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Simulation modelling and analysis of a JIT production system

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Abstract

The JIT production systems have been a focus of interest to researchers. Although there are numerous simulation studies analyzing and evaluating the JIT system in a stochastic environment, experimental design studies on the multi-item, multi-line, multi-stage JIT systems are not performed in depth. This paper aims to explicitly examine the performance of a multi-item, multi-line, multi-stage JIT system and to show how this system reacts under different factor settings. This system is modeled in SLAM II, which is a FORTRAN-based simulation language. Experimental results are reported and further research direction is given.

Keywords: Just-in-time (JIT); Production system; Multi-line; Simulation analysis

1. Introduction

According to the Kimura and Terada [1] and Huang et al. [2], the multi-stage production processes can be classified into two types: push systems and pull systems. Most of the American and European production systems employ push systems whereas the Japanese JIT system employs pull systems. The main difference between the two systems is that in the pull system, the material is routed from the preceding stage to the succeeding stage according to the consumption rate of succeeding stage. This means, in pull (JIT) systems, material flows only as it is pulled from succeeding stage.

JIT production systems have a simple goal: produce the required items, at the required time, in the required quantities. In the ideal JIT system, inventory level at each stage is one unit, but this goal cannot be achieved in real manufacturing environments due to the stochastic nature of demand and processing times. When a demand is generated at the end of the line, the preceding stage's output (in-process items) is transferred to the succeeding stage where it is processed. The removal of in-process items at the preceding stage starts the manufacture of an additional unit at that stage to replace the one just taken. As a result, each stage processes "just in time" to meet the demand needed by the succeeding stage.

In JIT systems, production process and material movement are controlled by the Kanbans. A Kanban is a card on which certain information for the pulling of material is printed. It serves as a communication tool to start production of next unit and to pull processed item between production stage (s).

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Concerning the number of types of Kanbans, JIT systems can be categorized into two: (i) two-cards Kanban system, (ii) single-card Kanban system. In two cards Kanban system, each station has two inventory points: one is the inbound inventory which keeps input items, one is the outbound inventory which keeps processed items. In this type system, generally two types of Kanbans are used: (i) production Kanban, (ii) withdrawal Kanban. Production Kanban is used to authorize the production of the next unit within a stage whereas withdrawal Kanban is used to pull a processed unit from a stage to a following stage.

On the other hand, in single-card Kanban system, each station has only outbound inventory and single-type Kanban which is commonly known as conveyance Kanban. As pointed out by Sarker and Harris [3], the number of companies implementing the two-cards Kanban system is rather small. Because of easy to implement, most of the companies prefer the single-card Kanban system.

Although there are numerous simulation studies analyzing and evaluating the JIT system in a stochastic environment, experimental design studies on the multi-item, multi-line, multi-stage JIT systems are not performed in depth. None of these studies heavily concentrated on the statistical aspects of experimental design features. Specifically, main and interaction effects between the factors and the statistical significances of these effects are not explicitly considered.This paper aims to explicitly examine the performance of a multi-item, multi-line, multi-stage JIT system and to show how this system reacts under different factor settings. Frequencies of processing time and demand arrivals are considered as sources of randomness. The effects of four factors on the system performance measures such as output rate, waiting time on work-in-process (WIP) points, WIP length and station utilization are tested.

Next section considers some simulation studies of JIT systems in the concerned literature.

2. A short literature review

In the last decade, many researchers have analyzed JIT systems in various aspects by using analytic or simulation techniques. Golhar and Stamm [4], Moras et al. [5] and Gunesakaran et al. [6] conducted a comprehensive literature survey based on the JIT studies. But, since this study is based on simulation, only the several simulation studies which are close to this study are considered.

Huang et al. [2], have simulated the single-product, multi-line (three lines) and multi-stage (four stages) production system in order to examine the effects of variable processing time, variable demand rates and bottlenecks on system performance. They showed that, the system with one Kanban and constant processing time gave the best results on system performance. The results indicated that increasing the number of Kanbans increased the output rate and inventory level but reduced the overtime. Furthermore, overtime increased strikingly as the coefficient of variation (CV) increases, increasing the demand variability resulted in higher overtime and lower inventory and output rate.

Sarker and Harris [3] simulated the single-product, multi-line (two lines), multi-stage (five stages) JIT production system to examine the effects of imbalancing between the stages on the system performance. They concluded that a perfectly balanced line gives the best results.

Villeda et al. [17] have examined the effects of processing time variability, number of Kanbans and imbalancing configurations. Their system consists of single-product, multi-line (three lines), multi-stage (four stages). The authors reported that the output rates with deliberately imbalanced stations were found to be superior to that of perfectly balanced configurations. It was also concluded that lower variation in processing times resulted in higher utilization and lower waiting times, increasing the number of Kanbans caused higher utilization and lower waiting times.

Sarker and Fitzsimmons [8] simulated the single-product, single-line, multi-stage (nine stages) JIT production system to explore the effects of processing time variation and the number of Kanbans (buffer size). The authors pointed out that JIT system with low work-in process (WIP) was always better, but it is less efficient than the push system, especially at higher CV of processing time. Furthermore, the output rate of a JIT system was found to be more sensitive to variability of processing time.

Sarker [9] has studied the single-product, single-line, multi-stage (nine stages) JIT production system in order to examine the effects using different processing time distributions. According to the results, the system with normally distributed service time was better than that with an exponential distribution. It is also reported that the system with constant processing time worked with 100% efficiency.

Meral and Erkip [10] have studied the single-product, single-line, multi-stage JIT production line to examine the effects of the line-design problems addressed as: (i) number of stations on the line, (ii) assignment of operations to work stations. Production rate was considered to be the primary performance measure, backorder time, inventory holding time, overtime and earliness were considered to be the secondary performance measures. It was reported that when the primary measure of performance was considered, balanced strategies were always superior to the bowl-phenomenon-based strategies in pull production lines with normal processing times, however, when the secondary measures of performance were considered, bowl strategies gave the better results in some cases.

Chaturvedi and Golhar [11] simulated single-product, single-line, multi-stage (nine stages) JIT production system to study the effects of demand and processing time variability on the system performance and to determine the minimum number of Kanbans for stochastic demand and processing times. The authors stated that normal and uniform processing times did not significantly affect the system performance for low CV. Furthermore, for any demand loading factor with normal demand and processing time distributions (CV = 0.1), two Kanbans allocated at each station gives the optimal system performance.

Chang and Yih [12] have simulated multi-product, single-line, multi-stage (three stages) production system to explore the effects of lot size and the number of Kanbans on the system performance. It was concluded that a smaller Kanban number reduced the outputs, smaller lot sizes resulted in longer cycle time and lower WIP under the same number of Kanbans.

3. System description and model development

The hypothetical system under study is consisted of two-products, three-lines and five-stations, therefore, it represents a multi-product, multi-line, multi-stage JIT production system [18]. Material flow is controlled by a single-card Kanban technique. Fig. 1 depicts the system considered in this study.

As can be seen from the Fig. 1, according to the basic principles of JIT production philosophy, when a demand is created at the end of the line, the information is sent back to the preceding station as a Kanban. The arrival of Kanban to any workstation can be considered as a signal for starting the production of waiting parts. If the product (WIP) is ready, it is immediately transferred to the next station. Therefore, this product (WIP)-Kanban flows continues until it reaches to the first station through the line.

3.1. *The simulation model*

A simulation model was developed by using SLAM II, a FORTRAN-based, simulation language [13]. Model assumptions are as follows;

1. A production day consists of 480 min.
2. The production line is dedicated to two products; each product has the same process routing but the different processing time along the line.

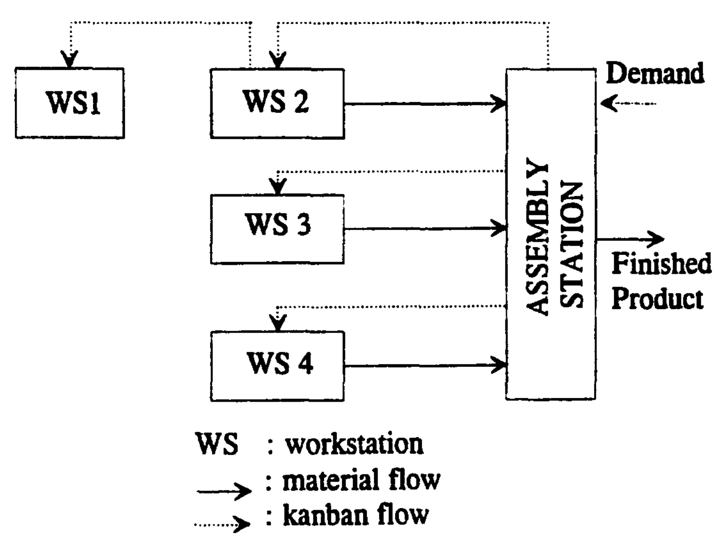

Fig. 1. Schematic representation of the JIT production line.

3. Processing times and demand arrival frequencies for each product are considered as sources of randomness.
4. One unit of raw material is used to make one unit of finished product.
5. Initial inventory at each station equals the number of Kanbans.
6. Kanbans are sent instantly between the stations.
7. Transportation time between stations are neglected.
8. Demand arrivals and processing times for each product are assumed to be uniformly and normally distributed, respectively.
9. Machine breakdown and maintenance activities are not allowed.
10. Jobs are scheduled in FIFO rule

Using these assumptions, SLAM II network model is developed. Because of the size of model its partial representation is shown in Fig. 2.

As seen from the Fig. 2, demand for two products are generated at CREATE nodes, CREA and CREB, respectively. An entity generated in CREATE nodes is arrived the ASSIGN nodes in which the product type and processing times are specified. After the ASSIGN nodes, the entity arrives the QUEUE nodes as a Kanban and assembled with the QUEUE nodes in which the processed items are placed by the ASM nodes. An entity emanating from ASM nodes reaches the GOON nodes which provide the Kanban and material flows in the system. One copy of entities from the GOON nodes is directed to the COLCT nodes in which the statistical results are collected, while the other copy is sent back to the succeeding stage as Kanban. Each simulation run is terminated by the TERM statements.

3.2. Verification and validation

As pointed out by Law and Kelton [14], "Trace" is one of the most powerful techniques in verifying the simulation program. In SLAM II, by adding MONTR, TRACE statement at the end of the program, it can be checked whether the model works as intended. In this study, model verification is carried out by using this technique and the model was found to work as expected.

As Fallon and Browne [15] mentioned, if the real data was not available, strict validation is impossible. Since the manufacturing system modeled is a hypothetical, strict validation could not be reached.

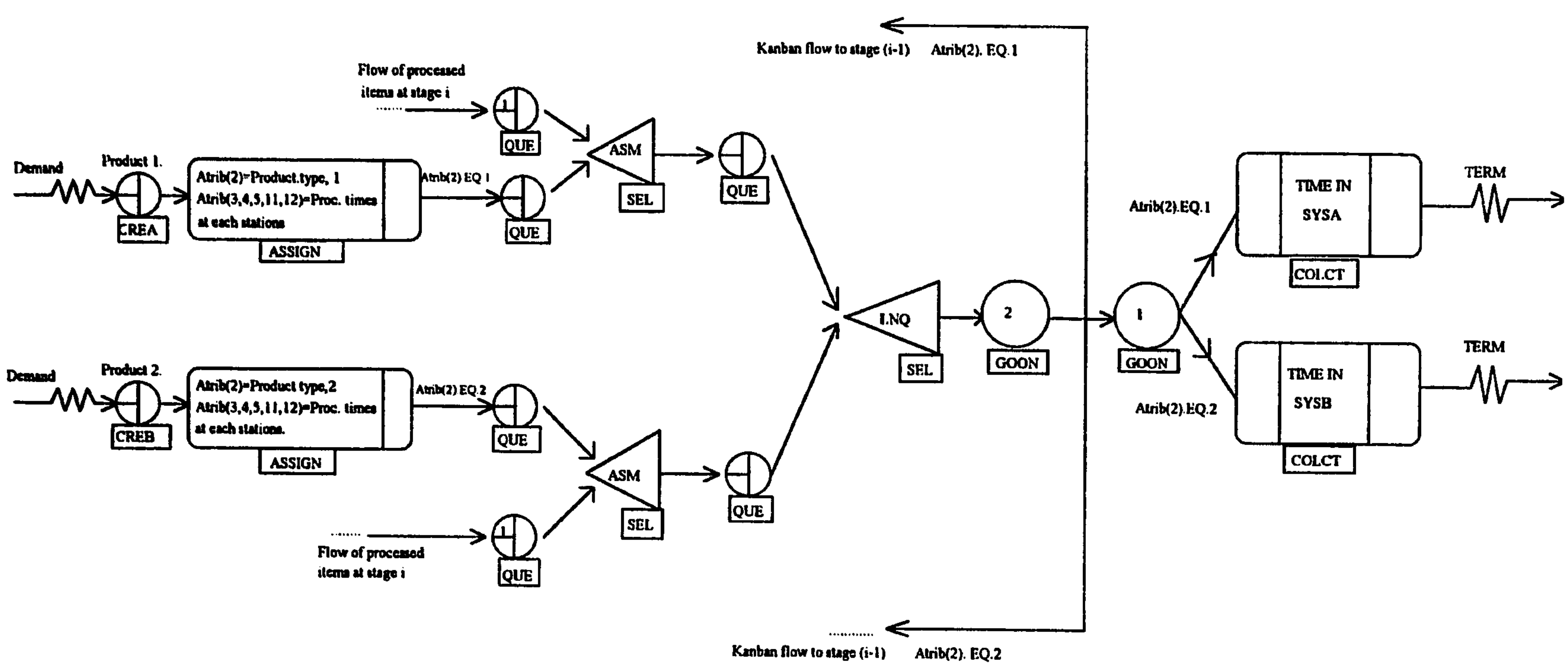

Fig. 2. Partial representation of SLAM II network model.

4. Experimental design

In the study, four factors are considered and the effects of these factors are tested on the system performance.

Factor settings:

1. *Number of Kanbans* (*NK*): This factor is tested in experimental design in three levels; 1, 2 and 3.
2. *CV of processing times* (*CV*): In the model, processing times are normally distributed with mean of 5 and 8 min for each product, respectively. Since the CV equals σ/μ, different CVs are obtained by varying σ parameters of normal distribution. Thus, CV is tested in the following three levels: 0.1, 0.2, 0.3.
3. *Degree of imbalance* (*DI*): Among the several imbalancing methods, a deliberate imbalancing method proposed by Hillier and Boling [16] which is known as Bowl phenomenon is applied in this model. Bowl phenomenon is based on assigning the lower processing times to middle station and can be defined as follows:

   Degree of imbalance (DI) =

   $$\frac{\mathrm{Max}[((\mathrm{TWC}/N)-\mathrm{Min}(\mathrm{PT}_i), (\mathrm{Max}(\mathrm{PT}_i)-(\mathrm{TWC}/N))]}{\mathrm{TWC}/N}$$

   where PT_i is the processing time at work station i, TWC the total work content of product on the line, N the number of stations along the line, and TWC/N the processing time at a workstation on the balanced line.

   Using the above formulation, three different DI values are obtained; 0.10, 0.25 and 0.40.
4. *Demand uncertainty degree* (*DU*): In the model, demand arrivals are assumed to be uniformly distributed with mean of 5 and 8 min for each product respectively. This factor is specified by using the time between creations (TBC) option which is available in CREATE node in SLAM II and has the following three levels:
   DU = 0 (No stochasticity)
   DU = Low stochastic ($U \sim (4, 6)$ for product A, $U \sim (7, 9)$ for product B)
   DU = High stochastic ($U \sim (2, 8)$ for A, $U \sim (4, 12)$ for B)

All the factors tested and their levels are shown in Table 1.

Selected performance measures are listed below:

PM_1: Total number of products (both two products) that have completed the final assembly operation, or shortly, total output rate (TOR)
PM_2: Total mean waiting time concerning the products waiting for processing on WIP points or shortly, total mean waiting time (TMWT)
PM_3: Total mean WIP length (TMWL)
PM_4: Mean utilization of stations (MUS)

Since this study contains four factors and three levels for each, $3^4 = 81$ design points are required in case of full (or complete) factorial design. If the five experiments will be made for each design points, a total of 405 experiments would be performed. In order to reduce the size of experimentation, a partial factorial design which is used successfully in the literature is applied. This is accomplished by separating all factors into the two-factor clusters and then analyzed each cluster

Table 1
Factors and factor levels employed in the experiments

Factors	Levels		
Number of Kanbans (NK)	1	2	3
CV of processing times (CV)	0.1	0.2	0.3
Degree of imbalance (DI)	0.10	0.25	0.40
Demand uncertainty (DU)	Deterministic A : 5 min B : 8 min	Low stochastic A : $U \sim (4, 6)$ B : $U \sim (7, 9)$	High stochastic A : $U \sim (2, 8)$ B : $U \sim (4, 12)$

Table 2
A Summary of simulation results obtained from six experiment

Experimental design cluster	Factors	Factor levels	Performance measures							
			TOR		TMWT		TMWL		MUS	
			Statistical efficiency	Performance measures value	Statistical efficiency	Performance measures value	Statistical efficiency	Performance measures value	Statistical efficiency	Performance measures value
I	X_1 – NK	↑	E	↑	E	↑	E	↑	E	↑
	X_2 – CV	↑	E	↓	E	↑	E	↑	E	↓
	$X_1 * X_2$	-	E	-	E	-	E	-	E	-
II	X_1 – NK	↑	E	↑	E	↑	E	↑	E	↑
	X_2 – DI	↑	E	↓	E	↑	E	↑	E	↓
	$X_1 * X_2$	-	NE	-	E	-	E	-	E	-
III	X_1 – NK	↑	E	↑	E	↑	E	↑	E	↑
	X_2 – DU	↑	E	↓	E	↑	E	↑	E	↓
	$X_1 * X_2$	-	E	-	E	-	E	-	NE	-
IV	X_1 – CV	↑	E	↓	E	↑	E	↑	E	↓
	X_2 – DI	↑	E	↓	E	↑	E	↑	E	↓
	$X_1 * X_2$	-	E	-	NE	-	NE	-	E	-
V	X_1 – CV	↑	E	↓	E	↑	E	↑	E	↓
	X_2 – DU	↑	NE	-	NE	-	NE	-	NE	-
	$X_1 * X_2$	-	NE	-	NE	-	NE	-	NE	-
VI	X_1 – DI	↑	E	↓	E	↑	E	↑	E	↓
	X_2 – DU	↑	NE	-	NE	-	NE	-	E	→
	$X_1 * X_2$	-	NE	-	NE	-	NE	-	NE	-

Note: ↑: increase, ↓: decrease, →: neither increase nor decrease, E: efficent, NE: not efficent.

independently. Therefore, six experimental design clusters are constructed and each cluster contains $3^2 = 9$ design points. Considering that five simulation runs are made for each design point, the total number of experiments, $9 \times 6 \times 5$, is 270. Since the two-factor clusters are constructed, only the main and two-way interaction effects are tested. Higher-order interaction terms are neglected in accordance with the "sparsity of effects principle" mentioned by Hines and Montgomery [7].

As stated earlier, each design point is simulated with five replications. Since SLAM II processor uses different seed numbers at each replication, independence of replications is ensured. The duration of individual simulation run (run length) is determined as 2880 min assuming the production system works six days and 480 min per day.

Since this simulation study can be considered as comparison of various system designs having different factor settings, the common random number (CRN) technique is applied for variance reduction to obtain the more precise results. This is achieved by assigning the same random number to different configurations.

To avoid the transient condition of simulation data, each workstation has been modeled to have one WIP inventory by assigning the initial queue capacities of post-operation queues to one unit as seen in Fig. 2. With this modelling approach, when a Kanban arrives to any station, WIP product is immediately available and is transferred to a succeeding station. So, the created entity does not spend any time before it arrives all the processing centers [3]. In such a system, there is no need to discard any transient data since the problem is modeled as a steady-state system.

In order to evaluate the experimental results statistically, analysis of variance (ANOVA) is applied by using the MINITAB statistical package and the total of 24 ANOVA tables are obtained. Statistical significance tests of effects are made at $\alpha = 0.05$ significance level.

5. Simulation results

As stated earlier, all the factors tested in this study are separated into the six design clusters having two factors. Since the four performance measures are selected, it is not possible to include all the results obtained from each cluster. So, only the results of first cluster are discussed in detail, but all of the results are briefly summarized in Table 2 in a tabular form within this paper. Similarly, only the four ANOVA tables associated with the first cluster are presented.

5.1. Effect on total output rate (TOR)

According to the ANOVA table (Table 3), test statistics shows that both the number of Kanbans and CV of processing times are effective on the TOR. Additionally, the interaction effect is found to be statistically significant.

Fig. 3. indicates the effects of these factors. An increase in the number of Kanbans yields the increase in output rate of the system but no increase is observed after two Kanbans. On the other hand, increasing the CV brings a lower output rate. As an interaction effect, for one Kanban, output rate behaves more sensitively to variations of CV, whereas it loses its sensitivity at higher Kanban levels.

5.2. Effect on total mean waiting time (TMWT)

ANOVA table (Table 4) indicates that both factors are effective on the TMWT. Moreover, it is observed that interaction effect is also effective on this performance measure.

The behavior of the performance measure can be visualized in Fig. 4. An increasing the number of

Table 3
ANOVA table for TOR

Source of variation	DF	SS	MS	F	P
X_1-Num. of Kan.	2	72363	36182	3614.15	0.000
X_2-Coef. of Var.	2	9865	4933	492.71	0.000
$X_1 * X_2$	4	11321	2830	282.7	0.000
Error	36	360	10		
Total	44	93910			

Note: DF: Degrees of freedom, SS: Sum of squares, MS: Mean square, F: F Value, P: P Value.

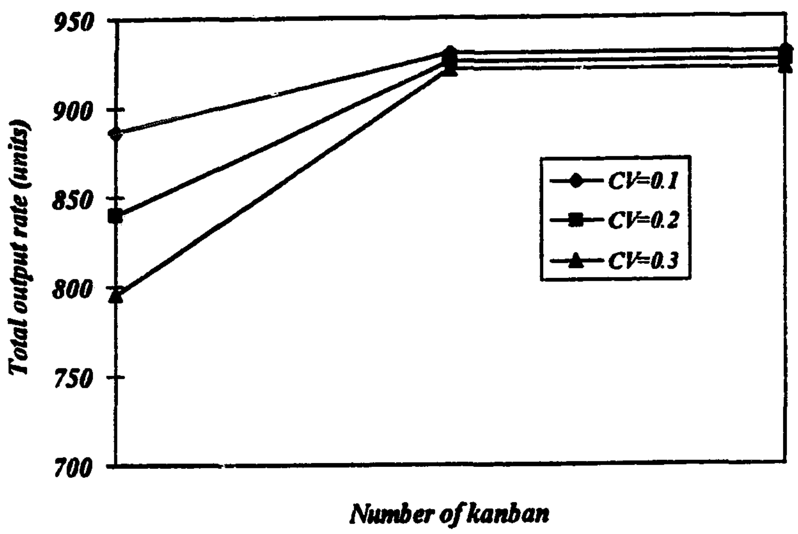

Fig. 3. Effect of factors tested in experimental design cluster 1 on TOR.

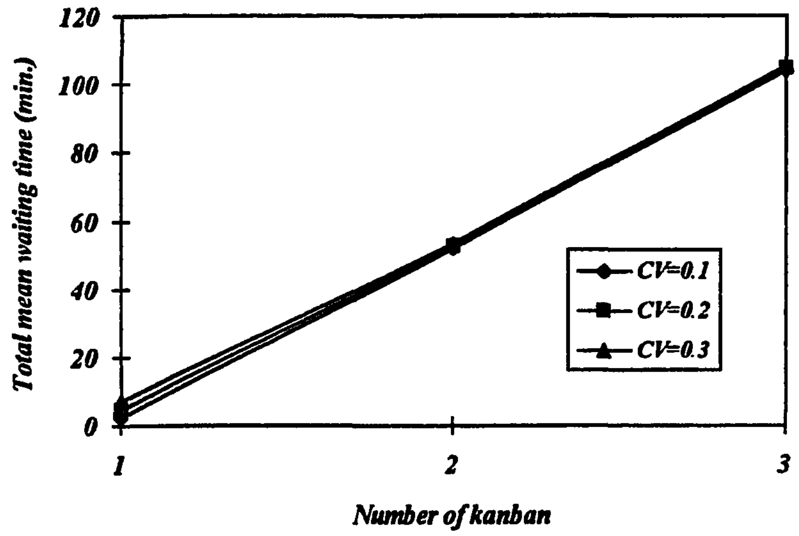

Fig. 4. Effect of factors tested in experimental design cluster 1 on TMWT.

Table 4
ANOVA table for TMWT

Source of variation	DF	SS	MS	F	P
X_1-Num. of Kan.	2	75413.6	37706.8	1.4E+05	0.000
X_2-Coef. of Var.	2	43.2	21.6	80.01	0.000
$X_1 * X_2$	4	24.4	6.1	22.62	0.000
Error	36	9.7	0.3		
Total	44	75491.0			

Table 5
ANOVA table for TMWL

Source of variation	DF	SS	MS	F	P
X_1-Num. of Kan.	2	1790.47	895.23	3.4E+05	0.000
X_2-Coef. of Var.	2	0.43	0.22	82.57	0.000
$X_1 * X_2$	4	0.51	0.13	48.51	0.000
Error	36	0.09	0.00		
Total	44	1791.5			

Kanbans brings a striking increase while increasing the CV causes a little increase in waiting times. On the other hand, for one Kanban, this performance measure is more sensitive to variations of CV than those for higher Kanban levels.

5.3. *Effect on total mean WIP length (TMWL)*

It is evident in ANOVA table (Table 5) that both the main and interaction effects are found to be statistically significant on this performance measure.

As can be seen from Fig. 5, the behavior of TMWL is similar to preceding performance measure. TMWL increases as the number of Kanbans and CV of processing time increases. However, increasing the CV causes the little changes on the TMWL, whereas increasing the number of Kanbans yields the striking changes on it.

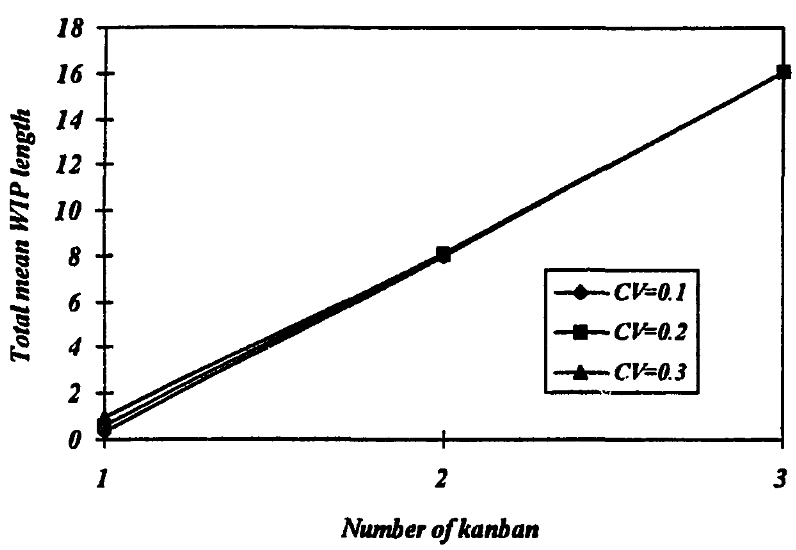

Fig. 5. Effect of factors tested in experimental design cluster 1 on TMWL.

5.4. *Effect on mean utilization of stations (MUS)*

ANOVA table (Table 6) shows that there is a statistical evidence about the existence of main and interaction effects.

Table 6
ANOVA table for MUS

Source of variation	DF	SS	MS	F	P
X_1-Num. of Kan.	2	0.083607	0.041804	2641.04	0.000
X_2-Coef. of Var.	2	0.010730	0.005365	338.95	0.000
$X_1 * X_2$	4	0.012669	0.003167	200.09	0.000
Error	36	0.000570	0.000016		
Total	44	0.107576			

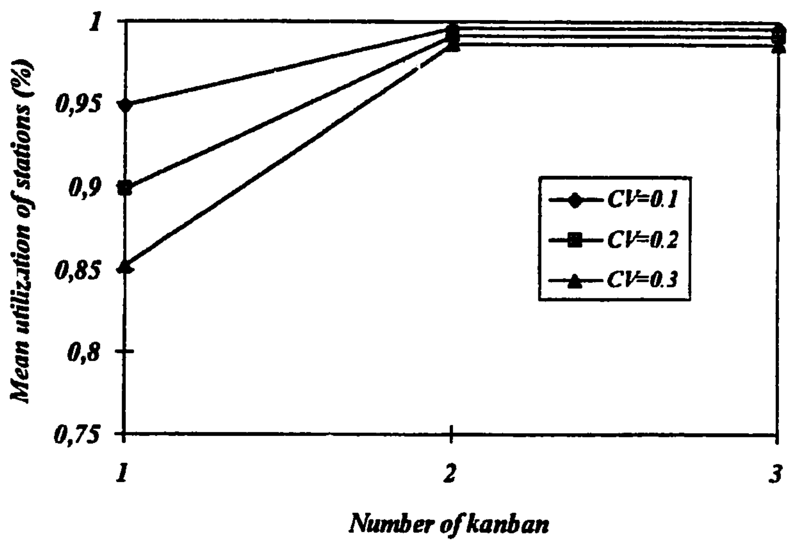

Fig. 6. Effect of factors tested in experimental design cluster 1 on MUS.

These effects can be seen from Fig. 6. Utilization increases as the number of Kanbans increases whereas it decreases as CV increases. It is interesting that no improvement on this measure occurred after two Kanbans. Furthermore, for one Kanban, there is a remarkable decrease in utilization as CV increases whereas, for higher Kanban levels, no significant difference on this measure encountered as CV increases.

6. Conclusion

In this paper, the performance of a multi-item, multi-line, multi-stage JIT system in a stochastic environment has been examined via simulation. The study provides a comprehensive experimental design features and explicit analysis on the simulation results. From the practical point of view, it may also be helpful to the manager in respect of obtaining the higher performance from the JIT production system. The obtained results which are briefly summarized in Table 2 reflects that, for all experiments, output rate and utilization are increased as the number of Kanbans increase, but no improvement is observed after two Kanbans. Also, increasing the number of Kanbans results in a striking increase in waiting times and WIP lengths. Therefore, it can be concluded that the ideal number of Kanbans is two for the system considered in this study.

On the other hand, CV and DI have the similar effects on the system performance. Output rate and utilization decreased as the CV or DI increases. Increasing the CV or DI yields the higher waiting times and WIP lengths.

According to the results, it is observed that DU has an effect on the system performance only in the third experimental design cluster. No statistical significant effect of this factor is encountered in remaining experiments. In searching for the behavior of DU in the third experiment, it is observed that output rate and utilization decreased, waiting time and WIP length increased as DU increases.

This study also shows that obtaining the better performance from the multi-item, multi-line, multi-stage JIT system depends on reducing or eliminating (if possible) variations related to processing time, demand arrivals and balance between stations as in the multi-item, single-line, multi-stage or the single-item, multi-line, multi-stage JIT systems. Although increasing the number of Kanbans gives the better output rate and utilization, it also raises the waiting times of WIP products. Therefore, the increasing the number of Kanbans as many as possible is not a reasonable way in order to gain the maximum benefit from JIT systems.

This study can be extended in various aspects. Relaxing the restrictive assumptions, expanding the system (i.e. more products, more lines, more stations), selecting the more different levels of these factors may give the more interesting results.

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