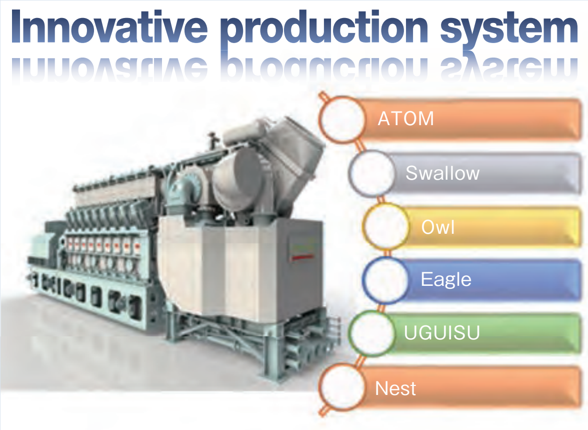
Establishment of an Innovative Production System to Support Flexible Production



In order to gain a competitive advantage in the increasingly competitive global market, we have developed and deployed an innovative production system for supporting high-quality and quick-delivery production aimed at overall optimization, with the combination of the Kawasaki Production System (KPS) and digital technologies. We have established this innovative production system with the aim of realizing Smart Factory, which supports flexible production that enables real-time coordination. Also, we have connected this system with our welding management system so as to make full use of human resources, materials, equipment and information.

Introduction

It is imperative to carry out high-quality, quick-delivery production and to realize cost reductions and profitability improvements while addressing intensifying competition to win orders as well as addressing changes in the management environment and responding to market and customer needs.

1 Background

Establishing an advanced flexible production system that enables real-time coordination by fully utilizing accurate information for manufacturing has become essential. Therefore, we aim to realize an unrivaled Smart Factory by establishing an innovative production system that seamlessly obtains information on human resources, materials, equipment, processes, procedures, and other matters related to manufacturing (big data) and will lead us to optimal production.

(1) KHI's production system (KPS)

We are promoting the Kawasaki Production System (KPS) at all of our sites involved in manufacturing. KPS's basic concept is to improve production efficiency by striving to thoroughly eliminate all waste related to human resources, materials, and equipment, establishing a system that fully utilizes these elements and shortening lead times by realizing just-in-time production, aiming to achieve the ideal vision. In other words, we pursue profits that can be obtained by improving factory controls such as production controls, process controls, and quality controls, and we obtain such unseen profits by improving and innovating in manufacturing. One source of these profits is hidden among muri (unreasonableness), mura (inconsistencies), and muda (waste) in manufacturing. If one can find and eliminate the unreasonableness, inconsistencies, and waste hidden at production sites, one can obtain profits. Unreasonableness refers to interruptions and forcing production sites to do jobs in an unscientific amount of time, which drastically worsens a production site's production efficiency. Inconsistencies refer to variance in quality and man-hours per production run. Reducing such variance produces profits. Lastly, waste refers to losses. At production sites, types of losses include time loss, material loss, and loss caused by failure. Manufacturing that reduces such losses produces profits.

(2) Advancement of digital technologies

In recent years, innovative digital technologies for manufacturing have been developed, such as cloud technology and AI technology. Supply chain management that employs cloud technology makes it possibly to instantly and effortlessly know the positions and statuses of materials. Also, the arrival of material transport equipment that employs AI has opened up possibilities for automatically transporting materials that differ per ordered model.

We have also been developing an electronic production

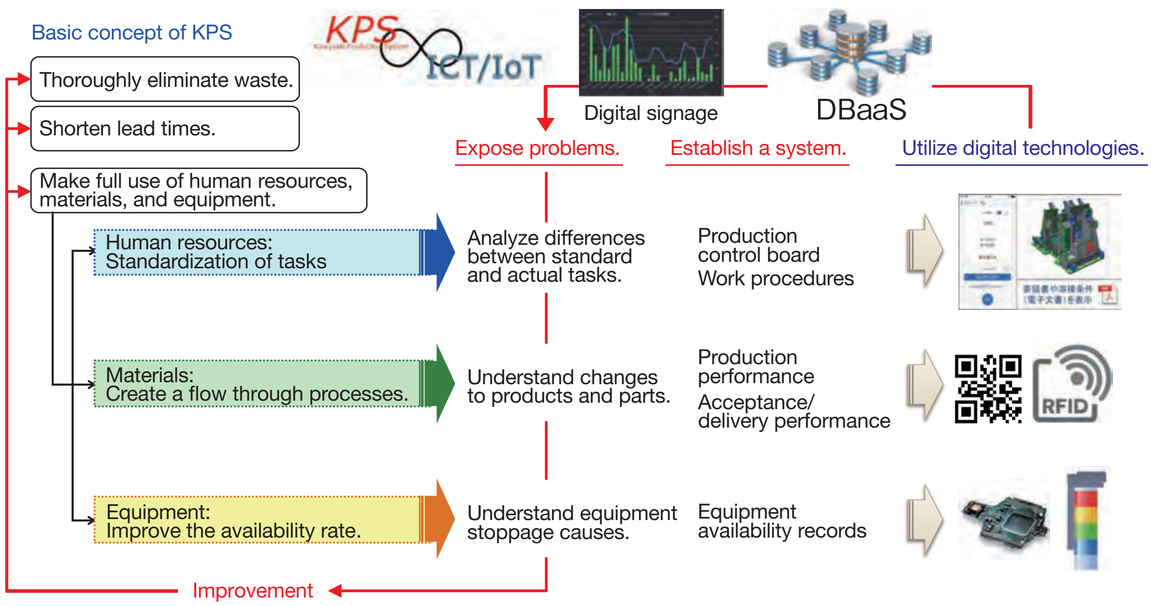


Fig. 1 Integration of KPS and digital technologies

control board, which provides detailed visual instructions for detailed tasks, and other element technologies that enable us to digitalize material IDs as well as digitally measure equipment availability and operations.

(3) Aiming to establish a KHI version of Smart Factory

The KHI version of Smart Factory is realized by integrating KPS with digital technologies as shown in **Fig. 1**.

We are moving forward with the Smart-K Project, which aims to establish a new core system that will play a main role in the production system. To realize it quicker at lower cost, we have decided to develop an innovative production system by adding practical functions to our existing core system.

2 Development policies for the innovative production system

The Energy Solution & Marine Engineering Company performs mixed production of variable types and volumes of six products (naval machinery, turbine, diesel, hydraulic, aerodynamic, and gas engine) at three factories (canning, machinery, and assembly). In the past, the complicated flow of materials was managed by a variety of work instructions at each factory.

To secure a competitive advantage for our products by strengthening our manufacturing capabilities for the future and to enhance lead time optimization aimed at overall optimization as well as a system for fully utilizing human resources, materials, and equipment, in addition to observing delivery dates within factories and to customers, we have decided to improve productivity by promoting KPS in individual build-to-order manufacturing and sophisticating factory management using digital technologies in cooperation and collaboration with Energy Solution & Marine Engineering Company.

Promoting KPS has enabled us to improve and innovate in manufacturing very quickly. To keep up, we needed to speed up the addition of functions to and release of applications. To address such needs, we proactively assimilated the development concepts of agile development, which quickly repeats the cycle of development, release, and improvement, and of a microservice architecture, which enables efficient development of individual functions of complicated applications.

3 Development items for the innovative production system

The innovative production system is configured by combining the applications (e.g., ATOM, Swallow, and OWL) shown in **Fig. 2**. The applications we have developed include those listed below.

(1) Centralized core system management function (ATOM)

This function centrally manages the standard data organized in the existing core system by promoting KPS.

(2) Schedule planning support (Swallow)

This function establishes new tasks to centrally manage and operate the schedule at each factory and prepares a consistent production plan table, medium-term

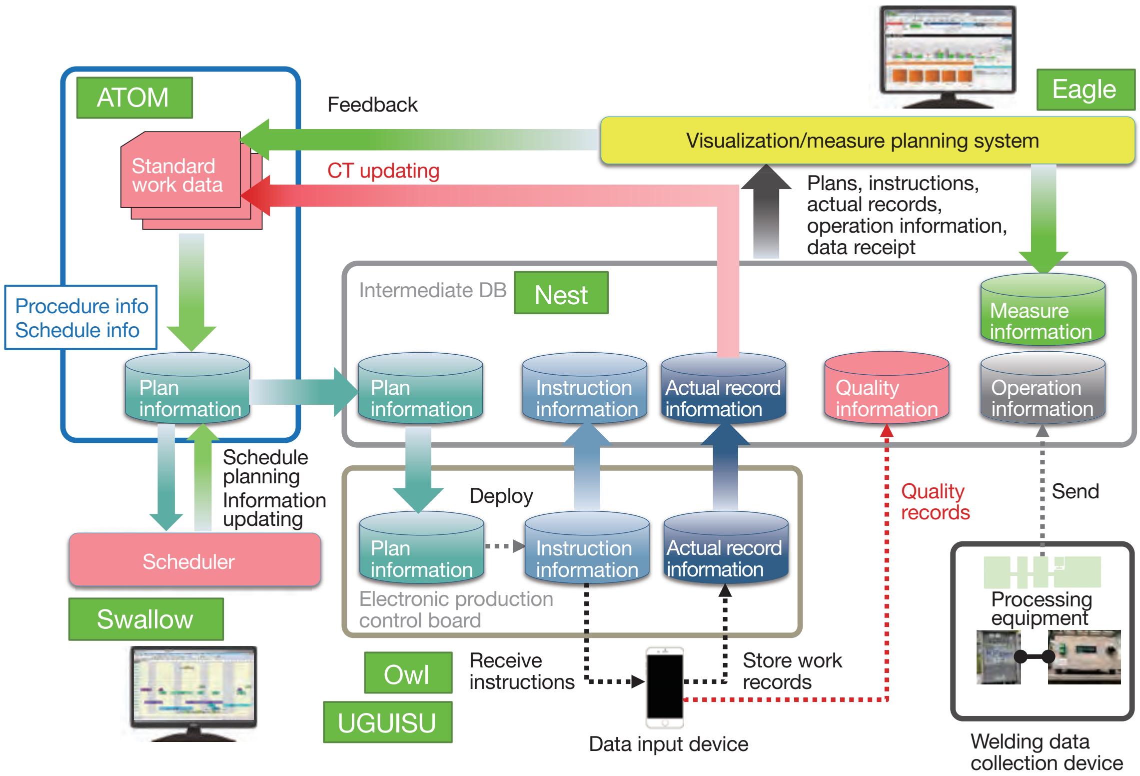


Fig. 2 Overview of the innovative production system

schedule, and short-term schedule according to the master schedule.

(3) Electronic individual production control board (OWL)

This function stores digital work instructions and work records that are connected to the standard data registered in the core system.

(4) Production status real-time visualization (Eagle)

This function introduces functions that collect and store work instruction data and work record data and visualizes the progress of processes and equipment operating statuses for multiple purposes. Also,this function is directly linked to KPS improvement activities, such as work time analysis and understanding the reasons for differences.

(5) Information consolidation via an integrated database (Nest)

These are databases used to centrally manage all manufacturing information related to production controls, process controls, and daily controls.

(6) Andon that visualizes work progress (UGUISU)

This function displays the work progress per worker and the time required to finish the remaining tasks, which enables the supervisor to manage the progress in real time.

4 Results of deploying the innovative production system

We have successfully established a foundation for Smart Factory, which enables visualization of production systems and quick iteration of the improvement activity cycle.

For example, the electronic production control board (OWL) plays the role of storing each day's work instructions and work records for each worker as shown in **Fig. 3**, and this has enabled us to flexibly address high-mix, low-volume production. The products handled at our factories include individually differentiated products, the shapes of which differ per customer, and repeat products, which are produced repeatedly several times a year, each of which requires characteristic manufacturing. Individually differentiated products require a function that separates long-term lead times into processes of appropriate lengths and provides work instructions. Therefore, we provide an interface that features an image of a calendar-based process sheet. In addition, for some repeat products, multiple workers are assigned to work together. We thus provide an interface for assembly work that features an image of a sheet that shows multiple workers' tasks in combination. Particularly at machine processing factories, a single worker must operate multiple pieces of equipment simultaneously and day/night shifts are implemented, so a function that facilitates the handover process between

Fig. 3 Electronic production control board (OWL)

workers who work during the day and workers who work at night is required. Furthermore, it is also necessary to have a function that provides instructions on regular tasks such as direct tasks for product production and indirect tasks to be performed daily such as morning meetings and equipment checks. To support instant understanding of work instructions that have been segmented into tasks taking one minute or less, electronic work procedures display photos and figures rather than text.

The production status visualization (Eagle) can now play a role as a BI tool, which tallies the work records stored by the aforementioned electronic production control board (OWL) and generates a graph of them. Equipped with a drill-down function that tallies work times in terms of different units such as products, processes, procedures, and tasks, Eagle can evaluate work records from various perspectives and expose problems. In addition, it enables one to ascertain work progress by evaluating the work records using an index known as the "achievement rate," which is the ratio of the target time versus the actual time; sorting the records in achievement rate order to make it easier to find problems with each task; and comparing the scheduled work volume against the finished work volume.

These functions standardize KPS daily controls, work instruction and work record collection via the electronic production control board, and the PDCA methodology for improvement activities by visualizing such data as shown in **Fig. 4**, thereby enabling anyone to implement advanced

Fig. 4 Visualization of muri (unreasonableness), mura (inconsistencies), and muda (waste)

improvements. Improvement methods have become more sophisticated and the PDCA cycle speed has been improved, and output levels have also been improved by repeatedly making improvements. On-site supervisors can now provide workers with detailed work instructions for the day, and the workers can carry out the work according to the instructed procedures without hesitation. By evaluating any deviations from the standard work time by using a clear figure of the achievement rate, we can immediately identify problems that have occurred during the work, investigate the causes, and take countermeasures, which has resulted in the elimination of unreasonableness, inconsistencies, and waste hidden within work.

As described above, although past improvements depended on the skills of supervisors—in other words, were improvements that depended on people—the digitalization of improvement tools has standardized improvement methods and enabled everyone to implement high-level improvements.

5 Connection with the welding management system

In addition to the utilization of digital technologies for processes and tasks, which has been realized by the innovative production system, we have also enabled data on equipment, which is another of KPS's elements, to be utilized in the production system by digitalizing welding management and connecting it to the innovative production system as shown in **Fig. 5**.

To respond to high-level quality requirements that involve complicated welding conditions, we have fundamentally reformed our welding management. Aiming to streamline work management, we collected various types of information generated from welders as data and employed digitization to transfer manual management that consisted of manual operations and handwritten documentation, which was the status quo prior to the introduction of the innovative production system, to automatic recording as needed. The welding data collection system we developed consists of three components: a welding data collection device (SB: Sensor Box) that retrieves data from welders, a quality control function that collects welder data and work record data as well as stores and visualizes them in the form of welding work records, and an electronic production control board (OWL) that instructs the welding workers about which sections are to be welded and welding procedures.

Introducing this system has enabled us to realize the following:

(1) Digital storage of welding information

Digitally stores welding information required for welding work records, which was handwritten in the past.

(2) Notification of deviations from welding conditions

Instantly notifies workers of any deviations in welding conditions from the welding range, such as welding current.

(3) Automatic collection and transmission of welding data

Obtains the welding current, welding voltage, and welding ON/OFF signal from a welder and the worker ID, production number, joint number, and other information

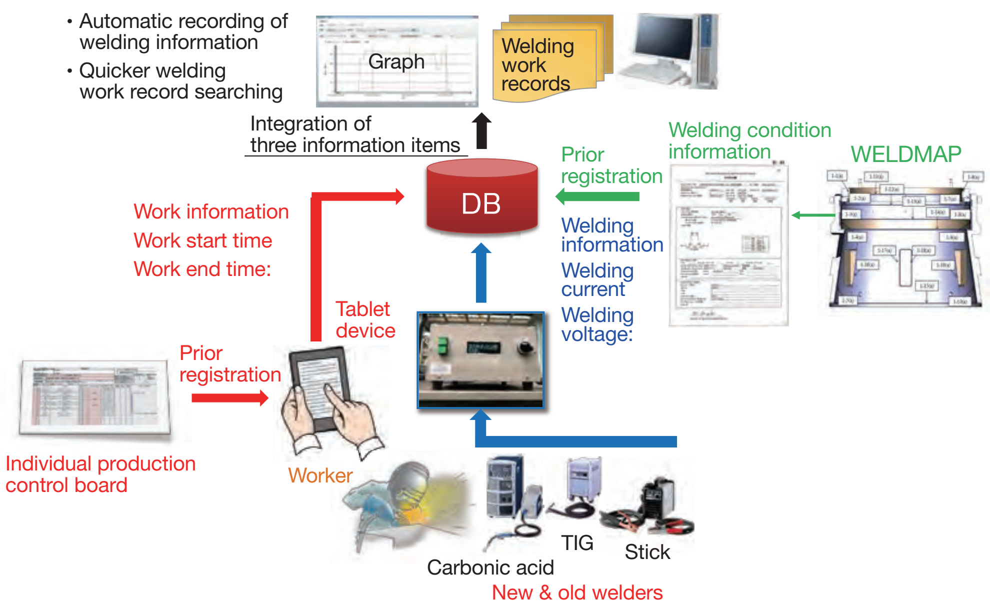


Fig. 5 Connection to the welding management system

from a barcode. Transmits the collected data to an upper-level storage/display application via wireless LAN.

(4) Quality control by visualization

Registers data transmitted from the welding data collection device in a database as needed and visualizes the welding current and welding voltage in real time. In addition, stores the welding information required for welding work records as electronic data and automatically maps the welding data to a specified welding condition recording sheet.

Conclusion

By establishing and introducing the innovative production system, we have secured and enhanced the fundamental technologies for Smart Factory. By deploying these horizontally, we have established a system for a specific project through which we aim to pursue and further deepen KPS's philosophy of "fully utilize human resources, materials, and equipment" as well as fully utilizing information.

With regard to collection and storage of production site data, we are now developing an environment for collecting information on human resources, materials, and equipment at actual production sites, by assigning digital IDs (digitalization) to materials and obtaining equipment operation data, and enhancing the horizontally deployable Smart Factory foundation that realizes quicker, lower-cost introduction of the environment through standardization and modulation. Actual production data collected and stored from the environment thus established can be used to follow-up on production progress and optimization, which is expected to realize quicker response and shorten lead times.

Going forward, we will make maximum use of the resources we possess including human resources, materials, and equipment, and we will contribute to further promoting KPS by sophisticating our digital technologies for manufacturing and striving to expand their range of applications.

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