A Hands-on Kanban Simulation Kit for Lean Manufacturing

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Abstract

The Kanban technique for lean manufacturing has been used in the United States for more than 20 years. Even though many mathematical models describing Kanban operation have been developed, and the software for production simulation is available, delivering the full lean concepts to manufacturers is still a challenge. It is difficult to develop a generalized mathematical model for the Kanban system incorporating all of its salient features. The objective of this paper is to introduce a lean manufacturing simulation kit developed recently. The simulation kit is called “Multi-product assembly line controlled by a Kanban mechanism for lean manufacturing.” Three Lego products—an ambulance, a helicopter, and a sailboat—are assembled on the production line. The simulation demonstrates lean manufacturing concepts, such as 5S, one-piece flow, Kanban mechanisms, kaizen events, and visual control. Product assembly flow is based on the pull principle and customer-demand-oriented production. During the simulation, Kanban circulation, work-in-process (WIP) level, cycle time, change over time, lead time, lot size, and throughput are recorded and analyzed. With the kit, the lean manufacturing theory behind Kanban operation has been visually revealed. Manufacturers can easily understand the Kanban principle and its applications.

Introduction

Lean manufacturing is a practice developed by the Toyota Corporation after WWII for reducing waste in a manufacturing system. Taiichi Ohno made this philosophy clear in his book *Toyota Production System* (1988). The most important objective of lean manufacturing is to increase production efficiency by eliminating waste, solving problems, and continuously improving. Waste is anything that adds cost, but not value, to a product. The tools of lean manufacturing include Value Stream Mapping, Standardized Work, Load Leveling, Kaizen, Kanban, Visual Control, 5S, Error Proofing (Poka-Yoke), and Problem Solving. They are all feasible and beneficial for small and medium-sized companies [1, 2].

Lean manufacturing has been used in the United States for more than 20 years. Unfortunately, it is not popular in small and medium-sized companies. Small and medium-

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sized companies traditionally use the materials requirement planning (MRP) system to guide their production. They often do not adopt lean tools in their companies because they think the lean concepts are against their management culture, or they think the lean ideas are nothing but another manufacturing method [3]. Why must the familiar, tried-and-true processes be put aside to start a new, uncertain one? The main problem is that small companies lack the training and materials to learn and educate their employees about lean concepts and lean tool applications. It is an urgent task for manufacturing researchers to introduce lean manufacturing concepts and to provide practical training methods to the small and medium-sized companies.

The objective of this study was to introduce a Kanban simulation kit developed recently. The simulation kit is described as a "Multi-product assembly line controlled by a Kanban mechanism for lean manufacturing." Three Lego products—an ambulance, a helicopter, and a sailboat—are assembled on the production line. The simulation demonstrates lean manufacturing concepts, such as 5S, one-piece flow, Kanban mechanisms, kaizen events, and visual control. Product assembly flow is based on the pull principle and customer-demand-oriented production. During the simulation, Kanban circulation, work-in-process (WIP) level, cycle time, takt time, change over time, lead time, lot size, and throughput are recorded and analyzed. With this kit, trainees can easily learn the concepts and principles of lean manufacturing. They can see the results of lean layout and compare them with the traditional manufacturing method. The final goal is to encourage more small and medium-sized companies to implement the lean manufacturing for the purpose of widely and more rapidly boosting the manufacturing sector in the United States.

The design of a Kanban system addresses the selection of two important parameters: the number of Kanbans and the lot size of part types. Shahabudeen et al. [4], using a simulated annealing algorithm technique, made an attempt to select the number of production Kanbans and withdrawal Kanbans at each workstation and the lot size for each part type required to achieve the best performance. An object-oriented simulation model of a two-card dynamic Kanban system capable of handling different types of parts with different demand requirements has been developed and used for the analysis. Each part type has its own number of production-ordering Kanbans and withdrawal Kanbans at each workstation. Feng and Yamashiro [5] studied a batch production system with volume flexibility in a supply chain for which a manufacturer procures raw materials and/or component parts from multiple suppliers in a lot and processes them into a single product. Ouyang and Chang [6] stated that the lead time can be shortened at an extra crashing cost, which depends on the length of the lead time to be reduced and the ordering lot size. Their objective is simultaneously to optimize the lot size, the reorder point, the setup cost, and the lead time. Meng and Heragu [7] used an open Queuing Network Analyzer (QNA) to determine batch size in a multi-item, discrete manufacturing system. They consider the effects of batch size on the parametric decomposition procedure of the QNA and modify the two sets of linear equations accordingly. Experimental results have shown the effectiveness of the method. Bernard [8] described the use of discrete event simulation to explain the concepts of lean manufacturing, including line balancing against takt time, pull versus push manufacturing, Kanban inventory control, and process variability reduction. Several simulation models were used to evaluate the impact of these lean concepts on production, work in process, and station/operator utilization. Masin, Herer, and Darel [9] developed and implemented a new simulation-based optimization method called Tradeoffs Programming (TOP) for the Kanban control. TOP is a technique closely related to multi-objective dynamic programming that attempts to optimize inseparable problems. They decomposed the overall system using efficiency frontiers of simulated performance measures of the subsystems.

Kanban System

The function of the Kanban is best explained through the use of an *N*-stage production system, as illustrated in Figure 1. Two adjacent plants, plants *i* and *i+1* in the figure, are isolated for illustration, as shown in Figure 2. In a Kanban operation, first, a withdrawal Kanban attached to a loaded container in a succeeding plant *i+1* is detached from the container and put into the Kanban post (WK) when the *first* part from the container is to be used. Second, the withdrawal Kanbans in the post are collected at a fixed or non-fixed interval and brought to the preceding plant *i* by the transportation vehicle. The withdrawal Kanban indicates such information as the quantity of parts to be filled in a container, the preceding and succeeding plants involved with the part, and the collection interval. The withdrawal Kanban is then attached to the container in a store at the preceding plant in place of the production ordering Kanban, permitting the worker at the preceding plant to produce the required amount of parts; the containers filled with parts together with the withdrawal Kanban are brought, in turn, to the succeeding plant by the vehicle. This Kanban cycle realizes a smooth, timely, and wasteless flow of parts between preceding and succeeding plants.

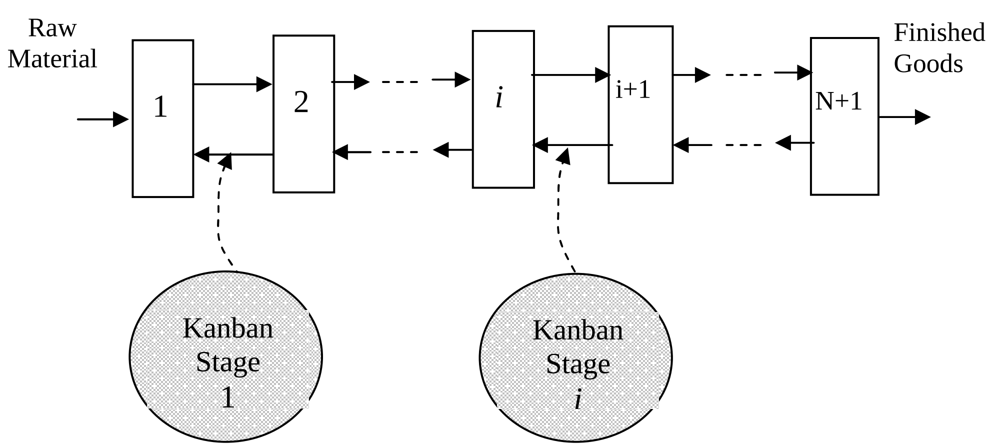

Figure 1. A multi-stage supply chain system with Kanban operations.

In this manufacturing system, production is first triggered by the demand at the final stage (the final processing). Production at each stage is triggered by its succeeding stage(s), and the information for the preceding stage is carried by Kanbans. This process is carried all the way back to the raw material acquisition stage. In this procedure, production is controlled (i.e., pulled) by demand.

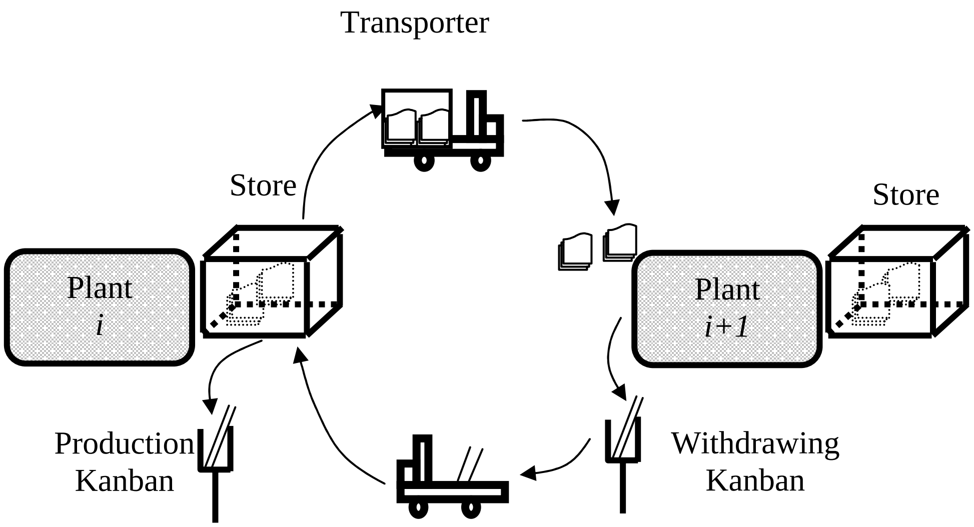

Figure 2. Operation of a Kanban production system.

Kanban Simulation Kit Development

The Kanban simulation kit was developed in the Industrial and Engineering Technology Department of Southeast Missouri State University (Scott Wright, Michael Schulte, and Yifeng Ren originally developed this kit in fall 2004). The simulation kit is designed as a multi-product assembly line. The kit simulates the assembly of three Lego products: an ambulance, a helicopter, and a sailboat (see Figure 3 for product drawings). The production line layout is shown in Figure 4. The production process requires three assembly workstations, one outsource assembly supplier, an order receiving station, a raw material room, and several material handlers. In Figure 4, PK (production Kanban) indicates a production Kanban post, and WK (withdrawal Kanban) stands for a withdrawal Kanban post.

The assembly plant can simulate four kinds, or phases, of manufacturing layouts:
Phase I: Classical manufacturing.
Phase II: 5S and lean manufacturing layout.
Phase III: Kanban-controlled small batch manufacturing.
Phase IV: One-piece flow and WIP control.

Phase I: Classical manufacturing
In this phase, the stations were not laid out in flow manufacturing. The parts that each station uses were put in one big bin and were not separated properly. The process card and tools were not situated in the right places. The raw materials inventory was located a long distance away. Parts in the storage room were not carefully stored and labeled. During the simulation, chaos was created: backtracking of parts delivery, long-distance transportation, waiting, queuing, starving, scraping, reworking. Operators had to get the raw materials by themselves. As a result, a high volume of WIP and lower output were seen.

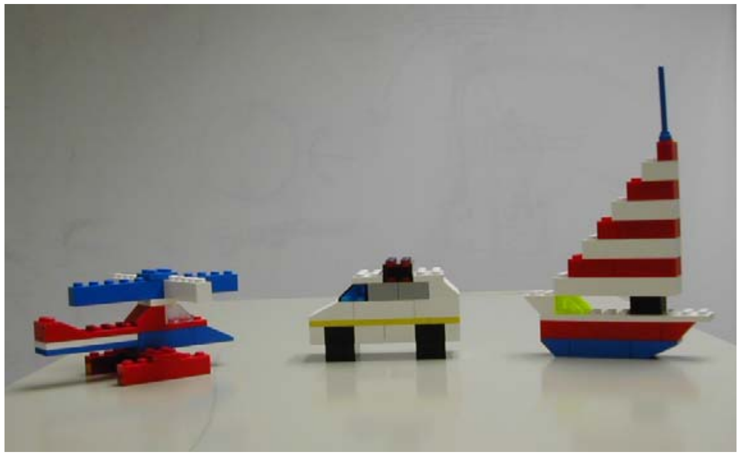

Figure 3. Three Lego products: the ambulance, the helicopter, and the sailboat.

Phase II: 5S and lean manufacturing layout

In this phase, the trainers organized the plant according to the 5S and lean manufacturing concepts. The stations were laid out in flow manufacturing, or in process sequence order. The parts that each station used were placed in individual bins and labeled. The process card and tools were set in the right place and were handy. The raw materials inventory was located nearby. Parts in the storage room were carefully stored and labeled. After the 5S campaign, trainers also simulated the same production as in Phase I. This time, they saw a reduction of backtracking of parts delivery, transportation, waiting, queuing, starving, scraping, and reworking. Therefore, Phase II results in the reduction of WIP and increase of output.

Phase III: Kanban controlled small batch manufacturing

In Phase II, after organizing by 5S principles, the production optimization was addressed. What was the optimal batch size to maximize the production with minimum WIP? Phase III answered this question with Kanban operation. The cycle time of each station for each process needed to be known. The production was organized in a pull manner, so the production started at the last station. The request for raw materials was sent to the preceding station by Kanbans. This process was carried all the way back to the raw material acquisition stage. In this procedure, production of the preceding station was pulled by demand of the succeeding station, as information about demand that was carried by Kanbans flowed backwards from the final station through the intermediate stations to the first station (the raw material acquisition). Phase III is descried further in the section dealing with the simulation of Kanban-controlled small batch production.

Phase IV: One-piece flow and WIP control

Lean manufacturing works best with small batch production. If the batch size is reduced to one, it is one-piece flow manufacturing. In one-piece flow, parts do not collect between operations. Each operation in the process is working on the next part for the following operation. The WIP between stations is minimized. The production at each station is signaled by the arrival of a semi-finished part from the preceding station. The raw material request is realized by the withdrawal Kanban. Although one-piece flow manufacturing is more efficient and productive, not all production lines can be run in that way. For one-piece flow, the largest cycle time in the line should be less than the takt time, and the line should be balanced (i.e., the cycle times should be even). A production line that must meet these requirements can run the one-piece flow.

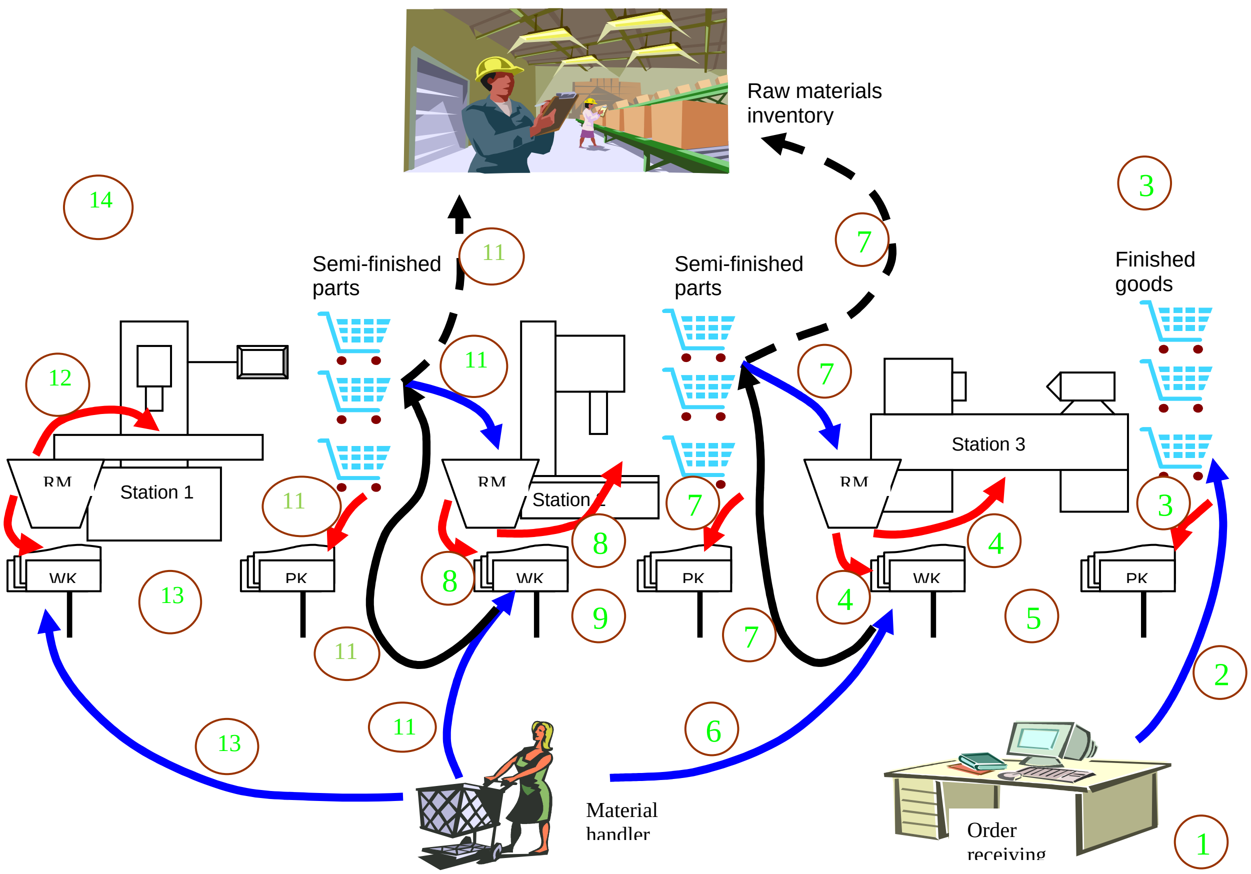

Figure 4. A Kanban-controlled three-station manufacturing system.
(RM stands for raw materials.)

As this research focused on Kanban and small-batch production, only phase III is simulated and reported. Methods of balancing the production line and simulating one-piece flow production will not be discussed in this study. These are topics for future research.

Kanban-controlled Small Batch Production (Phase III) Simulation

The simulation demonstrates lean manufacturing concepts, such as 5S, Kanban mechanisms, kaizen events, and visual control. Product assembly flow is based on the pull principle and a customer-demand-oriented production. The Kanban system is designed according to the two-card principle: one is the production Kanban and another is the withdrawal Kanban. The customer arriving time, the customer ordering quantity, and the type of product the customer ordered are all simulated randomly. The worker at the order receiving station breaks the quantity into the right lot size. Then he/she issues a production Kanban to the last workstation (station 3). Then, each station starts its processes when its production Kanban is shown. When a station needs raw materials, the worker at that station issues a withdrawal Kanban and places it at the withdrawal Kanban post. The material handlers collect withdrawal Kanbans after a certain interval and get the materials from the proper place (from the station or a source supplier), in the correct quantities and from appropriate materials, then deliver them to the right station. All information necessary for the material handler to deliver the materials—the material name, the place to get it, the quantity, where to deliver it, and when it is needed—is issued clearly in the withdrawal Kanban.

During the simulation, Kanban circulation, WIP level, cycle time, takt time, lead time, lot size, and throughput are recorded and analyzed. The production line runs only after a customer order arrives. It is customer-demand-oriented and operates under a pull principle. No planning is needed for it. The beginning of the simulation can be summarized as below:

1. Customer arrives and makes order.
2. Order-receiving processor breaks the order into small batches and issues a production Kanban.
3. Material handler picks up the production Kanban from the order receiving desk, goes to the last station to take the finished goods, and places the production Kanban in the PK at station 3. The number of finished goods taken at station 3 is the same quantity issued in the production Kanban.
4. Operator at station 3 sees the production Kanban and knows it is his/her time to start production as instructed by the production Kanban. He/she picks up the raw materials in bin RM. At the same time, he/she must detach the withdrawal Kanban from bin RM and must put it into the withdrawal Kanban post WK.
5. Station 3 starts production.
6. Material handler picks up the withdrawal Kanban from WK at station 3 at a fixed interval.
7. Material handler goes either to the semi-finished goods area at station 2 or to the raw materials inventory to pick up the raw materials required by station 3 with instructions on station 3's withdrawal Kanban. He/she then detaches the production Kanban from the bin (in cart icon in Figure 4) and puts it into the PK post at station 2. He/she attaches the withdrawal Kanban (of station 3) to the full bin and takes the full bin to station 3.
8. Operator at station 2 sees the production Kanban and knows it is his/her time to start production as instructed by the production Kanban. He/she picks up the raw materials

in bin RM. At the same time, he/she must detach the withdrawal Kanban from bin RM and must put it into the withdrawal Kanban post WK.

9. Station 2 starts production.
10. Material handler picks up the withdrawal Kanban from WK at station 2 at a fixed interval.
11. Material handler does the same work as in step 7.
12, 13, and 14. The same activities that happened at station 2 and station 3 occur at station 1.

The above 14 steps are shown clearly in Figure 4 by circled numbers and arrows. After the beginning stage, the system transits to a steady stage. Then, it runs smoothly as the Kanban circulates among stations, the raw materials inventory, and the outsource supplier.

Hypothesis Test

Simulation results of cycle time

In the simulation, the cycle time of each process should be determined first. The cycle times were recorded by stopwatch. Each time, at least 10 people participated in the experiment, with each person repeating the process three times. Thirty samples were recorded for each process. The results—the cycle times for processing three products (ambulance, helicopter, and sailboat) at three stations, respectively—are shown in Table 1.

Table 1. Experiment cycle times for processing three products: Ambulance, Helicopter, and Sailboat.

Product / **Process Station**	**Ambulance**		**Helicopter**		**Sailboat**	
	Sec./pc.	Min./pc.	Sec./pc.	Min./pc.	Sec./pc.	Min./pc.
1	38.62	0.64	13.03	0.22	14.76	0.25
2	34.93	0.58	15.34	0.26	16.83	0.28
3	36.79	0.61	21.55	0.36	28.31	0.47

From Table 1, it is observed that the Ambulance cycle times were almost even. Thus, it would be acceptable to run the Ambulance in one-piece flow production. The cycle times for the Helicopter and Sailboat were significantly different. Therefore, one-piece flow production does not apply; they should be organized in small batch production.

Hypothesis T-test Results

The hypothesis is made that small batch size manufacturing operated under the push principle is better than that under Kanban control. A t-test was used to test for significant differences at the .90 significance level. The data were obtained from the airplane simulation for both operations (in pull manner and push manner) simulated at six minutes every time. The batch size used in this study is 3. T-test results are given in Table 2.

Table 2. T-test results.

	Push Production	Pull Production
Sample size	$n_1 = 15$	$n_2 = 15$
Sample mean	$\bar{x}_1 = 4.8$	$\bar{x}_2 = 13.7$
Sample variance	$s_1 = 1.86$	$s_2 = 2.58$
The difference between the sample means	$\bar{x}_2 - \bar{x}_1 = 8.9$ Pieces	
Estimated Standard Error (ESE)	0.674 Pieces	
t – value at two-side 90% confidence interval at 28 freedoms	1.701	
Lower limit	$(\bar{x}_2 - \bar{x}_1) - t_\alpha ESE$ = 8.9 - 1.701 × 0.674 = 7.75 ≈ 8 Pieces	
Upper limit	$(\bar{x}_2 - \bar{x}_1) + t_\alpha ESE$ = 8.9 +1.701 × 0.674 =10.05 ≈ 10 Pieces	

From the t-test result, we are 90 percent confident that pull production controlled by Kanban for small batch size manufacturing (batch size = 3 in this test) produces between 8 and 10 more pieces than mass production in a six-minute simulation. Thus, our decision is made to reject the null hypothesis, and the Kanban-controlled small batch size manufacturing is preferred.

Conclusions

It is difficult to simulate all of the simulation kit's salient features in a short time. In this research, it is shown that the Kanban technique can be easily applied to small and medium-sized companies as long as their processes' cycle time and takt time are known. Small batch size manufacturing is generally more efficient than mass production. Overall, the Kanban simulation kit developed here can help students and manufacturers learn valuable applied lean manufacturing concepts and easily understand Kanban principles.

Future Research

To apply lean manufacturing tools to industry and make good use of the simulation kit, some potential research issues are listed below:

(1) A mathematical model of Kanban-controlled manufacturing systems is needed for predetermining the batch size. The model should include variables such as cycle times, takt time, and lead time; and parameters such as setup cost, holding (carrying) cost, and ordering/shipping cost.

(2) Verify the mathematical model by the results of the simulation kit. If we know not only the cycle time and takt time, but also the setup cost, holding (carrying) cost, and ordering/shipping cost at each station, we can test the optimal batch size obtained from the model by simulation.

(3) Determine a bin system for holding raw materials for each part at each station. Each part's consumption is different. Some processes need one part, and some need two or more parts. Also, the size of each part is different. The right number of bins to hold the parts needs to be determined so that the minimum WIP can be held. To determine the number of bins for each part, the replenish time to refill the empty bin also needs to be considered.

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Biography

DR. SHAOJUN WANG is currently an associate professor at the Department of Industrial and Engineering Technology at Southeast Missouri State University. He has distinguished himself as a capable professor and researcher in more than twenty years engaged in teaching and research projects in the manufacturing area. His doctoral dissertation, entitled “Control of Supply Chain Systems by Kanban Mechanism,” was at the forefront of supply-chain management for efficient manufacturing. In addition to teaching and scholarly development, he has been committed to the professional services to the local industries. He is a senior member of IIE, a professional member of SME, and a member of NAIT.