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Modeling of A Pull-Push Assembly Control System To Minimize Inventory and Demand Delay Costs

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This study deals with modeling and analysis of an electronic assembly line, which operates according to a pull-push system of production control. Weekly scheduled demands are met from finished products inventory, which in turn trigger production at the first station by signaling with certain number of kanbans, which are equal to the product quantity withdrawn. The successive assembly operations are performed using a push system of production control. The objective of the simulation analysis presented in this paper is to determine the optimum number of kanbans attached to the batches of products in the system to minimize the total system cost, which consists of inventory holding cost, demand delay cost, and transportation costs due to regular and additional shipments of demand.

Significance: This paper presents a real case application of JIT production control to an electronic assembly line using simulation modeling. Several costs are considered in the application and the optimum number of kanbans, which have significant effect on the inventory holding, demand delay, and late shipment costs, are determined. Numerical cases are presented to illustrate the modeling concept that could be applied to any serial assembly line system controlled by kanbans.

Keywords: Just-in-Time, Simulation, Kanbans, Pull-Push Assembly System, Work-in-Process.

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1. INTRODUCTION

One of the main problems faced in production and assembly systems is how to minimize the amount of inventories without causing excessive delays in meeting the demand on time. This problem is partly solved by a new production control method, referred to as just-in-time (JIT) or "pull" system of production control, which has attracted much interest in recent years, particularly in the case of high-volume assembly systems. Production at each stage is scheduled according to the demand for products from the succeeding stage. Shipments under JIT are usually in small, frequent lots. An information signaling card, called a "kanban", is used to manage and control the production and shipments. Kanban implementation can be either full or partial depending on the production line operation. In the case of partial implementation, the system is operated by both, a pull and a push system of production control. Companies which operate according to JIT system require that their suppliers also function accordingly.

Several studies have been carried out on the implementation and efficiency of JIT systems and hundreds of articles have been published after 1980. One of the most comprehensive literature review on JIT systems is presented by Golhar and Stamm (1991) who identify 860 articles and reviewed about 200 of them. Later, Yavuz and Satir (1995), Chun-Che and Kusiak (1996), and White, Pearson, and Wilson (1999) presented literature reviews related to various aspects of JIT systems. Berkley (1996) studied issues related to container sizes and number of kanbans. Takahashi and Nakamura (2002) compared a reactive kanban system to a CONWIP system. Ardalan (1997), Akturk (1999), and Aytug and Dogan (1999) studied the effects of kanban withdrawal cycle, kanban sizes, and priority rules on system performance. Sarker and Balan (1998) used inventory models to determine optimum number of kanbans for varying demand. Karaesmen and Dallery (2000) and Baynat, Buzacott, and Dallery (2002 studied generalized and extended kanban-controlled multi-product systems, with kanbans dedicated to single and multi-products. Kochel and Nielander (2002) developed a simulation model and a genetic algorithm to determine optimum number of kanbans. Kilsun, Chhajed, and Palekar (2002) compared pull and push systems with respect to service level, operating costs, and delivery times. Weitzman and Rabinowitz (2003) compared push and pull control strategies with respect inventory information updating rates. GrosfeldNir and Vanberkel (2000) and Huang and Kusiak (1998) also presented comparisons of push and pull systems in a multi-stage production system. Wang and Xu (1997) presented a simulation analysis of a hybrid pull/push production control strategy and indicated the efficiency of such systems. Savsar (1995, 1996, 1997, 2000) and Ertay (1998) analyzed JIT systems from different perspectives using simulation as well as other meta modeling approaches, including neural network. Matta et. al. (2005) presented simulation and analytical models to evaluate alternative kanban control policies in the design of assembly systems. Duri, Frein, and Di Mascolo (2000) and Liberopoulos and Koukoumialos (2005) studied the trade-offs between base stock levels, kanbans, extended kanbans, planned supply and lead times. Framinan et al. (2006) discussed a procedure for dynamically controlling the kanbans to increase the throughout on the line. In all of these studies, either mathematical models are developed based on restrictive assumptions or simulation models are utilized to determine certain decision variables related to JIT systems. None of these studies have considered several cost factors affecting the kanban decisions.

In this paper, we have extended the work done by Savsar (1997) and introduced a new cost function, which includes three important cost variables related to kanban controlled systems. A practical case of an electronic assembly line, which is designed to produce printed circuit boards (PCB) in mass quantities to be used in a succeeding system located elsewhere, is studied with simulation modeling and analysis. The line is operated according to demand using a combination of a pull and a push control strategy. Weekly demands, which are met from the final inventory of products, trigger the assembly operations by releasing production ordering kanbans to the start of the line. Subsequent assembly operations are then controlled by a push system of production control. The production and assembly operations are done in batches with a kanban attached to each batch of semi finished products. Batches of semi finished PCBs with attached kanbans are routed from station to station until completion. PCBs assembled during one week are shipped at the end of the week to the subsequent system, where these boards are integrated into communication and other electronic equipment. If the fixed quantity of weekly demand, could not be met with one shipment at the end of the week, additional shipments would be necessary during the week.

The objective of simulation modeling is to determine the optimum number of kanbans in the assembly system, including work-in-process and finished products inventory, to minimize inventory cost, cost of delays in meeting the demand, and the cost of transportation due to regular and additional delivery to the subsequent system when the demand is not met on time. The simulation model and analysis presented in this study is different from the previous studies in several ways. First, it addresses a real case application in which a combination of pull and push systems of production control is implemented in a factory to operate the system based on known demand. The kanbans from the last station on the line are transferred to the first station either weekly or daily, if weekly demand is not met on time. Thus, the kanbans are not sent to the immediately preceding station from the last, as practiced in most actual kanban implementations. Second, several cost components, such as inventory holding costs, demand delay costs, and transportation costs have been integrated into the simulation model and optimum number of kanbans needed in the system are determined by minimizing the total cost.

2. DESCRIPTION OF THE ASSEMBLY OPERATIONS

$$TC = C_h + C_d + C_s \tag{1}$$

$$C_h = \sum_{i=1}^{5} \sum_{j=1}^{5} c_h q_{ij} \tag{2}$$

$$C_d = \sum_{i=1}^{4} i c_d D_i \tag{3}$$

$$C_s = c_s + \sum_{i=1}^{4} c_s \delta_i \tag{4}$$

Where,

C_h = Total holding cost

C_d = Total delay cost

C_s = Total shipment cost

c_h = Inventory holding cost per unit per day.

q_{ij} = Number of units in work in process (WIPi and FPI).

c_d = Cost of delay per unit per day delayed.

D_i = Demand met on day i after meeting the regular weekly shipment ($D_i \geq 0$).

$\delta_i = 1$ if $D_i > 0$ and $\delta_i = 0$, if $D_i = 0$

c_s = Transportation cost per shipment during regular or additional shipments.

i = Index for week days

j = Index for WIP and FPI inventories (j=5 is the FPI inventory in the case of problem considered)

Note that holding cost is determined daily (from day 1 to day 5 of the week) by multiplying the total number of units in inventories by the delay cost per unit per day as given by equation (2). Total delay cost is calculated from equation (3) and it depends on daily demand met (D_i) being positive or zero. This quantity is multiplied by the number of days demand is delayed and the delay cost per unit per day. Total shipment cost is calculated by equation (4). Shipment cost is only c_s if it is done once during the week. However, it has to be accumulated daily over 4 days if $D_i>0$ in any day until day 5. In day 5 regular shipment is done. Total cost is updated daily depending on the state of the system at the end of the day. The process is simulated over a long period of time and the optimum number of kanbans that correspond to the minimum total cost is determined. In the next section, we present the simulation model to achieve this goal.

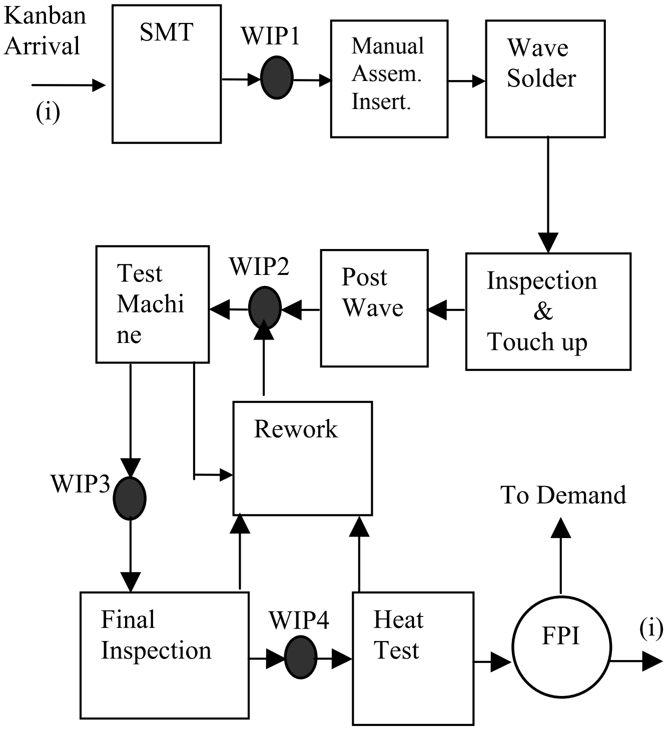

Figure 1. Basic Processes in the Electronics Assembly Line

3. SIMULATION ANALYSIS OF THE SYSTEM

A simulation model is built for the assembly line illustrated in Figure 1 using the ARENA (2002) simulation software. The general block diagram of the simulation model is shown in figure 2. The following notations are used in the figure:

W_z = Demand in batches at the end of week z
F_z = Number of batches of circuit boards available at FPI at the end of week z
D_z = Demand met (in batches) on time at the end of week z
P_z = Percent of demand met on time at the end of week z

During simulation, demand (W_z) for the circuit board is compared to the available units (F_z) in the final inventory. The amount of demand met (D_z) depends on the availability and the percent of demand met is determined as P_z =100% or $P_z = D_z / W_z$. Based on percent of demand met, inventory related cost components are determined and the total cost is calculated.

Each station is represented by a resource and the PCBs as entities moving through the line in simulation. The model starts with a Create module that sends 60 entities representing 60 batches (kanbans) at the end of every week. Those entities are then sent to a queue waiting to be matched with the number of entities waiting in the FPI queue. If the number of entities waiting in the FPI queue is equal to or larger than 60 then all the demand is met. On the other hand, if it is less than the required weekly demand, only the amount available at the FPI queue will be shipped and the rest will be met later during the week as board get assembled. In either case, the number of batches of demand met will each have a card representing a kanban attached to it and sent directly to first station which is SMT. From SMT onward the kanbans will move sequentially from one station to the next as a push system, meaning that as boards are completed in each station, they will be pushed to the next station until all assembly operations are finished. At the end, they will be batched and sent to FPI queue waiting to be shipped at the end of each day. It should be noted that intermediate assembly operations are controlled by a push system, except the kanban signaling from the FPI queue to the SMT which works as a pull system.

The system is simulated over a period six months and the average monthly total cost is estimated for different levels of kanbans allowed to circulate in the system. Fixed number of kanbans in the JIT system limit the number of in process inventories. In order to simulate the production system, related parameters and process time distributions need to be identified. Table 1 presents the operation time distributions and related parameters for the line, while table 2 presents the percent of rejections at each test station, which require rerouting to rework station as illustrated in figure 1.

Table 1. Process time distributions and parameters (μ, σ or a, b)

Process Stage	Process Time Distributions	Process Time Parameters
SMT	Constant	1.70 min
Manual Assembly	Normal	1.80 min, 0.18 min
Wave Solder	Constant	0.45 min
Inspection	Normal	2.70 min, 0.25 min
Post Wave	Normal	1.40 min, 0.15 min
In-Circuit Test	Constant	3.60 min
Final Inspection	Normal	2.70 min, 0.25 min
Heat Test	Constant	2.50 min
Rework Station	Uniform	2.70 min, 4.40 min

The number of kanbans are varied from 60 to 160 units assuming one kanban is attached to each batch of PCBs. Each batch contains 10 PCBs. Daily operations are assumed to continue for 480 minutes for 5 days per week and 22 days per month. The assembly system was simulated for six one-month periods of 10560 minutes each. Table 3 shows the cost related parameters that were used in the simulation model to find the optimum number of kanbans. Total inventory holding cost, total demand delay cost and total shipment costs were accumulated over the simulation period and the total system cost was calculated for each kanban level ranging from 60 to 160 units in each simulation. Figure 3 shows the total costs as a function of number of kanbans in the system. As it is seen in figure 3, inventory holding costs increase with respect to increasing number of kanbans, while demand delay costs decrease with respect to increasing number of kanbans. Shipment costs also show a decreasing trend, but not as significant as the other costs.

The total cost, which is the sum of three cost components, shows a decreasing trend and then an increasing trend with respect to increasing number of kanbans. Therefore, an optimum or minimum total cost exists with respect to Kanban numbers. The optimum happened to be at 120 kanbans for this assembly line with specified parameters and operational conditions. The minimum total cost was $6252.80 for the system at these optimum numbers of kanbans. Thus, in order to minimize the total system cost, the assembly system should be operated with 120 kanbans, each attached to a batch of 10 PCBs in the system. A deviation from this number would result in non-optimal system operation with respect to total costs.

Table 2. Percentage of rejection at test stations

Test Station	Percentage of Rejection
In-Circuit Test	30%
Final Inspection	5%
Heat Test	1%

Table 3. Cost parameters used in the simulation model

Cost Type	Estimated Cost values
Inventory Holding	$0.50 per unit per day
Demand Delay	$1.00 per unit per day late
Shipment	$25.0 per shipment

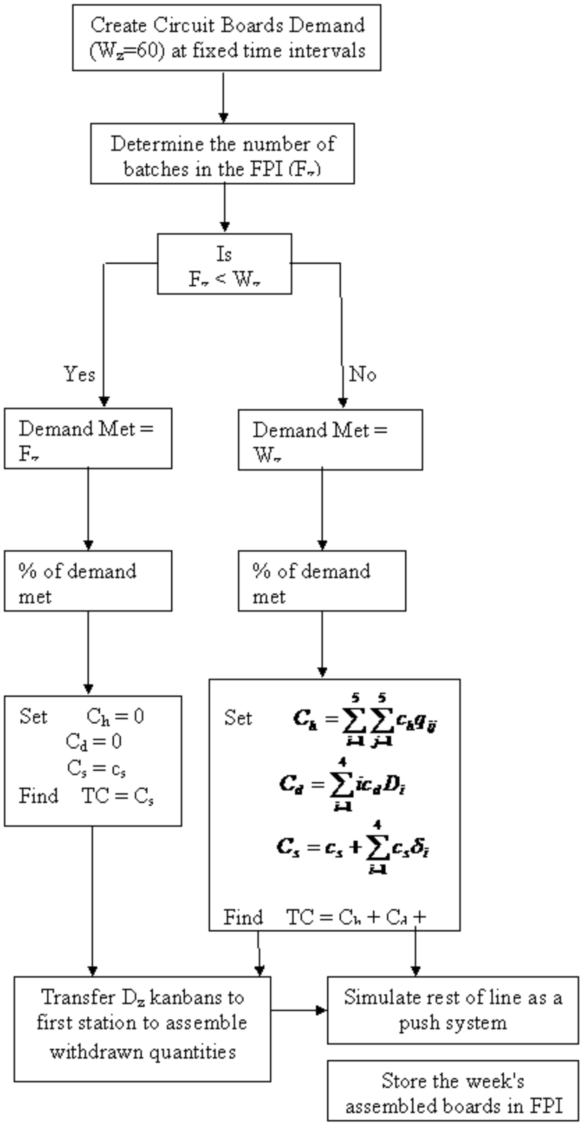

Figure 2. Simulation Block Diagram of the assembly system operated according system

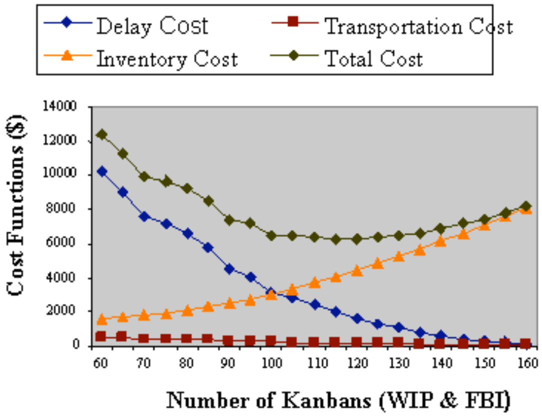

Figure 3. Total system cost versus number of kanbans allowed

In order to see the sensitivity of the optimum number of kanbans and the total cost to the changes in various cost parameters, we varied the inventory holding costs and demand delay costs in opposite direction by 40% and simulated again the system at various kanban combinations around the optimum. Figure 4 and figure5 show the results for these variations.

In figure 4, the demand delay cost is increased by 40% to $1.4/unit per day and the inventory holding cost is decreased by 40% to $0.3/unit per day. Since the transportation cost did not have a significant effect on the total cost, it was kept at the original value of $25/shipment. When the simulation was performed at different kanban values with these changes, the optimum number of kanbans was found to be 135, which is about 12.5% deviation from the original optimum of 120 kanbans. The minimum total cost was found to be $4683.40 in this case, which shows a 25% deviation (reduction) from the original minimum total cost of $6252.80. Thus, having made changes of 40% in opposite directions for the delay and holding costs, the change in the optimum number of kanbans was much less (i.e., 12.5%) and the change in total cost was relatively low (about 25%). This indicates that the model will produce useful results even if there are errors in estimating the cost parameters. Furthermore, it is expected that increasing demand delay costs would result in an increase in optimum numbers of kanbans to be allowed in the system. This result is also seen in this analysis given by figure 4.

Figure 5 shows the results when the demand delay cost was decreased by 40%, from 1.0 to 0.6; and the inventory holding cost was increased by 40% from 0.5 to 0.7. The transportation cost was kept constant at $25/shipment as before. In this case the optimum occurred at 100 kanbans, which is a 20% deviation from the original optimum of 120 kanbans. The minimum total cost was $6481.70, with a deviation of less than 3.7% from the original minimum total cost of 6252.8. Again, this result is extremely important since it indicates that an error in estimating some of the parameters does not have significant effects on the optimum results. Contrary to what was indicated in the previous case, here increasing inventory holding cost resulted in a reduction in the optimum numbers of kanbans since less kanbans would result in less in-process inventories with less holding costs.

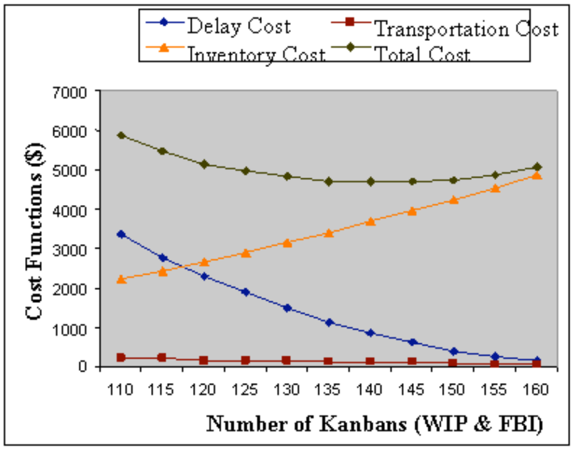

Figure 4. Total system cost versus number of kanbans allowed (when c_d is increased by 40% and c_h is decreased by 40%)

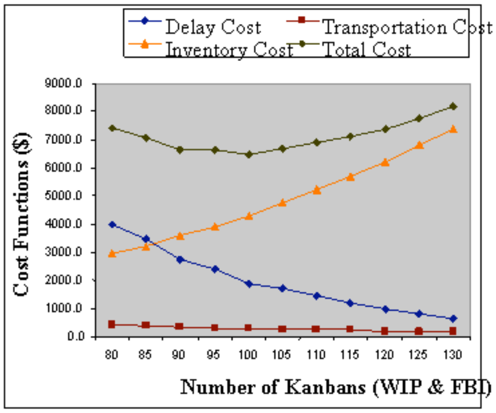

Figure 5. Total system cost versus number of kanbans allowed (when c_d is decreased by 40% and c_h is increased by 40%)

Finally, we investigated the cases when all costs are increased or decreased simultaneously. When all the costs were increased by 40% simultaneously, there was no change in the optimum level of 120 kanbans. Only the total cost was increased by 40%. Similarly, when we decreased all the costs by 40% simultaneously, again there was no change in the optimum number of kanbans of 120; only the total cost was decreased by 40%. Thus, the optimum number was not affected, but only the cost was shifted up or down depending on the shift in individual cost components, which were done simultaneously.

In order to generalize the relation between the total cost and the number of kanbans allowed, a regression model was developed for this assembly line. The following equation is a polynomial regression equation with about 99% correlation coefficient, where TC represents the total cost and K represents the number of kanbans allowed in the system.

$$TC = 1.559K^2 - 379.14K + 29250 \tag{5}$$

Setting the derivative dTC/dK=0 and solving for K, we obtain K=121.6 or approximately 122 kanbans to achieve minimum total cost of 6199. The total cost corresponding to any other number of kanbans can be easily computed from equation (5). For example, if the number of kanbans are set at K=300, TC=55,818, for K=200, TC=15782, and for K=20, TC=22,291.

4. CONCLUSIONS

One of the main factors that affect the performance of production and assembly systems is the amount of in-process inventories allowed in the system. While allowing a high level of in-process inventories would result in better customer service with respect to on-time product deliveries, excessive inventories result in very high storage costs. In order to avoid such costs, just-in-time production management techniques have been employed in many industries so that production operations are triggered by the demand. Most of the production/assembly operations today are managed according to JIT concept or the pull system of operation. There are some systems, such as the assembly system presented in this paper, that can be operated according to the demand but in a hybrid mode, namely using a combination of a pull/push coordination. In analyzing such systems, the goal is to determine the optimum numbers of kanbans that would balance the inventory holding cost against the demand delay costs. Kanbans restrict the in-process inventories and synchronize the production flow with the demand.

We have developed a simulation model for a case assembly system that is encountered in electronics board manufacturing. The system was modeled in such a way as to investigate the effects of the numbers of kanbans on total system cost. As it has been presented in the analysis above, two important cost components, inventory holding and demand delay costs, have conflicting nature with respect to the numbers of kanbans in the system. Therefore, the total cost results in a concave shape with a minimum value at optimum number of kanbans. In all cases investigated by simulation, this nature of system cost was evident. Transportation cost did not have a significant effect on the total cost mainly because shipments were needed only a limited numbers of times depending on the delay in demand. The model proved to be a useful tool since the results were relatively robust to the changes in cost parameters. It could be useful in simulating and analyzing other similar assembly systems. The model can be further extended to include other line characteristics, such as equipment failures, maintenances, and other operational conditions not included in this study.

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BIOGRAPHICAL SKETCH

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