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Development and Application of Object-Oriented Comprehensive Operation Control System for Sintering Process

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Abstract:

An object-oriented comprehensive operation control system has been developed for the sintering process at the No. 1 and No. 2 sinter plants of Oita Works. Compared with conventional artificial intelligence (AI) based operation control systems, the new object-oriented operation control system is smaller in program size and better in program simplicity and covers all steps of the sintering process. System maintainability has been sharply improved, the time from system design to completion has been shortened, and high and stable system availability for a long period of time has been accomplished. The system has helped to achieve operational improvements, such as higher sinter yield and smaller coke-oven gas (COG) rate, and to rationalize three-shift work.

1. Introduction

Many ironmaking process control systems are based on knowledge engineering. Such areas of knowledge engineering as the fuzzy theory, neural network, and expert system are used in combination, as represented by blast furnace operation control systems[1-3]. Knowledge engineering has been applied in the ironmaking processes for the following main reasons. There are great variations among raw materials and fuels and in air humidity and other disturbances. The in-process temperature is at such a high level that it is difficult to accurately measure. The dead time for process control is very long. Physical and chemical phenomena are entangled in a complex manner.

Conventional artificial intelligence (AI) based operation control systems generally embody the knowledge of skilled operators and systematize their thinking flow. This methodology tends to complicate the system configuration and to make the program size very large. In particular, the sintering process consists of many steps, including transportation, bin level control, mixing and agglomeration, as-segregated charging, ignition, sintering, and screening. When a comprehensive operation control system is built to cover all the steps of the sintering process, it inevitably becomes very large in scale.

As the operation control system increases in complexity and scale, it exponentially worsens in maintainability. For this reason, it is feared that such an operation control system may be unable

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to keep up with changes in equipment and operating conditions resulting from the development of new technology and may become obsolete prematurely.

Given these problems, there has been a rising call for the development of a new AI operation control system that can simplify the system structure while maintaining control accuracy and that can improve maintainability. An object-oriented, distributed, comprehensive operation control system has been developed and implemented at the No. 1 and No. 2 sinter plants of Oita Works.

2. Application of Knowledge Engineering to Sintering Process

2.1 Sintering process and conventional operation control system

Fig. 1 shows a general view of the sinter manufacturing process. The sintering raw materials include iron ore as the main material, flux for compositional control, coke breeze as fuel, and undersize sinter screened and returned as return fines. These raw materials are mixed and agglomerated in the drum mixer, and the resultant raw sinter mix is charged as segregated onto the sintering machine. The bed of the raw sinter mix is ignited on the surface in the ignition furnace, the coke breeze is continuously burned by downdraft air, and some of the mix is melted to form sinter cake of interconnected particles.

In the sintering machine, combustion, melting, solidification, and cooling continuously occur in this way from the top to the bottom of the sinter bed. After the completion of combustion to the bottom of the bed, the sinter cake is sized by crushers and screens. The sized product is sent as sinter to the blast furnace. The undersize fraction is recycled as return fines to the sintering process.

One factor responsible for the variations in the sintering process is the use of return fines. The properties of the return fines not only differ from those of iron ore as the main feed material, but also constantly vary, depending on the firing condition and on the conditions of such steps as cooling and screening. The use of the return fines constantly feeds back the effect of the past sintering condition to the sintering process, destabilizing the sintering process and greatly increasing the dead time in process control.

Among the other contributors to the variations in the sintering process are the particle size distribution; chemical composition and moisture content of the raw mix , which vary with time, and the particle size segregation of the raw mix in the bed depth direction , which varies in the width and machine length directions. These variations in the raw mix conditions alter the sintering reactions, with the result that the quality and quantity of product sinter vary.

As operation control systems for the sintering process that behaves in such a complex way as noted above, integrated control-oriented AI operation control systems have been built by introducing knowledge engineering in general and expert systems and fuzzy theory in particular. These control systems have greatly contributed to the operational stabilization of the sintering process. In the past few years, the operating conditions of the sintering process have significantly changed, as evidenced by the use of poor-quality, low-cost raw materials in large quantities and the change in quality required of the sinter. The operating methods of the sintering process have also changed. Under these circumstances, the flexibility to keep up with these changes is required of operation control systems for sinter plants. Conventional AI-based operation control systems were so complex and huge that their rapid modification was extremely difficult and their flexibility was low. Their basic structure had to be drastically reviewed and revamped to ensure rapid response to the changes taking place in the sintering process.

2.2 Basic design of new system

The following eight items were established as design criteria for the new system to achieve flexibility and field operator friendliness:

1)Simplification of control purpose and visualization of operating action judgment flow

2)Simplification of knowledge base and operating data evaluation sections

3)Easy system maintenance by operators who are not control experts

4)Stability of control against variations and disturbances

5)Stable operation of operation control system with high availability over long period of time

6)Increase in speed of tuning operation control system

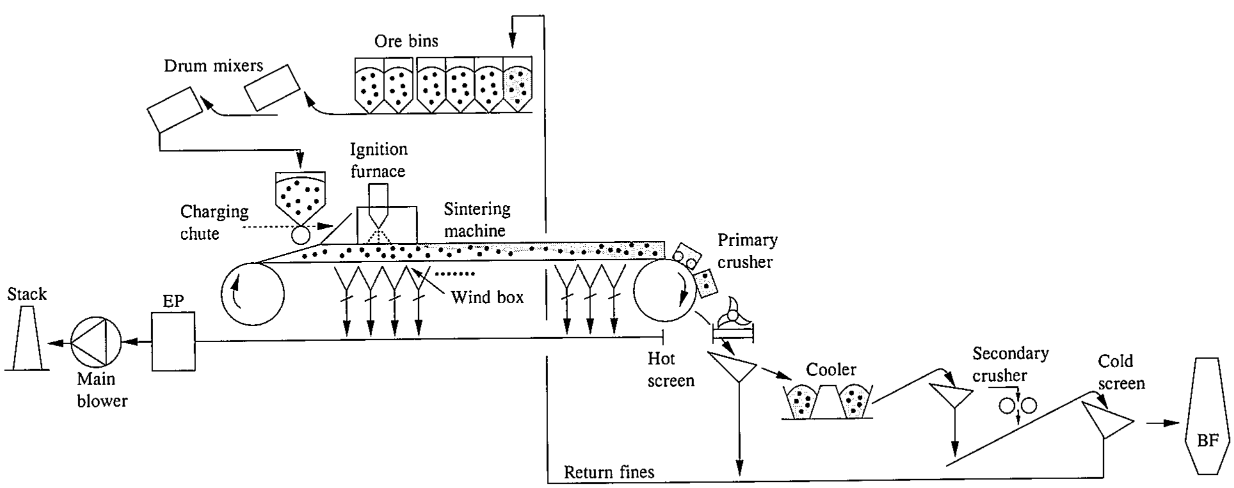

Fig. 1 Process flowchart of sinter plant

7)Reduction in program creation time
8)Coverage of entire sintering process

The basic system configuration was designed according to the above criteria. Compared with conventional operation control systems, the new system is characterized by the following four items:

1)Change from an integrated control-oriented, top-down system to a distributed object-oriented system
2)Separation of the operating data evaluation section from the knowledge base section
3)Modular structure of the operating data evaluation section
4)Addition of an on-line maintenance system

3. Characteristics of Comprehensive Operation Control System

3.1 Adoption of object-oriented operation control system

Table 1 shows the rule configuration of the system. This distributed object-oriented system has seven knowledge bases, which are independent objects. Each knowledge base object consists of multiple rule groups. There are 25 rule groups in total. Each rule group consists of the operating data evaluation section and the inference section. The processing flow of these items of information in the system is shown in **Fig. 2**.

The knowledge base objects have the following purposes:

Table 1 Rule configuration of system

	Control objects	Rule groups		Number of rules
		Automatic control	Semiautomatic control	
1	Sintering	2	4	1,528
2	Quality	0	8	692
3	Return fines	1	1	513
4	Production	0	3	1,122
5	Bedded ore pile change	0	2	445
6	Product screening	0	2	330
7	Heavy rainfall	0	2	491
Total		3	22	5,121

1)Sintering: The sintering conditions from raw mix feed to sinter cake discharge are optimized.
2)Quality: Sinter quality is controlled to prevent sinter quality variations.
3)Return fines: The amount of return fines to be blended is controlled to prevent variations in sintering conditions.
4)Production: Overall sintering operations, including sinter production adjustment and planning and sinter production cost evaluation, are coordinated.
5)Bedded ore pile change: When a bedded ore pile change is made, the sinter raw material bins are switched, a blend change is made, and sintering variations are prevented.
6)Product screening: The screening step is monitored and adjusted.
7)Heavy rainfall: Operational variations during a heavy rainfall are prevented.

The adoption of the distributed system has made it possible to minimize the number of programs in the rule groups and the scope of maintenance, to provide rapid response to improvements in maintainability and rule accuracy, and to reduce the system failure rate.

A dedicated programmer is assigned to each object, so that the knowledge of skilled operators can be accurately reflected in the programs. Programs can also be concurrently created to shorten the program preparation time.

One problem with an objected-oriented distributed system is the difficulty of mutual adjustment when multiple objects or rule groups are started simultaneously. This problem is solved by setting the action adoption priority of each object and rule group and the constraints for the simultaneous and parallel start of multiple objects and rule groups. These settings can be easily modified on the cathode-ray tube (CRT) screen.

3.2 Separation of operating data evaluation section from knowledge base section

Another main characteristic of the system is the complete separation of the operating data evaluation section from the knowl-

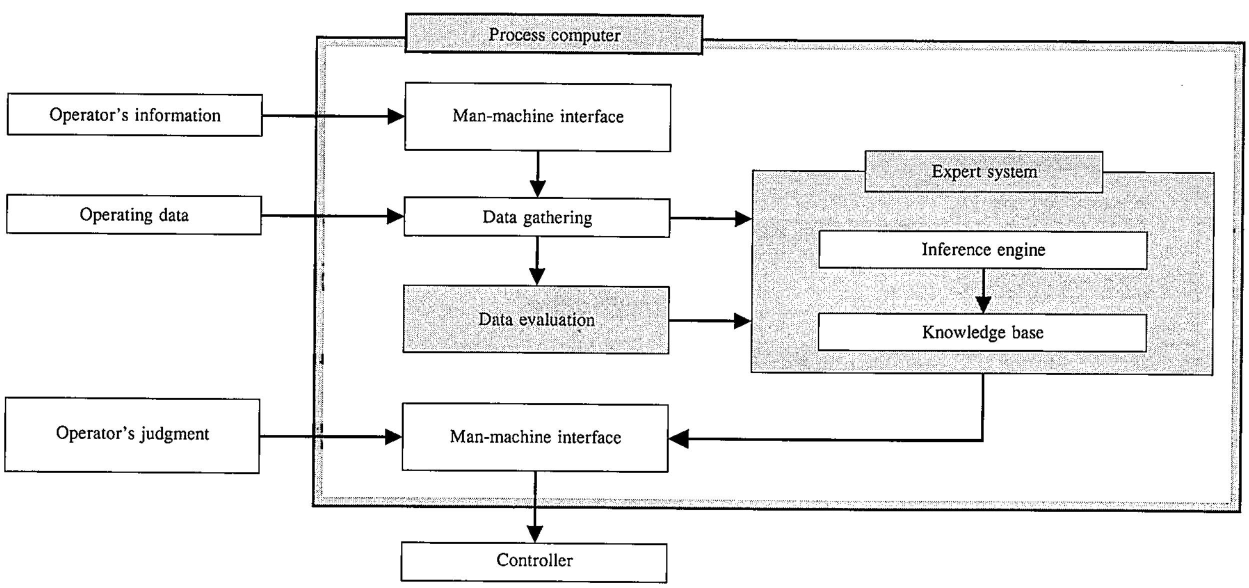

Fig. 2 Information processing flow of system

edge base section. This separation makes it possible to disclose the flow of the operating data evaluation structure to the operator. In addition, evaluation thresholds and functions can be set and modified on the CRT screen. The characteristics of this system configuration are shown in **Fig. 3**. With the adoption of this system, skilled operators can teach the system to learn to flexibly adapt to new operating conditions. This evaluation flow can also be utilized for field personnel education. Given the labor savings in programming and the simplification of system tuning and maintenance tasks, automation of the learning function is not introduced, and only the totalization of the rule application ratio is automated.

3.3 Modularization of operating data evaluation section

The operating data evaluation section is characteristic in that the operating data evaluation structure is not built as a black box as in a neural network but is modularized to clarify the evaluation steps involved. This modularization can sharply shorten the program production and tuning steps. More specifically, two items of operating data are simultaneously evaluated for a threshold, and two threshold evaluation results are combined to perform the next evaluation, as illustrated in **Fig. 4**. This procedure is repeated to finally reach one evaluation. The evaluation structure is a tournament type.

The evaluation functions are simple integers, not continuous linear functions using regression equations or fuzzy functions through stochastic variables. This is designed to assure robustness against very large variations inherent in the sintering process. This also agrees with the purpose that the results of intermediate evaluation should be displayed on the CRT screen in an easy-to-understand manner.

3.4 Setting of on-line maintenance functions

The following operating modes are established so that the operation control system can be easily maintained by operators in the field instead of by program maintenance experts. The operating modes can be selected so that one operating mode can be set for every 25 rule groups.

1)Automatic mode

The operation control system automatically controls the sintering process according to its judgement of the operating actions, without operator intervention. The system is usually used in this mode.

2)Semiautomatic mode

The operating action presented by the operation control system is displayed on the CRT screen and judged by the operator to see if it is practical or not. The system is operated in this mode to perform a very important action and to tune the operating data evaluation section or knowledge base section.

3)Manual mode

The manual mode is the same as the semiautomatic mode until the CRT screen display phase, but it is separate from the electrical control system. The manual mode is used for the off-line testing of the system during the extensive modification of a knowledge base, for example. It can also be used as a simulation function.

In addition, a knowledge base maintenance machine is installed in the field to allow the field operators to maintain the knowledge bases in a timely manner.

4. Application Benefits of Operation Control System

The comprehensive operation control system has stabilized the operation of the Nos. 1 and 2 Dwight-Lloyd (DL) sinter plants at Oita Works. The results are shown in **Fig. 5**. The sinter yield and COG rate have been improved. The sinter quality variations have also been reduced. **Fig. 6** shows the distribution of the modes in which the system has been operated since its start-up. The ratio of the automatic mode has risen rapidly. In the fifth

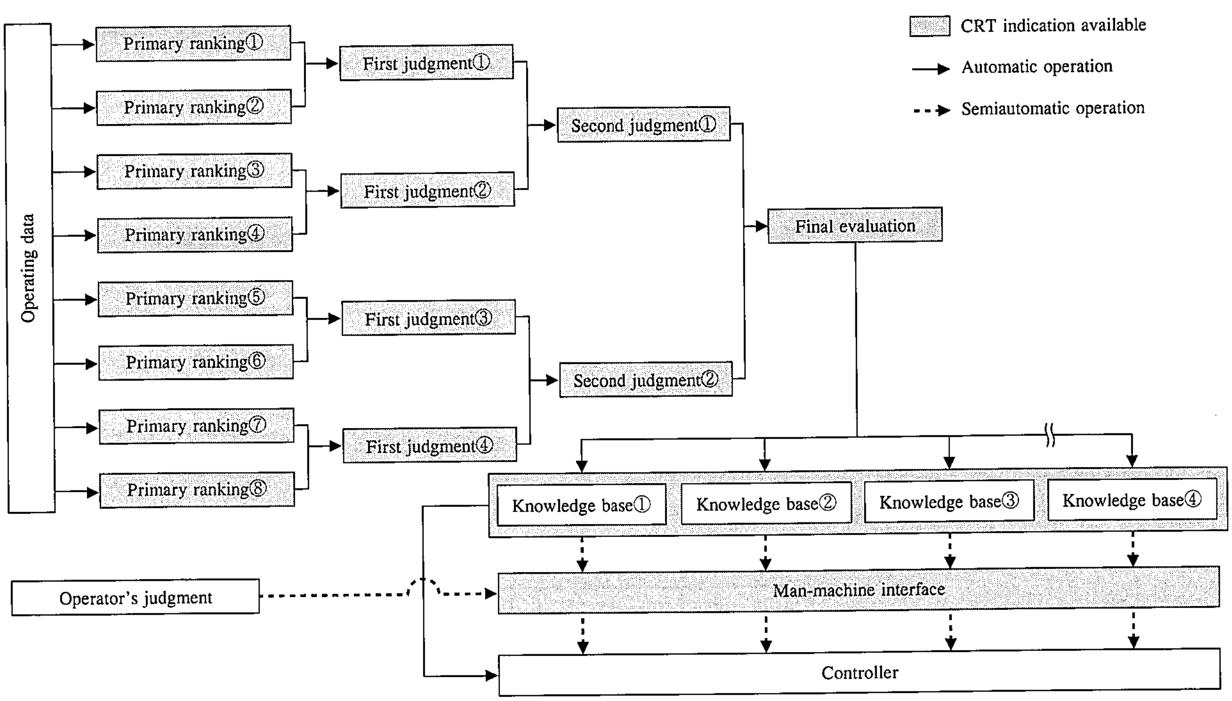

Fig. 3 Program configuration of system

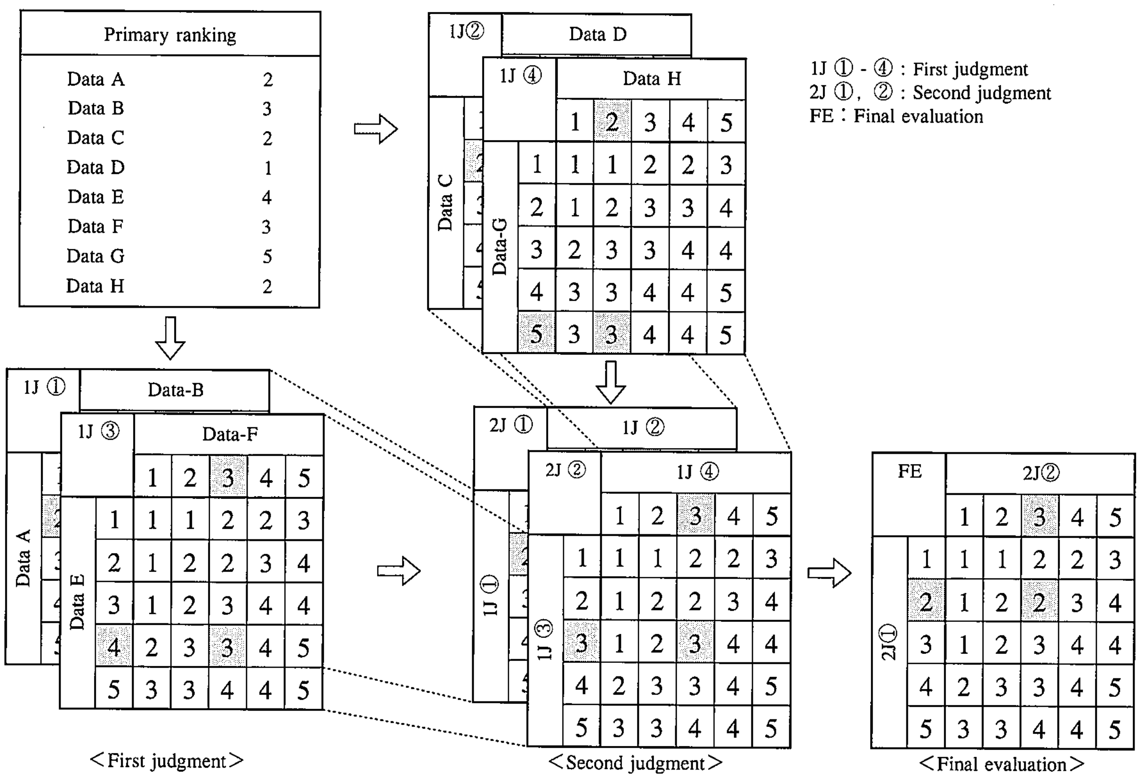

Fig. 4 Example of operating data evaluation flow

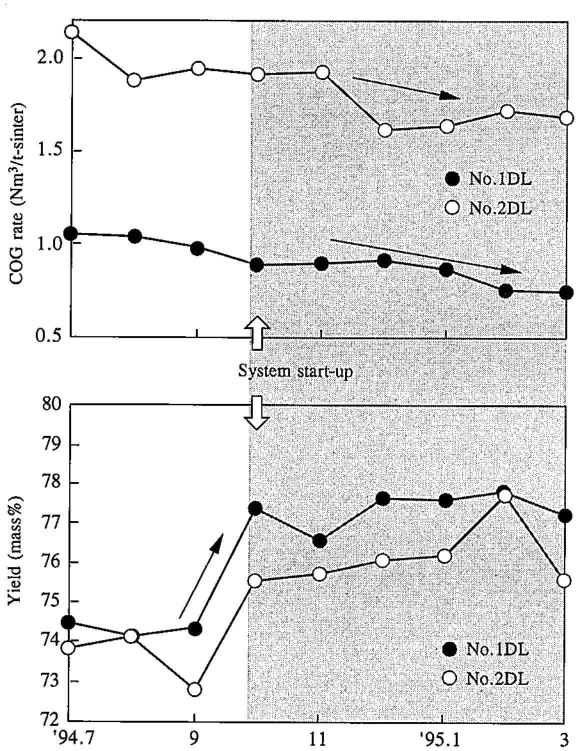

Fig. 5 Operating results of Nos. 1 and 2 Dwight-Lloyd (DL) sinter plants at Oita Works

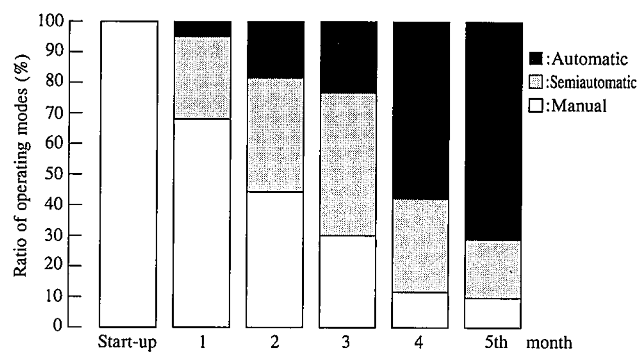

Fig. 6 Reduction in operator intervention by use of system

month after the start-up of the system, operator intervention was reduced by about 70%. Operation judgment and overall operation coordination are both systematized to reduce the number of shift foremen required.

The system development period was successfully shortened to 12 months from the originally estimated 18 months by the introduction of objects, separation of the operating data evaluation section from the knowledge base section, and modularization of the operating data evaluation section. The increase in the rapidity of tuning since the start-up of the system is shown in **Figs. 7** and **8**. After about five months, the agreement ratio of rules with respect to operators' judgment exceeded 90%, and the application ratio of rules with respect to all operating actions reached about 80%.

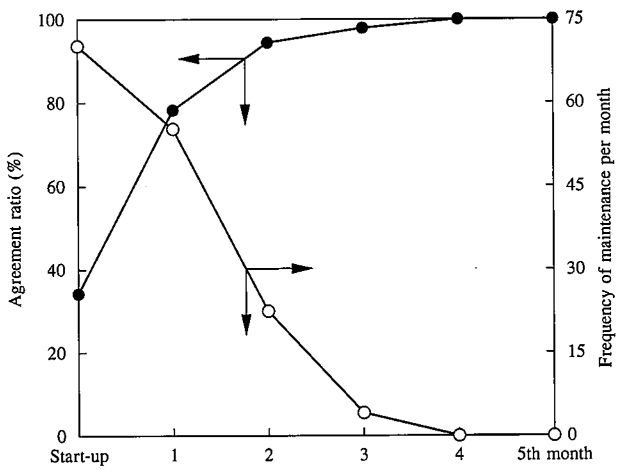

Fig. 7 Changes in agreement ratio and frequency of maintenance per month

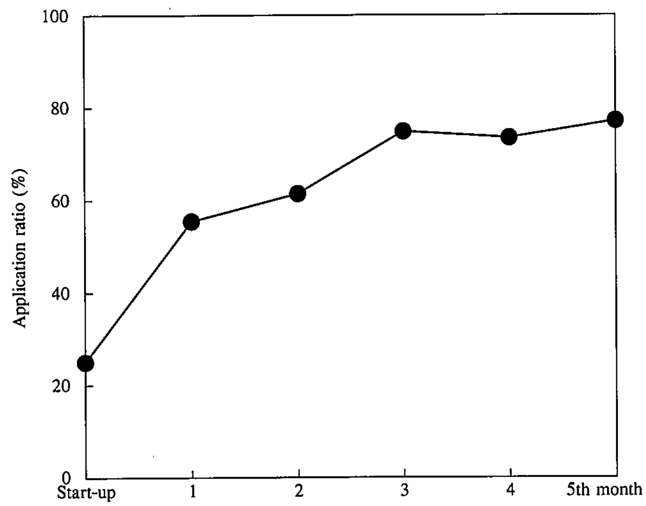

Fig. 8 Change in application ratio

5. Conclusions

The characteristics and benefits of the comprehensive operation control system introduced at the Nos. 1 and 2 sinter plants of Oita Works have been described above. The system is characterized by (1) adoption of a distributed system, (2) adoption of object-oriented flow, and (3) simplification and modularization of the evaluation structure. These measures have produced many practical benefits, such as improvement in system maintainability, reduction in system development time, and stable operation of the system at a high level for a long period of time.

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