Determining the Number of Kanbans in EKCS: A Simulation Modeling Approach

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Abstract— The objective of this study is to determine the optimum number of kanbans in Extended Kanban Control System (EKCS) 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 EKCS using discrete event simulation software i.e. Promodel. Simulations studies were performed for the three-stage EKCS 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 EKCS properties.

Keywords—EKCS, Machine breakdown, Optimization and Simulation.

I. Introduction

During the last two decades, researchers started investigating Japanese manufacturing concept and strategy in order to understand their success in the global market. One of the common topics was Just In Time (JIT) production planning and control method. In JITsystems, 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 limotations. Here the author has made an attempt to determine the number of kanbans in EKCS using simulation model.

There are many researchers who made an attempt to determine the number of kanbans, some of the contributions are follows: Liberopoulos.G and Dallery.Y [1] 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 [2] 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[3] 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[4] 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 [5] 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 [6] 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 [7] 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

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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[8], 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 JITproduction 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 [9], 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 [10], A planning model is developed 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 JackHu.S[11] 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[12] 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 EKCS, 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 EKCS is still in its development stage.

II. 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 failure (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.

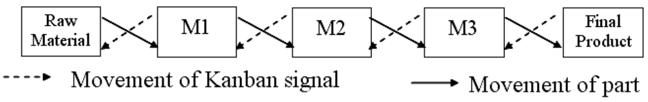

Figure 1: A typical single line with three manufacturing stages

III. EXTENDED KANBAN CONTROL SYSTEM (EKCS)

EKCS is a pull production control system combing with BSCS and KCS. The Figure 2 shows the queueing network model of EKCS with two stages in series and corresponding simulation model has been shown in Figure 3 using Promodel [13].

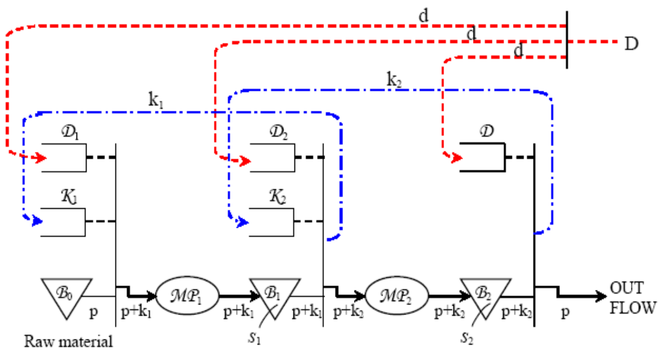

Figure 2: A two-stage production line controlled by EKCS

Queue B_i is the output buffer of stage i and contains pairs of stage-i finished parts and stage-i kanbans. Queue B_0 is the raw parts buffer. Queue D_i contains demands for the production of new stage-i finished parts. Queue D is the customer demands buffer. Finally queue K_i contains free stage-i kanbans. The EKCS depends on two parameters per stage, which are stage-i kanbans, k_i, and a base stock level s_i. In the initial state B_i contains s_i stage-i finished parts having stage-i kanbans attached to it. Queue K_i contains k_i - s_i free stage-i kanbans, and all other queues are empty. The EKCS operates as follows. When a customer demand arrives at the system, it is instantaneously split into N + 1 (equals to three in this two stages system) demands: the first demand joins queue D requesting the release of a finished product from B_2 to the customer, and N (=2) other demands, each one joining the input demand queue D_i of each stage i, i = 1, 2, requesting the production of a new part in stage i. 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 after detaching the stage-2 kanban. This kanban is then transferred upstream to K_2. Otherwise the demand is backordered and has to wait for a finished product to arrive in B_2. At the same time, when a demand arrives at D_i, i = 1… N: If there are both part with stage i-1 kanban in B_{i-1} and stage i kanban in queue K_i, the part is immediately detached from stage i-1 kanban. One stage-i kanban is removed from K_i, attached to the part and the pair is released into MP_i. At the same time, the stage i-1 kanban is transferred upstream to K_{i-1}. If there is either no part in B_{i-1} or no stage-i kanban in K_i, the demand is backordered and has to wait in D_i. As soon as, either B_{i-1} or k_i received the information, the cycle will be repeated.

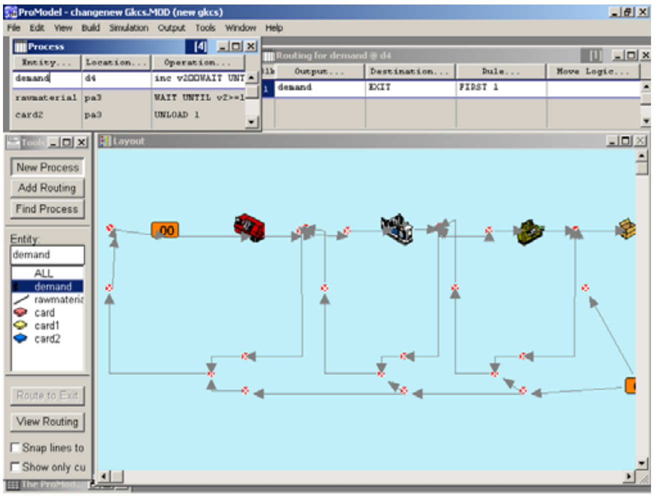

Figure 3: Simulation model of EKCS

IV. Problem Formulation

A. *Effect of number of kanbans when customer demand =10minutes*

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 23.Then the throughput remains constant, eventhough 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 EKCS needs 23 kanbans per stage to obtain the maximum throughput. If we increase the kanbans from 25 to 27, 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 23 per stage if the demand is 10 and without machine breakdown.

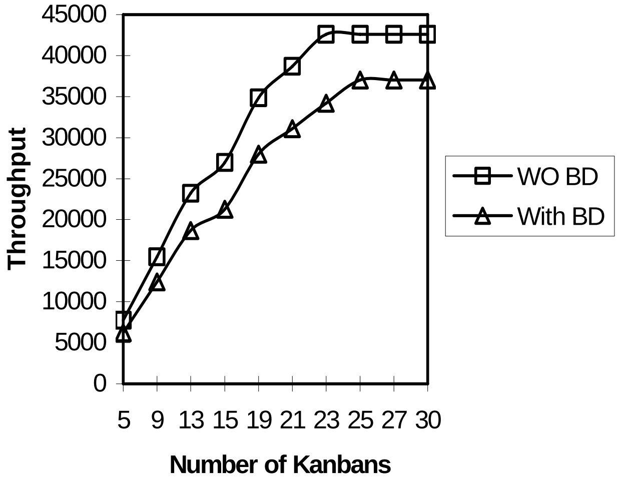

Figure 4: Effects on Throughput in Number of kanbans

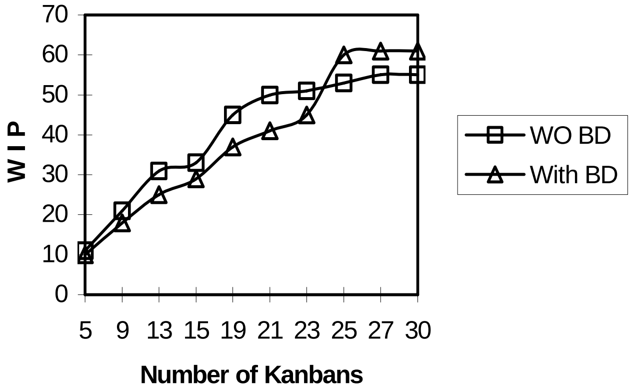

Figure 5: Effects on W I P in Number of kanbans

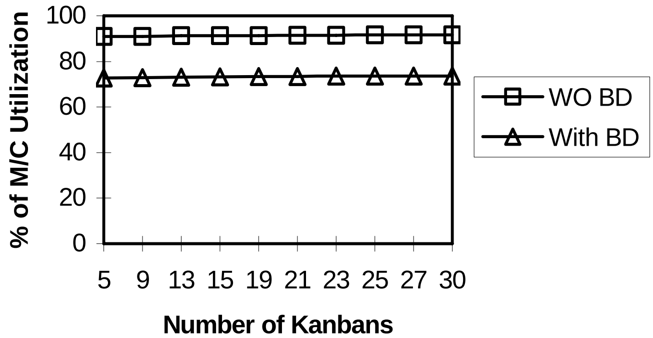

Figure 6: Effects on % of M/C Utilization in Number of kanbans

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 EKCS with breakdown is obtained at kanban size 27. If we increase the number of kanbans the throughput

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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 27 per stage if the demand is 10 and without machine breakdown.

B. Effect of number of kanbans when the customer demand =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 EKCS with and without breakdown is decreasing. This happens because, the mean processing time is constant ie when Exp (10) whereas the demand arrival rate was increasing.ie 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.

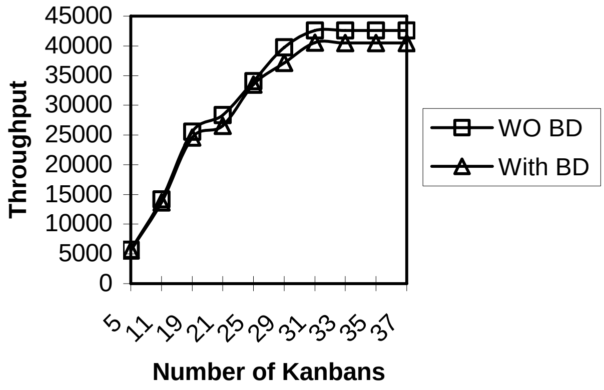

Figure 7: Effects on Throughput in Number of kanbans

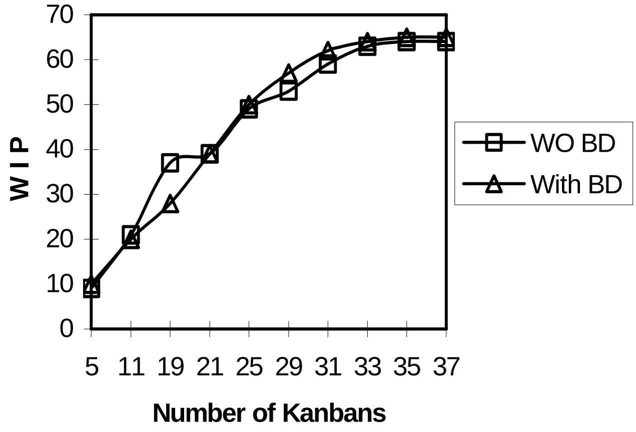

Figure 8: Effects on W I P in Number of kanbans

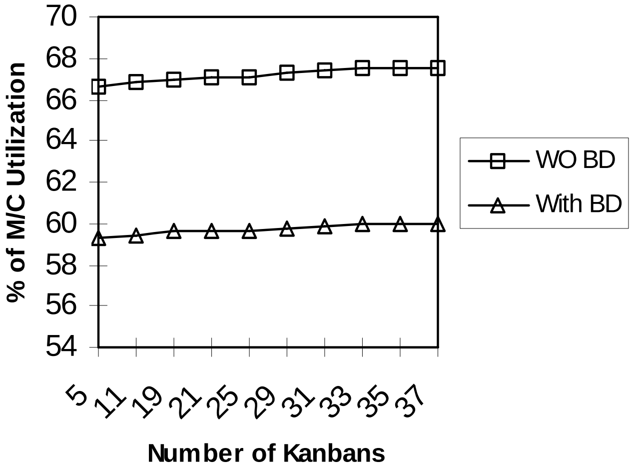

Figure 9: Effects on % of M/C Utilization in Number of kanbans

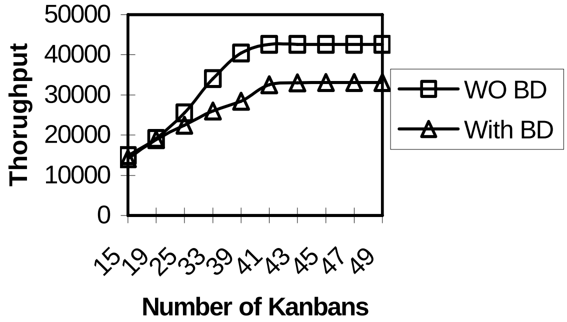

Figure 10: Effects on Throughput in Number of kanbans

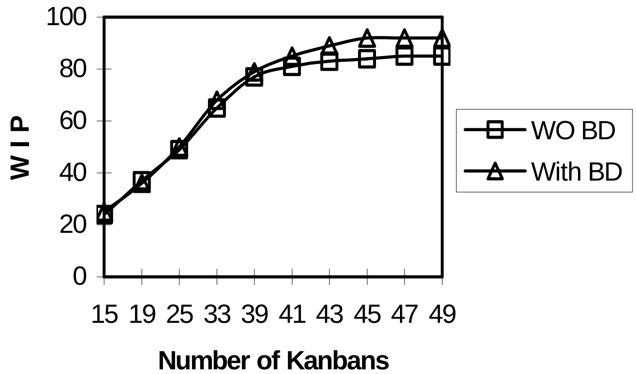

Figure 11: Effects on W I P in Number of kanbans

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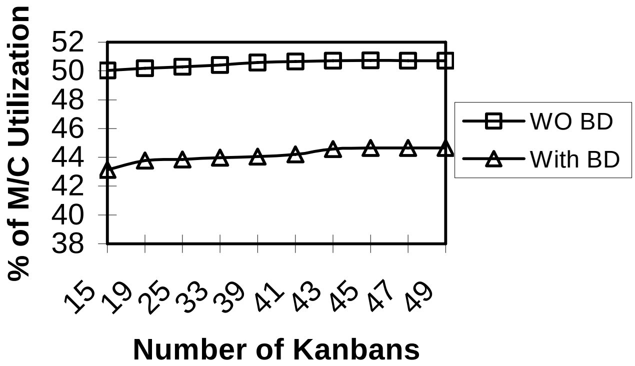

Figure 12: Effects on % of M/C Utilization in Number of kanbans

C. Justification

In this section, the author has justified the output results, which are shown in 4.1 and 4.2. by using EKCS properties. Dallery. Y and Liberopoulos. G [2000] has proved the property, the production capacity of the EKCS 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 EKCS satisfied the property because of two reasons. First, the throughput of the EKCS only depends on the number of kanbans per stage and not on the basestock of finished parts per stage. Second, EKCS has only one synchronization station between two consecutive stages. Further the authors have proved another property, i.e. EKCS with K_i=S_i or Ki=∞, i=1,……,N-1. As the arrival of the customer demand is increasing, the performance measure of EKCS is decreasing and tends to become equivalent. The results and graphs of EKCS 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 EKCS satisfied this property.

V. CONCLUSIONS

Simulation experiments were conducted in a typical single line three stage manufacturing systems. The author concluded that, the optimum number of kanbans for EKCS 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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