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Information Technology Supporting the Steel Industry and Its Trends

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Abstract

The steel industry is a basic material and process industry; it is characterized by production on order, high-mix low-volume production, and break-down manufacturing, wherein a few raw materials are turned into many diversified products. To enhance the productivity of such an industry, it is necessary to optimally group customers' orders into batches for each process, define the sequence of the orders within a batch and the sequence of the batches on a production facility, and minimize the inventory between processes. Having a logistics plan for delivering finished products to customers is also important. The sophistication of such planning work is required, and information system technology has been applied to it since the 1960s. This paper outlines the history of the application of the technology to the planning, and also the prospects of the application of the latest advanced information technologies to this field.

1. Introduction

The steel industry is a basic material industry; it manufactures to order widely diversified products from a few raw materials, and for this purpose, the products are made through a plurality of processes such as steelmaking to incorporate desired material quality, rolling to define product shape and size, and surface treatment to form surface properties, where required. To maximize the production capacity of individual processes, however, it is necessary to group together customers' orders suitable for continuous processing, and define the processing sequence of individual orders in the group. The criteria for the order grouping differ from process to process, and there are cases in which one type of grouping suitable for one process is totally unsuitable for another. In this situation, one of the main tasks of production planning is to form optimum order groups and define the order sequence in the groups for all manufacturing processes along the route from raw materials to final products, and information technology is expected to solve this complicated problem.

While semi-finished products from an intermediate process are then forwarded to a subsequent process, where the manner of order grouping may well be different, intermediate stock occurs at a storage yard for partly-finished products before they are fed to a subsequent process. Finished products, on the other hand, are shipped from the works for respective customers in batches. Thus, the transfer of semi-finished products inside works and that of finished products from works to logistics facilities near respective customers require careful planning, which is also an important task supporting the steel industry.

For the efficient operation of steel works, Nippon Steel & Sumitomo Metal Corporation adopted in 1968 an on-line information system, covering order grouping and logistics planning and working around the clock 365 days a year as the first case of its kind in any field of industry in Japan, and has fostered and improved the system ever since (see **Fig. 1**).[1, 2]

This paper introduces mainly the information technology (IT) used for the sophistication of production and materials transfer planning that supports steel manufacture, and in a later section, advanced IT, which has been actively used for upgrading system development work since the beginning of the current decade.

2. Task Definition

The manufacturing industry can be divided into two types: the build-up type manufacturing typical of the automotive industry, wherein many part types are assembled to form final products (see **Fig. 2**); and the break-down type manufacturing typical of the steel industry, wherein a few raw materials are turned into a great number of diversified products (see **Fig. 3**). When either of them is run ac-

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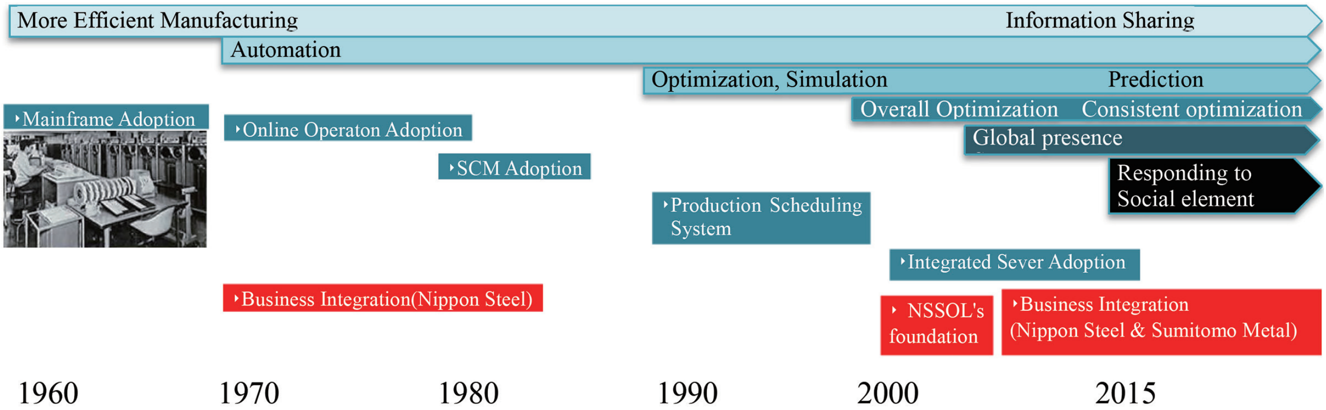


Fig. 1 History of information system application

cording to the production-on-order rule, whereas necessary parts are procured according to customers' orders, and which of them will be assembled when at which production stage is determined in the former, in the latter it is necessary to group orders from different customers into production batches, each of which can be manufactured under the same operation condition in a process, repeat the order grouping likewise for upstream processes to form larger batches, and define the manufacturing sequence inversely in this manner.[3, 4]

The first problem that the production control system of the steel industry has to solve is that production is performed against customers' orders even though it is a break-down type manufacturing industry, and that the amount of each order is one several-hundredth to one several-tenth of the minimum production batch of the process (for example, a converter) where the material quality is mostly determined.

Figure 4 shows the structure of Nippon Steel & Sumitomo Metal's information system for production management from order acceptance to product shipment. Since the lead time of the steel industry from raw materials to final products is very long, a rough sales plan and production plan are prepared beforehand based on marketing information from trading houses acting as the sales channels.

When orders are actually received thereafter, they are grouped, the rough monthly production plan formed beforehand is revised accordingly, and the products in real orders and virtual goods (products not yet finished but assumed to exist in semi-finished products, and that will be assigned later to received orders) are grouped for individual production processes.

Then, after the grouping, the processing sequence of the ordered products within a group (or a process batch) is determined. The processing sequence must be defined so as to maximize the productivity of the process line in consideration of the restrictions to realize the product quality of individual orders. **Figure 5** schematically shows how the processing sequence of a continuous rolling line is decided. The position of the product of an order in a processing batch formed through the grouping is defined in consideration of the material quality and operation conditions under the restrictions of width, thickness, hardness, weldability, etc. of the product.[5] However, if for some reason the plant operation fails to go according to the production plan, the plan has to be revised, and several alternative plans must be proposed to the operators as quickly as possible.

The second problem for the production control system is the logistics plan for semi-finished products inside the works and finished products to be shipped. Here, let us consider a case where products shipped from various mills on many ships are gathered at a warehouse at a seaport near a user's plant. **Figure 6** shows the flow of the marine transportation plan: the main office (HQ) has to collect information from the mills and devise complicated ship allocation plans using its own information system and those of logistics companies belonging to its group.

The following sections explain how the first and second prob-

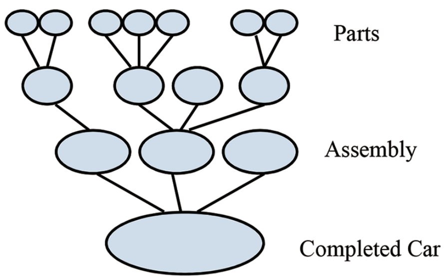


Fig. 2 Feature of assembly process —build up structure—

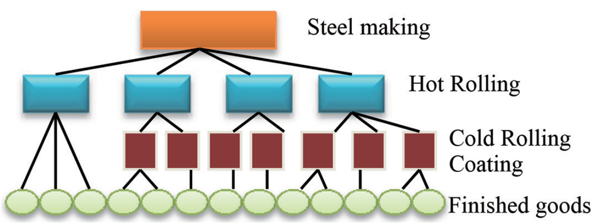


Fig. 3 Feature of steelmaking process —break down structure—

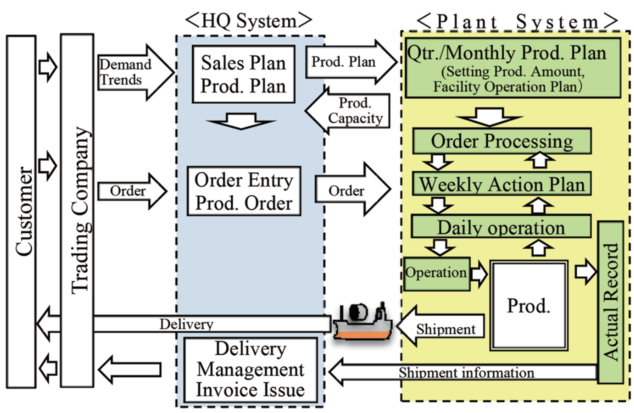


Fig. 4 Consistent system from order entry to shipment

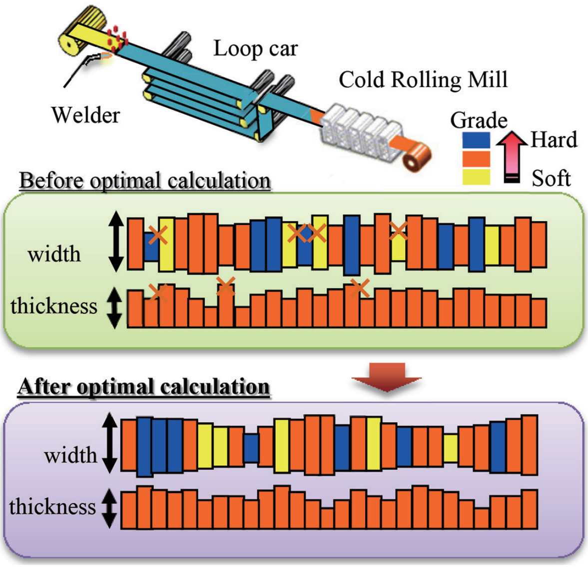


Fig. 5 Scheduling of process order

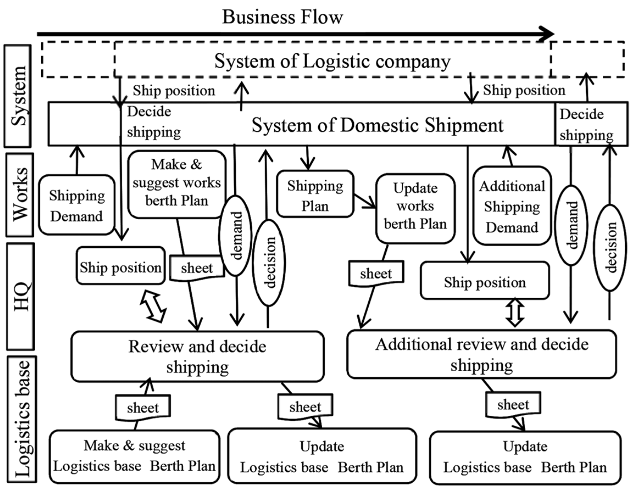


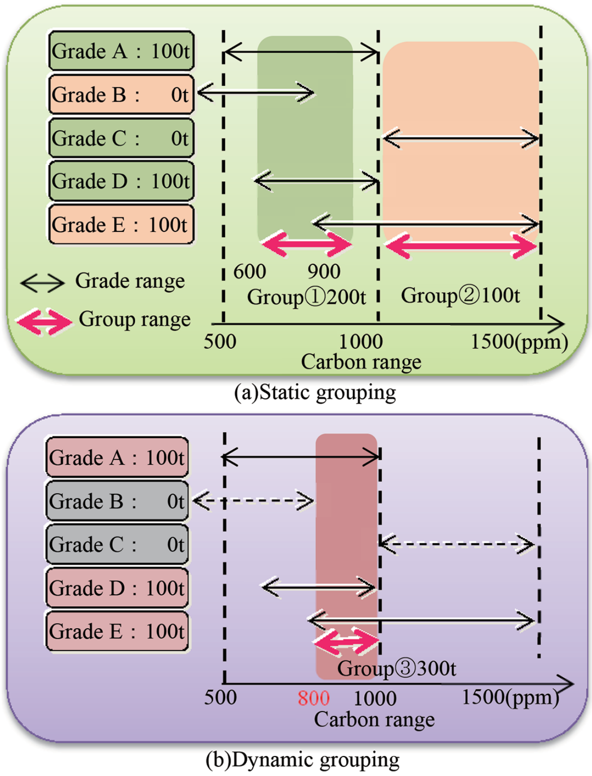
Fig. 6 Schematic of ship logistics plan

lems are solved using information systems and through approaches devised by the company.

3. Production Planning

Of the many plans that have to be drawn up for production control, the first one that needs to be prepared is explained below.

The amount of a production batch at a steelmaking plant, where the material quality is mostly defined, is usually a few hundreds of metric tons, and it is necessary to group together received orders of the same material quality to form a batch. **Figure 7** shows examples of group formation according to carbon content. Part (a) illustrates a case where a production batch prepared beforehand includes steel grades of similar carbon contents, and when an order of a steel grade included in the batch is received, a corresponding tonnage of the batch is allocated to the order. Here, grades A and D are put together into group ① of 200 t, and grade E forms group ② of 100 t. If the minimum operation batch of the converter, in which the carbon content is determined, of this steelmaking plant is 300 t, an excess of 100 t arises from the batch of group ①, and another excess



(a)Static grouping

(b)Dynamic grouping

Fig. 7 Schematic of process batch formation

of 200 t from that of group ②. By the method of part (b), in contrast, if it is possible to control the carbon content to a narrow range (200 ppm in this case), grades A, D and E form group ③ of 300 t, and there will be no excess.

Besides steel grade, similar grouping problems have to be solved for different processes with respect to product size, hardness, surface coating material, etc., and a great number of optimization calculations have to be conducted to compile a production plan. Decisions of the processing sequence in a production batch and other optimization problems are solved by different methods; the optimization calculations used for the production planning of Nippon Steel & Sumitomo Metal are listed in **Table 1**.

Table 2 is an organized list of the methods employed to solve the optimization calculations. General-purpose software tools are often used for basic methods such as linear programming and mixed integer linear programming, but when more complicated combined optimization is involved, techniques developed by the R&D laboratories of the company and those developed by the Systems Research & Development Center of NS Solutions Corporation (NSSOL) are also used.

As stated above, there are many methods and software packages practically usable for optimization calculation for a single production process available on the market, but when the number of calculation objectives is large, they are not satisfactory within the restricted time allocated for the job. In addition, when operation conditions change from time to time and calculations have to be repeated many times, computer capacity is often insufficient because the time allocated for the calculation is several tens of seconds at the longest. In addition, production planning covering two or more processes is far more difficult than that for a single process.

Figure 8 schematically shows how orders are grouped into pro-

Table 1 Optimization calculation methods used in Nippon Steel & Sumitomo Metal

Problem type	Decision content												Constraint condition			
	Group	Decision quantity			Decision combination						Order	Time	Combination		Decision order	
		Alloca-tion	Flow rate	Size, weight, time	1:1	1:N	M:N	Shape					1:N	With shape		
								1D	2D	3D			Relation of elements	Stacking problem	Range	Accumu-lation
Setpartition	●															
	●					●			●							
						●		●						●		
				●			●		●							
				●		●			●							
Resource allocation		●														
Maximum flow			●													
Knapsack						●										
Matching					●											
										●						
Shortest path						●							●			
				●												
Vehicle routing						●					●					
Vehicle routing with Time-Windows						●					●				●	
Asymmetric traveling salesman											●					
Asymmetric traveling salesman with Time-Windows											●				●	
Asymmetric traveling salesman with cumulative restriction											●					●
Asymmetric traveling salesman with cumulative restriction and Time-Windows											●				●	●
Job-shop scheduling												●				
						●						●				
				●		●						●				
Slab design				●		●										
1 dimension cutting stock						●		●								
2 dimension cutting stock						●			●							
Resource allocation + Job-shop scheduling		●				●						●				
Resource allocation + Job-shop scheduling + 1 dimension cutting stock		●				●		●				●				

Table 2 Methods of optimization calculation

Method of optimization		
Major division	Middle division	Minor division
Mathematical programming	Linear programming	Linear programming (LP)
		Mixed integer linear programming (MIP)
		Steepest descent method
Combination optimization	Constraint programming	Constraint programming (CP)
		Tabu search (TS)
		Genetic algorithm (GA)
Individual algorithm	Graph algorithm	Graph algorithm
Simulation	–	–

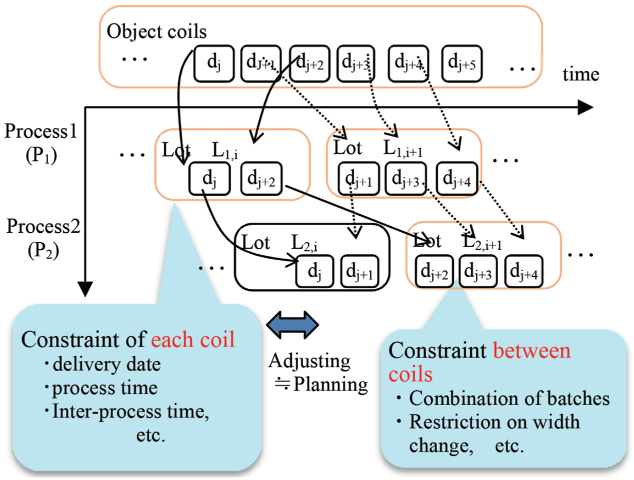


Fig. 8 Optimal calculation for several process

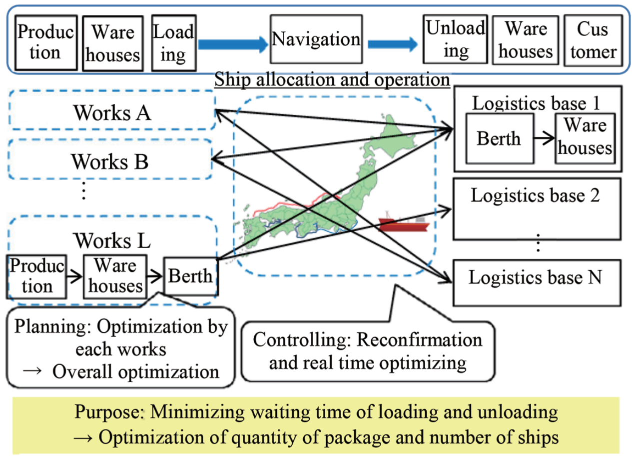


Fig. 9 Purpose of optimal logistics

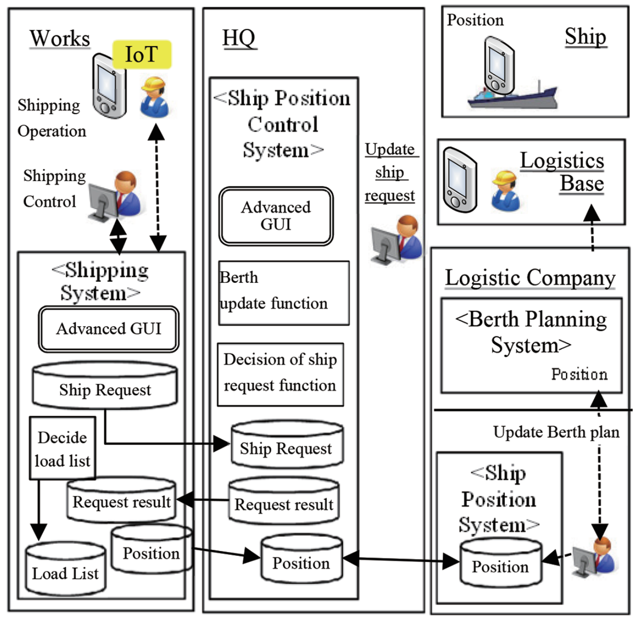


Fig. 10 Schematic of integrated logistic control system

duction batches for two processes and how the processing sequence is defined in each of the batches. When there is a sufficient storage area for semi-finished products between the processes and an indefinite amount of intermediate stock is allowed, Process 1 can operate under batch formation and a processing sequence best suited to it, and the semi-finished products from Process 1 can be accumulated in the storage area until the best operation batches and processing sequence for Process 2 are defined. Then Process 2 operates under the best-suited batch formation and processing sequence, and the productivity of both the processes can be maximized. The above mode of operation, however, is unrealistic because some of the products may fail to meet their delivery deadlines, and the amount of the intermediate stock may exceed the storage yard capacity. In actual practice, based on and within the restrictions of the production lead time allowed for individual orders, the best batch formations and processing sequences for two or more processes must be decided within a short time, and studies are being conducted to devise a method for solving the problem.

4. Logistics Planning

Product transportation planning is a difficult task because there are many steel works (loading ports) and unloading ports, and it is necessary to synchronize product loading and unloading plans with vessel allocation plans at all the ports, which may often change significantly due to weather conditions. As **Fig. 9** shows, marine transportation consists of loading, navigation and unloading, and additionally, waiting for loading and unloading, demurrage due to bad weather and navigation to another port after unloading. If it is possible to decrease the waiting time for loading and unloading, transportation efficiency is improved, and the utilization of the cargo hold space of vessels is optimized.

Conventionally, different berth plans were drawn up at different steel works, and vessel allocation plans were decided through numerous exchanges of information between the head office and individual works as shown in Fig. 6. However, to decrease the vessel waiting time and improve cargo hold utilization, the berth plans have been standardized for the whole company, a common, company-wide virtual database has been constructed, and an integrated logistic control system has been provided to enable efficient preparation of logistics plans (see **Fig. 10**).[6)]

5. Application of Advanced Information System Technology

The field of activity supported by information system technology has expanded remarkably as a result of the advance in computers, the progress of big data analysis, the development of artificial intelligence (AI), and expanded application of the Internet of things (IoT), whereby many things surrounding our daily life are linked through the Internet. The advances especially of data analysis and machine learning are such that they are now industrially practicable. Actually, Nippon Steel & Sumitomo Metal has introduced advanced information technology (IT) for efficiency improvement of staff activities, decision making in various fields by image recognition, etc. (see **Fig. 11**). Small and light-weight sensors and smart phones have made it possible to link information from moving objects and people with networks, which was impossible previously, and such new information channels are also used to closely monitor the safety and work conditions of personnel.[7–10)]

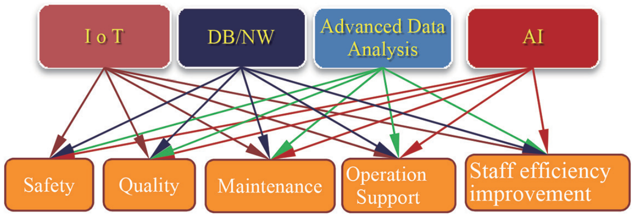


Fig. 11 Application of advanced information technology

6. Conclusion

Planning is a very important field of the steel industry where information system technology is applied; here it assists people's decision making. The industry has applied various new techniques and methods of information system technology to the planning activities whenever new methods of mathematical programming are developed and computer advancement enters into a new stage. However, automatic planning based completely on information system technology has been realized only in a small number of fields, and its role is limited mostly to information assistance for human decision making.

The latest techniques and methods of information system technology such as those described in the previous section, however, have become industrially applicable, and it is expected that many people engaged in planning activities will be freed from their difficult tasks. Application examples of such latest technologies are presented in other articles of this edition.

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