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MODULE-BASED MODELING AND ANALYSIS OF A MANUFACTURING SYSTEM ADOPTING A DUAL-CARD KANBAN SYSTEM WITH A DELIVERY CYCLE

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ABSTRACT

A systematic procedure for module-based modeling is designed and proposed to simulate of any multistage manufacturing flow type system adopting a dual-card kanban system with a delivery cycle. First, a functional analysis was performed to present kanban flows in exactly the same fashion in a simulation model as they actually appear in a real manufacturing system. One shipping area module, the required number of parts store modules, and one supplier center module were used to develop a designated simulation. Proposed modules have focused dialogs, animation, and modeling functionality. In addition, a procedure to obtain the necessity minimum number of kanbans to achieve no stock-out events is proposed. Then, a numerical example is shown to apply the proposed procedure.

1 INTRODUCTION

The kanban system is one of major means to achieve the philosophy of just-in-time (JIT) manufacturing to produce or retrieve the required number of necessary items at the correct time. The development of the JIT concepts utilize a simple card system referred to as kanban. The kanban system is said to be originally developed by the Toyota Motor Corporation. The application studies of the kanban system to Toyota production system (TPS) have been introduced to worldwide manufacturers (Sugimori et al. 1977). Since this introduction, the various characteristic aspects of the TPS such as the kanban system, total quality control, and total preventative maintenance have been studied and explored.

Nomura and Takakuwa (2004) proposed module-based simulation models for the flow-type multistage JIT manufacturing system. Their study focused on the kanban system with two types of kanbans by considering the conveyance time. Using the proposed modules for the JIT system, a simulation can be developed and performed quickly and easily. This study proposes a module-based simulation model adapting the dual-card kanban system with a delivery cycle. The proposed module was developed the following two points given in the proposed module by Nomura and Takakuwa (2004). The first point is to modularize the part types of the part store to represent the part store and to have a kanban cycle per one part types as a single module. The second point is to add the capacity of the container in the module.

In this study, first, the delivery cycle adopted in dual-card kanban system is described. Then, the module-based modeling system using three modules is proposed to construct a simulation model of any multistage manufacturing system. In addition, a procedure to obtain the necessary minimum number of kanbans to achieve no stock-out event is provided. A numerical example is shown to apply the proposed procedure.

2 LITERATURE REVIEW

First, the pioneering works concerning various elements of TPS were investigated through a detailed study of the Toyota Motor Corporation (Monden 1983). This study has greatly affected the subsequent research activities especially with respect to the methods or the procedures using kanbans and the equations used to compute the number of kanbans. Furthermore, some conditions used to produce or convey items using the kanban system have been presented (Spearman 1992). According to this study, three conditions are expressed when using a kanban: (1) demand arrives from the successor, (2) a required quantity of items exist at an inbound-buffer spot, and (3) machines and/or operators are ready for the process. Once all three conditions are satisfied, the corresponding kanban is detached from a container and the process begins.

In terms of optimization and evaluation of kanban systems, Pedrielli et al. (2015) proposes a combined solution of the optimization and simulation problems for the optimal operation of pull control systems under several control strategies. Khojasteh and Sato (2015) conduct an analytical comparison of three pull production control systems: Kanban, CONWIP and Base-stock in multi-stage production process.

There are two approaches to use simulation when studying the kanban system. One approach utilizes simulation to solve the mathematical models for the system (Kimura and Terada 1981, Mitra and Mitrani 1990). The other approach develops simulation models for the kanban system and then analyses the behavior of the system by setting some selected parameters.

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

The module-based modeling proposed in this study drastically reduces the time and effort required for modeling and increases the efficiency of constructing models and changing models only requires defining 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 JIT manufacturing. This study adopts a module-based modeling approach while maintaining the essential procedures and rules described by Monden and Spearman.

3 DELIVERY CYCLE ADOPTED IN DUAL-CARD KANBAN SYSTEM

JIT is a system of production that makes and delivers what is needed just when it is needed and just the amount needed. JIT relies on heijunka as a foundation and is comprised of three elements: takt time, continuous flow, and the pull system. Heijunka refers to leveling the type and quantity of production over a fixed period of time. Takt time is how often one part or product should be produced to meet customer requirements based on the rate of sales. Continuous flow refers to producing and moving one item at a time to match the takt time (Ohno 1988).

Kanban cards or kanbans are simply the most common examples of pull signals. They typically are slips of card stock with a bar code printed on the card stating information, such as the following (Narusawa and Shook 2008):

Part name and part number
Supplier or internal supply process
Pack-out quantity
Storage address
Consuming process address
How often it is to be withdrawn

Kanbans have two functions: they instruct processes to make products or parts, and they instruct material handlers, such as a Mizusumashi or a fixed-course pick-up worker, to move products or parts. The former is referred to as a production kanban, and the latter is referred to as a withdrawal kanban. Two types of kanbans are utilized in a dual-card kanban system or a two-card kanban system. Production kanbans tell a supplying process the type and quantity of items, such as products or parts, to make for a downstream process.Conversely, withdrawal kanbans authorize the conveyance of products or parts to a downstream process. They often take two forms: internal kanbans and supplier kanbans.

Six rules apply for using kanbans effectively:

(1) Customer processes withdraw items in the precise amounts specified on the kanban.
(2) Supplier processes produce items in the precise amounts and sequence specified by the kanban.
(3) No items are made or moved without a kanban.
(4) A kanban should always accompany each item; in other words, each item always has a kanban attached.
(5) Defects and incorrect amounts are never sent to the downstream process.
(6) The number of kanban is reduced carefully to reduce inventories and to reveal problems.

A notation of predetermined checking conditions and the associated delivery time for replenishment is written in the kanban, such as (1-16-3), which means that the item must be delivered sixteen ("16") times a ("1") day and the designated items must be replenished three ("3") delivery times after the kanban in question is brought to the supplier. The transition including the quantity of units in inventory, the timing of the order by the kanbans and the associated replenishment is shown in Figure 1.

4 MODULE-BASED MODELING SYSTEM

The kanban system in this study is composed of three sections representing the interaction of the parts between manufacturers and suppliers and one section representing the assembly line to consume the parts. The former three sections are (1) the parts store section to pick up the necessary parts from the rack by a Mizusumashi worker, (2) the shipping area section to order and receive the parts for the supplier, and (3) the supplier center section to supply the manufacturers. These sections are compiled into a template using the template-building features of Arena 14.7 Professional Edition (Kelton, Sadowski, and Zupick 2014). From the standpoint of efficiency of constructing models, the number of required modules and entries can be reduced significantly by introducing the proposed three modules, as shown in Table 1.

These three modules and assembly line sections work together in close cooperation via the Route, Station, Hold, and Signal modules. In general, to build a simulation model using the template proposed in this study, the number of parts store module must match the types of parts to be used, the number of the supplier center module must match the supplier to supply them, and for the shipping area module, the minimum is required.

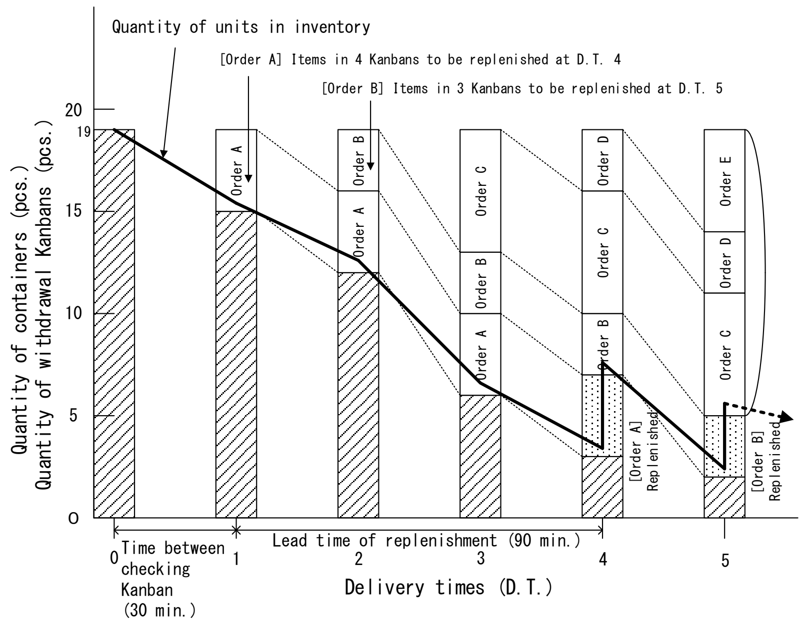

Figure 1: Units in inventory in kanban system: case of (1-16-3).

Table 1: Efficiency of constructing models.

Section Name		Number of modules	Number of entries
Parts Store	Build-in Modules	26	78
	Proposed Module	1	17
Shipping Area	Build-in Modules	7	23
	Proposed Module	1	5
Supplier Center	Build-in Modules	2	5
	Proposed Module	1	2

4.1 Parts Store Module

This section represents the parts store for storing parts used in the factory. This section is divided into two major sections. A Mizusumashi worker picks the quantity necessary which are indicated by the withdrawal kanban (W-kanban) (Figure 2). A Mizusumashi worker or a fixed-course pick-up worker is one of the popular means of realizing the manufacturing philosophy of JIT, and performs operations of supplying parts to designated assembly lines with their hands or human-powered carts (Nomura and Takakuwa 2006). The other section instructs the supply of parts from the supplier (Figure 3). Each supplier kanban (S-kanban) is expressed as the initial amount in the stock parts container. First, when the Mizusumashi worker or W-kanban arrives at the Station module (top left) from the assembly line, it is determined whether the pick-up is required from the parts store. If pick-up is not necessary, the worker is directed from the Route module in the lower right to the next parts store or to the shipping area.

Next, the Mizusumashi worker who is required to pick up parts verifies the stock of the parts on the rack, and if there is no stock, they wait until it is supplied from the supplier. Each part housed in the container is placed on the rack. When the Mizusumashi worker picks up the first part from the container, they remove the S-kanban attached to the container and pick the required quantity of parts. The removed S-kanbans are placed in a predetermined location on the cart in which the Mizusumashi worker uses to carry the part and are finally brought to the shipping area to be used to instruct the supplier. When the

Mizusumashi worker has picked the required number of parts, the worker moves from the Route module in the lower right to the next part store or to the shipping area.

In the kanban delivery cycle section, it generates control entities at a specified time interval based on the defined kanban cycles per part and sends a signal to the shipping area section. The parts store module is shown in Figure 4.

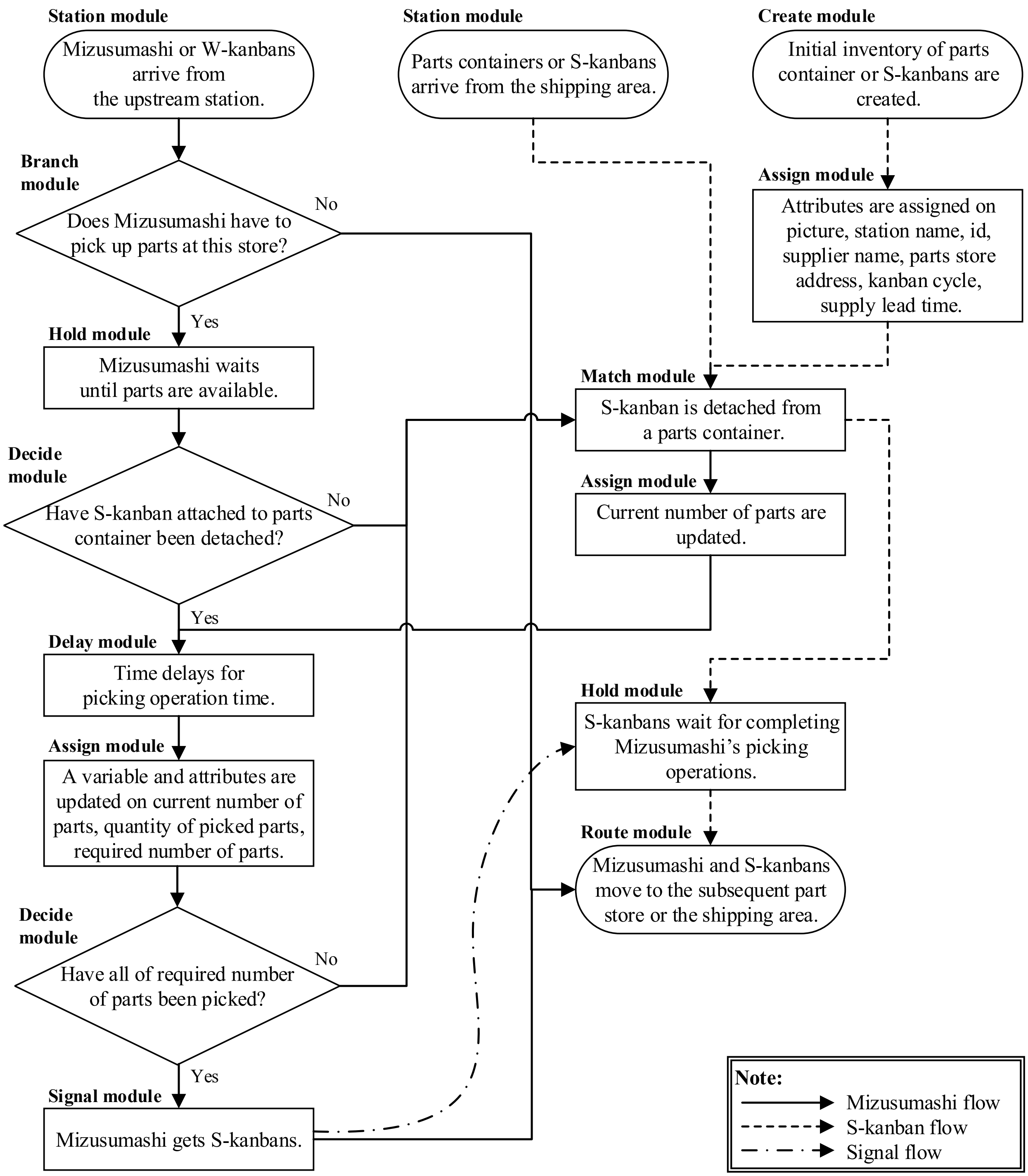

Figure 2: Logic of the parts store module – main section.

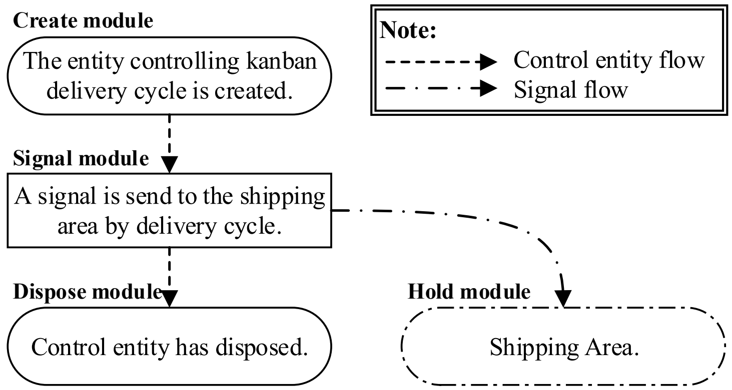

Figure 3: Logic of parts store module – kanban delivery cycle section.

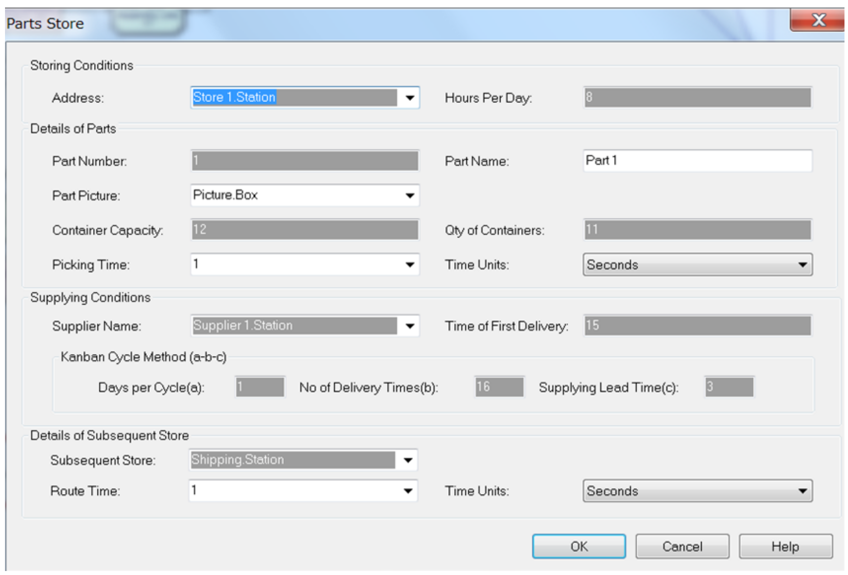

Figure 4: The parts store module.

4.1 Shipping Area Module

This is the section that performs ordering and receiving parts. Figure 5 shows a flow chart of this section. When the Mizusumashi workers from parts store arrive with the S-kanban in hand, they place the S-kanban in the kanban store and push the cart that was used to pick in the parts, and move towards the assembly line. The S-kanban is taken over by the truck drivers of the supplier visiting based on the kanban cycle and is transported to the supplier. Conversely, the parts container with the S-kanban that arrived from the supplier is transported to the corresponding parts store and stored in the rack. The shipping area module is shown in Figure 6.

4.2 Supplier Center Module

This is the section that supplies the part to the manufacturer. Figure 7 shows a flow chart of this section. When the S-kanban arrives at the suppliers, parts containers indicated by S-kanban are loaded on the truck according to the quantity required and supplied by the manufacturer. The supplier center module is shown in Figure 8.

4.3 Assembly Line Section

This is the section that represents the assembly line that consumes the part. Figure 9 shows a flow chart of this section. Production instructions or the customer demand is generated at time intervals for completing one piece of the product in the Create module (upper right), which is a variable representing the number of parts used when the subsequent Assign module is updated.

Conversely, the Mizusumashi worker verifies the number of consumed parts (i.e., the W-kanban number) at the assembly line at a predetermined time interval and moves towards the parts store. After picking work in the parts store, the Mizusumashi worker, who has placed the S-kanban in the shipping area, returns to this section to replenish the consumed part. In this study, the working time required for the Mizusumashi worker's part replenishment in the assembling line is omitted.

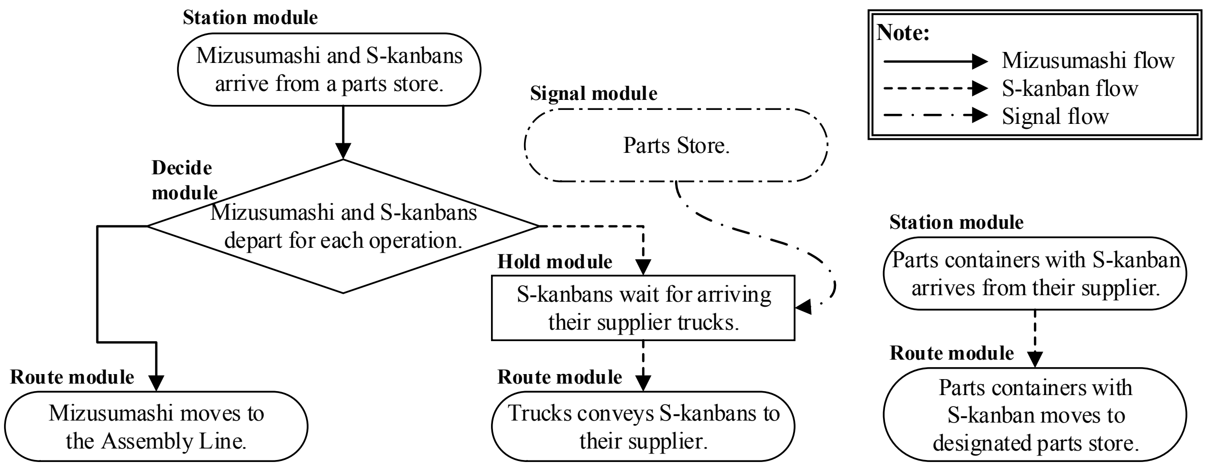

Figure 5: Logic of the shipping area module.

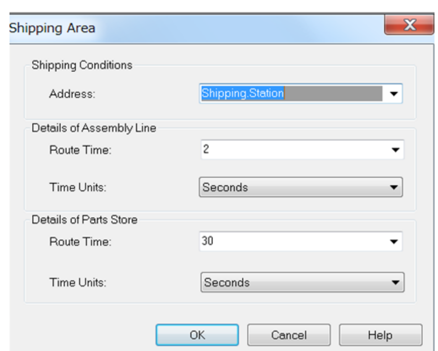

Figure 6: The shipping area module.

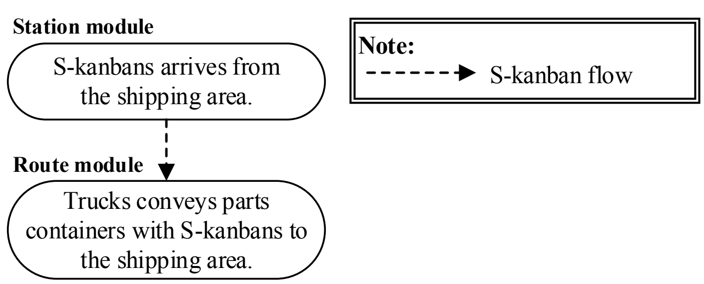

Figure 7: Logic of the supplier center module.

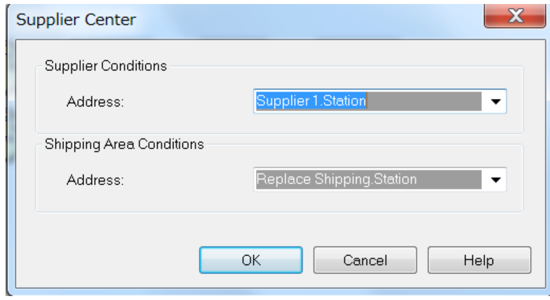

Figure 8: The supplier center module.

5 PROCEDURE TO OBTAIN THE NECESSARY MINIMUM NUMBER OF KANBANS TO ACHIEVE NO STOCK-OUT EVENTS

Once the simulation model containing the kanban system is built, the necessary number of kanbans required to avoid an out-of-stock event should be determined to implement the JIT manufacturing. The procedure proposed to determine the necessity minimum number of kanbans using the simulation is the following:

[Step 1] The expected value or number of kanbans to hold the quantity of items to be consumed during the interval of the sum of time between verifying the kanbans and the lead time of replenishment (K^E) is given by the following equation (Takakuwa and Miwa 2006).

$$K^E = \left[\sum_{i=1}^{R} \sum_{j=1}^{S_i} \frac{Ta(1+c)}{E(d_{ij})Pb} \right] + 1 \qquad (1)$$

where:

a (days): days per cycle for verifying the kanbans

b (times): number of delivery times per cycle of "*a*" days

c (times): number of delivery times to replenish the designated item

d_{ij} (sec./pc.): unit production time at production line *j* to be visited by Mizusumashi or material handler *i*

i: number of Mizusumashi or material handlers (i=1,2,…,R)

j: sequence number of Mizusumashi's visit (j=1,2,…,S_i)

P (pcs.): pack-out quantity of a container

R (persons): total number of Mizusumashi or material handlers

S_i (units): total number of production lines to be visited by each Mizusumashi or material handler *i*

T (sec.): daily working hours

In equation (1), [ ] is Gauss' symbol and is equal to the greatest integer that is less than or equal to the value in parentheses.

[Step 2] The safety stock quantity must be determined because actual demand would often be greater than the average. Hence, it is necessary to determine how much safety stock is required by performing simulation experiments. First, a simulation experiment is executed with the number of kanbans obtained by equation (1), where K^E is the initial solution.

[Step 3] Then, some additional simulation experiments are executed within the neighborhood of the number of kanbans, K^E. Finally, the necessary minimum number of kanbans to achieve no stock-out events is obtained when out-of-stock events vanish with a minimum number of kanbans.

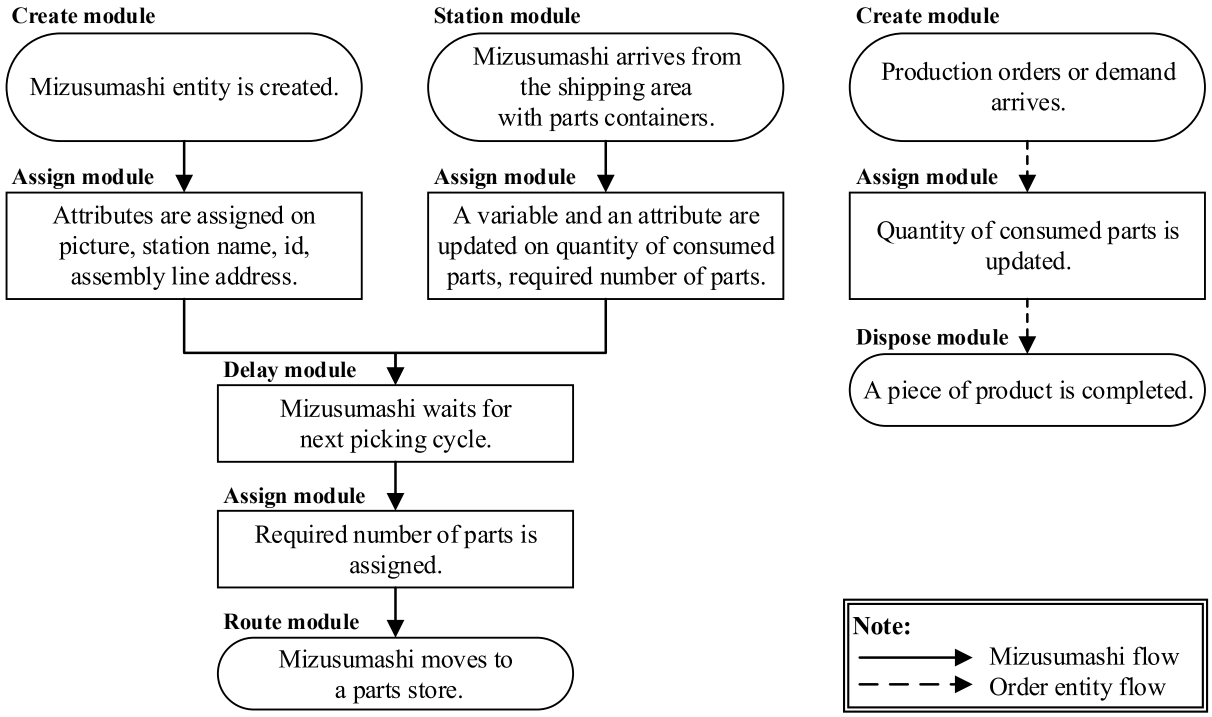

Figure 9: Logic of the assembly line section.

6 APPLICATION

Suppose that the conditions are set in the kanban system as shown in Table 2. These parameters are prepared based on an actual factory that installed a series of assembly lines for electronic devices. The kanban delivery cycle is (1-16-3), that is, a = 1 (days), b = 16 (times), and c = 3 (times), and the pack-out quantity of a container, P, is 12 (pcs.), the total number of Mizusumashi or material handlers, R, is 2 (persons), and the daily working hour, T, is 28,800 (sec.) or 8 (hrs.). First, in Step 1 of the procedure, 12 (pcs.) is the expected value or number of kanbans, as determined by equation (1).

Simulation experiment with a replication length of eight hours per day for thirty days is executed. Figure 10 shows the ratio of the cycle time and the total finished items per day. The ratio of the cycle time indicates the proportion relative to the cycle time per one when the number of kanbans is 12. When the number of kanbans increases up to 11 pieces, this value decreases to 1.0. When the number of kanbans increases up to 11 pieces, the total number of finished items increases. A necessary minimum of kanbans of 11 is determined from the results obtained by executing the simulations. This is the number of kanbans such that an out-of-stock event does not occur.

7 CONCLUSIONS

Module-based modeling of manufacturing system adopting dual-card kanban system with a delivery cycle is proposed in this study. An efficient module-based modeling method is presented for generating simulation programs for any multistage flow-type manufacturing system adopting a dual-card kanban system. A numerical example is shown to apply the proposed procedure. The simulation models can be made quickly through the use of a module-based modeling method developed in this study. The proposed procedure could 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. In addition, an effective procedure is proposed to obtain the minimum necessary number of kanbans to achieve no stock-out events.

Table 2: List of parameters.

Items			Parameters
Mizusumashi No.1 in charge of production line	Unit production time at production line No.11 (sec.)	d_{11}	TRIA(196,227,341) (*1)
	Unit production time at production line No.12 (sec.)	d_{12}	TRIA(59,155,379)
	Unit production time at production line No.13 (sec.)	d_{13}	TRIA(120,150,417)
Mizusumashi No.2 in charge of production line	Unit production time at production line No21 (sec.)	d_{21}	TRIA(216,250,375)
Mizusumashi No.1's time between checking quantity of units at production line (sec.)		L_1	NORM(688,65) (*2)
Mizusumashi No.2' time between checking quantity of units at production line (sec.)		L_2	NORM(655,60)
Pack-out quantity of a container (pcs.)		P	12
Daily working hours (sec.)		T	28800
Delivery cycle of Kanban		$(a\text{-}b\text{-}c)$	(1−16−3)
(*1) Triangular(Min,Mode,Max)			
(*2) Normal(Mean,StdDev)			

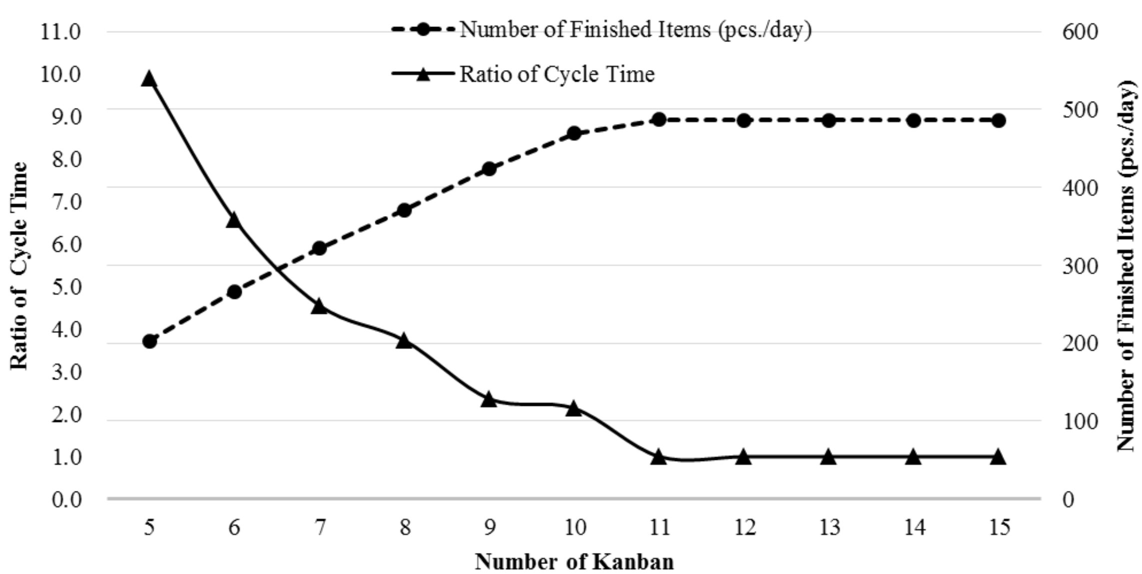

Figure 10: Result of the ratio of cycle time and the total number of finished items.

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