THE OPTIMIZATION OF NUMBER OF KANBANS IN GKCS WITH SIMULATION TECHNIQUE

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ABSTRACT

This paper presents to determine the optimum number of kanbans in Generalized Kanban Control System (GKCS) at three different demand frequencies and keeping the mean processing time as constant. The configuration of the single line with three manufacturing stages is assumed to have flow line production. The manufacturing system is modeled as network diagram of GKCS using discrete event simulation software i.e. Promodel. Simulations studies were performed for the three-stage GKCS model to find the optimum number of kanbans when the machines are subject to with and without breakdown. The optimum number of kanbans is selected in such a way that, where the throughput is maximum, the work in process is low and the machine utilization is high. The customer demand is assumed as 10,15 and 20minutes. Finally the obtained results are justified with GKCS properties.

Keywords: GKCS, machine breakdown, optimization, simulation.

1. INTRODUCTION

In recent years, the term just in time (JIT) has become a common term in repetitive manufacturing. It is used to describe a management philosophy that encourages change and improvement through inventory reduction and production planning and control. In JIT systems, level of work in process (WIP) is an important performance measure together with order lead-time. One way of inventory control in a JIT environment is to implement a kanban system. This system acts as the nerve of a JIT production system that, directs materials to work stations and passes information as to what and how much to produce. Determining the number of kanbans for each part is considered to be an important management decision, affecting the desired performance level. The decision aims at avoiding backorders at each station while keeping the inventory at its lowest possible level. Therefore, an effective method is required to determine the necessary number of kanbans. Several alternative approaches have been proposed for adjusting the number of kanbans like analytical method, simulation method, heuristics method etc. each method having its own advantages and limitations. Here the author has made an attempt to determine the optimum number of kanbans in GKCS using simulation model.

There are many researchers who made an attempt to determine the numbers of kanbans, some of the contributions are follows: Frein Y. and Mascolo M.D. [1] investigated the influence of these design parameters on the efficiency GKCS. They gave general rules and better understanding of GKCS, which help to whiling designing GKCS. They developed analytical model as well as simulation model. Wormgoor O. S. [2] developed an analytical model by using queueing network theory for the performance of single class and multi class GKCS. Then he has shown its applications for improvement and operational control of real world manufacturing system. Finally he has validated with simulation model. Liberopoulos G. and Dallery Y. [3] presented a unified framework for pull production control mechanisms in multistage manufacturing systems. In this work, a pull production control mechanism is a mechanism that coordinates the release of parts into each stage of manufacturing system that has been partitioned into several stages, with the arrival of customer demands for final products. First, four basic stage coordination systems namely Base Stock Control System (BSCS), Kanban Control System (KCS), EKCS and Generalized Kanban Control System (GKCS) were presented. Then they argued that, on top of each of these stage coordination mechanisms, it is possible to superimpose a local mechanism to control the WIP within each stage. Dallery Y. and Liberopoulos G. [4] introduced a new pull type control mechanism called Extended Kanban control system (EKCS). They discussed thoroughly the working principle of EKCS and their properties. Finally they compared with GKCS, how EKCS is superior to GKCS with numerical examples by using simulation and analytical model. Shahabudeed P. [5] made an attempt to select workstation and the lot size for each part type required to achieve the best performance using a simulated annealing algorithm. Each part type is having its own withdrawal and ordering kanbans. The lot size can varies with different part types. A bicriteria objective function comprising mean throughput rate and aggregate average kanban queue has been for evaluation. Kochel P. [6] combined simulation with Genetic optimization tool LEO. They briefly discuss the application of that software tool to find optimal order policies for multi location inventory models and to design an optimal kanban controlled manufacturing system and they gave future direction too. Alabas C. [7] did three simulation search heuristic procedures based on genetic algorithms, simulated annealing and tabu search were developed and compared both with respect to best results achieved by each algorithm in a limited time span and their speed of convergence to the results for finding the optimum number of kanbans while minimizing cost in a JIT manufacturing system. Ettl M. [8] presented two fundamental design issues in kanban systems and presented an efficient heuristic method for designing such systems. An analytical technique for modeling kanban systems and genetic algorithm was integrated in a heuristic design methodology, which evaluates the performance of kanban systems using alternative network partitions and allocations of kanbans. Finally they conclude that, the heuristic method provides a useful procedure to evaluate the impact of design alternatives and can thus serve as a rough-cut decision support tool, which assists managers in the planning of large scale manufacturing systems. Aytug H. [9] proposed a method to determine the number of kanbans in a pull production system by using simulation metamodeling is described. The method is demonstrated on a two-card kanban controlled manufacturing system. Through metamodeling, a relationship between the number of kanbans and the average time to fill a customer order is determined. Later this relationship is used in a model to determine the number of kanbans while minimizing costs. Ohno K. [10], dealt with JIT production system with the production and supplier kanbans under stochastic demand. A necessary and sufficient condition, called a stability condition, is derived under which the JIT production system has a stationary distribution of the backlogged demand. An algorithm is devised for determining optimal numbers of two kinds of kanbans that minimize and expected average cost per period and they proved their method with numerical solutions. Chang T.M. and Yih Y. [11], to determine the number of kanbans and lot sizes needed to achieve the best system performance. System objectives include minimizing the cycle time, minimizing operation cost and minimizing capital loss. A multi attribute utility function is constructed and a modified simulated annealing algorithm is proposed to search the maximal utility value. They compared the results with conventional algorithm and proved that, the proposed algorithm takes less computational time and they gave few more examples also. Bard J.F. [12], developed a planning model to assist line managers in determining an optimal kanban policy at each workstation. The objective is to work within the capacity of the system to balance cost and service over the planning horizon. The model takes the form of a mixed integer linear program and is solved with standard techniques. A number of alternative formulations are introduced that sharply reduce the computational burden with help of case study. Yang S., Wu C. and Jack Hu S. [13] studied discrete asynchronous transfer lines subject to exponential operation, failure, and repair processes. A mixed vector-scalar Markov process model is presented to describe the operation, failure and repair behaviors of multi-stage transfer lines with k unreliable machines and k-1 buffer. Some important steady-state system properties, such as the reversibility and duality of transfer lines, conservation of flow, and the flow rate-idle time relationship, are deduced from this model. Zbayrak M. [14] implemented different modes of JIT control in order to reduce lead times and WIP levels, while also providing quick customer response times and efficient quality assurance. However, balanced pull control is sensitive to machine breakdown. They concluded that, tight pull control performs very poorly in an unreliable manufacturing environment in terms of major cell performance criteria and it is strongly advisable that the control system be relaxed by mixing “pull” control with “push” control by introducing controlled buffers between work centers. Hence, despite the large amount of research on KCS and very little in GKCS, the impact of factors like demand, machine breakdown, number of kanbans and overall optimization has not been deeply studied. Especially determining number of kanbans in GKCS is still in its development stage.

2. PROBLEM FORMULATION

Consider a typical single line, which consists of three stage (M1, M2, M3) manufacturing system as shown in Figure-1. Assume mean processing time of each manufacturing stage equal to exponential distribution of 10 minutes. The number of kanban assumed to be 3, 5, 7, 9…. 50 per stage. Similarly, the customer demand is also assumed to be 10, 15 and 20 minutes. Moreover, the mean time between failures (MTBF) is considered to be exponential distribution of 50 hours per stage and mean time to repair (MTTR) is exponential distribution of 5 hours per stage. The manufacturing line is simulated with 600 hours, which include warm-up period of 75 hours, and number of simulation run is assumed to be 5.

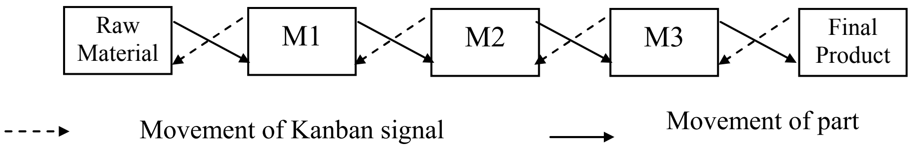

Figure-1. A typical single line with three manufacturing stages.

2.1 Assumptions

i. The inter arrival time of products is stochastic in nature;
ii. Each production stage has two inventory points. One at the beginning of the stage other at the end of the stage;
iii. There is a transportation stage between two adjacent production stages, however the transportation time is negligible as the transportation between production stages is always much shorter than the production time at the production stage;

iv. Each part type follows the same process routing in each line, processed on each station sequentially;
v. There is an infinite supply of raw material at the beginning of the first stage;
vi. The lines are subjected to machine failures with the MTBF and MTTR exponentially distributed;
vii. Clock downtimes are used to model downtimes that occur depending on the elapsed simulation time, such as when a downtime occurs every few hours, no matter how many entities a location has processed;
viii. The product will not be damaged or scrapped if a failure occurs; instead it is kept ahead of queue waiting for the machine for processing;
ix. Initially there is certain base stock available in the output buffer of the each stage;
x. The inter arrival time of the demand is deterministic; and
xi. Number of free stage kanbans are greater than the base stock kanbans in Generalized kanban control system (GKCS).

3. GENERALIZED KANBAN CONTROL SYSTEM (GKCS)

GKCS is a pull production control system combing with BSCS and KCS. Figure-2 shows the queueing network model of GKCS with two stages in series and corresponding simulation model has been shown in Figure-3 using Promodel [15].

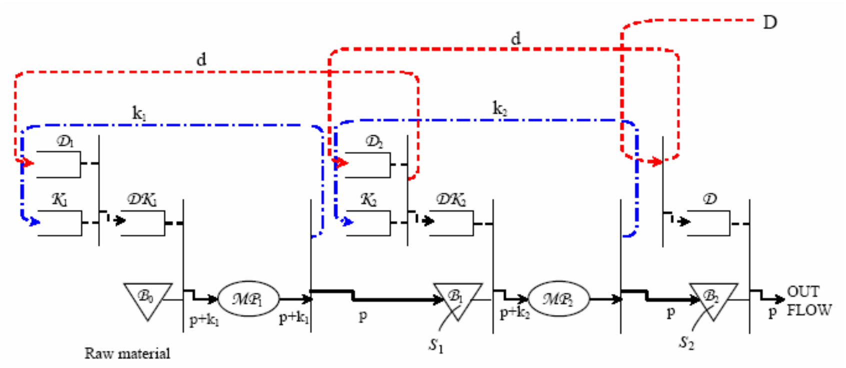

Figure-2. A two-stage production line controlled by GKCS.

In GKCS each stage i has k_i kanbans to authorize the production of stage i. Initially, all kanbans, k_i, in stage i are stored in queue K_i. Buffer B_i, $i = 1 \dots N$, has s_i finished parts of stage i with B_0 represents the raw material buffer. The demands of the production of stage-i parts are now stored in two queues: queue D_i only contains demands, where as queue DK_i contains stage-i kanbans that have been triggered by demand information from the downstream stage. GKCS depends on two parameters per stage, which are the amount of kanbans in each stage, ki and the base stock level of that stage,s_i. GKCS operates as follows. When a customer demand arrives at the system it is instantaneously split into two demands: the first demand will join queue D requesting the release of a finished product from B_2 to the customer, the second demand will join queue D_2 requesting the production of stage 2: When the first demand arrives at D, if a part is available in B_2 (which is initially the case), it is released to the Customer. Otherwise the demand is backordered and has to wait for a finished product to arrive in B_2. When the second demand arrives at D_2, if a stage-2 kanban is available in K_2 (which is initially the case), demand information is immediately transmitted upstream to D_1. Stage-2 kanban will move to queue DK_2 authorizing the production of stage 2. If a new part is available in B_1, it is instantaneously merged with stage-2 kanban in DK_2 and the pair (part and kanban) is released into MP_2. Otherwise the kanban has to wait in queue DK_2 for a finished part to arrive at B_2.If no stage-2 kanban is available in K_2, the demand has to wait for a stage-2 kanban. This demand information will be stopped going up stream. As soon as, either B_{i-1} or k_i received the information, the cycle will be repeated.

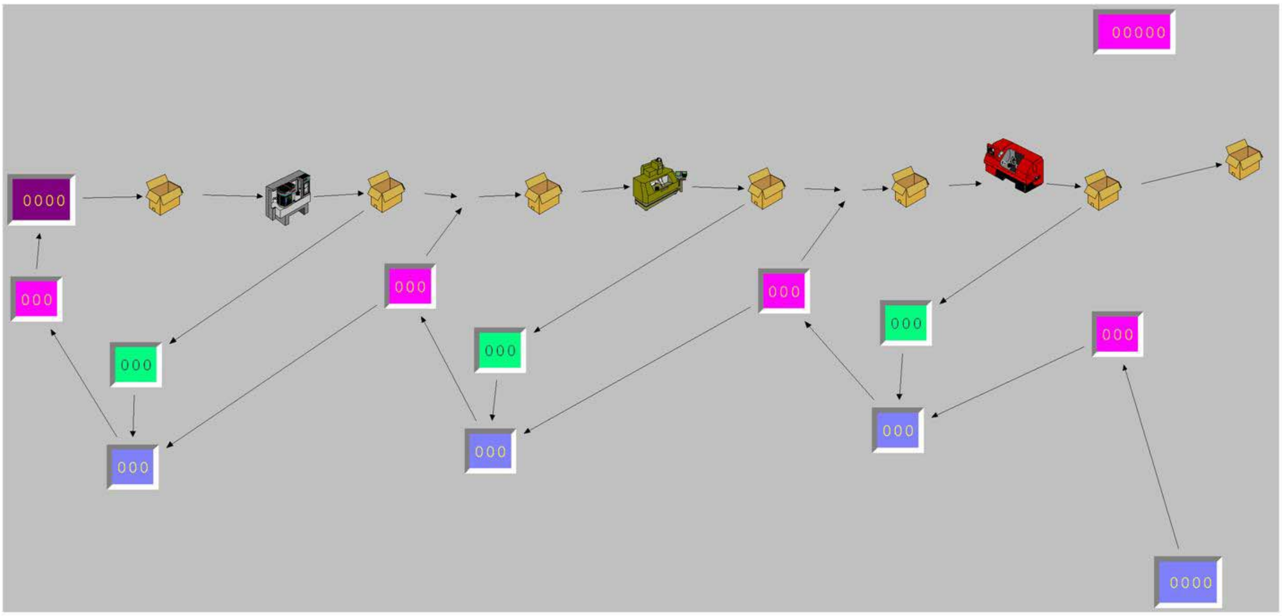

Figure-3. Simulation model of GKCS.

4. SIMULATION EXPERIMENTS AND ANALYSIS

4.1 Effect of number of kanbans when customer demand is 10 minutes

Simulation experiments were conducted and the results are plotted in Figures 4, 5 and 6, respectively. Figures show the comparative analysis of all three-performance measure, with or without machines breakdown. The machine breakdown affect the overall performance which is shown less than without machine breakdown. Further, it is observed that, if the number of kanbans were increasing, the throughput is also increasing gradually. This tends to continue when the number of kanbans is equal to 30. Then the throughput remains constant, even though the number of kanbans goes on increasing. This means that, the system reached its maximum production capacity level and it cannot produce beyond the maximum production capacity of the system. The maximum production capacity level in this case is 42600. Production capacity of a system can be defined as the throughput of the saturated system. When the customer demand is 10 without machine breakdown, the GKCS needs 30 kanbans per stage to obtain the maximum throughput. Further increase the kanban size the throughput is slightly varying and almost remains constant. Similarly, the work in process (WIP) and the % of machine utilization is also increasing along with kanban size, but to select the kanban size in such a way that, the throughput is high, work in process is low and % of machine utilization is high. From the Figures the throughput reached the maximum value further increasing the number of kanbans per stage, the throughput remains constant, work in process is further increasing and the % of machine utilization is slightly varying. Finally the optimum numbers of kanbans are 30 per stage if the demand is 10 and without machine breakdown.

When breakdown is applied, the effect of increasing the number of kanbans on the throughput, work in process and % of machine utilization is shown in the Figures 4, 5 and 6. From the Figures, the number of kanbans required to obtain the maximum throughput level is more when compared to the system without breakdown. When breakdown is considered the machines are getting down for every mean time between failure value (MTBF) and the machines will take some time to repair i.e., mean time to repair (MTTR). So the throughput is decreased due to machines being idle. Because of this factor, the production capacity of a system with breakdowns is less than the system without breakdown. The maximum throughput for GKCS with breakdown is obtained at kanban size 32. If we increase the number of kanbans the throughput remains constant. Similarly, the work in process (WIP) and the % of machine utilization is also increasing along with kanban size, but, it is better to select the kanban size in such a way that, the throughput is high, work in process is low and % of machine utilization is high. From the Figures the throughput reached the maximum value further increasing the number of kanbans per stage the throughput remains constant, work in process is further increasing and the % of machine utilization is slightly varying. Finally the optimum numbers of kanbans are 32 per stage if the demand is 10 and without machine breakdown.

4.2 Effect of number of kanbans when the customer demand is 15 and 20minutes

When the customer demand is increasing from 10 to 15 and 20minutes, the variation of performance measures with the increasing number of kanbans are shown in Figures 7 to 12. When the customer demand is increasing the throughput, work in process and average machine utilization is decreasing with and without breakdown. From the results it is observed that when the customer demand is increasing the throughput of GKCS with and without breakdown is decreasing. This happens because, the mean processing time is constant i.e. when Exp (10) whereas the demand arrival rate was increasing i.e. 15 and 20 minutes. In other words, demand rate is greater than the service rate (processing time). The work in process decreases when the customer demand increases. This phenomenon occurs because the finished parts at the end of flow line synchronize with demand and release of parts to the customer. The number of parts in second and third stage is start pile up until a demand and kanban signal is available for further synchronization, which are independent with each other. Therefore, the kanban, demand and finished parts in each stage synchronize equally in entire flow line.

4.3 Justification

In this section, the author has justified the output results, which are shown in 4.1 and 4.2 by using GKCS properties. Dallery Y. and Liberopoulos G. [3] have proved the property, the production capacity of the GKCS with parameters K_i and S_i, I = 1… N, is higher than the production capacity of the GKCS with the same parameters K_i and S_i. The results and graphs of GKCS satisfied the property because of two reasons. First, the throughput of the GKCS depends on the number of kanbans per stage and the base stock of finished parts per stage. Second, GKCS has two synchronization stations between two consecutive stages. Further the authors have proved another property, ie GKCS with $K_i = S_i$ or $K_i = \infty$, I = 1… N-1. As the arrival of the customer demand is increasing, the performance measure of GKCS is decreasing and tends to become equivalent. The results and graphs of GKCS satisfied this property too. The throughput, work in process and machine utilization of a system decreases if the system is subjected to breakdowns; still the GKCS satisfied this property.

5. CONCLUSIONS

Simulation experiments were conducted in a typical single line three stage manufacturing systems. The author concluded that, the optimum number of kanbans for GKCS at three different demand arrival rates (10, 15 and 20) were determined. With increase in number of kanbans the throughput, work in process and machine utilization is increasing. After certain state the throughput is slightly varying or almost remains constant even though the number of kanbans is increasing. But the work in process and % of machine utilization goes on increasing later on it will also be constant. The optimum number of kanbans is selected in such a way that, where throughput is maximum, work in process is low and machine utilization is high. With the increase in customer demand, the optimum number of kanbans was also increasing with and without breakdown at the same value of mean processing time. The optimum number of kanbans with breakdown is more than that without breakdown. This is because the throughput decreases when the breakdown occurs.

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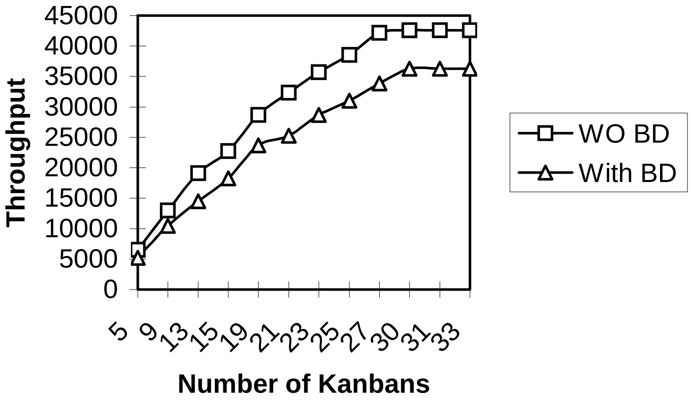

Figure-4. Effects on throughput in number of kanbans.

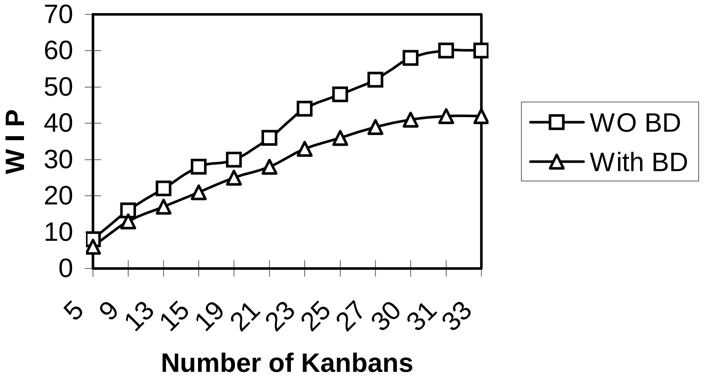

Figure-5. Effects on W I P in number of kanbans.

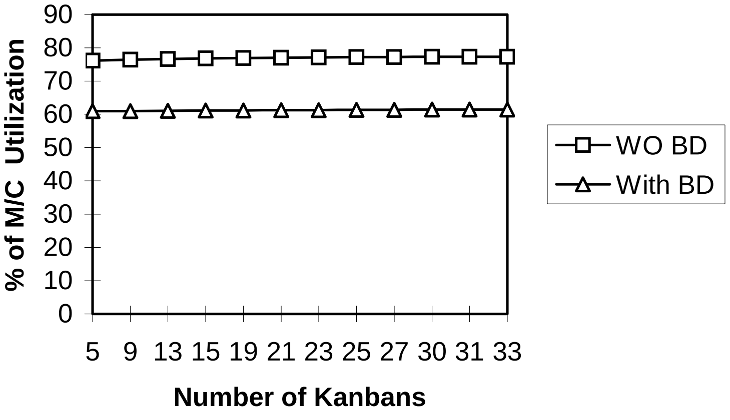

Figure-6. Effects on % of M/C utilization in number of kanbans.

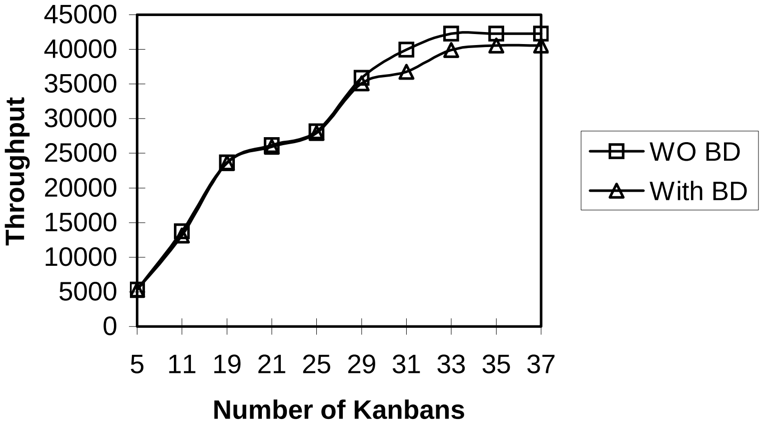

Figure-7. Effects on throughput in number of kanbans.

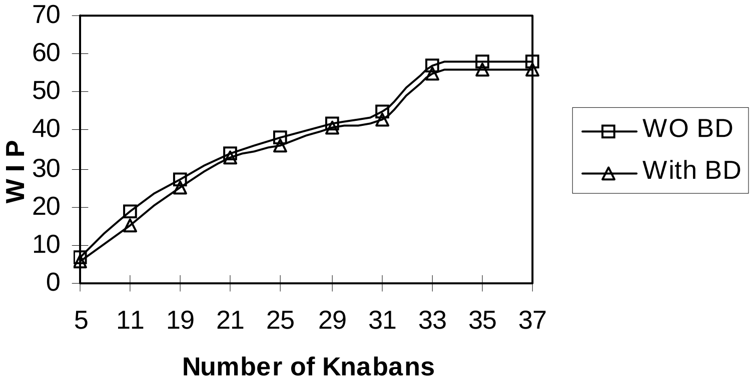

Figure-8. Effects on W I P in number of kanbans.

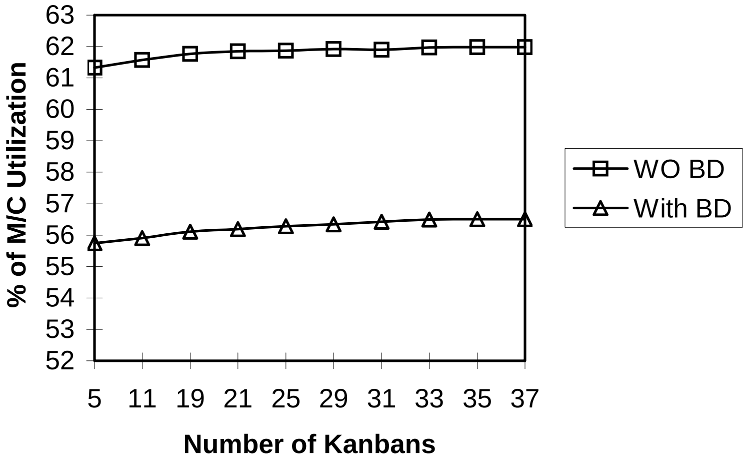

Figure-9. Effects on % of M/C utilization in number of kanbans.

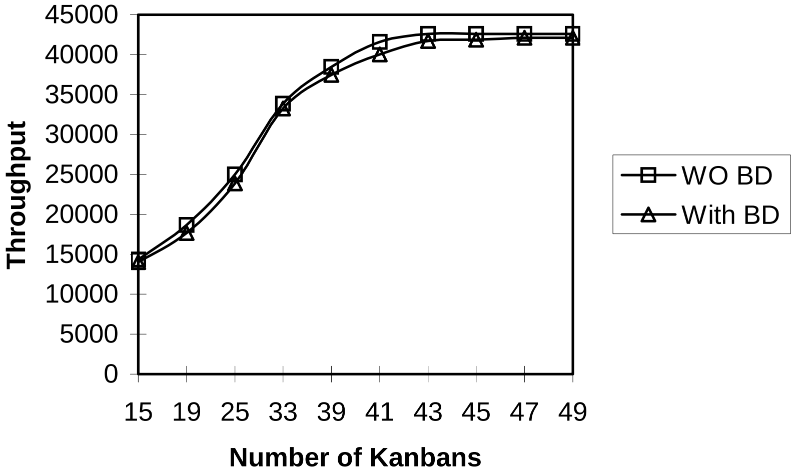

Figure-10. Effects on throughput in number of kanbans.

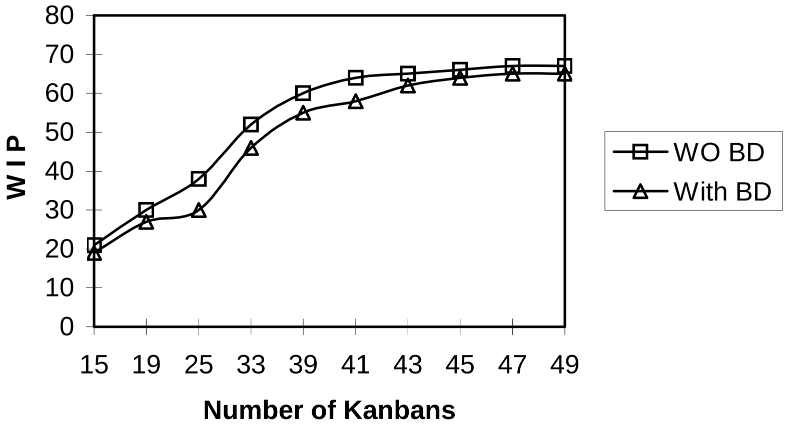

Figure-11. Effects on WIP in number of kanbans.

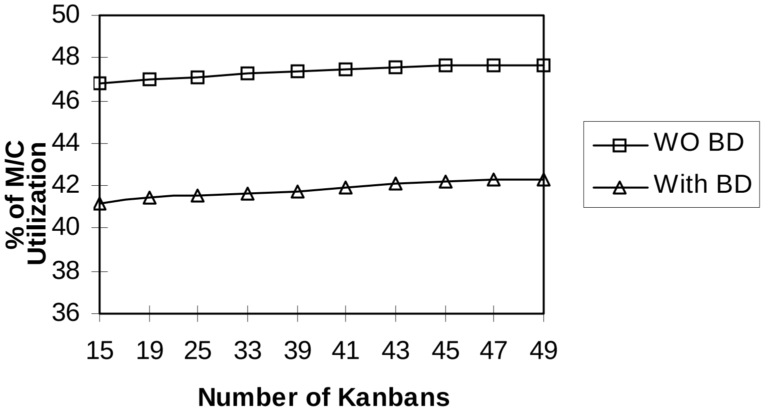

Figure-12. Effects on % of M/C utilization in number of kanbans.