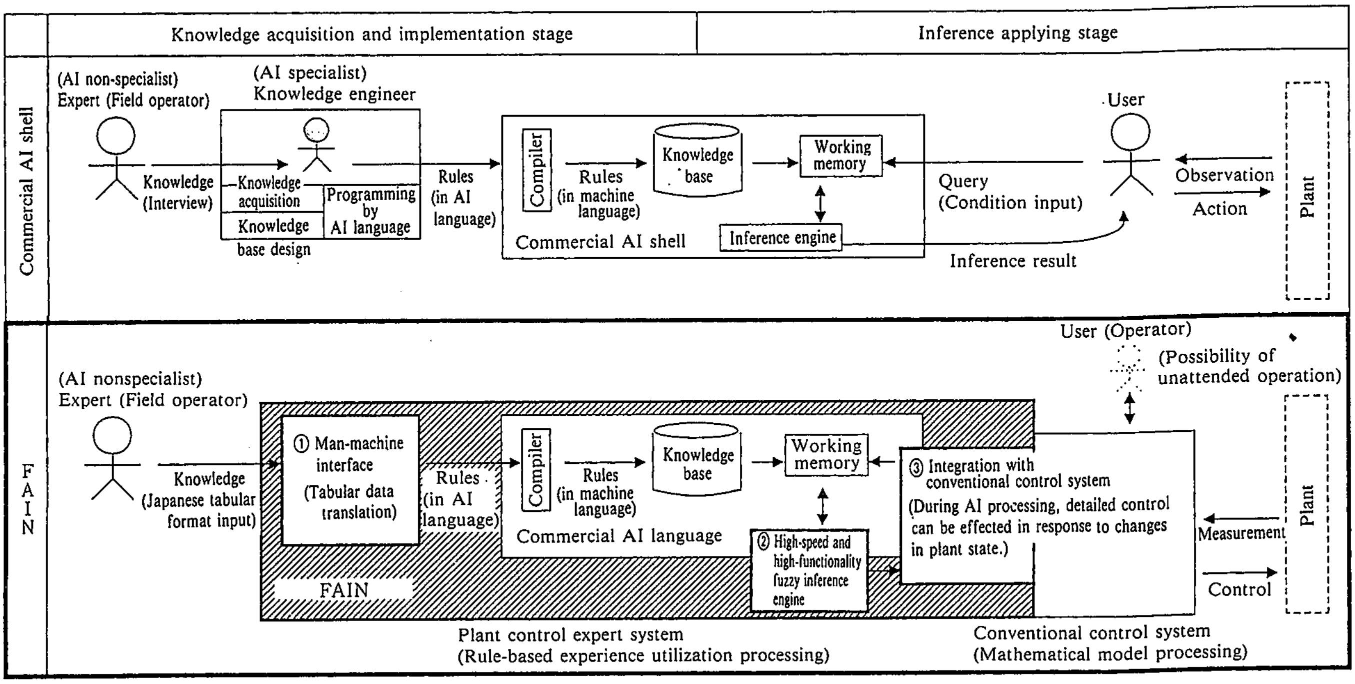

Fig. 4 Comparison of FAIN and commercial AI shell

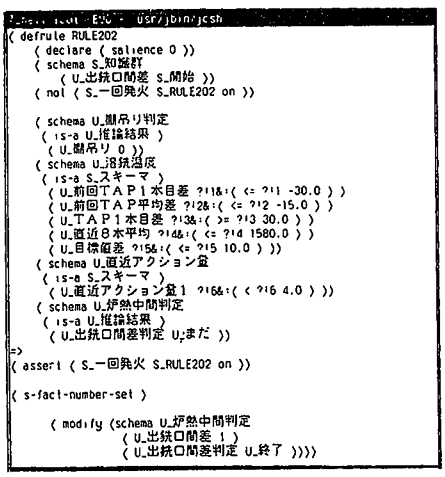

Fig. 5(a) Example of programming by commercial AI language

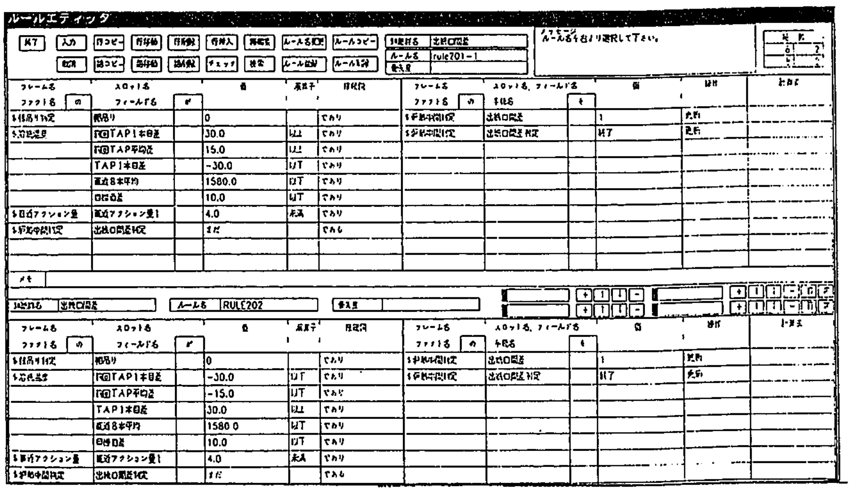

Fig. 5(b) Example of FAIN rule editor display (tabular format entry in Japanese language) with conventional commercial general-purpose AI shells.

(3) Easy integration with conventional control systems

FAIN can be easily interfaced with conventional control systems for reasoning control, such as start and stop of the knowledge base (rules) and function call, and process data exchange. The interfaces can be written in FORTRAN and C language. Multitasking (parallel processing of conventional control program and reasoning), essential for real-time control, is also possible.

(4) Support of fuzzy control function and rich inference verification functions

The fuzzy control function can handle ambiguous knowledge together with rule-based knowledge. FAIN also has the functions of tracing inference, explaining inference, and displaying fuzzy inference results in color graphics, and can easily verify the results of reasoning.

2.3 Knowledge representation and inference methods of FAIN

Conventional program development is of the waterfall type in which the specifications of a program are defined in greater detail in a top-down method, as shown in **Fig. 6**[1]. In the development of an expert system, on the other hand, it is difficult to determine all the required functional specifications and solution algorithms beforehand in a top-down method. Instead, such a prototyping method is employed that specifications can be added and corrected to allow the system to grow in a spiral-up manner. So in the development of FAIN, tabular-format knowledge representation and reasoning strategies were investigated and devised to suit the prototyping method. (If the specifications of the expert system are described by general-purpose tabular-format design documents, the program of the expert system can be automatically generated).

FAIN adopts the forward rule-based reasoning method for real-timeliness and simplicity. As data formats, facts in which a variable number of data items can be handled and frames in which hierarchical data can be handled are used. Since operational knowledge is often ambiguous, uncertain pieces of knowledge, such as certainty factors and fuzzy inferences, can also be handled.

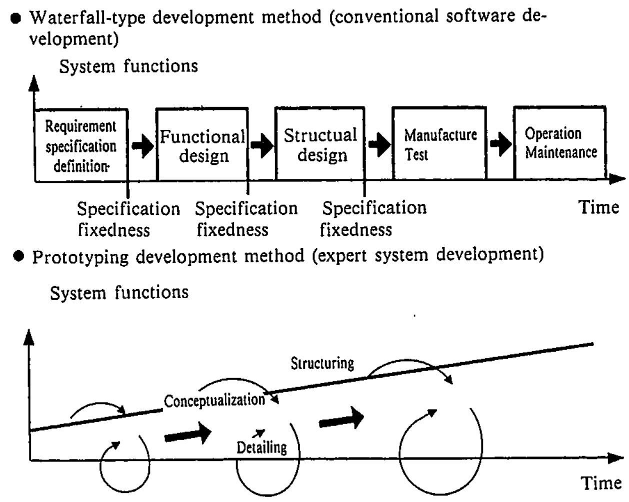

Fig. 6 Differences between conventional software development and expert system development methods

Reasoning is basically performed for rule groups (knowledge groups) in a predefined sequence. Depending on the situation concerned, reasoning sequence can be changed to another knowledge group, of course. If there are knowledge groups where fuzzy rules are stored, FAIN automatically switches to fuzzy reasoning. For example, the process data are preprocessed by the rules in knowledge group 1, the process status is intermediately judged by the fuzzy rules in knowledge group 2, and a comprehensive judgment is made by the rules in knowledge group 3. An expert system in which forward reasoning and fuzzy reasoning are fused can be easily built in this way.

2.4 Software platform of FAIN

Multiwindow and color graphic man-machine interfaces on the engineering workstation (EWS) provide the user with a comfortable expert system building environment. The engineering workstation field, however, is now in rapid transition technologically. The life cycle of machines is becoming shorter and shorter, with the operating system UNIX (basic software) and window system GUI (Graphical User Interfaces like X-Window) being frequently updated. To meet this situation, FAIN was developed using only universal functions in the international standards UNIX and X-Window without using any package software unique to a specific machine (see **Fig. 7**).

As a result, it became possible to unify most of the source programs of FAIN on the SUN and VAX machines that are similar in the OS and GUI, but are different in the software architecture. This unification enabled FAIN to be easily updated, to more readily respond to new machine models, and to reduce the maintenance cost. The adoption of a client-server model through X-Window provides such a configuration that FAIN can be run on an inexpensive stand-alone system to a large-scale network system where plural users can develop plural expert systems at the same time.

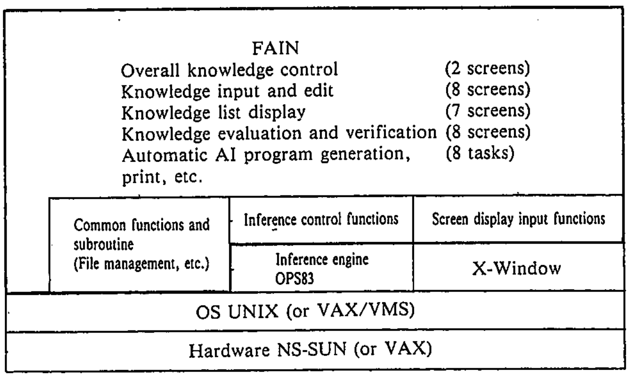

Fig. 7 Software configuration of OPS83 FAIN

3. Application Examples and Evaluation of FAIN

3.1 Outline and evaluation of application

FAIN is used as a practical expert system shell in more than 10 expert systems in and out of Nippon Steel, including a large-scale blast furnace operation support expert system. It is widely used as a prototype building tool in almost all steelworks of Nippon Steel, and is sold by Nippon Steel's Electronics & Information Systems Division Group to outside customers. **Table 2** lists several examples of FAIN application in-house. As shown, FAIN

Table 2 Examples of FAIN Application in Nippon Steel

Type	Expert systemt	Computer
Control	• Blast furnace control operation support • Continuous hot-dip galvanizing line control operation support • Reheating furnace combustion contolt	MC2000 (Nippon Steel) MC2000 (Nippon Steel) MC2000 (Nippon Steel)
Diagnosis	• Hot-rolled coil quality judgment	NS-SUN (Sun)
Planning	• Roll shop roll scheduling • Strutural steel plant screwdown scheduling	VAX (DEC) NS-SUN (Sun)
General	• Expert system building infra-structure in steelworks	NS-SUN (Sun) MC2000 (Nippon Steel)

is applied not only to process control expert systems, but also to rule-based diagnostic-type expert systems and material flow and transfer planning-type expert systems.

In each example, FAIN allows a useful expert system that is commensurate with the actual situation and need of the domain concerned, to be built with much fewer software man-hours than possible with conventional AI languages. It also allows field operators who are familiar with the characteristics of the operation or process concerned to directly participate in the maintenance of the expert system. The fusion of speed with fuzzy reasoning and forward reasoning made it possible to apply FAIN to the expert system of nonsteady-state operational diagnosis and control of rolling and other processes where second order response is demanded. FAIN is also useful as a prototype building shell in clarifying the scope of systematization from scratch, structure of the problem concerned and solution to the problem, and in finding design clues.

Described below is a case in which FAIN was applied to realize the world's first automatic operation of roll shop equipment in cooperation with a conventional control system at a new cold strip mill at Nippon Steel's Yawata Works.

3.2 Application of FAIN to roll shop expert system at new cold strip mill of Yawata Works

3.2.1 Outline of expert system

The roll shop, as shown in **Fig. 8**, is a facility that provides the cold strip mill with rolls of necessary surface specification in a timely manner according to the rolling mill conditions (roll change schedule). It consists of roll grinding machines, chock removers, roll changers, racks, and cars and machines to move the rolls among these pieces of equipment.

For the automatic operation of the roll shop devices, it is necessary to make a roll change scheduling (as to the roll change time and changed roll specification), to meet the changed roll specifi-

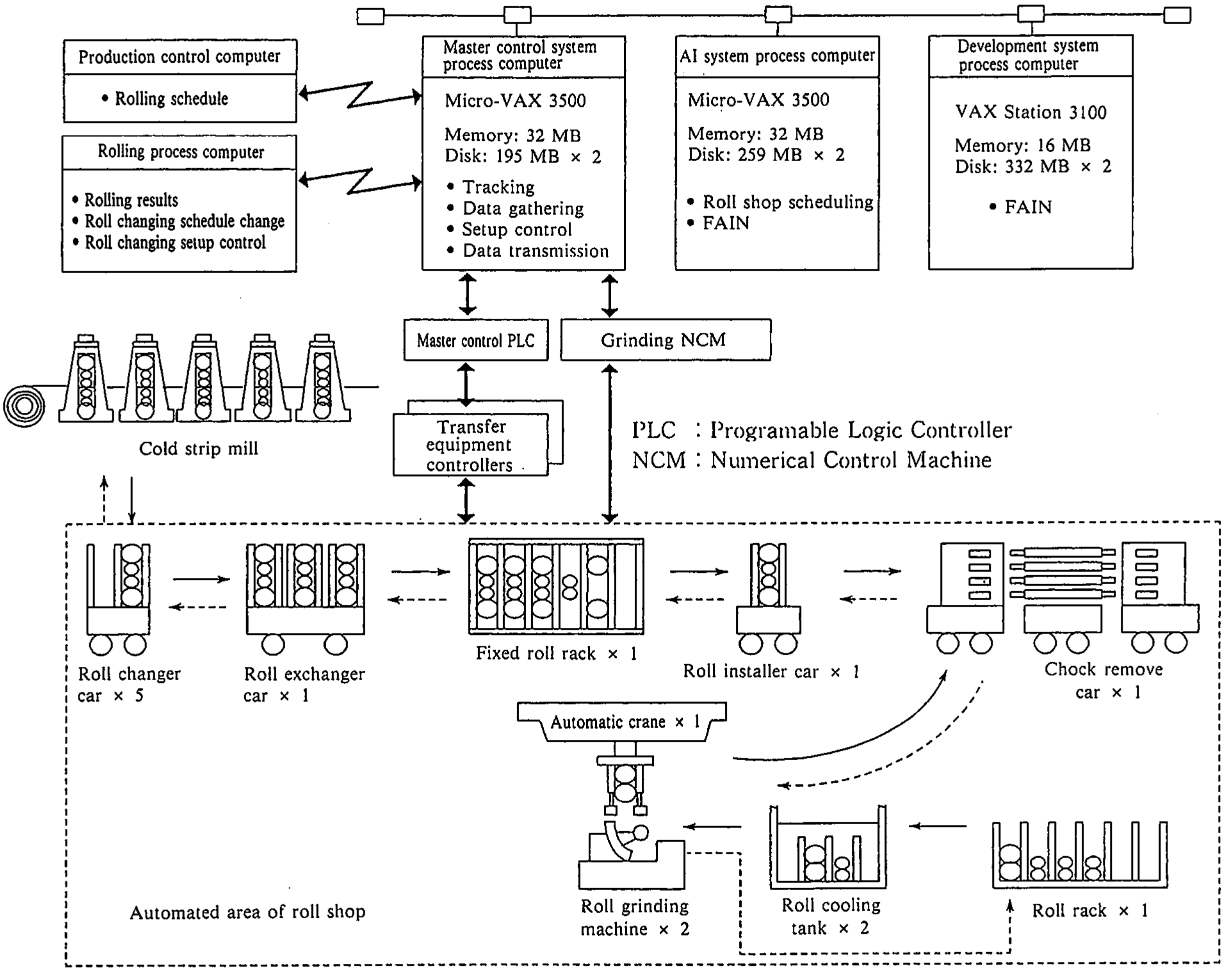

Fig. 8 Configuration of expert system for roll shop at new cold strip mill, Yawata Works

cation, and to select the changed rolls in such a way as to minimize the roll change preparation time according to the roll grinding status (finished, unfinished or withheld) and the specified position in the roll shop. It is also necessary to select the equipment and plan the operating sequence of the equipment according to the operation statuses of such equipment as roll grinding machines, roll transfer devices, and racks, in order to grind and move the selected rolls with high efficiency. In this way, the roll scheduling tasks that were previously performed according to field expert's experience must be systematized into something like a railroad train operation diagram system.

An expert system was constructed to incorporate all such rules of thumb, with a view to best exploiting the merits of an expert system with high flexibility and maintainability.

3.2.2 Advantages of expert system

Advantages of expert system are explained here in the case for example of selecting the transfer equipment to be used and planning the operating sequence for it. Transfer tasks that can be executed (transfer equipment that can be used) are determined, and a task of the highest priority is selected and assigned considering such factors as timely supply of rolls to a stand and high availability of grinding machines. This procedure is repeated. There are numerous, complex combinations of conditions that can be executed. If individually described by the conventional procedural processing method, the combinations involve a huge number of programming steps and processing times, delay the automatic operation of the roll shop transfer equipment, and deteriorate the maintainability of the roll shop control system.

The expert system, on the other hand, can judge at high speed whether or not the combinations of conditions hold by its powerful pattern matching function (condition part verifying function) and can represent the combinations of conditions that can be executed as thought by the human expert without being overly conscious of the processing descriptive sequence. If the rule priority representation capacity of FAIN is used, the priority of transfer tasks can be simply described, and the development and maintenance of the system can be easily performed without being conscious of the descriptive sequence.

3.2.3 Evaluation of expert system

(1) After startup adjustments, the automatic transfer equipment and the expert system have been smoothly operating, thereby proving the usefulness of the expert system.

(2) The expert system that involves the problem of optimizing complex combinations was successfully built in a compact form with relatively few rules and software man-hours, as shown in **Table 3**. This was made possible by the tabular-format knowledge representation characteristic of FAIN, knowledge arrangement by knowledge groups, and rich verification functions in addition to the above-mentioned advantages of the expert system.

(3) Partly in relation to (2) above, the system is satisfactory also in terms of processing time and maintainability.

Table 3 Scale of roll shop expert system

Item	Scale
Number of data items used for inference	12,164
Number of rules	299
Number of OPS83 source program steps automatically generated by FAIN	20,000 (steps)

4. Present Problems and Future Prospects of FAIN

With the usefulness of FAIN widely recognized through its application in Nippon Steel, there has arisen strong demand for a multi-vendor version of FAIN with improved portability of the knowledge base (rules) and without restrictions on the computer models on which FAIN can work. Nippon Steel's Electronics Research Laboratory is conducting work on the research and development of a superhigh-speed inference engine to take the place of commercial AI languages. The multi-vendor version of FAIN resuting from this research will be designated FAIN-II.

The following problems will have to be solved before expert systems can be applied to a wider spectrum of tasks, such as control and optimization of an entire steelworks, or staff design work:

(1) Development into shells for real-time planning tasks

As discussed above, FAIN is applied to many rule-based expert systems for process control and in-process material flow and transfer control. We will have to aim at expert systems for controlling material flow and transfer involving multiple processes and for sequentially making appropriate production plans in real time by ensuring matching between processes. Such expert systems will contribute to the increase of direct rolling ratio and reduction of work-in-process inventory. The Electronics Research Laboratory is carrying out research on the modularization of software addressing planning tasks, knowledge representation methods and high-speed inference engines, and graphic user interfaces. As an engineering arm of Nippon Steel, the Technical Development Bureau will make positive use of these reseach results of leading-edge software in developing more advanced expert systems and upgrading FAIN.

(2) Intelligent expert systems in true sense of term "intelligent"

Present expert systems can handle only such tasks that human expert knowledge can be arranged and represented as rules in a knowledge base. They leave a demand for expert systems that can perform more intelligent information processing tasks, such as analogical reasoning and learning, that go beyond the limits of today's rule-based expert systems. Nippon Steel is working on the practical use of structural steel quality design and rolling schedule determination expert systems by applying advanced knowledge processing technologies like case-based reasoning and hypothetical reasoning and with the research of automatic knowledge acquisition technology. These research results will be reflected in the future versions of FAIN.

5. Conclusions

Conventional software development tools, such as CASE and commercial general-purpose AI shells, are intended for computer specialists, whereas FAIN is the first tool developed for direct use by operators in the field. FAIN has provided field operators with direct access to the logic core upgrading of expert systems in correspondence with changes in production and operational conditions including operational know-how and operational standards. Expert systems thus continue to be essential and familiar tools for the field operators.

We will continue to go ahead with the application and improvement of FAIN in and out of Nippon Steel, develop a multi-vendor and planning version of FAIN, that is FAIN-II, by solving the aforementioned problems, and make expert systems more intelligent in the true sense of the term "intelligent"

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