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MODULE-BASED MODELING OF FLOW-TYPE MULTISTAGE MANUFACTURING SYSTEMS ADOPTING DUAL-CARD KANBAN SYSTEM

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ABSTRACT

A systematic procedure of module-based modeling is designed and proposed to develop a simulation of any flow-type multistage manufacturing system adopting especially the dual-card Kanban system. First, functional analysis is performed to present kanban flows exactly in the same fashion in a simulation model as they are actually appeared in the real manufacturing system. One Customer module, the required number of Workstation modules, and one Supplier module make a set to develop a designated simulation. In addition, a numerical example is shown to apply the proposed procedure.

1 INTRODUCTION

The Kanban system is one of major means to realize the philosophy of just-in-time (JIT) manufacturing to produce or retrieve required amounts of necessary items at the right time. The development of the JIT concepts utilized a simple card system called Kanban. The Kanban system is said to be originally developed by Toyota Motor Corporation, and it was devised in 1954. At the beginning, the system had been introduced tentatively in one section of a factory. After that, the system had been expanded to the entire manufacturing system and was established as a form of the technique in 1970 (Toyota Motor Corporation 1988). The application studies of the Kanban system to Toyota production system (TPS) have been introduced to worldwide manufacturers (Sugimori et al. 1977). Since then, the various characteristic aspects on TPS such as Kanban system, total quality control, and total preventative maintenance have been studied and explored.

As for a Kanban system, it has attracted international attention because it differs completely from the traditional production-control system. MRP is almost the opposite of Kanban and JIT from the standpoint of preferred environment. The push system controlled by planning with MRP had been introduced widely in a large amount of manufacturers. On the other hand, a Kanban system, that is JIT manufacturing, adopts the pull production system where items are processed at the upstream process, by receiving instructions from the downstream process. A vast amount of studies on the Kanban system has been performed from the standpoint of production management. As for determining the number of kanbans, several approaches have been presented using techniques such as mathematical programming, Markov chain and simulation (Akturk and Erhun 1999).

In this study, a series of the modules are developed for developing simulation models on the flow-type multistage JIT manufacturing system. This study focuses the Kanban system with two types of kanbans, i.e., the production kanban and the conveyance kanban, considering conveyance time. By using the proposed modules for JIT system, a simulation can be developed and performed quickly and easily.

2 LITERATURE REVIEW

First, the pioneering works on the various elements of TPS through detailed research on Toyota Motor Corporation were performed (Monden 1983). The study has affected greatly to the following research activities, especially on the methods or the procedures using kanbans and the equations to compute the number of kanbans. Furthermore, some conditions to produce or convey items under the Kanban system were presented (Spearman 1992). According to the study, three conditions are expressed in applying a kanban; (1) demand arrives from the successor, (2) there exist required quantity of items at an inbound-buffer spot, and (3) machines and/or operators are ready for process. Once all three conditions are satisfied, the corresponding kanban is detached from a container and the process gets started.

There are two approaches to use simulation for studying the Kanban system. One utilizes simulation in order to solve mathematical models for the system (Kimura and Terada 1981, Mitra and Mitrani 1990). The other develops simulation models for the Kanban system, and then to analyze behavior of the system by setting some selected parameters. A simulation model for a three-line four-stage JIT production system using Q-GERT is developed (Huang, Rees, and Taylor 1983). Imbalance of a multistage manufacturing system is examined by varying process time and demand rate. In addition, the two-line three-stage production system is constructed and studied, by using DYNAMO (Gupta and Gupta 1989). In the study, effects of changing the number of kanbans and container sizes are studied against system performances. Arena/SIMAN is used to code a flow-type four-stage Kanban system, and to develop a CONWIP model, showing detailed SIMAN codes (Marek, Elkins, and Smith 2001).

In developing simulation models for the Kanban system, it is important to represent properly the work procedures or kanban rules. Almost all simulation languages match the push production system well because they process codes from the top to the bottom. The Kanban system, however, adopts a pull system, and it is necessary to reverse the logic of workpiece flows for a push system, because demand is sent from the downstream workstation backward to the upstream one in the system (Carson 2002).

From the logical standpoint, Huang's model is not satisfied the third condition showed by Spearman, because machines and/or operators are available for process before detaching a kanban. Therefore, kanbans could be sent to the predecessor while the process is still being performed by workstation resources. In the study of Gupta and Gupta, a kanban would be detached if items in a container run out. This situation violates the rule described by Monden, because a kanban is detached just after using the first item in a container. In addition, demand flows initiate the workstation next to a supplier, i.e., the first stage in Marek's model. The initial number of kanbans seemed to be roughly computed, and the numbers of kanbans could be minimized using their proposed heuristics algorism.

Module-based modeling proposed in this study reduces time and effort for modeling drastically, and increases efficiency of constructing models and changing it only by setting a series of parameters. This modeling approach is utilized for developing simulation models such as a large-scale AS/RS-AGV system, and transportation and transshipment problems (Takakuwa 1996, Takakuwa 1998, Takakuwa and Fujii 1999). As the simulation models can be used as the test beds to examine the feasibility of the tentative plans (Enns and Suwanruji 2003, Takakuwa and Nomura 2004), the proposed module-based simulation models are useful to understand the characteristics of just-in-time manufacturing. This study adopts module-based modeling approach, keeping the essential procedures and rules described by Monden and Spearman.

3 MANUFACTURING SYSTEM ADOPTING DUAL-CARD KANBAN SYSTEM

3.1 Flow-Type Multistage Manufacturing System

Simulation models of processing work materials through a flow-type multistage manufacturing system, which consists of *N* workstations sequenced in the technological order, as shown in Figure 1, are constructed. At each stage an operator does a specified operation at the assigned workstation with incoming work material which has transferred from the previous stage, and transfers the finished material to the following stage. Thus, in passing through the manufacturing system of *N* stages, the raw material is converted into the finished product. A workpiece is transferred between two consecutive workstations at a relatively constant rate and is generally performed by material handling systems. This type of the system is suitable for producing a series of similar products, and the demand for products should be large and well-balanced enough to justify economically setting up the production line.

3.2 Dual-Card Kanban System

In a Kanban system, two kinds of kanbans that are the production kanban (P-kanban) and the conveyance kanban (C-kanban) direct workstations to produce or convey items. Although two kinds of kanbans are utilized in a dual-card Kanban system or a two-card Kanban system, the system using either production kanbans or conveyance kanbans is called a single-card Kanban system or a one-card Kanban system. In the latter case, empty containers typically substitute for kanbans to instruct production or conveyance. This study focuses on a dual-card Kanban system.

Figure 2 shows how kanban and items or workpieces move between workstations or inside the workstation. When a demand or a C-kanban arrives from the succeeding workstation, the C-kanban is exchanged for the P-kanban that has attached to a container of items at an outbound-buffer spot. The container and the C-kanban are sent back together to the successor. The detached P-kanban is placed on the scheduling board. As an operation is done, an operator takes a P-kanban from the top of the scheduling board and brings the required number of containers instructed by this P-kanban

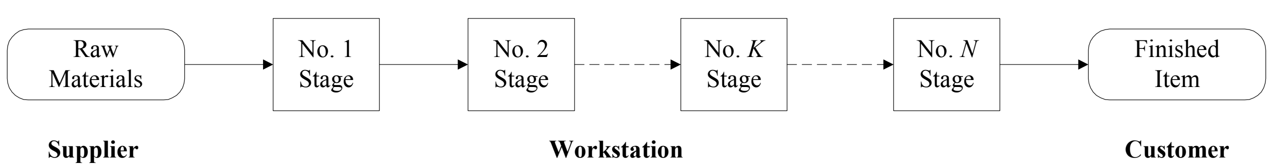

Figure 1: Schematic Model of a Flow-Type Multistage Manufacturing System

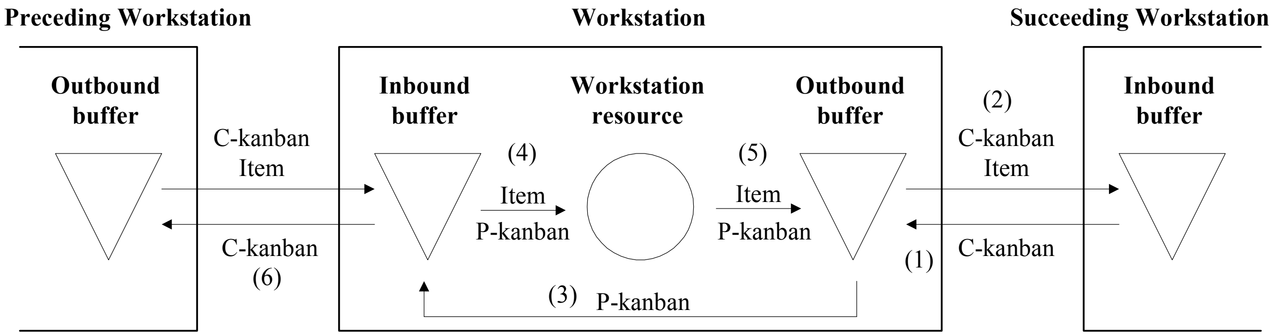

Figure 2: Dual-Card Kanban System

from an inbound-buffer spot, and then the next operation is to be started. In the meanwhile, a C-kanban is detached from the container, and is left in the conveyance kanban post. A material-handling operator checks this kanban post periodically or immediately, and then sends C-kanbans to the predecessor. Figures in the parentheses in Figure 2 stand for the order of the procedure. This process continues upstream even to the suppliers, who may also receive C-kanbans as a signal for their next shipment to the facility.

4 MODULE-BASED MODELING SYSTEM

As mentioned earlier, the flow-type multistage manufacturing system with a dual-card kanban system is considered in this study. This paper deals with the system in which it takes time to convey a workpiece between workstations, and workpieces are produced with the lot size of the capacity of a container at each stage. In addition, the values of such time parameters as the production, travel, and inter-arrival time, can be deterministic or stochastic.

The logic on the Kanban system comprises three sections: (1) Customer section to create demand, (2) Workstation section to perform production and conveyance, and (3) Supplier section to provide raw materials. These sections are compiled into a template, that is, the Customer module, the Workstation module, and the Supplier module, respectively, by using the template-building features of Arena 8.0 Professional Edition (Kelton, Sadowski, and Sturrock 2004). These three modules work all together in closer cooperation via the Route and Station modules in these modules. One Customer module, the required number of Workstation modules, and one Supplier module make a set to develop a designated simulation. In addition, these three modules contain animation features such as the required workstation resource and stations. Therefore, the simulation model created with a series of the proposed modules represents a dual-card Kanban system exactly, and animates behavior of the system as well as kanban flows.

4.1 The Customer Section

This is a section to handle with arrival of demand at the system and shipment of finished items. The flow diagram of the Customer section is shown in Figure 3. Customer demand is generated at the Create module and is sent through the Route module. Customer demand represents the quantity for one lot of finished items processed at the last workstation. Meanwhile, the finished items allocated to customer demand arrive at this section, and leave the system. The Customer module is shown in Figure 4.

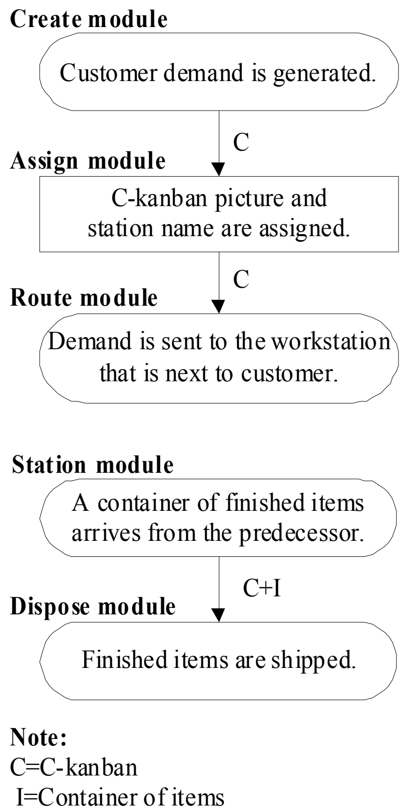

Figure 3: The Customer Section

4.2 The Workstation Section

This is the main section to perform production and conveyance using kanbans. The flow diagram of the Workstation section is shown in Figure 5. The number of each kanban is

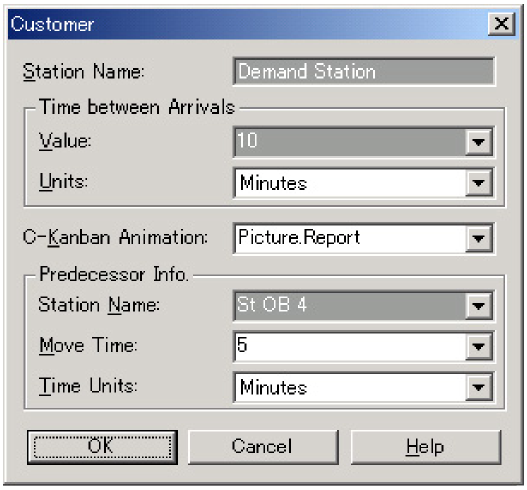

Figure 4: The Customer Module

represented as the initial quantity of containers or kanban entities. First, a demand or C-kanban entity arrives at the Station module (the top of Figure 5) from the succeeding workstation and proceeds to the following Match module. Entities that have departed from the successor arrive at the Station module via either the Route module (the lower right of Figure 5) in the relevant Workstation section or one in the Customer section. This demand entity is matched with a container of items produced at the current workstation. The entity of a C-kanban and a container is sent back to the successor through the Route module (the middle of Figure 5). This Route module sends the entity representing a container with items to the successor's Station module in the Workstation section (the middle of Figure 5) or the Customer section after a C-kanban has been attached to the container. A P-kanban goes to the Hold module and awaits until a resource is available for processing and the required

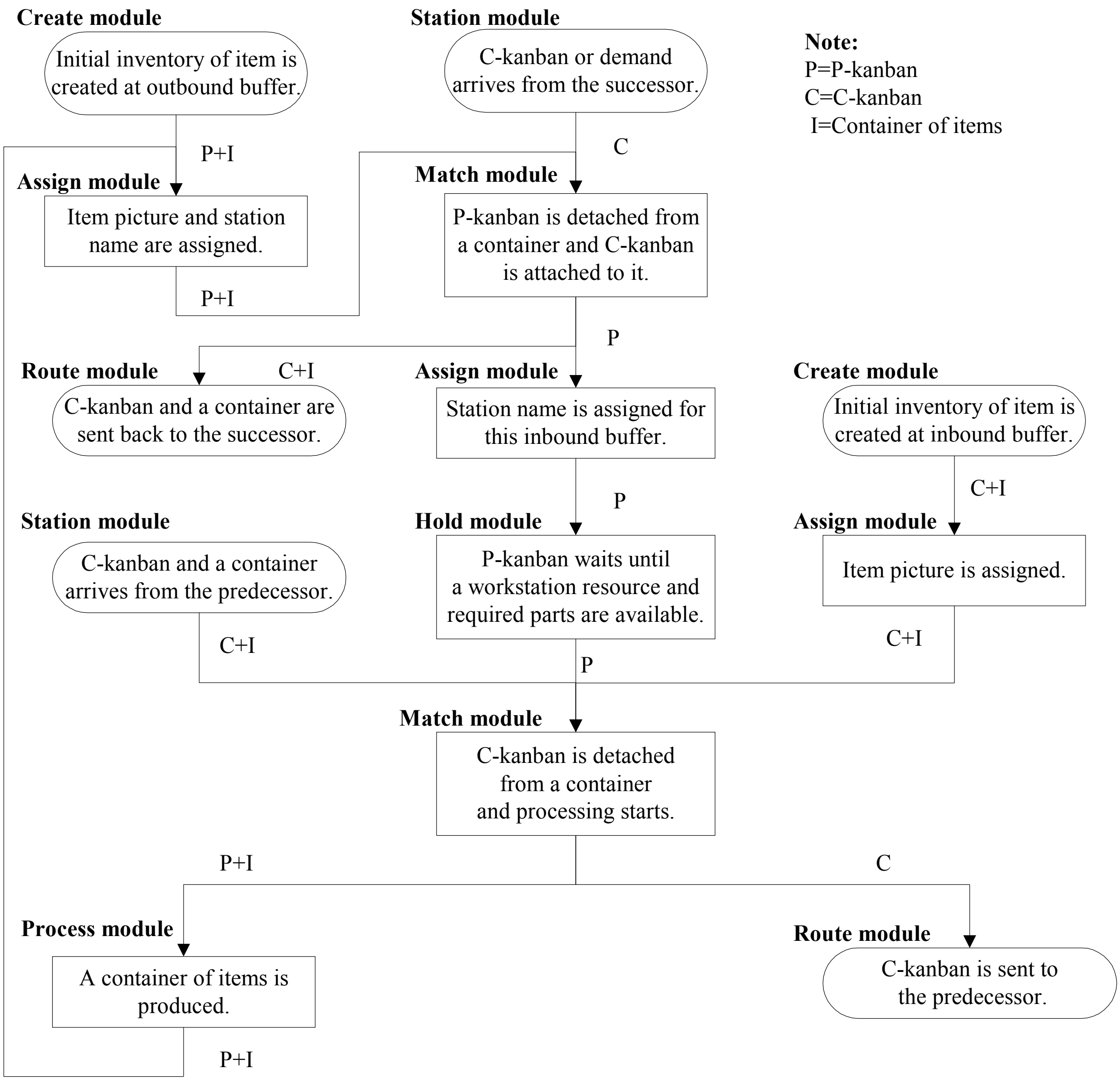

Figure 5: The Workstation Section

items are sent from the preceding workstation. Here, an inventory-buffer or an inbound-buffer spot is represented as one of queues at the following Match module (the bottom of Figure 5). As a resource and required items are available, the P-kanban and the container of items pass through the Match module. Then, production is to be started at the Process module. When production is completed, they are sent to the Match module (the upper art of Figure 5) corresponding to the outbound-buffer spot. In the meanwhile, the Route module (the lower right of Figure 5) sends a C-kanban to the predecessor's Station module in the Workstation section (the top of Figure 5) or the Supplier section in order to replenish consumed items. The Workstation module is shown in Figure 6.

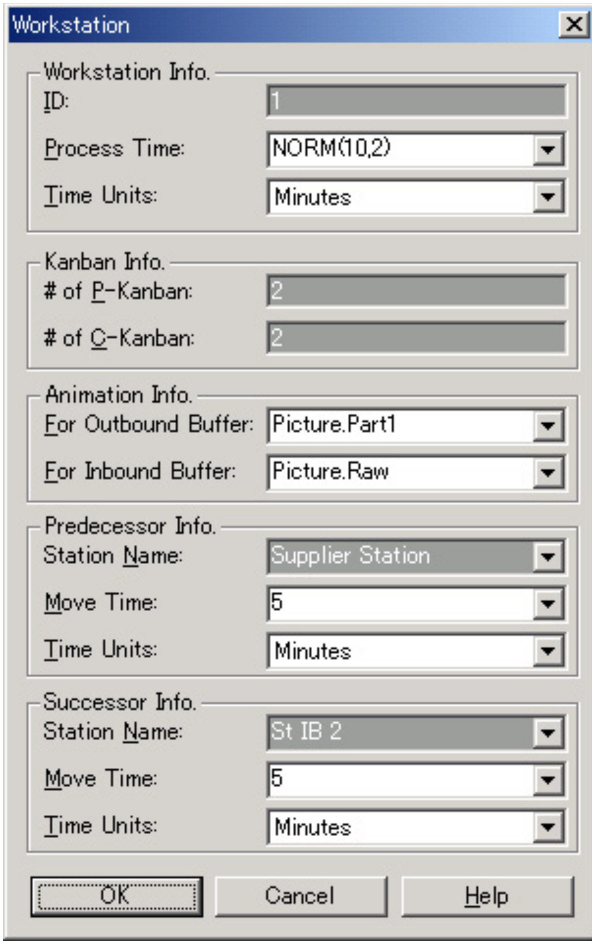

Figure 6: The Workstation Module

In the Workstation section, the Kanban system is represented appropriately by holding entities until the designated conditions are satisfied. P-kanban entities represent arrivals of demand and it will remain at the Hold module until the other two conditions are satisfied. One of queuesat the Match module (the below of Figure 5) holds containers with items as an inbound buffer. When the relevant resource is available and a container is at the inbound spot to send an entity to the next module, all of three conditions to resume production are satisfied. In addition, C-kanban movement to the preceding stage executes instantaneously, but not regularly.

4.3 The Supplier Section

This section provides raw materials for the system. The flow diagram of the Supplier section is shown in Figure 7. When a C-kanban requesting raw materials arrives at this section, raw materials are provided immediately from the Route module. In this study, let us suppose that the system has raw materials infinitely and handling time for the corresponding operation is not included. The Supplier module is shown in Figure 8.

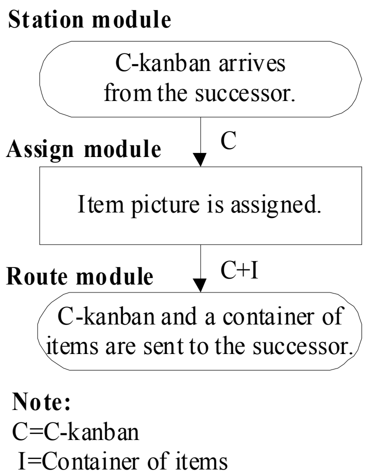

Figure 7: The Supplier Section

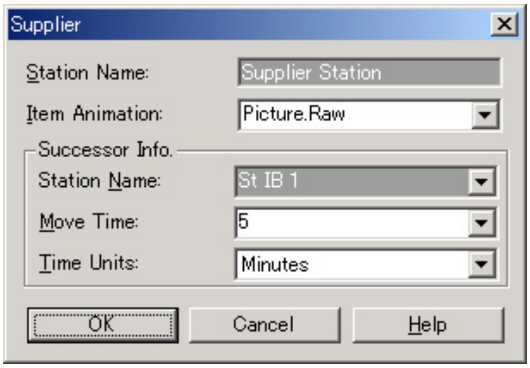

Figure 8: The Supplier Module

5 SAMPLE MODEL

A flow-type four-stage manufacturing system adopting the dual-card Kanban system is applied to develop a model using a series of the proposed modules. One Customer module, four Workstation modules, and one Supplier module are used in this model. The inter-arrival time for demand generated at the Customer module is ten minutes. The workstation (i.e., No. 4 stage) that is next to the customer is Workstation 4 and the first station is Workstation 1. Process time at each workstation is normally distributed with a mean of ten minutes and a variance of two minutes. Conveyance time of one way between Workstations 2 and 3 is ten minutes, and conveyance times except between the two workstations are five minutes. Now, the number of kanbans, M, is given by the following Equation (1) proposed by Monden:

$$M = \{DL(1+\alpha)\}/d \qquad (1)$$

where D is the demand rate, L is the leadtime, d is the container size and α is a safety factor. This system supposes to produce items by a container at each stage; hence, d is set to 1. In addition, the leadtime for production or conveyance is expressed per unit container with items. For instance, in the case of calculating the number of P-kanbans at Workstation 3, or the quantity of initial inventory in the outbound-buffer spot at stage 3, L, i.e., production lead time, is 10 minutes, and α is set to 0.2. Then, M is 1.2, and the number of kanbans is two by rounding up the value of M. In another case, as the number of C-kanbans at Workstation 3 is computed, L is 20 minutes because conveyance lead time of one way is 10 minutes. Therefore, the number of C-kanbans, that is, the quantity of initial inventory at the inbound-buffer spot at stage 3, is three. To apply the equation for all stages, the number of C-kanbans at Workstation 3 only is three, and all other numbers of kanbans are two. The list of all parameters inputted to all required modules is summarized in Table 1, and the actual facets of corresponding modules were shown in Figures 4, 6 and 8 in the previous sections.

Ten replications are executed, using a replication length of one whole day or 24 hours except for warm-up period of one hour. A screen image on running a simulation model is shown in Figure 9.

From the result of a simulation, the number of customer demand is 144, and 142.3 finished items are shipped. The utilizations of the resources at four workstations are 0.96 at stage 1, 0.95 at stage 2, 0.97 at stage 3, and 0.98 at stage 4, respectively. The total flow time, which represents a time length from entering the system to exiting the system of the workpieces, is 189.5 minutes on average. Of the total flow time, 32 percent (60 minutes) is being transferred, 47 percent (89.7 minutes) is waiting time as work-in-process inventory, and 21 percent (39.8 minutes) is process times. In addition, the number of P-kanbans detached a container is 6.09 pieces and that of C-kanbans is 5.04 pieces.

6 CONCLUSIONS

1. The logic of the dual-card Kanban system is described to present both production and conveyance Kanbans flows in executing simulation.
2. An efficient module-based modeling method is presented for generating simulation programs for any flow-type multistage manufacturing system adopting the dual-card Kanban system.
3. A numerical example is shown to apply the proposed procedure. It is found that simulation/animation models can be made quickly, by using a module-based modeling method developed in this study.
4. The proposed procedure might be applied to more general manufacturing systems in which multiple types of products are produced, or more complicated production processes are introduced, by modifying the logic of each module proposed in this study.

Table 1: List of Parameters

Module	Item	1	2	3	4
Customer	Customer station name	Demand Station			
	Time between arrivals	10			
	C-kanban animation	Picture.Report			
	Preceding station name	St OB 4			
	Move time to preceding station	5			
Workstation	Workstation ID	1	2	3	4
	Process time	NORM(10,2)	NORM(10,2)	NORM(10,2)	NORM(10,2)
	# of P-kanban	2	2	2	2
	# of C-kanban	2	2	3	2
	Item animation for outbound buffer	Picture.Part1	Picture.Part2	Picture.Part3	Picture.Product
	Item animation for inbound buffer	Picture.Raw	Picture.Part1	Picture.Part2	Picture.Part3
	Preceding station name	Supplier Station	St OB 1	St OB 2	St OB 3
	Move time to preceding station	5	5	10	5
	Succeeding station name	St IB 2	St IB 3	St IB 4	Demand Station
	Move time to succeeding station	5	10	5	5
Supplier	Supplier station name	Supplier Station			
	Item animation	Picture.Raw			
	Succeeding station name	St IB 1			
	Move time to succeeding station	5			

(Time: in minutes, Number of kanbans: in pieces)

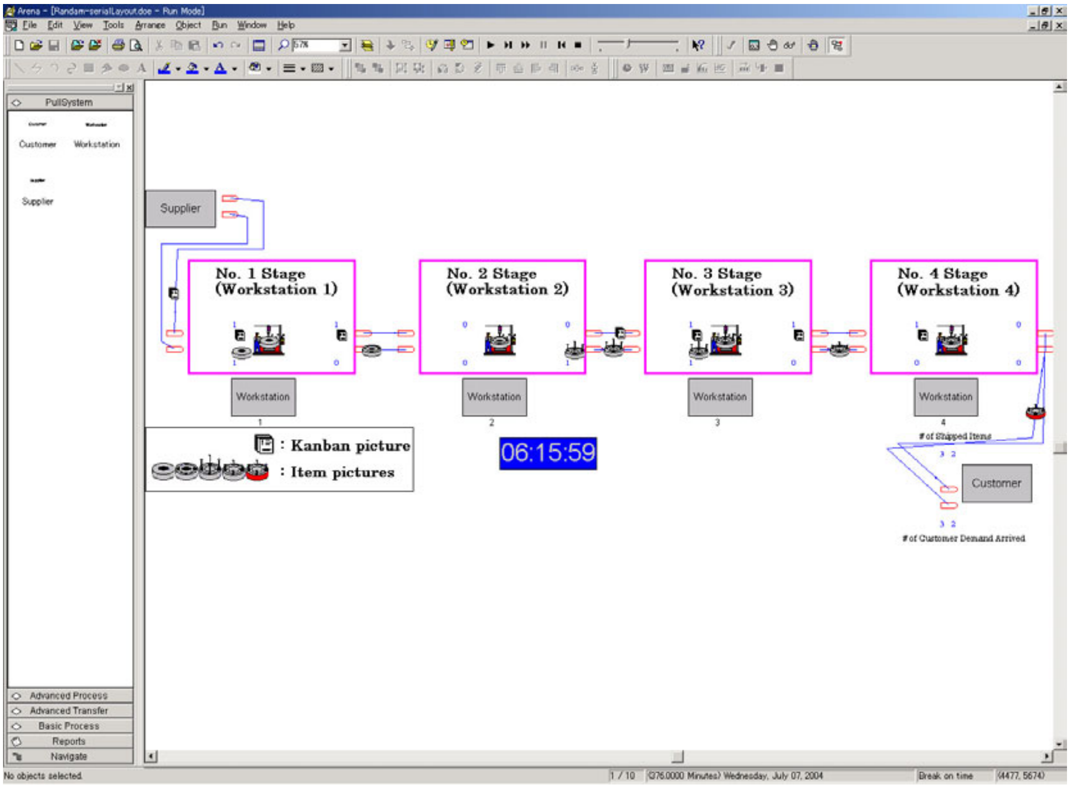

Figure 9: Animation of Sample Model

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