Simulation-based Production Scheduling Solution for Flexible Production

Today's business environment is characterized by increasing uncertainty, including worldwide parts shortages, growing diversity in customer preferences, and public demands for products to take account of the environment. Confronted with this, manufacturers, especially those in the automotive industry, have an increasing need for flexible production practices that allow them to adapt to fluctuating demand and operational changes. When scheduling flexible production, operational considerations call for the ability to cope with the complexity of production scheduling while also being able to respond quickly when needed. Similarly, the challenge for production management systems is to be able to start on a small scale and then to scale up with flexibility as the production line is expanded. In response, Hitachi is developing a simulation-based optimization engine for the scheduling of flexible production and a scheduling solution that will be made available as a microservice. This article presents an overview of the solution and the plans for the future.

Taisei Massaki
Noboru Fujita
Tatsumasa Isono
Norisuke Fujii, Ph.D.
Kohei Miyata

1. Introduction

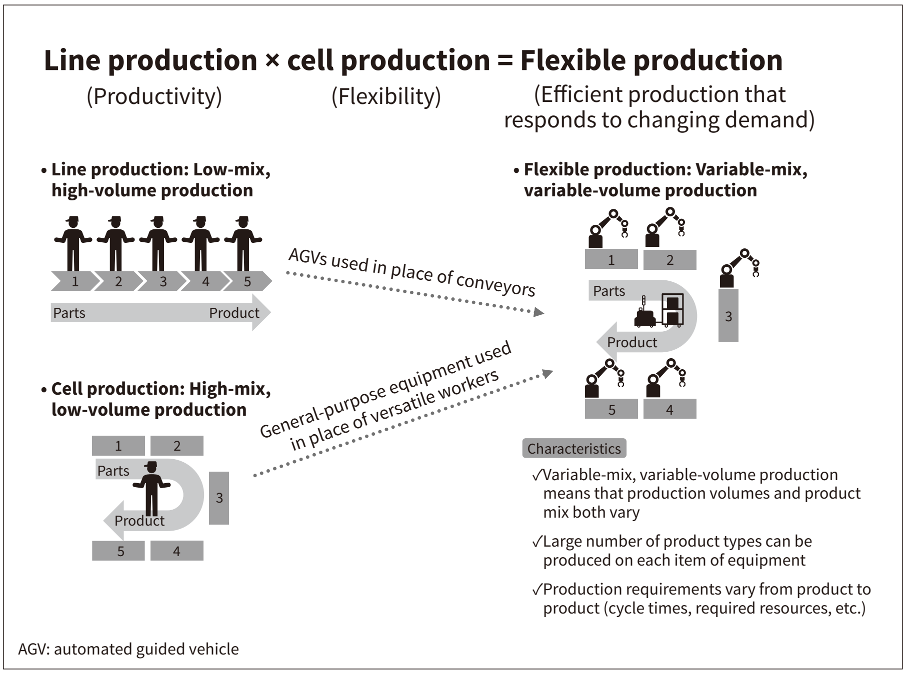
1. 1 Conditions in Manufacturing Industry and Implications for Flexible Production

The pace of change in society over recent years has been remarkable, with the manufacturing industry experiencing unprecedented levels of uncertainty and instability. Along with restrictions on corporate activity due to COVID-19, supply shortages for semiconductors and other inputs driven by rising global demand, shorter product lifecycles, and growing diversity in customer preferences, companies are also being called upon to fulfil their social responsibilities by supplying products that take account of the environment. On top of this, manufacturers, especially those in the automotive industry, require variable-mix, variable-volume production capabilities in order to supply a diverse range of products in the quantities required[(1), (2)]. This has led to heightened interest in flexible production practices that can adapt to demand fluctuations and operational changes.

This article focuses in particular on the issues associated with achieving flexible production, covering the operational and production management system challenges of production scheduling, also giving an overview and describing the future plans for a digital scheduling solution that is currently being developed to address these issues. In developing this solution, Hitachi is drawing on knowledge of information and operational technology (IT and OT)[(3)] that it has built up over many years of working in manufacturing.

Figure 1 — Features of Flexible Production

Flexible production enables variable-mix, variable-volume production, with the flexibility to adapt to production schedules that change on a daily basis. This is done by combining the attributes of low-mix, high-volume production lines, and cell production for high-mix, low-volume production.



1. 2 Overview of Flexible Production

This section gives a general introduction to flexible production, an approach to manufacturing that enables variable-mix, variable-volume production. Production lines achieve high levels of efficiency using conveyers and other equipment dedicated to the production of a limited range of products. Cell production, in contrast, allows for the manufacture of a wide range of products by versatile workers. The aim of flexible production is to combine both of these attributes at the same time. In flexible production, automated guided vehicles (AGVs) and materials handling systems are used in place of conveyors and productivity is enhanced by automation. By using general-purpose equipment in place of special-purpose equipment or skilled workers, it also enables high-mix production at a level close to what would be achieved by those skilled workers (see **Figure 1**). This provides the flexibility for variable-mix, variable volume production in accordance with production schedules that change on a daily basis.

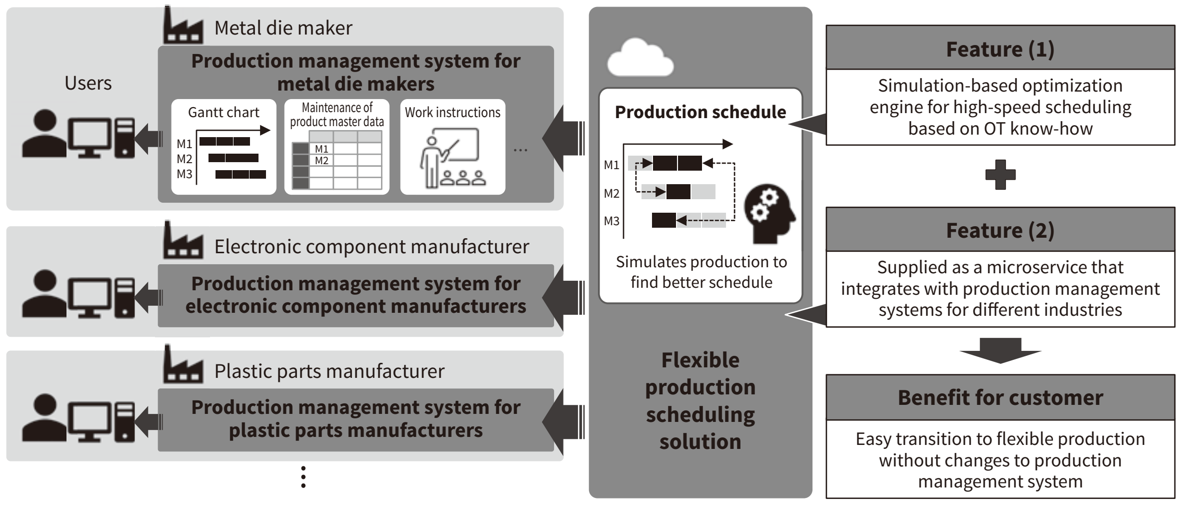
1. 3 Difficulties of Transitioning to Flexible Production

This section describes the operational and production management system challenges of production scheduling when making the transition to flexible production. Because flexible production is all about variable-mix, variable volume production, production volumes and product mix vary on a daily basis in response to fluctuating demand. Moreover, as the installation of general-purpose equipment increases the number of different products that can be manufactured using the same equipment or line, it provides a higher degree of production freedom. However, it also adds to production scheduling constraints, with a need to consider production conditions that are specific to each product, such as cycle time, required resources, and whether setup changes are needed. The downside of this is greater planning complexity, a consequence of the huge number of possible combinations of which products to produce, on which equipment, and in which order. Even experienced technical staff find it difficult to devise production schedules under such circumstances. Furthermore, this calls for the flexibility to revise production schedules in response to sudden changes in supply and demand conditions or, in the event of downtime due to equipment faults or other problems, to generate new schedules that can recover without interrupting production. How to ensure that scheduling can respond quickly in such circumstances is a key issue.

Meanwhile, companies interested in flexible production span the full range from end-product manufacturers to parts suppliers. Depending on the size of their business and the conditions under which they operate, some of these will likely pursue flexible production lines on a large scale while others will make a gradual transition in which existing and flexible production lines coexist. In either case, there is a growing need to ensure that the existing production management system maintains its usability for plant-based users. To address this, what is needed is to develop a system specifically for use with optimization engines that can obtain solutions satisfying the various production scheduling constraints needed for flexible production to work, and to make these easy to integrate with existing systems so as to reduce the time and cost of implementation and allow the transition to start on a small scale. Also desirable is flexible scalability so that the required functions and resources

Figure 2 — Overview of Flexible Production Scheduling Solution

The flexible production scheduling solution can integrate with production management systems for different industries to generate production schedules quickly. This provides a way for customers to adopt flexible production practices for scheduling while continuing to use the functions of their existing production management system.



OT: operational technology

can be made available when needed, and in the quantities required, based on how fast production is ramped up.

2. Flexible Production Scheduling Solution

Two critical issues when making the transition to flexible production are: (1) the ability to cope with the complexity of production scheduling while also being able to respond quickly when needed, and (2) the ability for the system to start on a small scale and then scale up as needed. The flexible production scheduling solution was devised to address these two challenges (see **Figure 2**).

To address the first issue, the solution features the use of simulation to assess how well the production line will function and a simulation-based optimization engine that can generate production schedules quickly, utilizing Hitachi OT know-how to improve productivity. Similarly, the second issue of scalability is addressed by making the solution available as a microservice that provides a standalone production scheduling function that can interoperate with the production management systems used in different industries. These features can smooth the transition to flexible production by adding a production scheduling function suitable for this purpose as an upgrade to the existing production management system with which the customer is already familiar. The following sections describe these features in more detail.

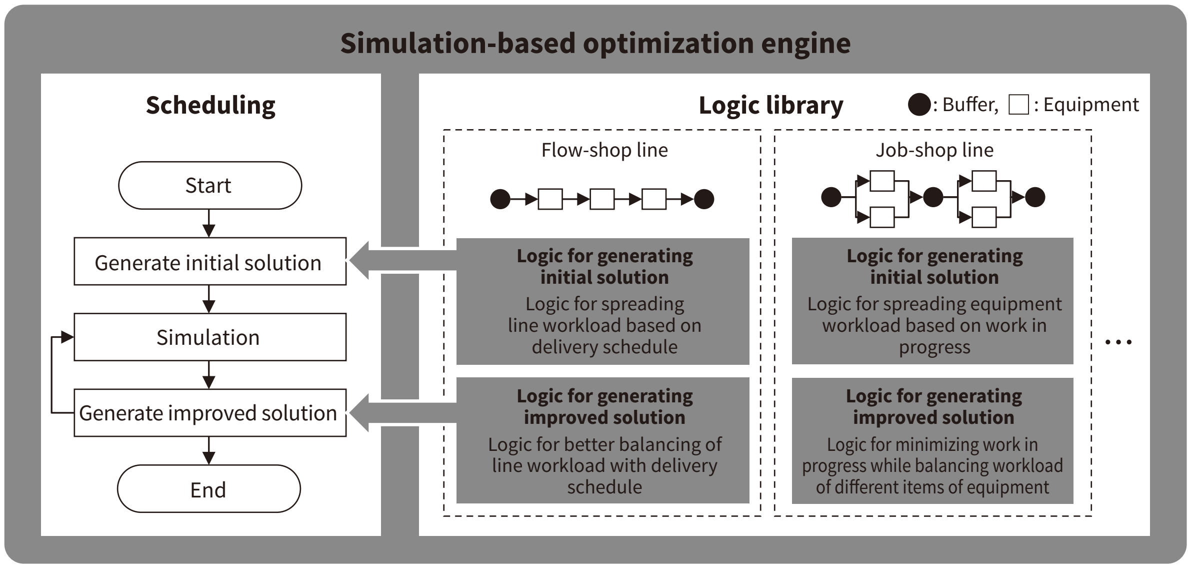
2. 1 Simulation-based Optimization Engine

Existing production scheduling systems intended for flexible production combine the use of meta-heuristics for scheduling with detailed prediction of complex goods movements[(4), (5)]. The problem with this approach, unfortunately, is the long computation times it requires, such that workable schedules are not available in time.

In contrast, the simulation-based optimization engine shortens the computation time by augmenting the conventional search algorithm with scheduling logic based on the characteristics of the line concerned. **Figure 3** shows a block diagram of the optimization engine. The engine is made up of a library of scheduling logic for different line characteristics and a scheduling function that utilizes this logic. In the example of a flow-shop line that manufactures a number of different products, because each of these products needs to be worked on for a different length of time, the schedule needs to distribute this workload in a way that also meets the delivery schedule. In this case, an initial solution is generated in which products enter the line in delivery date order and the work is spread between each of the line workstations. A solution search is then performed on the basis of the tradeoffs between these two objectives. For a job-shop line, in contrast, the requirement is to spread the equipment workload while reducing the quantity of work in progress. In this case, the initial solution is generated by assigning equipment based on the amount of work required for each product. The order in which each one is worked on is determined so as to minimize the amount of work in progress left waiting between process steps. A solution search is then performed based on the tradeoffs. By selecting the appropriate logic for the type of line being scheduled, an optimal schedule can be produced quickly.

Figure 3 — Block Diagram of Simulation-based Optimization Engine

The simulation-based optimization engine is made up of a library of scheduling logic for different line characteristics and a scheduling function that utilizes this logic. The complexity and responsiveness requirements associated with flexible production are dealt with by selecting logic appropriate to the line being scheduled.

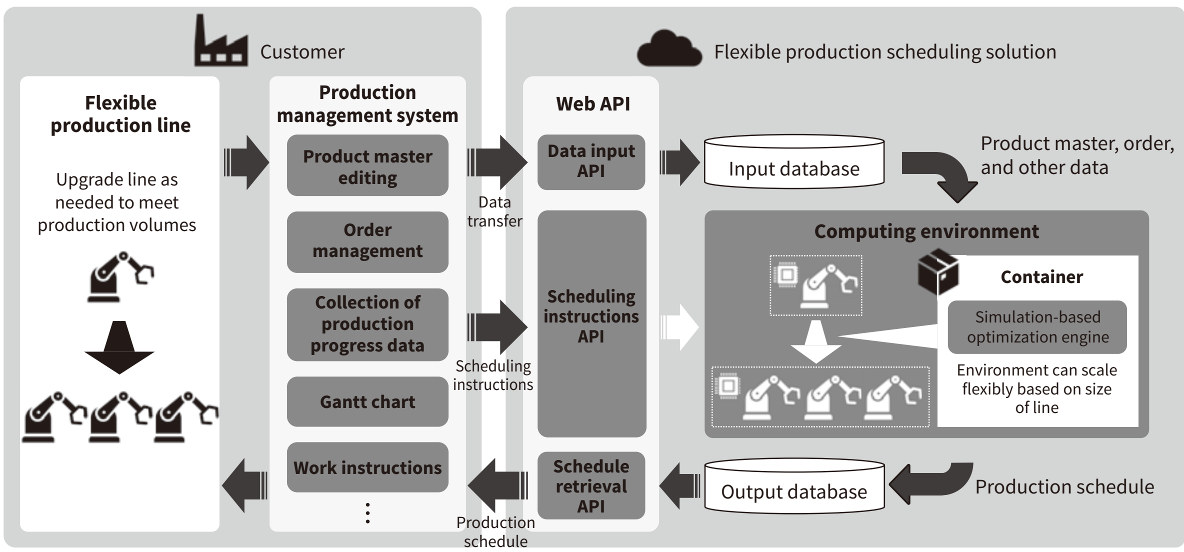


2. 2 Delivery as Microservice

Making the transition to flexible production requires changes to the existing production management system, including the addition of a production scheduling function suitable for flexible production lines[6]. The conventional way of doing this would have been to upgrade the system to use third-party scheduler software running on the on-premises hardware. Unfortunately, because of the expense and the long time it takes to implement the upgrade, it is difficult to adopt flexible production on a small scale initially. The lack of flexible scalability also poses a problem because the system needs to be progressively updated as the scale of production ramps up.

Figure 4 — Block Diagram of Flexible Production Scheduling Solution

The flexible production scheduling solution uses a container implementation for the simulation-based optimization engine to obtain the required computational resources as needed for scheduling production based on the instructions from the customer.



API: application programming interface

In response, Hitachi developed the flexible production scheduling solution as a microservice. This configuration provides the ability to start small and then scale up. The simulation-based optimization engine has a container implementation that runs in the cloud and interfaces with the existing production management system by means of an application programming interface (API). **Figure 4** shows a block diagram. Along with the computing environment for the container implementation of the simulation-based optimization engine, a web API is also included for managing the microservice. This web API is used to obtain the product master records and order information needed for scheduling and returns a result in the form of a production schedule. This enables customers to perform flexible production scheduling without having to make major changes to the systems with which they are already familiar. The microservice configuration also allows for the container environment to be set up with sufficient computational resources based on the scheduling instructions from the production manager at the site. This means that computational capacity can be scaled in step with upgrades to the flexible production line.

3. Conclusions

This article has presented an overview of a flexible production scheduling solution, describing what Hitachi has been doing to enable better and more sophisticated scheduling practices that are in step with the trend in manufacturing toward flexible production.

As it works toward the full-scale commercial deployment of the solution, Hitachi intends to continue assessing the benefits of the solution and value that it is currently undertaking through collaborative creation with customers. These plans include testing how well the solution interoperates with existing production management systems. This is being done to verify ways in which the many companies that are interested in flexible production can adopt the solution without having to make major changes to their existing production management systems.

Hitachi also intends to utilize digital solutions to facilitate greater sophistication and automation of production management tasks. These future plans involve utilizing the production schedule data obtained by the deployment of this solution together with production line data to go beyond production scheduling to investigating and trialing ways of improving the quality of the product master data that is critical to scheduling and facilitating its efficient maintenance.

References

1) Ministry of Economy Trade and Industry et al., "Summary of the White Paper on Monodzukuri 2022 (FY2021 White Paper on Manufacturing Industries)" (May. 2022), https://www.meti.go.jp/english/press/2022/pdf/0531_004a.pdf
2) K. Yano et al., "World Economic Scenarios and Risks to 2025," Hitachi Souken Journal, 17-1 (May. 2022), https://www.hitachi-hri.com/english/journal/__icsFiles/afieldfile/2022/05/30/17-1-3.pdf
3) Hitachi, Ltd., "Hitachi's OT," https://www.hitachi.com/products/it/control_sys/ot/
4) F. Pezzella et al., "A Genetic Algorithm for the Flexible Job-shop Scheduling Problem," Computers & Operations Research, 35, pp. 3202–3212 (Oct. 2008).
5) I. A. Chaudhry et al., "A Research Survey: Review of Flexible Job Shop Scheduling Techniques," International Transactions in Operational Research, 23, pp.551–591 (May. 2016).
6) B. K. Choi et al., "MES (manufacturing execution system) Architecture for FMS Compatible to ERP (enterprise planning system)," International Journal of Computer Integrated Manufacturing, 15, pp. 274–284 (May 2002).

Authors

Taisei Massaki
Co-creation & Architecture Promotion Department, Technology Strategy Division, Industrial Digital Business Unit, Hitachi, Ltd. *Current work and research:* Business incubation and service development of digital solutions for manufacturing industry.

Noboru Fujita
Co-creation & Architecture Promotion Department, Technology Strategy Division, Industrial Digital Business Unit, Hitachi, Ltd. *Current work and research:* Business incubation and service development of digital solutions for manufacturing industry.

Tatsumasa Isono
Systems Department 4, Automotive Systems Division, Industrial Digital Business Unit, Hitachi, Ltd. *Current work and research:* Concept planning, and PoC and system implementation of DX/IoT project for the automotive industry.

Norisuke Fujii, Ph.D.
Industry Automation Research Department, Center for Sustainability – Controls and Robotics Innovation, Research & Development Group, Hitachi, Ltd. *Current work and research:* Research and development of manufacturing-execution system and production scheduling technology.

Kohei Miyata
Industry Automation Research Department, Center for Sustainability – Controls and Robotics Innovation, Research & Development Group, Hitachi, Ltd. *Current work and research:* Research and development of production scheduling technology.