Arena Modules for Modeling Kanban-Controlled Manufacturing

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A company may reap the full benefits of kanban control only after determining an optimal or near-optimal system configuration. Finding such a configuration requires methods that can determine key performance measures, such as replenishment cycle, average fill rates, average inventory levels, etc. In industrial application the kanban-controlled systems are complicated multi-stages systems with restricted manufacturing capacity. Therefore, the existing analytical (mathematical) methods are only applied to determine just mentioned key performance measures fast and raw way. On the other hand the computer simulation is widely useable method and it may generally be used to analyze the true performance of a complex system

1. Introduction

The production management approach Just-In-Time (JIT) gained worldwide prominence when the rest of the world noticed the increasing success of Japanese companies in the late 1970s and early 1980s. As one major operational element of JIT, the kanban control system became a popular topic in western research and industry. Manufacturing companies outside Japan began to use kanbans to control production and flow of material. The Kanban system was 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). Since then, the Toyota production system (TPS), which has only one element Kanban system, became well known worldwide. As for a Kanban system, it has attracted international attention because it differs completely from the traditional push production-control system. 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. Some analytical evaluation methods can be found in the literature, particularly for systems with a single product. Analytical (mathematical) evaluation methods are needed that can determine key performance measures quickly, even if these methods only approximate the true performance of the system. Finding the best configuration requires methods that can determine key performance measures, such as replenishment cycle, average fill rates, average inventory levels, etc. Computer simulation may generally be used to analyze the performance of a system, but to identify an optimal configuration, many different system variants may have to be evaluated.

In this study, a series of the modules are developed for developing simulation models on the flow-type multistage Kanban manufacturing system. This study focuses the Kanban system, i.e., the single-card and the dual-card kanban. By using the proposed modules for Kanban system, a simulation of multistage manufacturing systems can be developed and performed quickly and easily.

2. Classification of Kanban systems

The least complex variant of a kanban-controlled manufacturing system with multiple products is a system with a single multi-product manufacturing facility. Besides the production facility, the system contains a scheduling board, an output store for finished products, containers to store and carry finished items, and one set of kanbans for each product in the system.

Traditionally, a kanban is a tag-like card (kanban is Japanese meaning "card" or "visible record"). One kanban must be attached to each container in the output store. The number of kanbans is limited, restricting the maximum amount of finished items in the system. When a container is withdrawn, the accompanying kanban is detached from the container and placed on the scheduling board. Alternatively, the kanban may be detached when the last item is removed from the container (this is equivalent to using a fixed number of containers to limit the maximum inventory of a product). Also, removed kanbans may be put in a kanban collection box located in the output store before they are transferred to the scheduling board, either when a given number of kanbans has accumulated or when a specified amount of time has elapsed from the last transfer. A detached or "active" kanban authorizes manufacture of one standard container of the product indicated on the card. When a container has been filled with the prescribed number of items, the now "inactive" kanban is affixed to the container and the container is transferred to the output store.

Multi-stage kanban systems may be classified by the rules for transferring containers from the output store of one stage, say stage m, to the input store of the following stage, say stage m+l. At least four different set of rules may be found in the literature. In some systems, the output store of a stage is also the input store of the next stage. Consequently, there is no need for a transfer mechanism. In systems with separate output and input stores, the transfer of containers from the output store to the input store may be executed at different points in time. In *Table 1*, we summarize four different material transfer schemes. Each type is shortly explained in the following sections.

Table 2.1. Classification of Material Transfer Schemes

Output Store Stage m = Input Store Stage m + 1	Output Store Stage m $\neq$ Input Store Stage m + 1		
Type l Withdrawal immediately before start of production	**Type 2** Withdrawal immediately after activation of kanban	**Type 3** Fixed quantity, variable withdrawal cycle	**Type 4** Fixed withdrawal cycle, variable quantity
One-Card System		Two-Card System	

Type-1 material transfer. The output store of a stage is also the input store of the following stage, and material is withdrawn from the store immediately before start of production (*Fig.1*). This scheme has been labeled *late material transfer*.

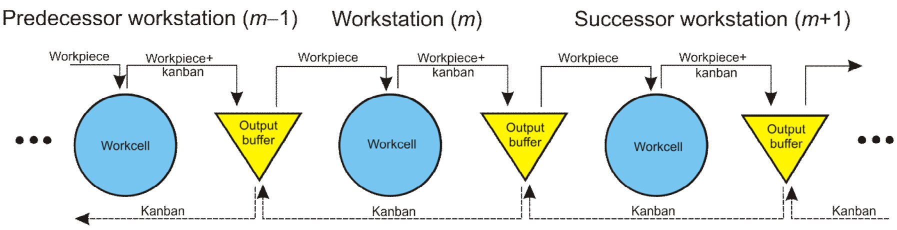

Figure 1 Single-card Kanban system (Type-1)

Type-2 material transfer. The output store of a stage is physically separated from the input store of the next stage. The material from the output store of stage m is withdrawn immediately after activation of a kanban in stage m+l (the active kanban authorizes the withdrawal of a container with input material). The kanban is attached to the container and both join the queue in front of the manufacturing facility of stage m+1. If the output store of stage m is empty upon activation of a kanban in stage m+l, then the transfer is delayed until the manufacturing facility of stage m completes a container with the appropriate parts. This scheme is called *immediate material transfer*.

Type-3 and type-4 material transfer. The output store of a stage is physically separated from the input store of the following stage, and an additional set of cards, called withdrawal, conveyance, delivery, move, or transportation kanbans, is used to organize the transfer of containers between the stages. These systems are commonly referred to as two-card or dual-card kanban systems (*Fig. 2*), in contrast to one-card or single-card kanban systems that only use a single-card type. A withdrawal kanban must be attached to each container in the input store of a stage. When a container is taken up for production, the withdrawal kanban is removed and put into a kanban collection box. Eventually, a carrier takes the withdrawal kanbans out of the box and moves to the output store of the preceding stage. There, he withdraws a full container for each withdrawal kanban in his possession, removes the regular kanban from each container, and attaches one of the withdrawal kanbans instead (the regular kanbans are often called production kanbans in two-card kanban systems). Then he carries the containers to the input store of stage m+l. The removed production kanbans are put into a box from which they are eventually collected by a worker who places them on the scheduling board of stage m. If the carrier finds fewer containers in the output store than he holds withdrawal kanbans in his possession, then he returns the extra kanbans to stage m+l and puts them back into the kanban collection box in the input store of stage m+l.

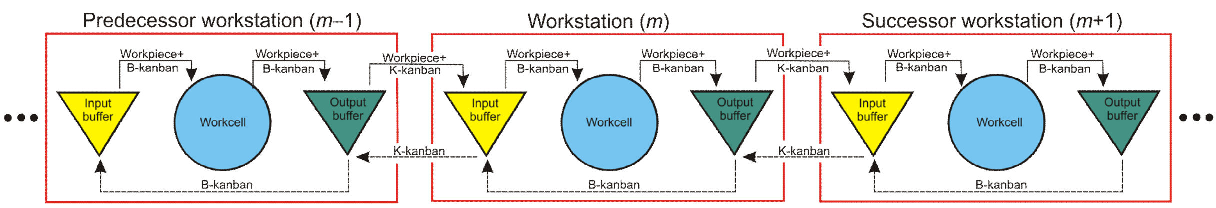

Fig. 2. Dual-card Kanban system

The point in time when the carrier removes the withdrawal kanbans from the kanban collection box is determined by one of two different schemes: (1) fixed quantity, variable withdrawal cycle (type-3 material transfer), or (2) fixed withdrawal cycle, variable quantity (periodic material handling, type-4 material transfer). In the first scheme, the carrier removes the withdrawal kanbans when a predetermined fixed number of cards has accumulated. The length of the withdrawal cycle, that is, the time between consecutive material transfers, may therefore vary. With the second scheme, the carrier removes the kanbans periodically, following a predetermined fixed schedule. Here, the withdrawal cycle is fixed and the number of cards may vary. Note that type-3 material transfer is equivalent to type-2 material transfer if the fixed withdrawal quantity is set to one.

3. Characteristics and application of the developed modules

The Arena Professional Edition is an advanced, hierarchical structured simulation system which provides an interactive environment for building, graphically animating, verifying, and analyzing simulation models. Due to the hierarchical structure with the Professional Edition, you can design a unique Arena template that is specific to your particular project, company, or industry. With the Professional Edition, you can create complete simulation building blocks, called modules and after translation modules can be integrated into template. In our case we will develop different type of kanban modules and will integrate them into template called *Kanban.tpo*.

The restricted extent of this study does not make possible the detailed presentation of the steps of the development and the background logic of the modules therefore we devote more time to outline the characteristics and application opportunities of the modules. The self-developed *Kanban Process* template consists of six modules (*Customer_S*, *Customer_D*, *Workstation_S*, *Workstation_D*, *Supplier_S* and *Supplier_D*) which are applicable for modeling both of single-card and dual-card Kanban systems. In the name of the modules the extension *S* and *D* refer to single-card and dual-card system. The common feature of the modules, that not only the train of thought of their development, but the logic of their application similar. To the function of all models need a customer and a supplier station that can be modeled with *Customer* and *Supplier* modules. According to the number of the production stages, required number of workstations can be inserted between the supplier and the customer stations. We suppose that a batch of parts or jobs is flowed in the model between stations and we do not examine its combination. Stations, rows and resource pictures are attached to the modules to utilize the animated opportunities of Arena model. On paths (*Route*) between the stations (*Station*) can be displayed the motion of the entities. The pictures of resources (*Resource Picture*) show the state of the resources (*Busy*, *Idle*, *Inactive*). The *Queues* represent the length of the queues inside the modules. The entity pictures that symbolize the motion of the workpieces and kanban cards can be chosen optionally. The time parameters like inter arrival time, or route time may be deterministic ones and stohastic. To the last cases the available distribution functions can be picked from pull-down lists.

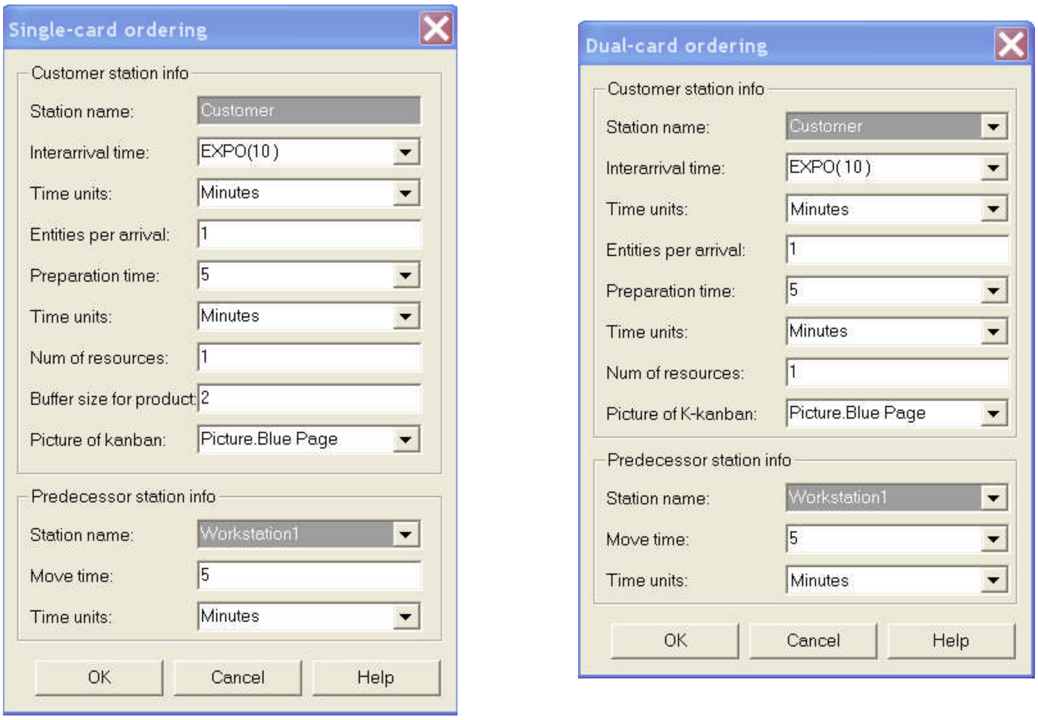

Figure 3 Dialog boxes of *Customer_S* and *Customer _D* modules

In the models the modules named *Customer_S* and *Customer_D* generate customer demand and provide the pull effect. The completed dialogue windows of these modules are displayed in Figure 3. The most important parameters of modules: the name of the stations, the interarrival time of the customer, the preparation time of an ordering, the number of the resources, predecessor station name, move time between the last workstation (predecessor station) and the customer station. The picture to animate kanban cards can be given optionally.

Workstation_S and *Workstation_D* modules which simulate the workstations significantly differ from each other regarding their complexity and their data requirement. In the single-card system the output buffer of the production stair is the input buffer of next production stair

(*Figure 1*). Opposite this in a dual-card system the output buffer of the production stair separates from the input container of the next production stair physically and all production stair has own input and output buffer (*Figure 2*). The motions between the input and the output buffer are generated by the inside kanban (*B-kanban*) and between the output buffer and the input buffer of the next workstation are managed by the outside kanban (*K-kanban*).

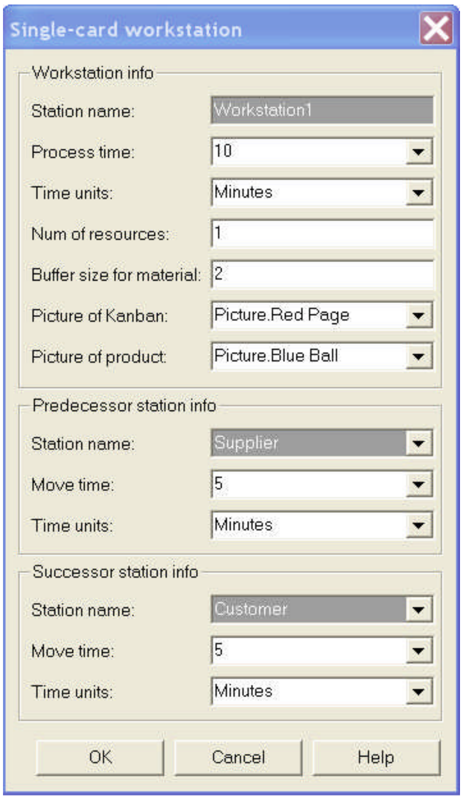

Figure 4 Dialog box of *Workstation_S* module

Dialog window of single-card workstation module (*Workstation_S*) is depicted in *Figure 4*. Beside the station name, which is module and station identifier, the additional input parameters are the next. The process time and the number of resources determine the capacity of the workstation. The buffer size for material defines the initial inventory of the input buffer, which simultaneously is the output buffer of the predecessor station. In the dialog window the identifier of the previous and a next station are obligated field, and the transportation time can be given optionally. The detached or "active" kanban cards are streamed onto the previous station and the inactive kanban cards together with workpieces (products) are moved onto the next station.

The dual-card workstation (*Workstation _D*) module has more input parameters (*Figure 5*). Beside the listed parameters of the single-card workstation (*Station name, Process time, Num of resources, Buffer size for material, information of the predecessor and successor station*) here has to grant the buffer size for product and the move times of the inside kanban yet.

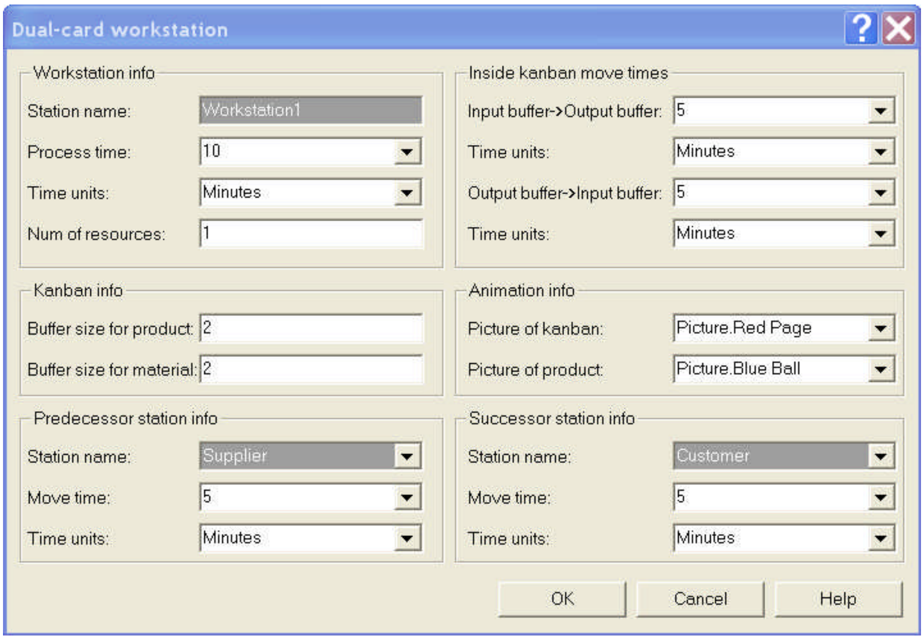

Figure 5 Dialog box of *Workstation_D* module

To the animation we may elect optionally pictures for kanban and product in both modules. To a dual-card module, logically two stations an input and an output buffer are attached which can be animated.

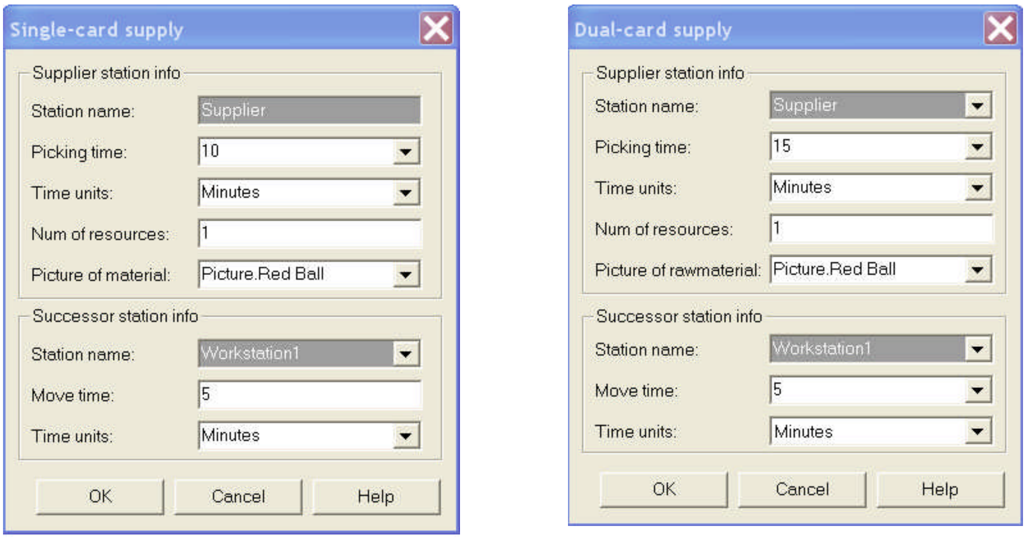

Figure 6 Dialog boxes of *Supplier_S* and *Supplier_D* modules

Supplier_S and Supplier_D modules provide the material supply and considering their function and their parameter claim are totally identical. The dialog windows of the modules are shown in the *Figure 6*. The input data of the modules: the name of the station, the picking time, the number of resources (employees or devices) and the data of the next station. We consider the buffers of these stations infinite big one, which means there is always sufficient raw material in these storages, so the processes never starve. The picture of the raw material entity leaving the station is optional.

Let us look at demonstration for the application of the modules a simple one dual-card single-stage Kanban process. Customers arrive according to an exponential distribution with 10 minute average arrival intervals into the system. The transportation time of outside kanban (*K-kanban*) and inside kanban (*K-kanban*) are 5 and 2 minutes. The picking time is 15 minutes, the process time is 10 minutes on the workstation and the preparation time is 5 minutes on the supplier station. The length of the simulation time is 100 hours in the example.

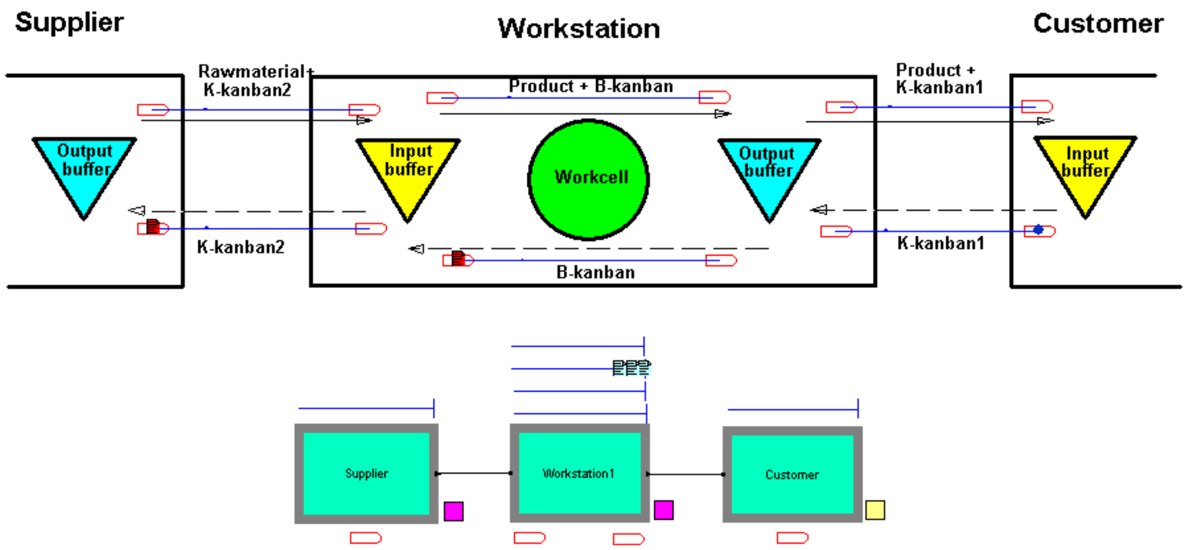

Figure 7 A model of dual-card single-stage Kanban system with animation

Figure 7 depicts the flowchart model and the animation of the example. The flowchart consists of the module instances with queues (half-line above the modules), with resources (squares on right hand side of the modules) and with stations (shapes under the modules). In the animation the buffers, the stations, the routes connecting the stations and the entities moving between the stations (kanban cards and workpieces) appear.

User Specified

Output

Output	Value
Beszallito.Anyag beszallitasok intenzitasa db per min	0.06633333
Beszallito.Anyag beszallitasok szama osszesen	398.00
Beszallito.Beszallitasra varakozo anyagrendelesek atlagos szama	0.3318
Megrendelo.Rendeles teljesites intenzitasa db per min	0.06683333
Megrendelo.Teljesitett rendelesek szama osszesen	401.00
Megrendelo.Termekrendelesek intenzitasa db per min	0.0987
Megrendelo.Termekrendelesek szama osszesen	592.00

Figure 8 Extract from the User Specified statistics

The primary objects of the simulation are the examination of the behavior of a given system, the localization of the bottle-neck of a process and the determination of the resource utilization, etc. The answers onto these questions can be found in the standard (*Entity, Queue, Process, Resource*) statistics being made in parallel with the simulation and in the user defined (*User Specified*) statistics. Statistics defined to Kanban modules inform the intensity of the flows between the stations, the length of the queues inside the stations, number of the entities leaving from and coming to the stations. The extract of these statistics belonging to the sample example may be studied in *Figure 8.*

4. Results

The new modules described in the study are applicable for modeling single product multi-stages single and dual-card Kanban systems. Using the modules complex multi-stages simulation models can be built quickly. On one hand the function of existing systems can be analyzed on the other hand new systems can be planed with the developed models. The modules of multi product Kanban systems may be developed similar way with the mentioned concepts and the modification of the described module logic.

REFERENCES

1. Arena Professional Reference Guide, Rockwell Software Inc., 2000.

2. **Akturk, M. S., and F. Erhun.** (1999): An overview of design and operational issues of kanban systems. International Journal of Production Research 37 (17): 3859-388 1.

3. **Benkő J.** (2011): Logisztikai folyamatok szimulációja. Egyetemi jegyzet, Szent István Egyetemi Kiadó, Gödöllő.

4. **Huang, P. Y., L. P. Rees, and B. W. Taylor.** (1983): A simulation analysis of the Japanese just-in-time technique (with kanbans) for a multiline, multistage production system, Decision Science 14: 326-344.

5. **Kelton, W. D., R. P. Sadowski, and D. T. Sturrock.** (2004): Simulation with Arena. 3rd ed. New York: McGraw-Hill.

6. **Krieg, G. N.**(2005): Kanban-Controlled Manufacturing Systems. Springer-Verlag Berlin Heidelberg.

7. **Mitra, D., and I. Mitrani.** (1990): Analysis of a kanban discipline for cell coordination in production lines. I. Management Science 36: 1548-1 566.

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