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Information Systems

Production Control Systems at Steelworks

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Production Control Systems at Steelworks*


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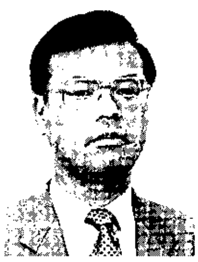
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1 Introduction

Because of the enormous data processing requirements in steelworks production control, Kawasaki Steel undertook computerization at an early date. Beginning with batch processing methods, the company successively introduced on-line real-time systems, generally establishing production control systems in its major plants by the latter half of the 1970's.

Subsequently, however, to meet customers' increasingly stringent requirements for product performance and delivery time, the development of new products under a policy emphasizing higher added values and the rationalization of production processes, including principally the automation of facilities and the synchronization and continuation of operations, were promoted. To meet these needs, more sophisticated production control systems were required. At this time, however, some systems developed earlier were becoming obsolete, which made it difficult to meet the new requirements by remodeling existing systems. This necessitated the refurbishment of systems based on a new concept.

In this situation, the entire company committed itself to the refurbishment of production control systems, principally at Chiba and Mizushima Works. A gradual switchover to new systems has been achieved since the mid-1980s.

The planning function has been substantially developed, and includes building of a weekly scheduling system which integrates all products and processes. On the operational level, the line operation function and material handling between processes have seen a marked expansion, which has occurred simultaneously with the rationalization of facilities. From the viewpoint of rationalization of the office system, the strengthening of

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functions has also been extended to the area of staff support.

This paper discusses the production control systems of the steelworks which have been developed in terms of the following three items with sheet and strip as their main object:

(1) Integrated production process planning system at Chiba Works as a weekly scheduling function.
(2) Steelmaking, hot-rolling, and cold-rolling systems at Mizushima Works with respect to execution control and operation control functions.
(3) Standards management system at Chiba Works, which constitutes part of the quality assurance function.

2 Basic Concept of System Building

Steel production comprises many processes and related facilities, including ironmaking, steelmaking, continuous casting, rolling, finishing, heat treatment, and surface coating. Each facility has its own specific quantitative limitations on manufacturing lots and chance restrictions. These limits, which are attributable to the specifications of the facility and the characteristics of the operation, mean that a certain amount of excess inventory is required in each process. The existence of in-process inventory extends lead times and causes energy loss in the processes between steelmaking and hot-rolling. Both of these problems are detrimental in terms of cost. On the other hand, in order to meet customers' increasingly sophisticated and diverse needs, better chance and lot flexibility and a reduction in lot size are required, creating additional pressure for rationalization.

The response to this situation has involved both production facilities and operational techniques, and information systems: Continuation of processes, chance-free operation, and the synchronization of neighboring processes by shortening of changing-over time have been pushed forward, in concert with the refurbishment of systems. The basic concept here was the realization of synchronized and continued operation through the integration of production facilities and technology.

There is no doubt that the increase of labor productivity is a fundamental task in industry; therefore, labor-saving was also among the important goals of this project.

2.1 Problems in Synchronization and Continuation of Operation

The problems in achieving synchronization and continuation of operation can be summarized by the following four points:

(1) Ensuring the balance of processing volumes between facilities.
(2) Adjusting the processing order of products between adjacent processes (proper timing of feed).
(3) Simplifying and expediting the flow of materials and products.
(4) Avoiding disruption of feeding process schedules.

2.2 Strategy for Problem Solution

In solving these problems, the roles to be played by production facilities and operational technologies are of considerable significance. To take full advantage of potential capacity, upgrading of the information system, including management technology, is also indispensable. The information systems at various stages from planning to operation in steelmaking, hot-rolling, and cold-rolling were refurbished as part of the rationalization of production and material handling equipment. The strategy corresponding to each problem is described in the following.

2.2.1 Ensuring of balance of processing volumes among facilities

It goes without saying that the balance of capacities among individual facilities is a precondition for balanced processing volumes. In the complex, diversified steelmaking process, however, it is essential to control material input and flow so as to avoid placing an inordinate burden on any single facility and ensure that materials shortages do not occur. The general aim is to maximize overall production capacity while preventing undue prolongations of lead time.

To achieve this aim, the continuous casting capacity must be increased while maintaining the capacity balance between continuous casting and hot-rolling, which occupies a specially important position in the manufacturing process. Once this is achieved, the next goal is to realize a fully developed planning function, principally in connection with the weekly scheduling system, aimed at securing an overall balance in the works.

2.2.2 Chance flexibility for processes and facilities

A reduction in production chance restrictions at each facility makes it possible to optimize production schedules between up- and down-stream processes. Facilities developed and installed for this purpose include the slab-sizing press between the continuous casting and hot-rolling processes and work roll shift mill at the hot strip train. This equipment has greatly enhanced the flexibility of mold width chance and roll chance.

In the information system, on the other hand, synchronization is pursued in terms of weekly and daily scheduling of the steelmaking-hot rolling sequence and the pickling-cold rolling-continuous annealing sequence. In addition, a function to support synchronized operation has been realized by developing a simulator for time forecast as a tool to support the schedule adjustment function of both the steelmaking and hot-rolling processes.

2.2.3 Simplifying and expediting of material flow

Ideally, two or more processes should be integrated into a single continuous process. It is also desirable to minimize the need for off-line operations such as reconditioning. This is principally achieved by facility mechanization. In process continuation, the continuation of the pickling-cold rolling sequence has been realized, and CAL equipment newly installed for the annealing-finishing process. Further, facilities have been installed for the automation and continuation of the conditioning process for continuously cast slabs, for augmentation of the hot rolling-width divider, which is used to divide slabs cast in double width into narrow width products, and for coil transportation in the coil yard.

2.2.4 Securing of on-schedule flow of materials and products

Material flow allowing on-schedule operation is secured by maintaining operational stability and a quality which minimizes rejections.

(1) Stability of Operation and Quality
To date, a variety of improvement and rationalization measures have been adopted for production facilities and operation technologies. Further progress in the stability of operations and product quality will require the introduction of microcomputer-based diagnostic functions for quality and facilities and improvement of the configuration of the tundish of the continuous caster, among other tasks.
Full development of the quality control and assurance functions of information systems will especially be pursued. To control product quality, a management system of standards for quality design and operation is presumed, so that a chain of these steps, i.e., institution and revision and transmission to line operators of standards, is now supported by a computerized information system. For quality assurance, feedforward of quality analysis has been enhanced to elaborate the aimed quality targets.

(2) Material Handling
The information system gurantees on-schedule operation which is supported by computerized information on material location and transportation. For example, perfect tracking of materials and products from the hot metal stage through cold rolling, and computerizing piece-by-piece location identification and transportation instructions for all materials and products.

(3) Corrections at the Time of Schedule Disruption
Correction is necessary to limit the effect of deviations from schedule. Because this requires rapid detection, the operational monitoring function and operation adjustment function require upgrading.

3 Weekly Scheduling System

3.1 Necessity of System Building

The facilities for sheets and strip at Chiba Works comprise large numbers of facilities, as shown in **Table 1**. Each of these units operates at a monthly production rate of several tens to several hundreds of thousands of tons, and has its own characteristic chance and quantity restrictions. To secure scheduled production and meet the delivery schedule requirements of individual orders under this type of production configuration, production management with special emphasis on good planning is essential. Because a large amount of energy is both used and generated in steel manufacturing, a planning-oriented policy is also important from the viewpoint of maintaining the works' energy balance.

A long cherished dream in steelworks management has been the establishment of a schedule directed at the optimization of operations through integration of all facilities and products. Meeting a precise plan at the weekly scheduling level and covering the entire steelworks, however, is very difficult in actual practice, because of the numerous chance restrictions at each facility and such disrupting factors as the occurrence of defects. The preparation of an accurate plan requires the processing of an enormous amount of data in a short time, which also entails high information processing costs.

Nevertheless, in recent years the necessity of manufacturing quality products on a shorter delivery schedule has become more pronounced. To meet need, it was

Table 1 Main production facilities for sheets and strip at Chiba Works

Process	Facility	No. of units
Steel making	· Basic oxygen furnace	4
	· Continuous casting machine	2
Hot rolling	Hot strip mill	2
Pickling	· Pickling line	4
	· Continuous annealing & pickling line	1
Cold rolling	· Cold strip mill	3
	· Double cold reduction mill	1
	· 80″ reversing mill	1
Annealing	· Annealing furnace	3
	· Continuous annealing line	3
Surface coating	· Continuous galvanizing line	3
	· Electrolytic galvanizing line	1
	· Electrolytic tinning line	2
	· Tin-free line	1

essential to establish a new weekly scheduling system aimed at optimization of the entire steelworks. This optimization involved not only the rationalization of manufacturing facilities, which are mainly targeted for synchronization and continuation, but also the interrelation of manufacturing functions with other systems, including energy, with the operational balance of all processes taken into consideration from the viewpoint of information systems.

There had been progress in production technology such as the promotion of chance-free operation at each facility, the rationalization of material flow between facilities, and improvement in operational techniques. Enormous progress has also been made in information processing technology, where a prodigious amount of data may now be processed quickly and at comparatively low cost. These advances have brought to maturity the conditions for the building of an effective weekly scheduling system.

3.2 Outline of the System

A new system in which the integration of product types and of processes has been pursued was put to practical operation at the end of July 1987, and is called the Integrated Production Process Planning System because of its feature.

This system receives actual data from the steelmaking, hot-rolling, and cold-rolling systems, and order information from the order entry system. A weekly production process plan is made out using about 60 000 items of information as to slabs and coils, about 4 000 items of order information, and about 310 types related to standards and specifications registered in the standards management system.

The results of weekly production process scheduling, including the prearranged processing dates for the all facilities concerned, are conveyed to the steelmaking, hot-rolling, and cold-rolling systems. With the weekly scheduling results as an operational guide, daily scheduling, in which more precise operational conditions and the latest operational situation are reflected, is prepared daily for each system.

For the energy system, information for the calculation of the energy balance is provided. Information for evaluation is exchanged between the scheduling and integrated data analysis systems.

3.2.1 System function

The system composition and processing flow are shown in **Fig. 1.** ① Product and order information, including the latest information as to slabs and coils, which is basic for scheduling, is identified and edited for planning. Orders are assigned to surplus slabs. ② Next, in-process slabs and coils and orders are distributed to each facility with the balance well adjusted. ③ The personnel in charge of planning, on studying the above results, indicate a parameter for the correction of the distribution results. ④ Upon receipt of these instructions, the slabs, coils and orders are again distributed. ⑤ Subsequently, to improve planning accuracy, products are organized into lots by cast or by charge, that is, grouped by operational process so that each lot has similar characteristics; the processing order of the lots is then determined. ⑥ The person in charge of scheduling, reviewing these results, attempts to correct problems. ⑦ Slabs and coils are designed on the basis of orders assigned to each facility, arranged into lots, and assigned processing an order. ⑧ Because assignment changes the lot size when orders are converted into slabs and coils, lots are reviewed to determine the facilities by which the slabs and coils are to be processed individually, and to schedule processing dates. ⑨ The results of the weekly scheduling thus prepared are edited and conveyed to the steelmaking and hot-rolling systems. ⑩ The results of this scheduling are compared with operational results, and evaluation materials provided as to various management indices.

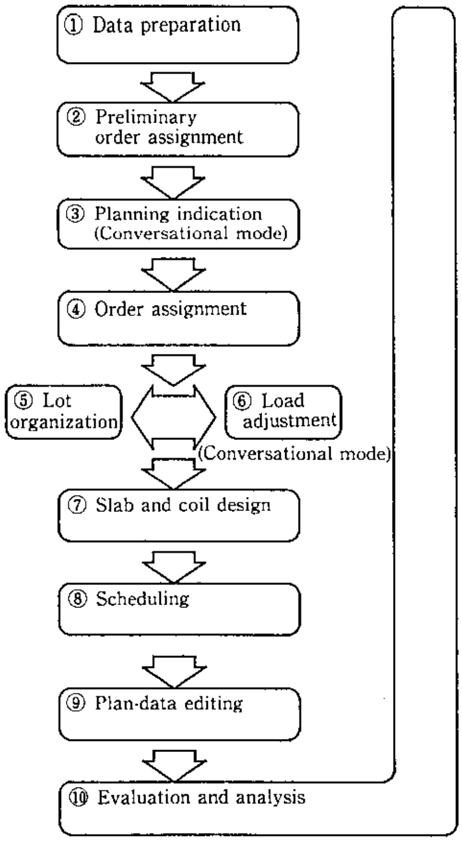


Fig. 1 Outline of weekly scheduling system

3.2.2 Characteristics of the system

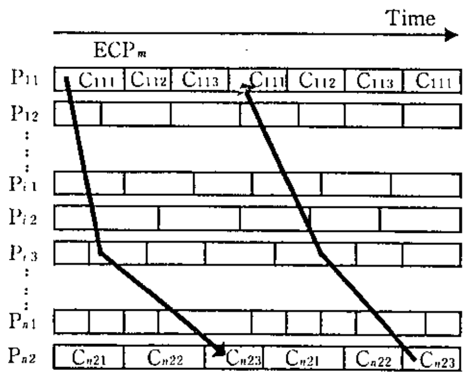
As characteristics of this system, the following five points are enumerated:

(1) Weekly Scheduling on a 7-Day Basis

This system uses weekly scheduling on a 7-day basis in concert with the work schedule of the planner and the large operational cycle of the works.

(2) Scheduling of Prearranged Processing Dates Covering All Processes
Prearranged processing dates as to slabs and coils left in-process and orders scheduled for production are assigned to the facilities, which exceed about 70 in number and range from steelmaking to final process. Furthermore, scheduling extends to the prediction of dates of warehousing more than one month later.

(3) Order Assignment to Each Facility with Operational Plan Taken into Consideration
Delivery dates are guaranteed, the balance of the load over all facilities is adjusted, and the synchronization ratio is enhanced. To increase the practicality of execution, lots are organized by cast and charge for all facilities. The method of maintaining an overall balance, which is especially important, is described below.
As shown in **Fig. 2**, an operation schedule (chance order) is established for all facilities with processing chances aligned in time series. The critical chance path (CCP) indicates the latest chance which will meet the delivery dates of individual orders, while the earliest chance path (ECP) indicates the earliest processing schedule for individual orders and for products already in process after tapping. CCP is obtained by tracing back in consecutive order from the final process. ECP, on the other hand, is obtained by continuously tracing in the downstream direction from the earliest tapping chance for the orders not yet tapped, or from the earliest chance in the subsequent process for products in process. CCP and ECP define the window which determines priority in the production order assignment. Assignment of orders or products to facilities so that the scheduling falls within these limits will guarantee delivery schedule[1].
The assignment procedure is conducted in two steps, temporary assignment for major facilities and final assignment for all facilities. In tentative assignment, which is conducted for facilities assumed to be key points in maintaining the overall load balance, products and orders are assigned to groups of facilities having similar functions in accordance with priority determination indices in reverse order from the extreme downtream process. While guaranteeing assignment times in the downstream process, however, assignment is performed in the upstream direction using the same procedure.
According to the order of assignment for the upstream processes, which is made for all facilities, products or orders are consecutively assigned to facilities starting from the upstream processes and working downstream, and given the earliest possible processing chance. The processing schedule is determined so as to avoid gaps in production at any facility by calculating the required time for processing at the individual facilities.



P_{ij}: The jth facility with the ith function
C_{ijk}: The kth production chance of the P_{ij} facility
ECP_m: The earliest chance path for the mth order (or product)
CCP_m: The critical chance path for the mth order

Fig. 2 Schematic illustration of the earliest-chance-path and critical-chance-path functions in the order assignment to each facility

(4) Slab and Coil Design in Weekly Scheduling
The designing of slab and coil is the second most important function of weekly scheduling after lot organization and load adjustment. Slab and coil design covers a range of activities from the utilization of standard slabs for the maximization of unit weight to the assortment, as necessary, of orders already assigned to each facility or already determined as to processing order in such a way as to maintain an overall balance. This contributes to standardization and the increase of product unit weight, thereby also helping to reduce the amount of remainder in a slab or coil.

(5) Centralization and Visualization of Information
Because the scheduling system is a decision-making process, full computerization is difficult, requiring the adoption of a man-machine conversational mode which takes advantage of the relative strengths of both man and computer. A figure and graphic output system, as shown in **Photo 1**, has been incorporated to facilitate judgment by planners. Further, terminals are centralized in the production planning room where a large screen is installed so that two or more planners can work together using the same information. **Photo 2** shows a planners' meeting in the production planning room.

3.3 Effects

The operation of this system has facilitated various activities: Specific identification of the operation schedule of respective facilities and changes in inventory caused by the preparation of schedules for the whole

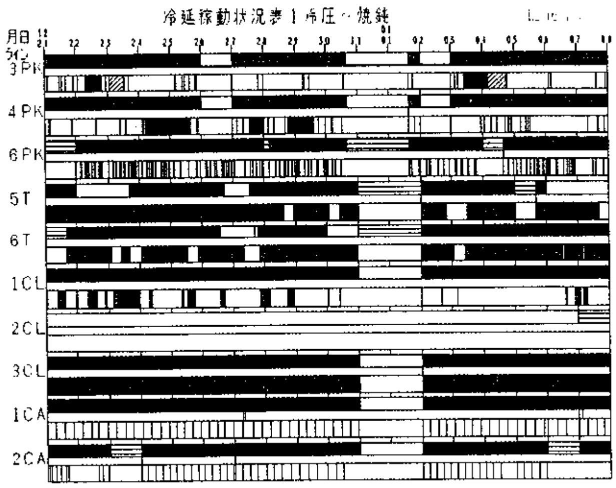


Photo 1 An example of the result of assignment displayed on CRT

Photo 2 Schedule planner's meeting using the wide screen

facilities as to slabs and coils in-process and all orders; identification of specific problems before the execution of actual operation; normalization of in-process products; improvement of synchronization among facilities; and smooth operational control of each facility.

Regarding the design of slabs and coils, the amount of remainder in a slab or coil has been reduced while unification and enlargement of product unit weights have been achieved.

In addition, the transmission of the results of weekly scheduling to the energy system has made possible the calculation of an accurate weekly energy balance.

The goals stated above, set at the incipient stage, have been achieved. It is hoped that the utilization, as tools, of the features of this system which allow quantification of various problems of production and material flow will stimulate specific activities to improve facilities and operation.

4 Execution Control and Operation Control

4.1 Necessity of System Building

This part of the production control systems, which covers activities from daily scheduling to operational control, including even actual data processing, has been the object of computerization since the earliest introduction of system, and has already been employed on line over virtually the entire steelworks. In the meantime, however, customers' requirements for the product quality and sophistication, and for delivery date because increasingly stringent, as did the company's needs for technical development and the rationalization of operations. This called for a drastic improvement in information systems, as described later. Moreover, simultaneous with the developments described above, some of the company's computers became obsolete, and were inadequate as a base for the addition of functions to the conventional system. These factors necessitated an extensive refurbishment of the system.

4.1.1 Accommodation of sophisticated customer requirements

The increasing sophistication of quality requirements includes principally dimensional accuracy, surface condition, formability, and corrosion resistance. Customer's specifications are confirmed at the Head Office stage, and are broken down at the steelworks, into various manufacturing specification items such as operational instructions, control specifications, and inspection specifications, as required in each process. These items, in response to the increasing sophistication and diversification of customer requirements, have yearly become more exacting and particular, requiring strengthening of support for the information system.

4.1.2 Upgrading of operational instruction and information for field judgement

Enhancement of the scheduling function alone is insufficient to realize synchronization and continuation of operations. It is also necessary to improve material handling between plants and processes, the monitoring of operations, and the correction function.

To ensure as-scheduled operation, it is necessary to provide precise operational instructions even in off-line areas such as yards, and strengthen the function of material handling control, whch should be consistent in all processes.

4.1.3 Accommodation of new facilities and highly-automated operation

As it relates to field operational techniques, the installation of new facilities and remodeling of existing facilities have been implemented with the aim of synchronization and continuation of operations. In response to the operational synchronization and continuation, a highly automated operation support system for new facilities and upgraded control method for existing facilities was required to strengthen the target quality-making function of each process.

4.1.4 Intensification of analysis and control

Management of information on operation and quality is strengthened to achieve quick, multi-faceted analyses and better control in response to the analysis needs of better quality products. Such information is important for the production support systems for energy, facility maintenance, and cost. In this regard, a refinement of the information mesh and a shortening of the information collection cycle was necessary for attaining integration of the systems in the steelworks.

4.2 Outline of the System

The processes over which the production control system at Mizushima Works has been refurbished range widely, as shown in **Fig. 3**. Regarding steelmaking, hot-rolling, and cold-rolling in this system, the production control systems for billets and integrated production control system for cold-rolling went on-stream as a first stage in December 1983 and in January 1984 respectively at the time of facility expansion. The production control system for sheets and strip, including the weekly scheduling system, went on-stream in March 1987 as a second stage[2-5]

Figure 4 shows the configuration of the whole system, which principally consists of the steelmaking, hot-rolling, and cold-rolling systems. The execution control system in this configuration comprises various functions such as daily scheduling, which determines the manufacturing order and manufacturing specifications for each kind of product, adjusting for daily operational variations, manufacturing instructions, the gathering of data, progress control for orders, and daily and monthly reports. The operation control system, on the other hand, consists of functions such as operational corrections, operational instructions, material handling, and judgment.

Characteristic functions of the execution control system and operation control system are discussed in the

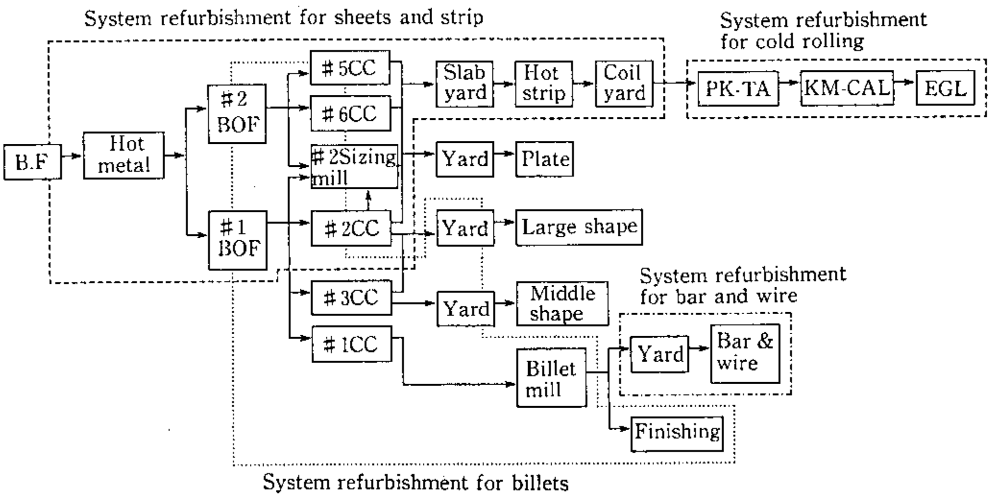


Fig. 3 Refurbished system scope at Mizushima Works

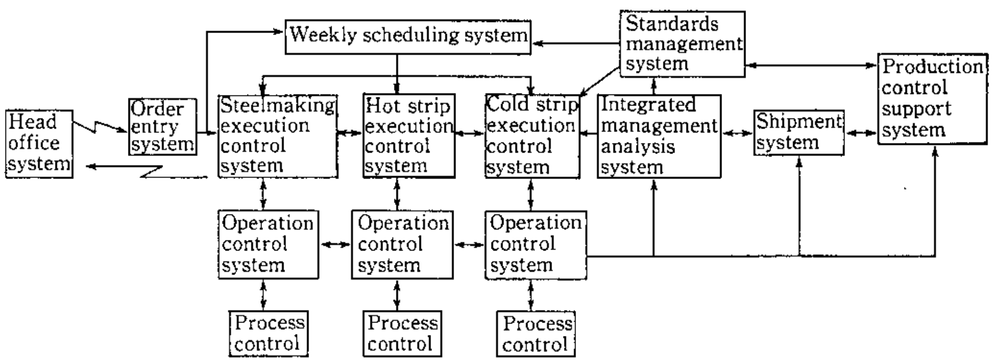


Fig. 4 Configuration of the steelmaking, hot-rolling and cold-rolling systems at Mizushima Works

following.

4.3 Functions of Daily Scheduling and Manufacturing Instruction

The conventional system covering activities from scheduling to the issuing of instructions is of a configuration in which various functions were combined: specifically, lot design, which includes casting lot design and hot-rolling cycle lot design, lot scheduling, and manufacturing lot specification design.

In the processes of steelmaking, continuous casting, and hot-rolling, which played an important role in latest round of synchronization and continuation of operations, scheduling and instruction functions of high practical accuracy have been realized by separating and explicitly positioning various functions as shown in **Fig. 5**. In other words, various functions have clearly been separated into each scheduling system, so that lot design and lot scheduling functions are assigned to the weekly scheduling, manufacturing order determination for each product in a lot to daily scheduling, and manufacturing specification design of lots to manufacturing instruction preparation. A method was also adopted in which scheduling information involving manufacturing time and the manufacturing specification information are separately transmitted to each operation control section.

In this manner, short time planning of weekly scheduling and daily scheduling has become possible, and at the same time, rapid manufacturing instruction and operational adjustment to match the speed of the continuing material flow has been realized.

The daily scheduling and manufacturing instruction functions are so systematized that the process of pickling–cold rolling–cleaning–annealing, which is a major production sequence, can be scheduled and instructions given in unit form, based on weekly scheduling information. This has reduced the levels of inventory stocked between processes and shortened lead times.

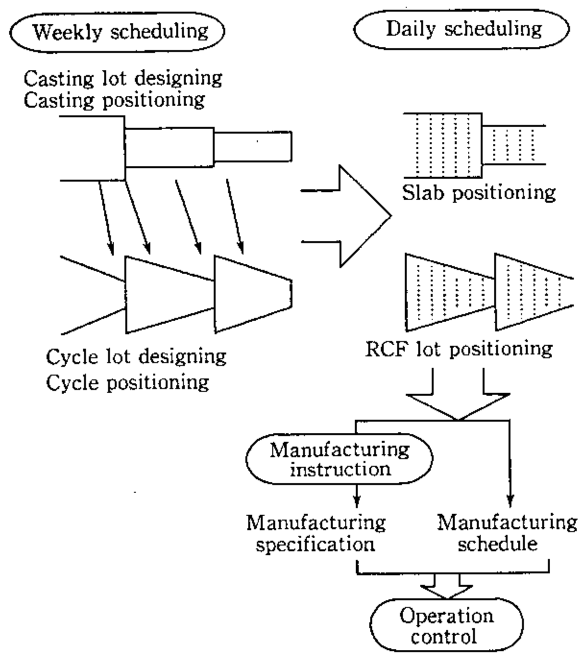


Fig. 5 Function of the weekly and daily scheduling and the manufacturing instruction

The manufacturing instruction function for each finishing line in the hot-rolling and cold-rolling sectors is all conducted entirely in an on-line conversational mode, allowing rapid adjustment to daily operational variations.

4.4 Operational Correction Function

In synchronized and continued operation, operational variations in a single process will cause major disruption of the entire process, requiring a system by which such operational disruptions are rapidly detected to allow for quick action. During the refurbishment of the production control system for billets, an operational correction function was developed principally for the processes between the steelmaking plant and billet plant. This system was extended to the processes from hot metal pretreatment control to the hot rolled coil yard, a substantially complete implementation.

An integrated operation schedule correction function is furnished through the processes from ironmaking and steelmaking to various hot-rolling mills. The configuration of the function is two-storied; the higher rank comprises an integrated control room with a correction function covering departments in the Process Control Dept.; the lower rank is composed of individual field process control rooms with an in-department correction function. The daily scheduling function was assigned to the integrated control room so that corrections can be conducted smoothly on a 24-hour basis. In the information system, the following functions are provided.

4.4.1 Operation monitoring function

This function is so designed that the variations between the scheduled processing time and the actual time at 39 points in the major processes from ironmaking to hot-rolling are indicated simultaneously in real-time, and warnings are given on the basis of judgments as to the delay ratio in synchronized scheduling.

Regarding material handling, on the other hand, product-by-product tracking, detection of rejects, and monitoring of the balance of hot-metal inventory, amount of slab inventory in each yard and cargo-ready status can be performed in real-time. Functions also include a timing simulator which predicts material handling situation several hours in advance. To facilitate visual identification of conditions, a graphic display system has been adopted to realize precise, rapid monitoring, judgment, and correction.

4.4.2 Scheduling correction function

When operations deviate from plan, it is necessary to quickly restore the original scheduling by changing manufacturing order and manufacturing time while minimizing the effect on synchronization and continuation. The scheduling correction function includes: (1) change of manufacturing order, (2) change of manufacturing time, (3) change of manufacturing route and method, and (4) check of the compatibility of various restrictive manufacturing conditions accompanying changes.

In synchronized and continued operation, process scheduling is conducted on a minute-unit basis. Any change of scheduling in a single process will affect both upstream and downstream processes, requiring a vast amount of time for schedule recalculation. It is also necessary to quickly check for problems in the manufacturing process which may have resulted from the changes. The system is so configured that this can be accomplished by merely inputting the changed information; all other processing is performed automatically by computer.

The operational schedules for steelmaking and hot-rolling are transmitted to the energy control system on-line in real-time for precise supply-and-demand control of gas, power, and oxygen, improving energy saving results.

4.5 Material Handling and Material and Product Control Functions

The tracking of the location of products and the automation of transport instructions on manufacturing line were instituted at an early stage. The automation of the slab and coil yards, on the other hand, lagged behind because of the complexity of material handling and the lower return on investment.

To achieve synchronized and continued operation, however, a higher material flow speed is essential. To this end, a comprehensive grasp of the material flow situation in real-time is necessary as a basis for appropriate material flow control.

In the refurbishment of the system, the material handling function, including hot-metal transport, the slab yard, and the coil yard, was strengthened; the refurbishment covers the entire material flow route, ranging from the blast furnaces, where hot-metal is received, to the cold-rolling mills.

4.5.1 Hot-metal transport process

To cope with product sophistication, dephosphorization facilities were newly installed, making transport routes more complex. To achieve higher levels of synchronized operation between this process and the downstream processes of continuous casting and hot-rolling, it was necessary, in the transport process, to improve operational accuracy relative to schedules by enhancing the material handling function.

The information system, therefore, was given the following automatic functions[6,7]:

(1) Full-automatic tracking of the position and heading directions of torpedo cars and diesel cars, and control of their destinations, using a license plate reader and channel selector controlled by an induction radio.
(2) Automatic collection of data concerning the fill level and weight of hot-metal in torpedo cars.
(3) Automatic assignment of loaded torpedo cars to blowing charges.
(4) Automatic determination of the content and time of the dephosphorization and desulfurizatin of hot-metal in torpedo cars.
(5) Simulation of hot-metal inventory balance.
(6) Centralized control in the hot-metal process control room.

Of the above functions, (1) and (2) are controlled by process computers and (3) to (6) with business computers. This has brought about a dramatic increase in material flow speed between the blast furnaces and converters, as-scheduled supply of hot-metal to the coverters, numerical reduction in torpedo car requirements, and better hot-metal temperature.

4.5.2 Hot-rolling and cold-rolling processes

As shown in **Table 2**, the automation of the transportation of materials and products has been achieved for the slab yard and coil yard of the hot-rolling mill

Table 2 Automation pattern of storage yard at Mizushima Works

Process	Yard	Tracking products	Transportation instruction	Crane operation	Transfer equipment operation
Hot strip	Slab	A	C & man	M	A
	Coil	A	C	M	A
Cold strip	Tandem (Entry section)	A	C	A	A
	Tandem (Exit section)	A	C	A	A
	CAL (Entry section)	A	C	A	A
	CAL (Packing section)	C & man	C	M	A
	CAL (Exit section)	C & man	C	M	A
	EGL (25t yard)	A	C	A(P)	A
	EGL (50t yard)	C & man	C	M	A
	BAN (Exit section)	C & man	C	M	M
	Refining line (Entry section)	C & man	C	M	M

Symbol A: Automatic M: Manual
C: Computer P: Pallette car

and each coil yard of the cold-rolling mills in a configuration appropriate to characteristics of each yard.

Specifically speaking, newly installed facilities are unmanned, fully-automated operations, while the existing facilities have been converted to crane-plus-one-man operation, with the operator providing transportation instructions via a computer terminal installed in the crane. Especially at yards where multi-slab or coil pile are handled one-man operation is made possible by the installation of a location detector in the crane.

The basic functions of the slab yard and coil yard systems consist of the planning of yard operating schedules, preparation of transportation instructions, yard address control, and operation control of facilities on the ground.

Preparation of transport instructions is the most important function. This operation determines, by computer, the receiving yard address, channels of transportation, and shipping yard address. The substantiation of the scheduling function mentioned earlier has made possible the accurate prediction of shipment timing at the time of material and product receipt, allowing determination of the most appropriate location of stocking of lots to be shipped.

Both the identification of the present location and that of all the facilities in the yard, such as conveyers, transfer equipment, and coil markers, have now been automated.

The improvements described above have reduced material and product flow time from continuous casting to hot-rolling by half, speeded up material and product flow in the coil yards, and greatly reduced manpower requirements in the yards.

4.6 Quality Assurance Function

With the sophistication and diversification of the quality requirements of products, manufacturing technologies have become correspondingly diverse. Progress in synchronized and continuous operation makes stable operation and quality levels indispensable.

Quality assurance includes quality design, quality instruction, the achievement of high quality in each process, quality judgment, quality analysis and evaluation, and quality improvement activities. These functions have been incorporated in the order entry, instruction preparation, operation control, and integrated data analysis systems. The individual functions of steelmaking, hot-rolling, and the cold processes have been markedly improved.

4.6.1 Quality design

The results of quality design affect the assignment of manufacturing units and the planning of manufacturing scheduling. Of the specification design tasks conventionally done at the time of order entry at the steelworks, those for customer orders of a unique or unusual nature are now done in the Head Office.

To improve the accuracy of synchronized scheduling at the steelworks, the design of the necessary items for schedule formulation, which was formerly done at the instruction preparation stage, is now performed at an earlier stage, i.e., the order entry stage. The assignment of functions has been clearly defined so that at the order entry stage, specifications for manufacture and control which can be determined on an order-unit basis are set, while at the instruction preparation stage, specifications for manufacture and control are set on a production lot basis, in which, for instance, tapping charge orders are combined.

Improvement of accuracy in quality design was achieved by improving the automation ratio of specification design and by providing the specification design function, which requires human attention for a specification design simulator function to permit advance confirmation of the relationship between quality items.

4.6.2 Quality instruction

Quality instruction is of two configurations: one in which specific operational instructions are transmitted from terminals such as display devices and printers installed in various fields to the operators, and another in which facilities are automatically controlled by process computers. In this refurbishment, automation has been vigorously pursued, and a higher computerization ratio has been achieved.

As operations have changed from simple to more sophisticated and complex, information for operators has also changed from numerical and syllabary information to longer syntactic items in ideogrammatic form, and further to graphic and vocal information.

In addition to static quality instructions, a dynamic instruction mode corresponding to changes in the operational situation has become important to continued progress in synchronization and continuation. In other words, it is necessary to feed forward various quality and operational results in upstream processes and make operational corrections in real-time. The feedforward networks of various processes in the ironmaking—refining—continuous casting—hot rolling—cold rolling sequence were constructed principally for business computers. The feedforward items include: the operational condition of various processes, such as casting speed, chemical composition, temperature, weight, dimensions, and configuration. These items are finely reflected in operational corrections such as refining control, casting control, slab cutting control, slab conditioning method, reheating control, hot-rolling control, cooling control, and cold-rolling control.

4.6.3 Ensuring quality in each process

In an attempt to stabilize operation and quality, the level of automation has been raised over all the processes from the pretreatment of hot-metal to cold-rolling. **Table 3** shows the principal control functions which are

Table 3 Summary of process control system refurbishment at Mizushima Works

Process	Functions	Result
Hot metal	Torpedo car tracking	◎
	Pretreatment control	◎
Steelmaking	Calculation of sub-materials quantity	○
	New blowing control	○
	2nd refining control	◎
Continuous casting	Casting process control	○
	Cutting process control	○
	Machine diagnosis	◎
	Conditioning line control	◎
Hot strip mill line	Slab handling control in yard	◎
	Reheating furnace control	○
	Sizing press control	◎
	Mill-pacing	○
	Step-up control	○
	Cooling water control	○
	Coil handling control in yard	◎
	Machine diagnosis	◎
No. 1 cold tandem mill line	Mill-pacing	◎
	Set-up control	○
	Flying thickness change control	○
	Flying width change control	◎
	Tracking of welding points	◎
	Coil dividing control	◎
CAL	Sheet temperature control	◎
	Preset for various operational conditions	◎
	Tracking of welding points	◎
	Coil dividing control	◎
	Machine diagnosis	◎
EGL	Plating amperage control	◎
	Preset for various operational conditions	◎
	Tracking of welding points	◎
	Looper position control	◎
	Coil dividing control	◎
	Machine diagnosis	◎
	Control for transfer equipments	◎

Notation: ◎: Newly developed
○: Improved

supported by process computers. Computer devices have been replaced, newly installed, and augumented in almost all processes, and at the same time the control level has been dramatically improved[6-11]. With business computers, the number of digits of information per coil transmitted to the process computer in the cold-rolling process has been increased to approximately 6 000.

To ensure quality in each process, it has become important not only to automate process control but also to reinforce the control of the facilities themselves.

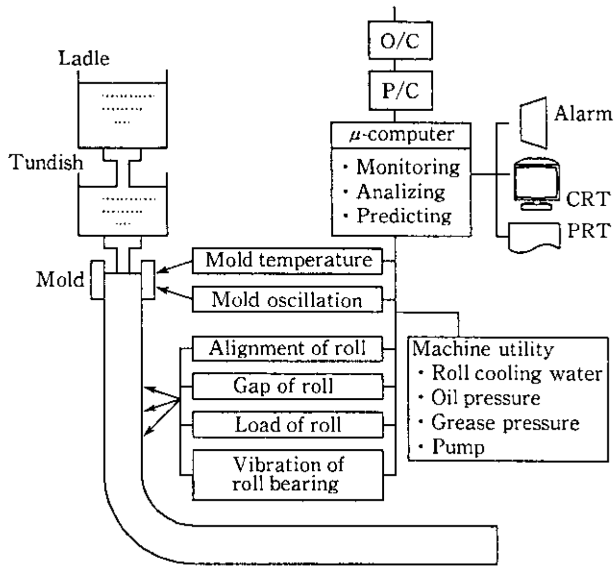


Fig. 6 Quality and machine diagnosis system for continuous casting

From this point of view, the on-line identification of the facilities situation has been made feasible through the strengthening of the historical-information control-function of various accessory equipment, which greatly affects quality; such items include the torpedo cars, converter ladles, and CC molds.

For important facilities such as the continuous caster, a product quality and facility diagnosis function has been provided[12]. As shown in **Fig. 6**, mold temperature and mold oscillation are measured with various sensors. The results are processed by microcomputer as a means of forecasting breakout.

4.6.4 Quality judgment

Quality judgment has two functions, actual judgment as to acceptance or rejection and decision as to the method of disposal after rejection. In synchronized and continuous operation, speed and reliability are particularly important. In the refining and continuous casting processes, the quality judgment system is so conducted that information as to casting results and chemical composition is automatically collected, allowing instantaneous judgment of the quality of every slab. The results of judgments are, as mentioned earlier, reflected in the feedforward network system. With the hot-rolling process as well, operational results such as thickness, width, temperature, and coiling shape are automatically collected and subjected to automatic judgment and determination of disposal by computers.

4.6.5 Analysis, evaluation, and improvement of quality

For the control of quality levels, the integrated data analysis system, which allows the integrated analysis of quality levels covering all processes, was refurbished, greatly reducing the cycle time from the early investigation of quality anomalies to the revision of the relevant specification, and bringing about in improvement in staff productivity.

Quality and operational data is automatically collected and stored in the form of serial order data on a second-by-second basis, and also available in distilled form. This data reaches 90 000 items in the processes of steelmaking, hot rolling, and cold rolling.

4.7 Effects

The execution control function and operation control function for sheets and strip covering the processes from ironmaking to cold rolling, including process control, have been thoroughly renewed.

With the innovations contributing to synchronization and continuation of processes as a fundamental pillar, improvement in the level of automation has been materialized thanks to the synergistic effect of improvement in manufacturing facilities, manufacturing technologies, and information systems, and the hoped-for results have been achieved in the areas of energy-saving, reduction of manpower, reduction of inventory requirements, and shortening of production of the lead-time.

As the industrial environment changes, information systems must be improved to meet new conditions. The operation system, which directly supports the manufacturing process, must be developed to higher levels, with the totally automated factory as the ultimate goal.

5 Standard Management System

5.1 Background of the System

The company has from its incipiency promoted the standardization of various tasks such as quality design, manufacturing scheduling, and operations. The concrete standards which reflect the results of standardization activities are prepared in written form, i.e. as standards documents, and instituted. The standards document, by elucidating the objectives and technical background of the prescribed control items, specifies criteria to be observed and thus provides a ground for the actions of those engaged in production and production control.

At Chiba Works, standards are instituted and applied in accordance with the following system:

(1) Quality Control Standards
Standards prescribed as to the manufacturing terms and inspection terms necessary to ensure the product functions required by customers.

(2) Production Control Standards
Standards prescribed as to process control terms such as production scheduling and process progress control from the viewpoint of production quantity control and delivery date assurance.

(3) Manufacturing Technology Standard
Standards prescribed as to facility terms and operational terms for the optimization of yields, unit consumption, efficiency, and capacity. The main purpose of this standard is to minimize cost within given quality and delivery date limitations.

These standardization activities have brought about the establishment of a highly organized production system at Chiba Works. Continued upgrading of this production system will be pursued to ensure that the standards are updated in response to changing conditions which affect production plans. In standardization, moreover, individual goals are not always compatible with total optimization, and conformance with overall objectives must be maintained. For this reason, a well organized system which controls the maintenance of standards documents and their application is necessary.

5.2 Necessity of System Building

Production control activities based on the prescribed standards will be automated and mechanized as the activities take the shape of sets of more detailed standards. A method in which the provisions of standards are tabulated as a "standards table" and are reflected in the computer system has to date been positively utilized. However, this type of table places mutually contradictory requirements on the system: Tables as standards documents must be readable by workers, while as computer data they must be highly processable, creating a dilemma of how to maintain the conformance of the two-types of tables.

There are many cases where structural changes in standards tables are required, for example, the additions and/or changes as specifications for new products are required, and changes in manufacturing conditions following the improvement of facilities. This requires a change in computer processing procedures for retrieval and reference, i.e., a change in programs used in the determination of reference values, to which strenuous effort has been devoted.

Additionally, the problems arising from the institution and revision of the standards themselves entail great difficult. The institution and revision of one standard will normally affect other standards. A change in the quality control standard naturally calls for a revision of relevant manufacturing technology standards, and there are many interrelated quality control standards. When changes are made, a failure to identify all the standards affected by the change will entail nonconformity, and may result in grave quality assurance problems. Conventionally, there was no system capable of coping with such problems, and it was necessary to rely on the knowledge and experience of experts.

At Chiba Works, the movement toward diversified sophisticated, high added-valued grades of products in small-size lots is now underway. In this situation, where the complexity of the production system is becoming increasingly great, the necessity of coping with these problems is imperative.

5.3 Outline of the System

As a part of the refurbishment of production control systems, a standards control system was developed. The objectives of this system are high efficiency and an upgrading of standards control tasks, with a guarantee of individual and mutual conformance of standards and standard tables as a principal concept. To attain this goal, the following functions have been realized:

(1) Unified control of the standards by the establishment of a database for standards dispersed among a number of departments.
(2) Unified control of standards by the establishment of a database for standards tables.
(3) Identification of mutual relationships by the establishment of a related-structure database for standards and standards tables.
(4) Control of standards by a document management system.

This system controls in one group all standards relating to production control, and is positioned to control all production control systems through reference values. All the standards tables used by each production control system are registered in the database of this system and transmitted to each system.

In parallel with the development of the system, the following tasks were carried out under a works-wide project structure, and the standards system was refurbished.

(1) Preparation of bases for provisions of standards.
(2) Coordination of descriptive outlines of standards.
(3) Specification of relationships among standards.
(4) Specification of relatationships between standards and standard tables.
(5) Standardization of standards table design.

5.4 System Function

This system consists of three functions, a document management function, a standards table management function, and a related configuration management function. The standards table management function and the other two functions went into operation in July 1986 and April 1988 respectively. The outlines of these functions are given in the following.

5.4.1 Document management

Standards management work such as preparation, revision, issuance, and distribution/receipt of standards documents is performed at the workstation, and includes as features:

(1) Building of a hierarchically-structured document database responding to specifications and standards systems.
(2) Support of multi-media documents including tables, graphs, line drawings, and images.
(3) Decision by ID card.
(4) Distribution/receipt control by electronic mailing.
(5) Composition of standards tables and documents (editing and printing).

5.4.2 Standards table management

This function supports the preparation and revision of standards tables and their reflection in each of the production control systems which directly supports production control activities. Operational efficiency has been improved and better accuracy achieved. Features include:

(1) Tabular type data operation utilizing a relational database.
(2) Standard value maintenance and information transmission to production control database in a conversational mode operation.
(3) Augmentation of checking function of input data.
(4) Check and confirmation of standard value revision operation by execution of off-line simulation of standard value determination logic.
(5) Automatic creation of standard value determination programs.

5.4.3 Relation management among standards

The standards document management operation is supported by identification of the scope of effect of the contents of standards document provisions. This function is capable of multipurpose retrieval, having the function of plural retrieval by keywords, etc., as well as the management of related relationships as defined in advance. The aims of the system include:

(1) Construction of a database with a multirelational structure of an aggregate-retrieval type.
(2) Easy keyword registering by selective methods such as cutting out from documents or mouse.
(3) Catenated search of related standards and standards tables.
(4) Output of diverse control information such as chart display and warnings.
(5) Automatic distribution of standard documents and standards tables.

This system is provided with security management functions such as reference, qualification checking for renewal and approval, and operational history records as other common functions.

5.5 Features of System

This system supports engineering staff. As the level of the users is high, the required functions must be dynamic and of a non-routine and multifunction type. For these reasons, development was promoted under a policy of "pursuit of system extendability and flexibility" and "securing of independence of various production control systems". Features include:

(1) Simplification and abstraction of systematization requirements.
(2) Phased development by prototyping.
(3) Simplification of interface between this system and

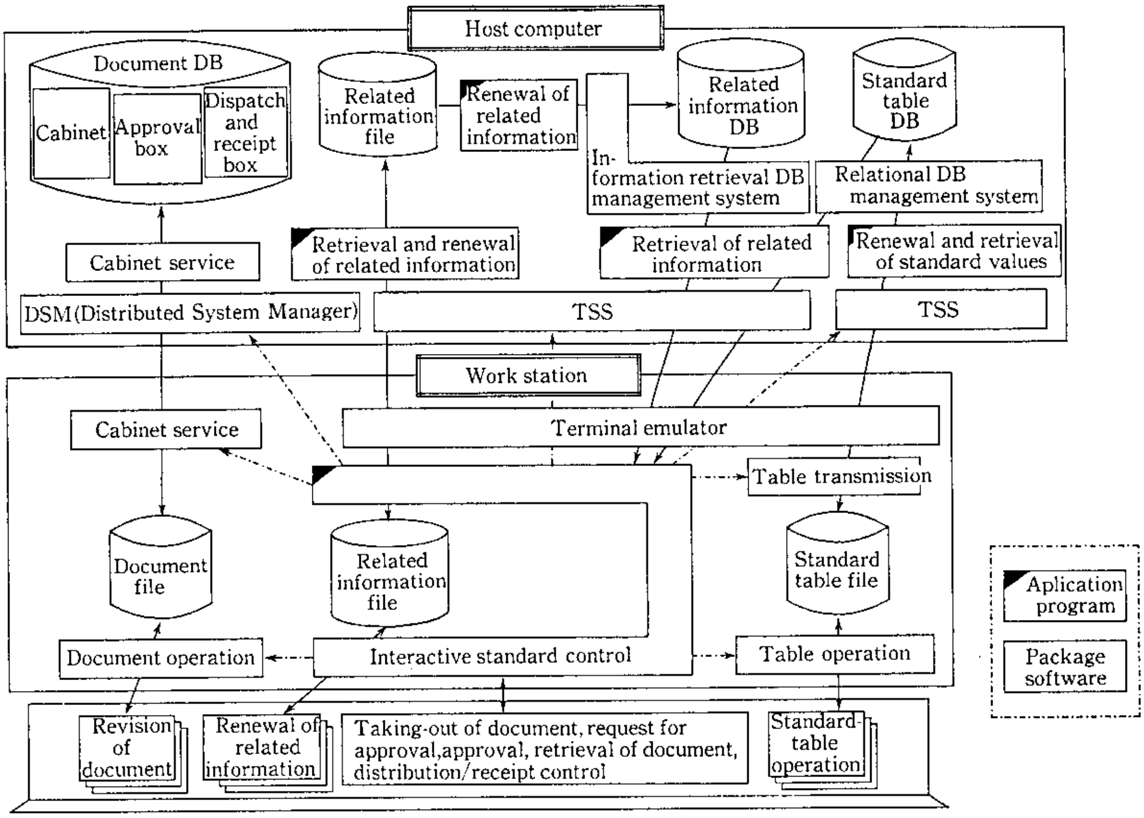


Fig. 7 Software configuration of the standards management system

production control systems.

(4) Efficient utilization of commercial software.

The uniqueness of the system lies in the integration and high performance of its man-machine interfaces. Conventionally, high level functions have been realized separately in word processors, personal computers, and document retrieval systems. Here, these tools were integrated so that operation could be carried out as easily as when dealing with standards documents at the desk. **Figure 7** depicts the overall configuration of the system in the form of a software composition diagram. The main points are as follows:

(1) Easy operation by use of mouse.
(2) Smooth operation by multi-window and multi-task methods.
(3) Realization of multi-media detabase.
(4) Realization of a distributed processing system using workstations.

5.6 Effects

The operation of the standards table management function allows the department in charge of the standards to maintain its own standards tables. The procedure of standard value determination has been made open, and thus, an overview of the configuration of the determining of standards values and manufacturing coditions has become directly visible at the operating department. The augmentation of the checking function at the time of standards revision has improved accuracy. These results have greatly reduced the burden on the system department, as well as resulting in the development and maintenance of the system.

The higher efficiency and upgrading of the entire standards management operations, including the document management function and related structure management function, have been achieved. The conformance guarantee for the standards and standards tables, which was the most important object, has also been actualized.

As stated above, the hoped-for ends have been attained, resulting in an infrastructure supporting higher efficiency and sophistication of the standards management operation.

6 Conclusions

With synchronization and continuation of operations as a fundamental policy, the refurbishment of the production control systems at the steelworks was carried out. This project can be summarized as follows:

(1) A weekly scheduling system was developed in which an operation balance among individual facilities is ensured while shorter lead times for all products and processes were achieved within the content of the extremely complex overall steel production process.

(2) Based on a concept of schedule-oriented management, the execution control and operation control systems of steelmaking, hot-rolling, and cold-rolling were expanded and substantially developed as an overall function, including the material handling control function (which conducts tracking of materials and products and controls transportation) and the quality assurance function.
(3) A standards management system was developed taking full advantage of the latest information processing technology in quality assurance activities, with the aim to supporting engineering staff.
(4) The anticipated results in energy-saving, equalization of inventories, shorter lead times, stabilization of quality, and better yield control have been achieved, permitting a marked reduction in manpower in material and product handling in the slab and coil yards.

The development of new products and production technologies has continued unabated, and further progress in high temperature hot charge rolling and planning for new facility construction in the fields of cold-rolling and surface coating are now underway. In addition, renovation of the shipping system has also commenced. All this means that there is no stage at which the development of production control systems will be complete. As progress in the production environment continues, constant change and growth on the systems side are also required. It is the authors' belief that in response to advances in production technology and the growth of information processing technology, the realization of a computer integrated manufacturing (CIM) system must now be made a goal of primary importance.

References

1) S. Fukumura, S. Matsukawa, and E. Tonooka: *Operations Research*, **31**(1986)6, 346-352
2) K. Ohsugi, T. Ueda, O. Taniri, M. Habu, Y. Nakagawa, and H. Itakura: *Kawasaki Steel Giho*, **17**(1985)1, 23-31
3) T. Tokumaru, T. Nakanishi, M. Kodama, J. Yamasaki, and K. Ohsugi: *Tetsu-to-Hagané*, **72**(1986)10, A211
4) A. Kibata, S. Hirasaki, K. Hatakeyama, H. Ueno, S. Asagoshi, and K. Hirohata: *Kawasaki Steel Giho*, **16**(1984)3, 165-172
5) S. Takizawa, T. Naoi, A. Harimoto, H. Nikaido, and T. Kondo: *Tetsu-to-Hagané*, **74**(1988)8, 1338-1345
6) N. Misaki, H. Take, K. Hirayama, M. Awaya, A. Yamane, and T. Iwamura: *Tetsu-to-Hagané*, **73**(1987)4, S272
7) A. Yamane, T. Iwamura, I. Tone, N. Misaki, K. Hirayama, and A. Ueda: *Tetsu-to-Hagané*, **73**(1987)12, S267
8) M. Nariishi, K. Hirayama, A. Hina, H. Tanaka, T. Iwamura, and S. Takizawa: *Tetsu-to-Hagané*, **73**(1987)4, S370
9) T. Iwamura, K. Miyahara, H. Yamane, K. Hirayama, M. Nariishi, and A. Hina: *Tetsu-to-Hagané*, **73**(1987)4, S264
10) T. Komatsu, N. Suganuma, T. Eto, T. Naito, K. Doi, and K. Hirohata: *Kawasaki Steel Giho*, **18**(1986)3, 243-249
11) T. Iwamura, H. Torikoshi, H. Miura, R. Owaki, and Y. Segawa: *Tetsu-to-Hagané*, **73**(1987)12, S381
12) K. Orito, and K. Ikeda: *Kawasaki Steel Giho*, **18**(1986)1, 25-29