SIMULATION ENVIRONMENT FOR MANUFACTURING CELL TO SUPPORT FULL PRODUCTION PERFORMANCE AT PRODUCT LAUNCH

Hironori Hibino

Technical Research Institute of JSPMI
(Japan Society for the Promotion of Machine Industry),
1-1-12 Hachiman-cho, Higashikurume-city, Tokyo, Japan, 203-0042
hibino@tri.jspmi.or.jp

Abstract

It is now important to reduce lead-time from the manufacturing system design stage to the manufacturing system implementation stage and support full production performance at the product launch, because manufacturing industries face various problems such as shorter product life cycle. Before a manufacturing system is implemented, it is difficult to complete all the facility control programs for several pieces of equipment used in the manufacturing system currently. Before the real manufacturing system runs, methods to confirm implementation of production management applications, which need to evaluate and improve manufacturing systems at the product launch such as a facility behaviours record application, have not been developed. These difficulties stopped precise and rapid support of a manufacturing engineering process.

In order to solve these difficulties, it is necessary to develop a method to mix and synchronize real equipment, virtual factory models on the computers, and production management applications.

In our research, in order to reduce the lead-time from the design stage to the implementation stage, a manufacturing engineering environment (MEE) is proposed. MEE consists of a manufacturing cell simulation environment (MCSE) and a distributed simulation environment (DSE). MCSE, which is used to create and evaluate facility control programs while mixing and synchronizing real equipment, virtual factory models, and production management applications before manufacturing systems are implemented, is emphatically proposed in detail. MCSE consists of a manufacturing cell simulator, a soft-wiring system, and ORiN. The manufacturing cell simulator simulates facility behaviours by using data from the soft-wiring system. The soft-wiring system connects real world data, simulation world data on the manufacturing cell simulator, and data on manufacturing management applications without hard-wiring. The soft-wiring system also connects manufacturing cell and production management applications. ORiN is a standard distributed network system for manufacturing systems. Finally the case was carried out to evaluate MCSE.

Keywords: Manufacturing cell, simulation, PLC, robot, production launch.

Author's biography

Dr. Eng. HIRONORI HIBINO is a Senior Researcher of the Technical Research Institute of Japan Society for the Promotion of Machine Industry (JSPMI), which is an affiliate of the Ministry of Economy, Trade and Industry in Japan. He is a guest professor at the Tokyo University of Agriculture and Technology concurrently. His research fields are distributed simulation, manufacturing system design using simulation, manufacturing cell simulation for combinations of real world and simulation world. He is an academic member of JSME, JIMA, and JSPE. He is also a director of the Scheduling Society of Japan.

1 Introduction

Recently, manufacturing industries face various problems such as shorter product life cycle, more diversified customer needs[1]. It is now important to reduce the lead-time from the manufacturing system design stage to the manufacturing system implementation stage. A manufacturing system simulator plays an important role in designing and evaluating manufacturing systems by using a virtual factory model at the manufacturing system design stage[2][3][4]. At the manufacturing system implementation stage, it is important to make and evaluate facility control programs for a manufacturing cell, such as ladder programs for programmable logical controllers (PLCs) rapidly[5].

Ordinarily the facility control programs not only control a single piece of equipment such as a robot and a sensor, but often control several pieces of equipment simultaneously[6]. Therefore contents of the programs are usually complicated. It is thus very important to evaluate the programs before executing the programs using real equipment. Concerning the facility control programs for a single piece of equipment such as parts of a robot program and a NC program, it is now possible to evaluate the programs on computers[7].

However, before a manufacturing system is implemented, it is difficult to complete all the facility control programs for several pieces of equipment used in the manufacturing system. Although it is essential for completing the facility control programs to get real data from the real equipment with precise timing, it is not possible to get the data before the manufacturing system is implemented. Before real manufacturing system runs, methods to confirm implementation of production management applications, which need to evaluate and improve manufacturing systems at the product launch such as a facility behavior record application, have not been developed. These difficulties stopped precise and rapid support of a manufacturing engineering process. Consequently the lead-time to get full production performance at the product launch is not reduced. To solve these difficulties, it is necessary to develop a method to mix and synchronize real equipment, virtual factory models on the computers, and production management applications.

In our research, in order to reduce the lead-time from the design stage to the implementation stage, a manufacturing engineering environment (MEE) is proposed. MEE consists of a manufacturing cell simulation environment (MCSE) and a distributed simulation environment (DSE), where 'environment' means a tool-set like an integrated development environment (IDE). MCSE, which is used to create and evaluate facility control programs while mixing and synchronizing real equipment, virtual factory models, and production management applications before manufacturing systems are implemented, is emphatically proposed in detail.

MCSE consists of a manufacturing cell simulator, a soft-wiring system, and ORiN. The manufacturing cell simulator simulates facility behavior by using data from the soft-wiring system. The soft-wiring system connects real world data, simulation world data on the manufacturing cell simulator, and data on manufacturing management applications without hard-wiring. The soft-wiring system also connects manufacturing cell and production management applications. ORiN is a standard distributed network system for manufacturing systems. Finally, evaluation of the performance of cooperative work is shown.

2. Manufacturing Engineering Environment

A manufacturing system is defined as a CIM reference model in ISO standards[8]. The manufacturing system is classified into six layers in the model. Figure 1 illustrates the typical system structure. In general, the sequence controller means a PLC, and the motion controller means a robot controller or a single axis controller. And simulation is mainly used at the design stage of each layer.

The manufacturing engineering procedure is usually based on the waterfall model. Although the original purpose of the waterfall model is to reduce the waste of loop-back and re-doing, still there are many loop-backs for each manufacturing engineering process. Without reducing these loop-backs, shortening manufacturing system development time is difficult. The development stage is composed of the design stage and the implementation stage, and its development time is defined by the following equation.

$$Development\ time = Loop\ frequency \times Average\ loop\ time$$

Therefore, it is necessary to reduce the loop frequency or to shorten the loop time for development time reduction.

To reduce the loop frequency, the upper-layered design process should be highly precise. Current simulators on the market such as a manufacturing line simulator are designed for special purposes. In order to design and implement the manufacturing system, many-faceted evaluation is required. To realize this, it is necessary to collaborate with several simulators, or to collaborate with the simulators and real equipment. The collaborations lead to the wide-use of the simulator at the implementation stage that was difficult so far. Consequently, the average of loop time also can be reduced because of quick loop-backs in the simulation. However the simulators on the market are not considered the above usages.

Therefore we propose a manufacturing engineering environment (MEE) to connect the design stage and the implementation stage. MEE consists of two sub-environments. One sub-environment is a manufacturing cell simulation environment (MCSE). The main role of MCSE is to make and evaluate facility control programs for a manufacturing cell while mixing and synchronizing real equipment, virtual factory models, and production management applications.

Another sub-environment is a distributed simulation environment (DSE). The main role of DSE is to connect MCSE and manufacturing system simulators at the design stage. Distributed simulation is defined as the execution of a simulation while connecting and synchronizing several different simulators. In the past, we have researched the distributed simulation technologies for manufacturing systems evaluation. The distributed simulation technologies are applied in DSE, and the two environments are mutually connected by a gateway system[2][3][9][10].

Figure 2 shows an outline of MEE, where 'emulator' means software simply imitating the existing equipment. On the other hand, 'simulator' means software which has an extended function to the real world such as time management. In this paper, we propose MCSE in the following chapters in detail.

3. Manufacturing Cell Simulation Environment

To realize the manufacturing cell simulation environment (MCSE) which simulates manufacturing cell behaviors by synchronizing the real controllers and the

emulators of real controller, the following functions are necessary.

1. A simulation function to simulate manufacturing cell behaviors by using data from a real world which consists of the real controller and the emulators of real controller.
2. A wiring function to logically wire the real world data, the simulation world data on a simulation world implemented the simulation function, and data on manufacturing management applications.
3. A transmission function to transmit the signals
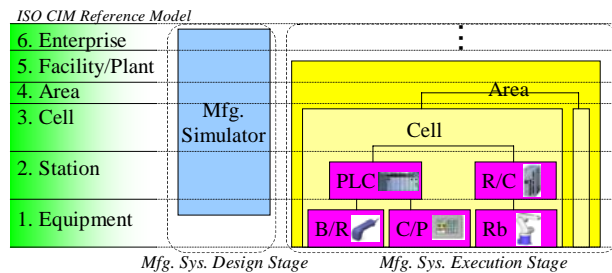
Fig.1 Manufacturing system structures and a usage range of the simulation in the CIM reference model.
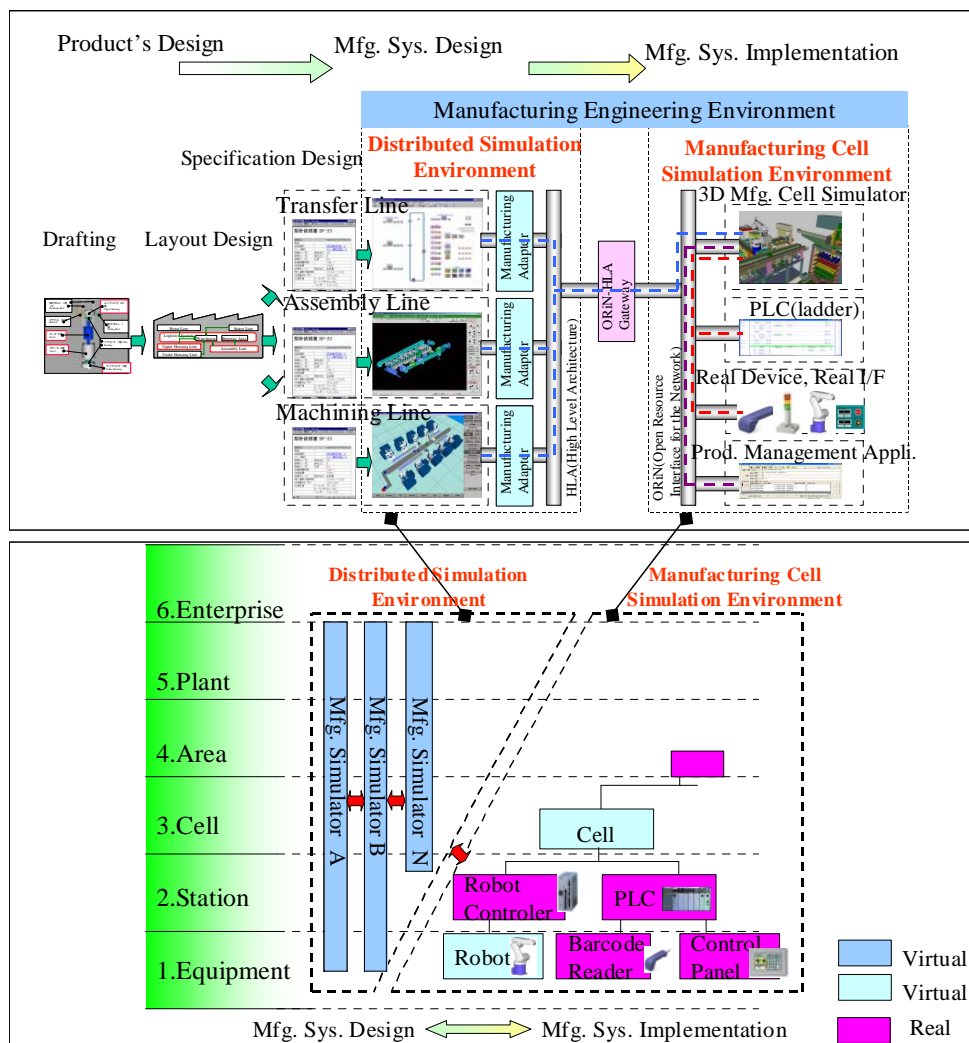
Fig. 2 An outline of our proposed manufacturing engineering environment.

and the data between the simulation world and the real world without considering the differences between the real controllers and the emulators.

4. A network interface function to connect the real controller and the emulators with a standard manner.

In order to realize these functions, we propose a manufacturing cell simulator to accomplish the simulation function 1, and a soft-wiring system to perform the wiring function 2. The manufacturing cell simulator simulates mechanical behavior in accordance with signals from the soft-wiring system.

The function 3 and 4 are achieved by ORiN. ORiN (Open Resource interface for the Network / Open Robot interface for the Network) is a middle-ware based on an object oriented technology[11]. It provides a standard access method to various controllers.

ORiN consists of two parts, an engine and a provider. The ORiN engine provides the application interfaces and some sophisticated common functions. An ORiN application operates abstracted equipment. This means that the real equipment is capsuled by the engine. The abstracted equipment model is defined by the ORiN specification. And the ORiN provider absorbs the differences between abstracted equipment and real equipment. For example, a request from the engine (originally from an application such as the soft-wiring system) is converted into a dedicated protocol of the real equipment such as a PLC and a robot in the provider.

The soft-wiring system and the manufacturing cell simulator are running on ORiN. Using ORiN, the proposed systems can become more general because of the independence from the equipment's specifications. Figure 3 shows an outline of MCSE. Figure 4 shows information flows of manufacturing cell simulation environment. Figure 5 presents an outline of ORiN.

4. Soft-wiring System

In real manufacturing systems, wiring between controllers is usually used hard-wiring. As MCSE is used before manufacturing systems are implemented, we need to evaluate the facility control programs of the controller without hard-wiring. Therefore the soft-wiring system, which logically wires the real world data, the simulation world data, and data on manufacturing management applications, is necessary. This system executes the following steps for each controller asynchronously and independently.

Step 1. Making connection to real equipment or its emulator through ORiN.

Step 2. Observing the item value of the equipment continuously.

Step 3. Propagating the value to linked item whenever it detects the change of value.

However there are many types of data on the controller such as integer type, real type, character type

and so on. In order to simulate manufacturing cell behaviors using signals and data from a real world, it is necessary to transform data on the real world (or a simulation world) into utilizable data on the simulation world (or the real world). The real world means that a world consists of real equipment. The simulation world means that a world consists of equipment emulators and manufacturing cell simulation models. Therefore the soft-wiring system realizes to logically wire the real world data and the simulation world data which are modeled on a simulation world. The system mainly needs to have the following functions for step 3.

1. A function to logically wire data between the real world and the simulation world while transform-
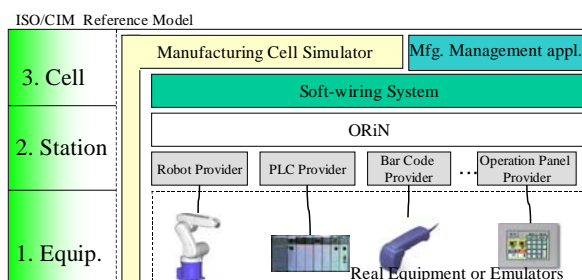

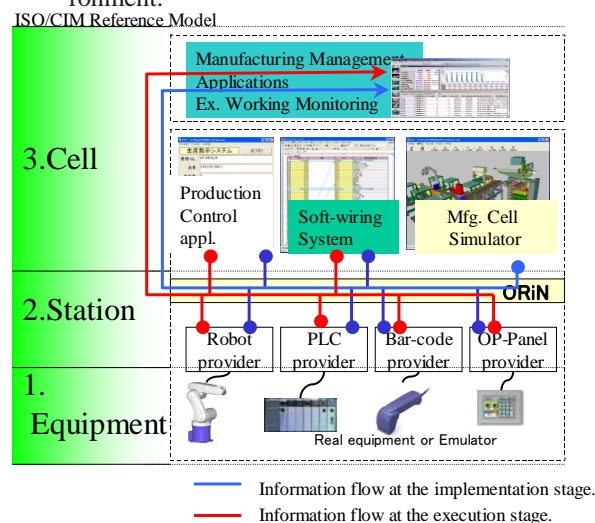Fig. 3 An outline of manufacturing cell simulation environment.

Fig. 4 Information flows of manufacturing cell simulation environment.
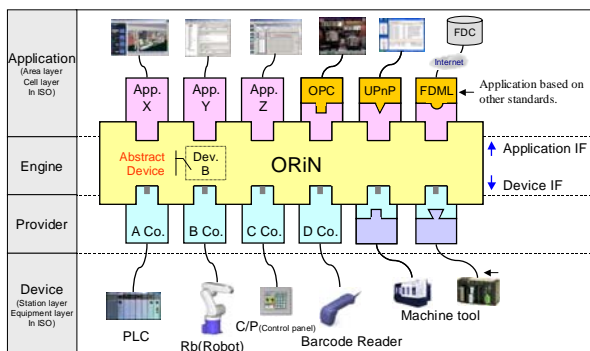

Fig. 5 An outline of ORiN.

ing and propagating data in response to data types.

2. A function to perform the data conversions such as BCD (Binary Coded Decimal) data conversion, data masking, data type conversion such as 'String to Integer', data calculation and so on.
3. A function to filter out data which are over a limitation value as a dead band function.
4. A function to record a data transition log to evaluate a timing chart of an action sequence.

The soft-wiring system which includes four functions was developed in C++ program language. Figure 6 shows an outline of the soft-wiring system.
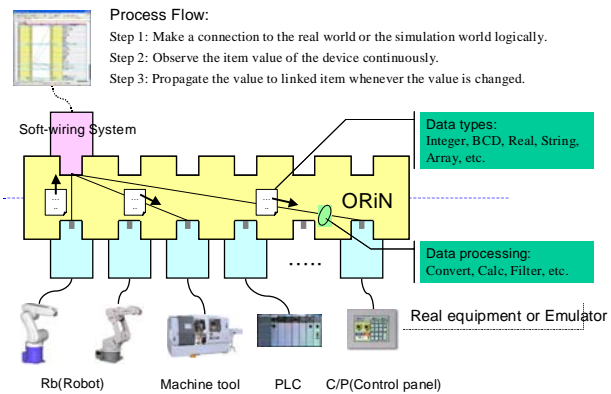
5. Manufacturing Cell Simulator

In real manufacturing systems, it is possible to evaluate facility control programs by producing materials with flow while synchronizing real equipment. As MCSE is used before manufacturing systems are implemented, it is impossible to evaluate the facility control programs by the same way. Therefore we need to have a world to simulate producing materials with flow while mixing and synchronizing real equipment, its emulators and virtual factory models. We propose the manufacturing cell simulator to realize the world. Figure 7 shows an outline of the simulator.

The manufacturing cell simulator simulates manufacturing cell behaviors using signals and data from the real world through the soft-wiring system. The manufacturing cell simulator needs to have mainly following functions.

1. A definition function to define behaviors for manufacturing cell simulation models.
2. An animation function to visualize 3D manufacturing cell simulation models by synchronizing with the results of manufacturing cell behaviors.
3. A connection function to link the simulation world data to the real world data through the soft-wiring system.

We propose that the behaviors are expressed by a tree structure. One task of computer processes is defined on one node of the tree structure. Complex tasks can be defined by combining several nodes. And there are main four types of nodes.

1) Flow control nodes such as branch, join, and trigger.
2) A link node to link data on the simulator to the soft-wiring system
3) An animation control node to execute the animation function
4) A script node to define the details of behavior.

All nodes of the tree are executed in series or in parallel. The vertical direction is executed sequentially, and the horizontal direction is executed in parallel.
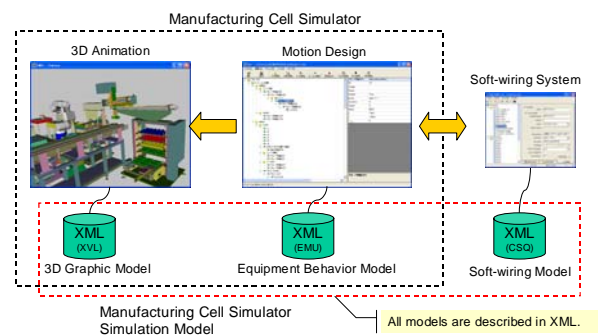

Fig. 6 An outline of soft-wiring system.

Fig. 7 An outline of manufacturing cell simulator.

A link node 2) can refer the real world data through the soft-wiring system. Then the manufacturing cell simulation model in the simulation world is behaved in response to the referred data. The node also can output data to the real world data through the soft-wiring system. Then the equipment in the real world executes processes in response to the output data. That is, the links are bi-directional connection. For instance, when a cylinder reaches the terminal point, the cell simulator can output a signal to the soft-wiring system; it means that the system can output a signal to both real equipment and an emulator. And then the equipment which received a signal can continue to execute a program by the signal.
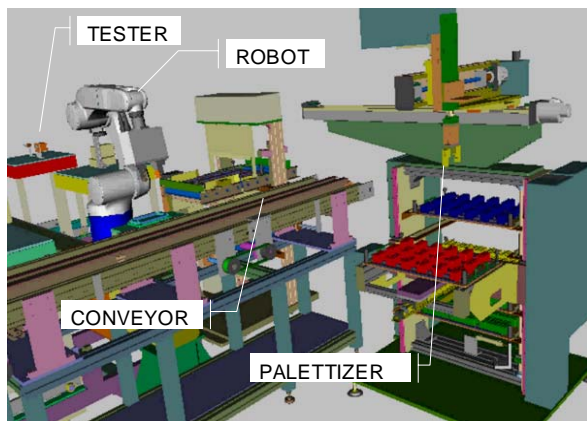
6. Case Study

A case study was carried out using a hypothetical case of small size of a manufacturing cell which consists of a robot, a tester, a palettizer and a conveyor. This case study consists of a robot controller, a bar-code reader and a palate as real equipment. And a PLC emulator and operation panel emulator are also connected. On the other hand, there are four systems, production control system, manufacturing cell simulator, soft-wiring system, and working monitoring system. The production control system and the working monitoring system are real systems running in the real manufacturing system. Figure 8 shows the case study models on the manufacturing cell simulator.

A typical procedure in this case study shows the followings. Figure 9 presents one of the typical procedures in this case study. Figure 10 shows the system structure of this case study. Figure 11 presents one of the working monitoring applications windows which are monitored the manufacturing cell in this case study.

1. The barcode reader receives production order information by a KANBAN.
2. The production control system receives the production order information via ORiN.
3. The production control system indicates to investigate the quantity of a product along the production order information toward the PLC via the soft-wiring system.
4. The assigned product is picked up and moved to the conveyor by the palettizer in the simulator. These behaviors are controlled by the PLC via the soft-wiring system.
5. The assigned product is translated in front of the robot by the conveyor in the simulator. This behavior is controlled by the PLC via the soft-wiring system.
6. The assigned product is picked up and moved to

the tester by the robot. These behaviors are controlled by the PLC and the robot controller via ORiN.
7. The assigned product is investigated by the tester in the simulator.
8. Results of this investigation in the simulator are informed to the PLC via the soft-wiring system.
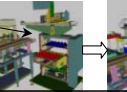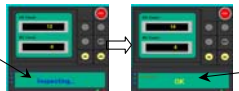
Procedure	System behaviors in the case study
STEP1	126340-6099 KANBAN Bar Code Reader
STEP2	Production Control Application
STEP3	PLC
STEP4	
STEP5	
STEP6 STEP7	
STEP8	Control Panel OK Patlite
STEP9	
STEP10	

Fig. 8 Case study models on manufacturing cell simulator.
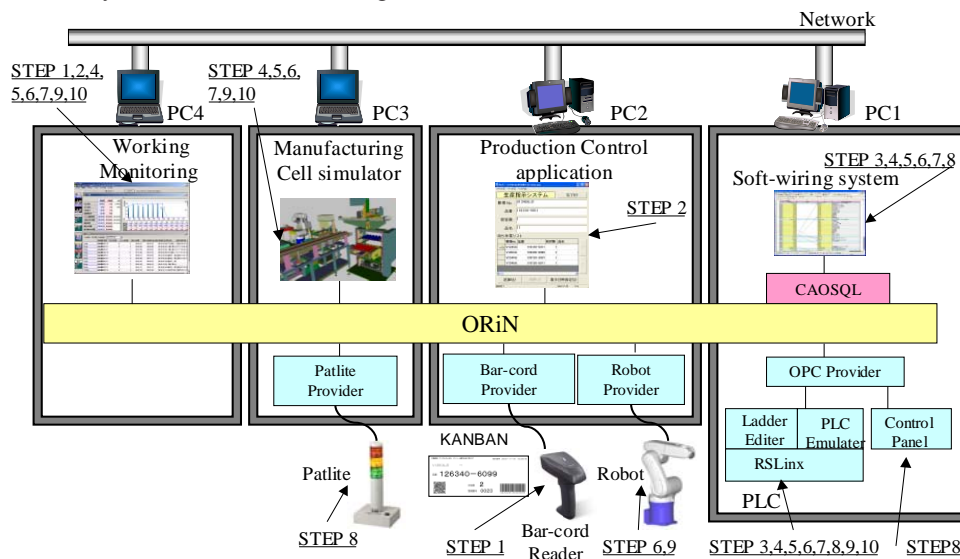
Fig. 9 Typical procedure in this case study.

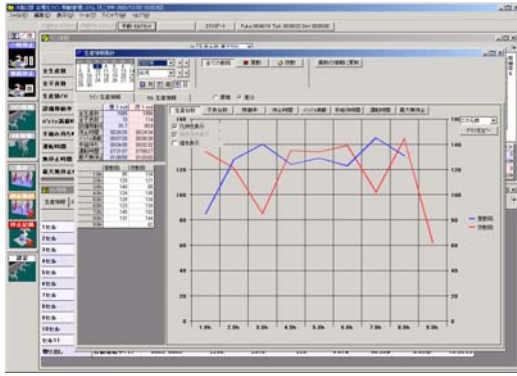Fig. 10 System structure of this case study.

Fig. 11 Working Monitor in this case study.

Then the control panel displays the results via the PLC. The Patlite shows a kind of neon signs along the results via the PLC.

9. The assigned product is picked up and moved from the tester to the conveyor by the robot. These behaviors are controlled by the PLC and the robot controller via ORiN.

10. The assigned product is translated to the end of conveyor by the conveyor in the simulator. This behavior is controlled by the PLC via the soft-wiring system.

11. The assigned product is destroyed in the simulator.

We confirmed that the simulation world and the real world could be combined and synchronized using the real equipment, the emulator, the virtual factory models and so on. We also confirmed that verification of the facility control programs such as ladder program in the PLC could be confirmed by combining and synchronizing the simulation world and the real world. We also confirmed that practical usages of manufacturing management applications such as working monitoring application could be confirmed by combining and synchronizing the simulation world and the real world.

Through this case study, we confirmed that MCSE could be used in the implementation stage. MCSE including the soft-wiring system and the manufacturing cell simulator and ORiN, is valid to carry out efficient manufacturing system implementation at the implementation stage.

7. Conclusion

In this paper, the manufacturing engineering environment (MEE) to support manufacturing engineering processes using simulation technologies is proposed. The manufacturing cell simulation environment (MCSE), which includes the soft-wiring system and the manufacturing cell simulator and ORiN, is proposed and developed.

The results were:

1. To propose a concept of MEE to support manufacturing engineering processes using simulation technologies.

2. To propose MCSE to realize making and evaluating facility control programs while mixing and synchronizing real equipment and virtual factory models before manufacturing systems are implemented.

3. To clarify necessary functions for a manufacturing cell simulator and a soft-wiring system in MCSE.

4. To confirm through a case study that a simulation world and a real world could be combined and synchronized using the manufacturing cell simulator and the soft-wiring system.

5. To confirm that verification of ladder programs could be confirmed by combination of the simulation world and the real world before real manufacturing cells are implemented.

6. To confirm that practical usages of a working monitoring application as manufacturing management applications could be confirmed by combination of the simulation world and the real world before real manufacturing cells are implemented.

7. To confirm that MCSE is valid to carry to support full production performance at product launch.

Acknowledgements

References

[1] Mehrabi, G., Ulsoy, G. and Koren, Y., Reconfigurable manufacturing systems: key to future manufacturing, *Journal of the Intelligent Manufacturing*, 11:403-419, 2000.

[2] Hibino, H. and Fukuda, Y., A synchronization mechanism without rollback function for distributed manufacturing simulation systems, *Journal of the Japan Society of Mechanical Engineers*, 68:2472-2478,2002. [in Japanese]

[3] Hibino, H. and Fukuda, Y., A user support system for manufacturing system design using distributed simulation, *Production Planning and Control*, 17:128-142,2006.

[4] Wohlke, G. and Schiller, E., Digital planning validation in automotive industry, *Proceedings of the IFIP WG 5.7 Working Conference on Human Aspects in Production Management*, 1:120-128, 2003.

[5] Fukuda, Y., The state of the arts for digital engineering, *Journal of the Japan Society of Mechanical Engineers*, 106:230-233, 2003. [in Japanese]

[6] Pires, J. and Costa, J., Object-oriented and distributed approach for programming robot manufacturing cells, *Robotics and Computer Integrated Manufacturing*, 16:29-42, 2000.

[7]   Milfelner, M. and Cus. F., Simulation of cutting forces in ball-end milling, *Robotics and Computer Integrated Manufacturing*, 19:99-106, 2003.

[8]   ISO/TR10314-1, Industrial automation: Shop floor production: Part 1: Reference model for standardization and methodology for identification of requirements, 1990.

[9]   Hibino, H., Fukuda, Y., Yura, Y., Mitsuyuki, K. and Kaneda, K., Manufacturing adapter of distributed simulation systems using HLA, *Proceedings of the 2002 Winter Simulation Conference,* 1099-1109, 2002.

[10]   Inukai T., Hibino H. and Fukuda, Y., The Gateway of Real Factory and Virtual Factory using ORiN and HLA, *Proceedings of the 5th International Conference on Machine Automation* , 429-434, 2004.

[11]   Inukai, T. and Sakakibara, S., Impact of open FA system on automobile manufacturing, *Journal of the Automotive Engineers of Japan*, 58:106-111, 2004. [in Japanese]