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MODULE-BASED MODELING AND ANALYSIS OF JUST-IN-TIME PRODUCTION ADOPTING DUAL-CARD KANBAN SYSTEM AND MIZUSUMASHI WORKER

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ABSTRACT

In this study, we design and develop module-based modeling scheme that can conveniently represent a manufacturing system adopting a dual-card kanban system with a delivery cycle. By combining the designed modules, it is possible to express models of various systems comprising multiple parts, production lines, suppliers, and Mizusumashi (fixed-course pick-up). The module-based modeling scheme is useful for understanding the characteristics of just-in-time manufacturing and helping decision makers build simulation models based on the modules. We focus on modularization of the assembly line and the parts carrying Mizusumashi in a JIT manufacturing system. The proposed modules have focused dialogs, animation, and modeling functionality. In addition, a procedure for finding the optimal number of tray containers and kanbans to achieve no stock-out events is proposed based on the simulation model that integrates the kanban system and the Mizusumashi system. Then, the proposed procedure is applied to a numerical example.

1 INTRODUCTION

Just-in-time (JIT) is a production system that makes and delivers what is needed just when it is needed and just in the amount needed. In the JIT production method, the stock in hand should not be more than what is necessary. However, inventory is required to prevent shortage (out of stock) from seriously affecting the production line. To realize this, the kanban system and the Mizusumashi system are used.

Kanban is one of the information systems that conveys information about the amount of parts to be picked up and the amount of production by using cards, the so-called kanban (Monden 1983). Mizusumashi (fixed-course pick-up) is one of the popular means of realizing the philosophy of JIT manufacturing to produce or retrieve the required amount of necessary items at the right time. Workers move between assembly lines and storage units for parts regularly and bring the required amounts of necessary types of parts onto the line. Such workers are called Mizusumashi in the context of a popular Japanese production system, that is, the Toyota production system, also called as the JIT manufacturing system (Nomura and Takakuwa 2006).

In this paper, we focus on module-based simulation of the JIT manufacturing system. The model that integrates the kanban system and the Mizusumashi system is complicated, and it is difficult to develop a simulation model for various situations easily. From the decision-making viewpoint, constructing a simulation model based on the idea of modules is useful. Miwa, Nomura, and Takakuwa (2016) proposed a module-based simulation model by adapting the dual-card kanban system with a delivery cycle. In addition to these modules, we propose an assembly line module that considers the number of tray containers on an assembly line and a Mizusumashi module that carries the parts. Furthermore, by defining the minimum necessary quantity for each tray container and kanban under the constraint that no shortage occurs, we define an “optimization” problem.

First, the characteristics of the kanban system and the Mizusumashi system are described. Next, module-based simulation of the JIT manufacturing system is proposed. Furthermore, procedures for determining the minimum necessary number of trays and the number of kanbans without going out of stock are described. Finally, the proposed procedure is applied to solve a numerical example.

2 LITERATURE REVIEW

JIT production methods have been researched extensively. Kumar and Panneerselvam (2007) reviewed the JIT-Kanban system and indicated the studies focusing on the determination of kanbans and the corresponding solutions by using suitable models and tools. Some authors have developed simulation models and meta-heuristics such as genetic algorithm, tabu search, and simulated annealing for JIT-Kanban to obtain better solutions. As modeling approaches for obtaining optimal solutions, there are mathematical models (Kimura and Terada 1981), queuing models (Seki and Hoshino 1999), and simulation models. Gupta and Al-Turki (1998) and Hao and Shen (2008) applied simulation models to optimize the required number of kanbans.

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

The Mizusumashi system is one of the popular means of realizing the philosophy of JIT manufacturing, which used to produce or retrieve the required amount of necessary items at the right time. Workers move between assembly lines and storage units for parts regularly and bring the required amount of necessary types of parts onto the line. Ichikawa’s (2009) analysis of laptop assembly using cell production considered Mizusumashi.

The module-based modeling proposed in this study drastically reduces the time and effort required for modeling and increases the efficiency of models construction, and changing models only requires defining a series of parameters. This modeling approach is used 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). The module-based modeling approach provides flexibility and efficiency for updating models with new features. As the simulation models can be used as test beds to examine the feasibility of tentative plans (Enns and Suwanruji 2003, Takakuwa and Nomura 2004), the proposed module-based simulation models are useful for understanding the characteristics of JIT manufacturing. This study adopts a module-based modeling approach while maintaining the essential procedures and rules of JIT manufacturing described by Monden (1983) and Spearman (1992).

3 DUAL-CARD KANBAN SYSTEM AND MIZUSUMASHI

3.1 Dual-Card Kanban System

JIT relies on heijunka as its 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 the frequency with which one part or product should be produced to meet customer requirements based on sales rates. Continuous flow refers to producing and moving one item at a time to match the takt time (Ohno 1988). Kanban system, Mizusumashi, and Andon are especially applied to realize JIT production.

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, as shown in Figure 1. The former is called a production kanban and the latter a withdrawal kanban. These two types of kanbans are used in a dual-card kanban system or a two-card kanban system. Production kanbans tell a preceding process the type and quantity of items, such as products or parts, to prepare for a subsequent process. Conversely, withdrawal kanbans authorize the conveyance of products or parts to a subsequent process. As soon as a withdrawal kanban arrives at a preceding process, a production kanban is removed from a parts container containing the designated part and exchanged with the withdrawal kanban. Then, the parts container is routed to a subsequent process together with the withdrawal kanban.

The detached production kanban is put on a scheduling board. After an operator finishes an operation, he takes a production kanban out and starts performing the following operation using the designated parts placed on a part storage unit. At the same time, he removes the withdrawal kanban placed on the part container and places it on a withdrawal kanban post.

Mizusumashi workers supply parts and convey the kanbans on a withdrawal kanban post. This procedure is executed repeatedly. Since the arrival of kanbans conveyed from a subsequent process triggers production, production is executed based on the exact amount of customer needs; overproduction, which is one of the "seven wastes," is avoided.

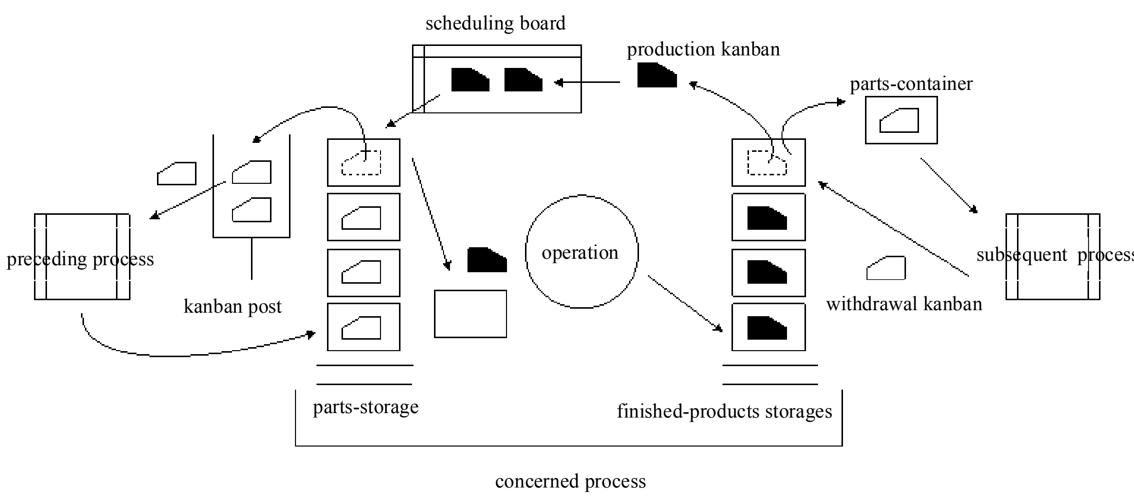

Figure 1: Dual-card kanban system.

3.2 Mizusumashi

Mizusumashi workers supplies parts to designated production lines with their hands or human-powered carts. They use two methods for supplying parts, namely, periodic reviewing and continuous reviewing or ceaseless reviewing. In supplying parts by using the periodic reviewing method, a Mizusumashi worker checks the amount of parts in work-in-process inventories at a production line in a predetermined time interval and replenishes the number of parts corresponding to the capacity of the parts container that the operator picked up at the last time. In the continuous reviewing method, the point of time of replenishing and checking parts occurs simultaneously. A Mizusumashi worker checks the parts in a work-in-process inventory for the next replenishment at the time when the worker completes supplying parts corresponding to the previous review. Hence, a Mizusumashi worker always moves around on the shop floor in the latter method, while the worker waits until the next review time arrives after the last parts supply in the former one. This fashion of movements is the reason why these workers are called Mizusumashi, which means a whirligig beetle in Japanese.

4 MODULE-BASED MODELING SYSTEM

4.1 Module Design in Kanban 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 that consumes the parts. The former three sections are (1) parts store section from which Mizusumashi workers pick up the necessary parts from racks, (2) the receiving area section where parts for the supplier are ordered and received, and (3) the supplier center section for supplying the manufacturers. These sections are compiled into a template by using the template-building features of Arena 14.7 Professional Edition (Kelton, Sadowski, and Zupick 2014). From the standpoint of model construction efficiency, the number of required modules and entries can be reduced significantly by introducing the three proposed modules (Nomura and Takakuwa 2004; Miwa, Nomura, and Takakuwa 2016). In this paper, the former three modules, namely, parts store, receiving area, and supplier center, are modified according to this research, and show mainly the assembly line module and the Mizusumashi module for carrying parts in the assembly line section. These modules work together in close cooperation via the Arena standard modules such as route, station, hold, and signal modules.

Interrelationships among the sections are shown in Figure 2, including the customer order and the production systems.

1. When a purchase order is received from a customer, products from a finished-parts storage are shipped. In addition, production kanban, P-kanban, is removed from the finished products, and a production instruction is released for a production line.
   As production is performed, associated parts are used, and finally the tray container becomes empty. Then, the empty tray container is collected for later replenishment. In this sense, an empty tray container plays the role of withdrawal kanban, W-kanban.
2. A Mizusumashi worker visits the parts store in sequence to pick up the designated number of parts, puts them into a tray container, and then places a W-kanban. When parts are taken out from a parts container, supplier kanban, S-kanban, is removed from it. A Mizusumashi worker moves to the next parts store or receiving area carrying parts with the W-kanban and the S-kanban.
3. A Mizusumashi worker places the S-kanban at the specified position in a receiving area and returns to a production line to replenish parts. By contrast, a supplier's truck visits a receiving area periodically to collect S-kanban based on the specified delivery cycle. Then, the truck returns to a supplier.
4. The truck arrives at a supplier, containers of shipping parts together with the S-kanban are loaded on the truck for subsequent delivery to the manufacturer.
5. When a truck from a supplier arrives in a receiving area, containers of parts together with S-kanban are delivered. Then, the containers are conveyed to the assigned position in a parts store.

The characteristics of the production system are as follows:

- Mizusumashi is responsible for transporting parts to the assembly line and circulating a predetermined route without interruption.
- Tray containers are used for parts storage on an assembly line, and part containers are used for storing parts in a parts store.

- When a tray container becomes empty, the W-kanban is removed from it, and the empty tray container is collected. When the first part is taken out, the S-kanban is removed from the parts container.
- On the assembly line, empty tray containers are collected at the time of the Mizusumashi survey, and two or more empty tray containers may be collected at the same time.
- In this system, the "fixed withdrawal cycle method" is adopted, in which parts are recovered and replenished at time intervals determined for each part.

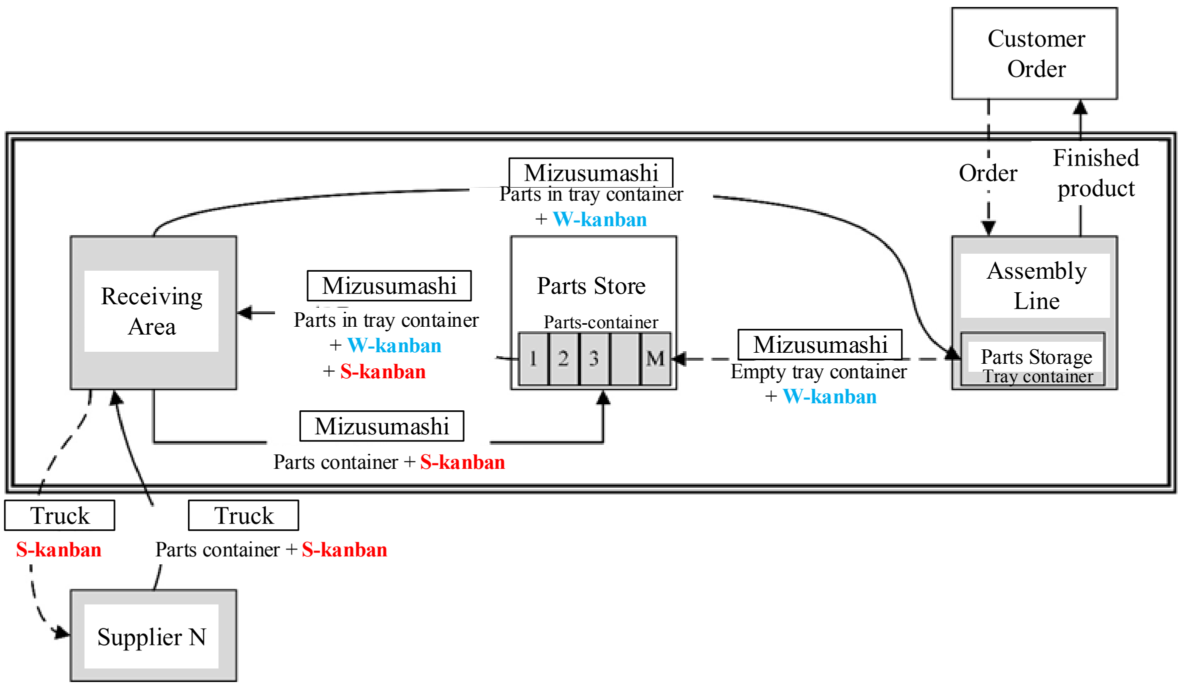

Figure 2: Kanban System with Mizusumashi.

4.2 Mizusumashi Module and Assembly Line Module

The Mizusumashi module represents periodically replenishment operation of Mizusumashi workers. Figure 3 shows a flowchart of this module. A Mizusumashi entity is generated at the beginning of a simulation run. It waits for the next review period at the waiting station, and then moves to a dedicated assembly line. After replenishing tray containers at the assembly line, Mizusumashi returns this module and waits for the next review period. The Mizusumashi module is shown in Figure 4.

The assembly line module represents the consumption and replenishment of tray containers on an assembly line. Figure 5 shows a flowchart of this module. Assembly operation starts when the following three conditions are satisfied: 1) a production instruction or customer demand is received, 2) there exist required parts in the rack of a tray container, 3) a line worker is ready for process. Production instructions are generated in the create module (upper left). Tray containers are initially created in the create module (upper middle) and are replenished by Mizusumashi from receiving area in the separate module (right). A rack of tray containers is represented by the hold module (upper middle) - Separate module (middle) - Match module (left).

Empty tray containers are placed on the used tray box (hold module; lower middle). When a Mizusumashi worker visits this assembly line for periodical review, he/she collects the empty tray containers and moves to parts store for picking up the designated number of parts and filling them into tray containers. The assembly line module is shown in Figure 6.

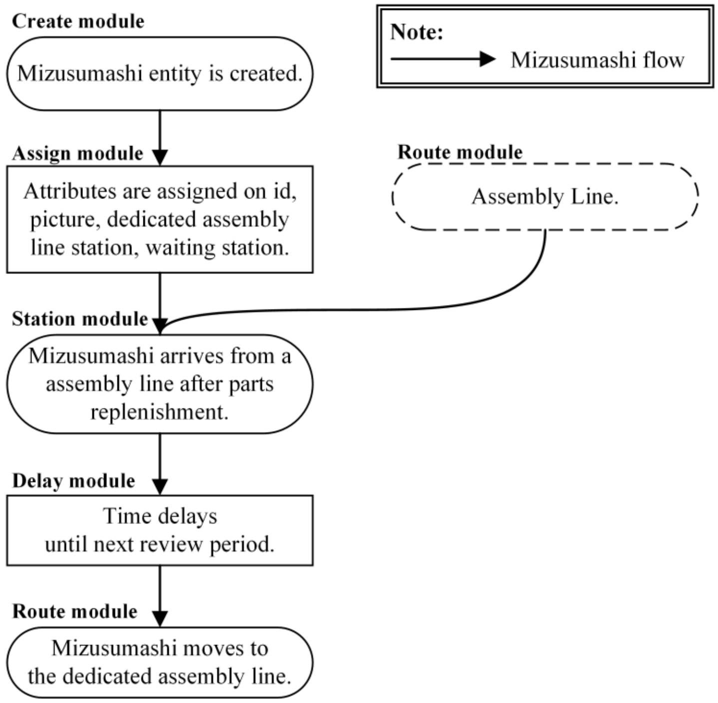

Figure 3: Logic of Mizusumashi module.

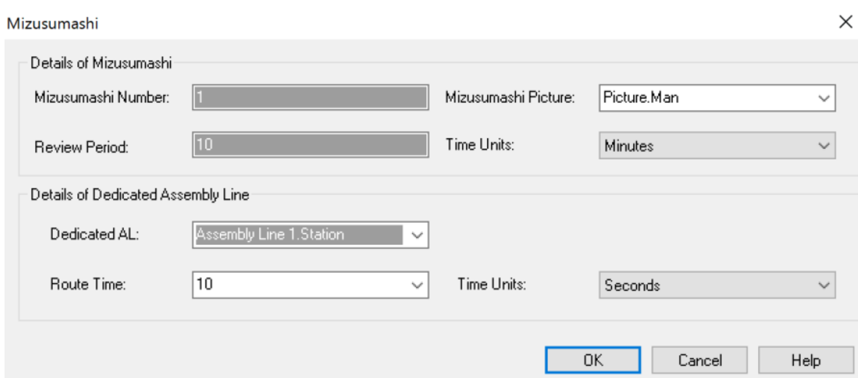

Figure 4: Mizusumashi module.

5 PROCEDURE TO OBTAIN NECESSARY MINIMUM NUMBER OF TRAY CONTAINERS AND PARTS CONTAINERS TO ACHIEVE NO STOCK-OUT EVENTS

Once the simulation model containing the kanban system is built, the necessary number of tray containers and kanbans required to avoid an out-of-stock event should be determined to implement JIT manufacturing. It is important to decide an appropriate number of tray containers for smooth production. If the number of tray containers is inadequate, operations would stop frequently due to part shortages. By contrast, keeping an excessive number of tray containers would lead to an unnecessarily large work-in-process inventory in the rack on an assembly line.

The procedure proposed to determine the necessary minimum number of dual-card kanbans, or tray containers and parts containers, using the simulation is as follows:

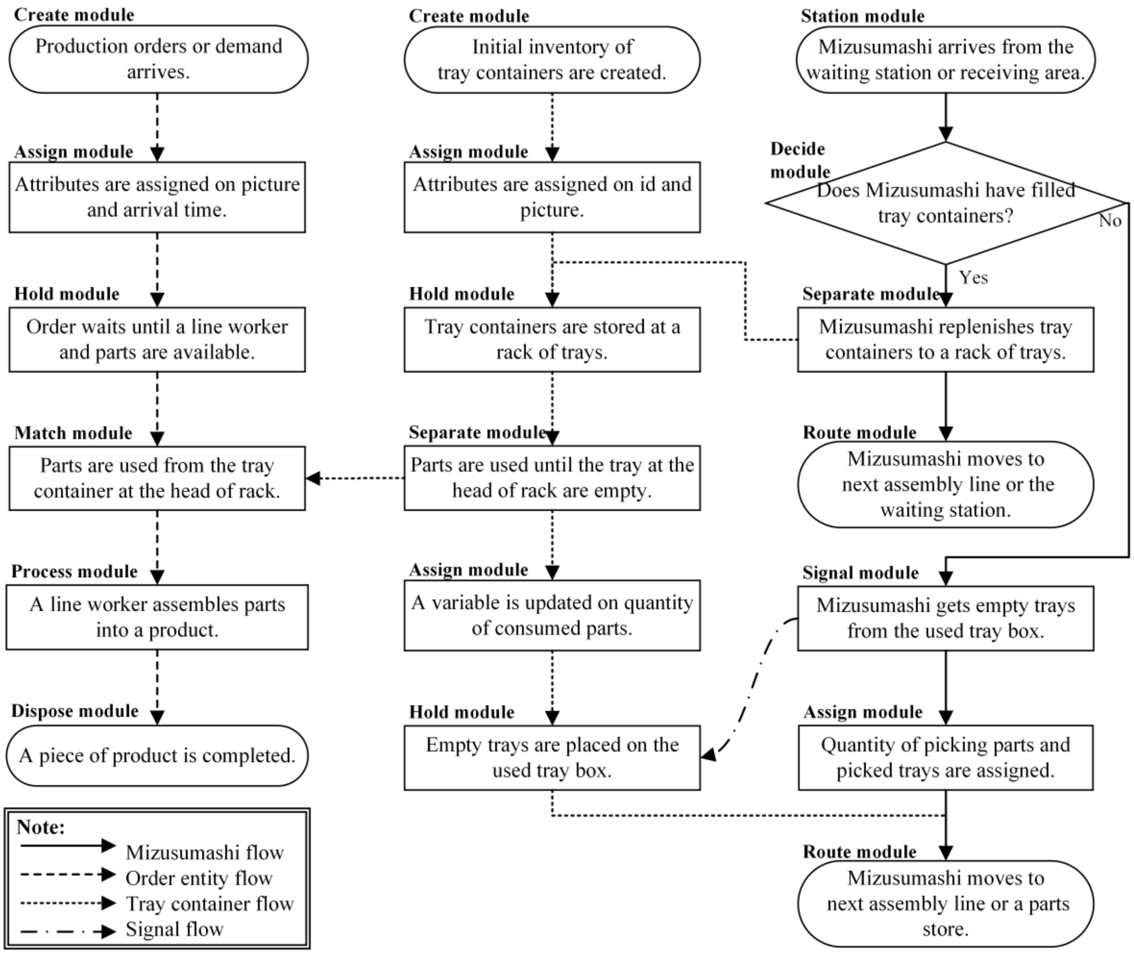

Figure 5: Logic of assembly line module.

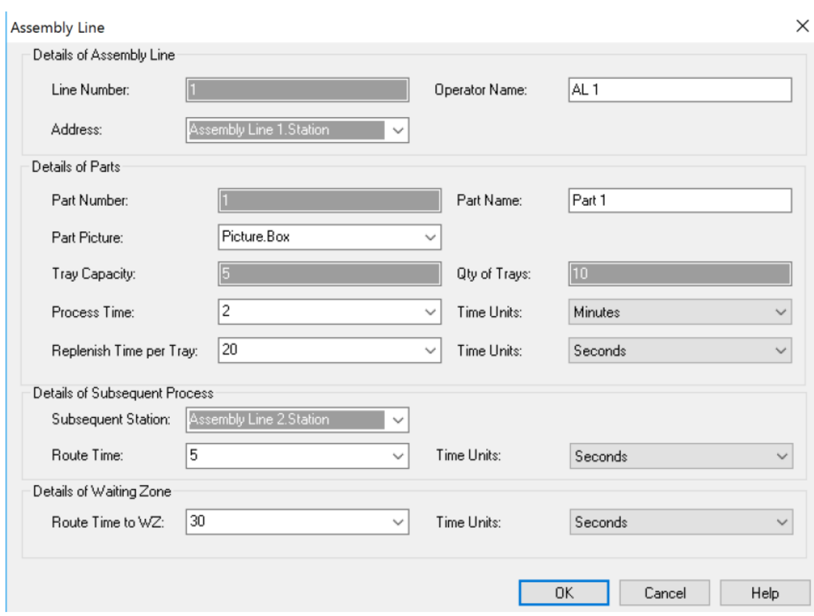

Figure 6: Assembly line module.

[Step1] By considering the replenishment system of inventory control (Lewis 1970), the expected number of tray containers, M^E, can be given by the following equation (Nomura and Takakuwa 2006).

$$M_{ij}^{E} = \left[\frac{X_i + E(L_{ij})}{E(d_i)N} \right] + 1 \tag{1}$$

where:

d_i (sec/pc): unit production time on production line j
i: number of Mizusumashi or material handlers ($i = 1, 2, \ldots, R$)
j: sequence number of a Mizusumashi worker's visit ($j = 1, 2, \ldots, S_i$)
L_{ij} (sec): lead time to supply parts to production line j by Mizusumashi or material handler i
N (pcs): pack-out quantity of a tray 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
X_i (sec): review period for Mizusumashi i.

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

[Step2] The expected value or number of parts containers to hold the quantity of items to be consumed during the interval of the sum of time between verifying the parts containers and the lead time of replenishment (K^E) is given by the following equation (Miwa et.al 2016). The notation of predetermined checking conditions and the associated delivery time for replenishment is written in the kanban, such as (*a*-*b*-*c*), which means that the item must be delivered sixteen ("*a*") times a ("*b*") day and the designated items must be replenished three ("*c*") delivery times after the kanban in question is brought to the supplier.

$$K^{E} = \left[\sum_{i=1}^{R} \sum_{j=1}^{S_i} \frac{Ta(1+c)}{E(d_{ij})Pb} \right] + 1 \tag{2}$$

where:

a (days): days per cycle for verifying the kanbans
b (times): number of delivery runs per cycle of "a" days
c (times): number of delivery runs to replenish a designated item
d_{ij} (sec/pc): unit production time on production line j to be visited by Mizusumashi or material handler i
i: number of Mizusumashi or material handlers ($i = 1, 2, \ldots, R$)
j: sequence number of Mizusumashi's visit ($j = 1, 2, \ldots, S_i$)
P (pcs): pack-out quantity of a parts 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 (2), [ ] is Gauss' symbol and is equal to the greatest integer that is less than or equal to the value in parentheses.

[Step3] The safety stock quantity must be determined. Because actual demand is often greater than the average demand, and a Mizusumashi worker does not usually supply the same parts, the lead time between checking inventories and supplying parts varies each time. Hence, it is necessary to determine the amount of safety stock required by performing simulation experiments. OptQuest is used to determine the best value for one or multiple objective functions (Kleijnen and Wan 2007). In this study, OptQuest is adopted to determine the optimal number of kanbans.

First, the number of parts containers is to be determined. A simulation experiment is executed with the number of parts containers obtained by equations (2), where K^E are the initial solutions. Then, the obtained number of tray containers would be accommodated in the assembly line. The objective of the

problem is to minimize the sum of the numbers of parts containers, K_u (u = 1, 2,…, m). The optimization model is as follows:
Find K_u so as to
minimize:

$$\sum_{u=1}^{m} K_u \tag{3}$$

subject to:

$$\sum_{u=1}^{m}\sum_{h=1}^{n} z_{uh} = 0 \tag{4}$$

where:

z_{uh} : shortage number of tray containers on parts u in line h (h = 1,2,…,n).

Thus, the necessary minimum number of parts containers to avoid stock-out events is obtained.

[Step4] Next, the number of tray containers is to be determined. A simulation experiment is executed with the number of tray containers obtained by equations (1), where M^E are the initial solutions. In addition, the number of parts containers are set as obtained in Step3. The objective of the problem is to minimize the sum of the numbers of tray containers, M_{uh} (u = 1, 2,…, m, h = 1,2,…,n). The optimization model is as follows:
Find M_{uh} so as to
minimize:

$$\sum_{u=1}^{m}\sum_{h=1}^{n} M_{uh} \tag{5}$$

subject to:

$$\sum_{u=1}^{m}\sum_{h=1}^{n} z_{uh} = 0 \tag{6}$$

where:

z_{uh} : shortage number of tray containers on parts u in line h (h = 1,2,…,n).

Finally, the necessary minimum number of tray containers to avoid stock-out events is obtained when out-of-stock events vanish with the minimum number of tray containers and parts containers.

6 APPLICATION

A set of proposed modules for modeling the kanban system is applied to build the simulation model of an actual factory. Let us consider that one type of product is produced using five types of parts supplied by one Mizusumashi worker. The daily working hours, T, 8 hours or 28,800 seconds. In addition, it is assumed that the production line has an enough capacity to meet customer demand. The conditions and parameters such as delivery cycles of each part and capacities of tray containers and parts containers are summarized in Table 1. For example, the kanban delivery cycle of Part 1 is (1-16-3), that is, a = 1 (days), b = 16 (times), and c = 3 (times). For Part 1, the capacity of a parts container at the parts store is five pieces, and the capacity of a tray container for supplying the assembly line is five pieces.

The tray containers and the parts containers are assigned spots within the limited shelf space on the assembly line and in the parts store, respectively. In addition, the expected necessary numbers of tray containers and parts containers are obtained by equations (1) and (2), respectively. Then, the necessary minimum or the optimum number of kanbans is obtained by executing the simulation with OptQuest. The replications for performing OptQuset is set to 10. The capacities of tray containers and parts containers, expected necessary numbers, and resultant necessary minimum numbers of each part are summarized in Table 2. Regarding Part 1, at most thirty containers can be put on the parts store's shelf and at most three tray containers can be put on the shelf in front of the assembly line. The expected necessary numbers are seven and one pieces, and the obtained necessary minimum numbers are six and three pieces, respectively.

Thus the minimum numbers of tray containers and part containers to achieve no stock-out events are obtained by applying the proposed procedure. An animated model is shown in Figure 7.

Table 1: List of parameters.

Module	Item		1	2	3	4	5
Mizusumashi	Details of Mizusumashi	Mizusumashi Number	1				
		Mizusumashi Picture	Picture. Man				
		Review Period	10(min.)				
	Details of Dedicated Assembly Line	Dedicated AL	Assembly Line 1.Station				
		Route Time	10(sec.)				
Assembly Line	Details of Assembly Line	Line Number	1	2	3	4	5
		Address	Assembly Line 1.Station	Assembly Line 2.Station	Assembly Line 3.Station	Assembly Line 4.Station	Assembly Lin5.Station
		Operator Name	AL1	AL2	AL3	AL4	AL5
	Details of Parts	Part Number	1	2	3	4	5
		Part Name	Part 1	Part 2	Part 3	Part 4	Part 5
		Part Picture	Picture. Part1	Picture. Part2	Picture. Part3	Picture. Part4	Picture. Part5
		Tray Capacity	5	5	10	20	10
		Qty of Trays	3	3	2	4	4
		Process Time	TRIA(196,227,341)	TRIA(59,155,379)	TRIA(120,150,417)	TRIA(216,250,375)	TRIA(135,180,255)
		Replenish Time per Tray	20(sec.)	20(sec.)	20(sec.)	20(sec.)	20(sec.)
	Details of Subsequent Process	Subsequent Station	Assembly Line 2.Station	Assembly Line 3.Station	Assembly Line 4.Station	Assembly Line 5.Station	Store 1.Station
		Route Time	10(sec.)	10(sec.)	10(sec.)	10(sec.)	30(ces.)
Parts Store	Soring Conditions	Address	Store 1.Station	Store 2.Station	Store 3.Station	Store 4.Station	Store 5.Station
		Hours Per Day	8	8	8	8	8
	Details of Parts	Part Number	1	2	3	4	10
		Part Name	Part 1	Part 2	Part 3	Part 4	Part 5
		Part Picture	Picture.Part1	Picture.Part2	Picture.Part3	Picture.Part4	Picture.Part5
		Container Capacity	5	12	10	455	30
		Qty of Containers	30	6	16	3	8
		Picking Time	15(sec.)	15(Sec.)	15(Sec.)	15(Sec.)	15(Sec.)
	Supplying Conditions	Supplier Name	Supplier1.Station	Supplier2.Station	Supplier3.Station	Supplier4.Station	Supplier5.Station
		Time of First Delivery	60	60	60	60	60
		Kanban Cycle Method(a-b-c)	1-16-3	1-16-3	1-8-2	1-16-3	1-16-3
	Details of Subsequent Process	Subsequent Store	Store 2.Station	Store 3.Station	Store 4.Station	Store 5.Station	Receiving. Station
		Route Time	5(sec.)	5(sec.)	5(sec.)	5(sec.)	60(sec.)
Receiving Area	Receiving Conditions	Address	Receiving.Station				
	Details of Assembly Line	Route Time	15(sec.)				
	Details of Parts Store	Route Time	15(sec.)				
Supplier	Supplier Conditions	Address	Supplier 1.Station	Supplier 2.Station	Supplier 3.Station	Supplier 4.Station	Supplier 5.Station
	Receiving Area Conditions	Address	Replace Receiving.Station	Replace Receiving.Station	Replace Receiving.Station	Replace Receiving.Station	Replace Receiving.Station

Table 2: Result of number of kanbans.

		Part 1	Part 2	Part 3	Part 4	Part 5
S-kanban with parts container	Maximum number	30	6	16	3	8
	Expected number	7	4	5	1	2
	Optimum number	6	4	4	1	1
W-kanban with tray container	Maximum number	3	4	2	4	4
	Expected number	1	2	1	1	1
	Optimum number	3	4	2	2	2

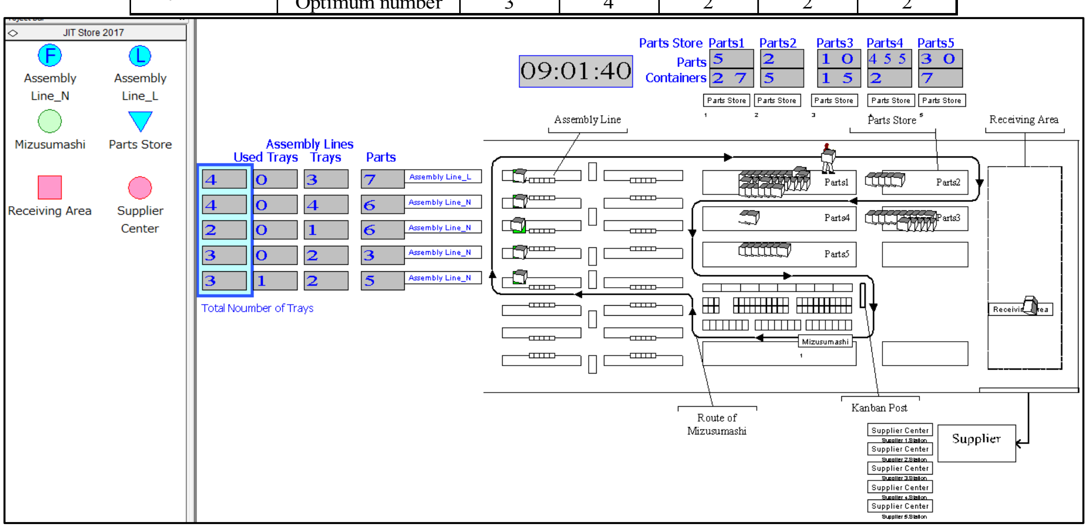

Figure 7: Simulation model.

7 CONCLUSIONS

In the JIT manufacturing system, a module-based simulation modeling scheme that integrates the kanban cycle, suppliers, Mizusumashi, and assembly lines is proposed. The logic of the dual-card kanban system and Mizusumashi are described to present kanban and Mizusumashi flow for executing simulation. Procedures to determine the required minimum number of kanbans to prevent part stock-out events is proposed. A numerical example is solved using the proposed procedure. Decision makers can easily build a production system with multiple lines, parts, and Mizusumashi in a short time and understand system characteristics easily. Moreover, it is possible to quantitatively grasp the quantity positioned as the safety inventory quantity.

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