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# FLOOR INVENTORY TRACKING OF A KANBAN PRODUCTION SYSTEM

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## ABSTRACT

A model was developed for tracking production floor inventory for a Kanban manufacturing production system. The production (Kanban) parameters used include percent loading, percent availability, yield, lead time, batch time, and cycle time. The model was constructed for a discrete, non continuous simulation of a multi stage dual-card Kanban production system. The performance of the model was monitored by tracking WIP, orders completed, average time in the system, and the production throughput in the JIT/Kanban production environment.

The results and the evaluation technique will prove useful in tracking production floor inventory and selection of the right Kanban technique to implement in a given manufacturing process. It will also provide valuable information for anticipating production capabilities of a Kanban system before actual implementation using the simulation technique presented in this paper.

## 1 INTRODUCTION

Inventory is defined as "The raw materials, semi-finished parts and assemblies, and finished goods that are in a production system at any point in time." Inventory may incur cost in several ways. The variation in cost factors will depend on layout as well as operation. Targeting and monitoring production floor inventory as a cost control measure is an effective tool in production and inventory control. By tracking the production floor inventory, one can manage inventory more efficiently and make decisions based on the actual production performance at each level.

This paper shows a technique using simulation of a JIT (Just-In-Time) system in a realistic but simplified production setting. In particular, this study investigates a Kanban inventory control system which is the type of system most often used as the production scheduling technique for a JIT system.

## 2 KANBAN PRODUCTION SYSTEM

Consider the Dual-Card Kanban production system shown in Figure 1. It is assumed that both process A and C are dedicated processes and process B makes withdrawals from both A and C, Schonberger (1983). It is also assumed that the production processes replace only what has been withdrawn, and the operation sheet at the beginning of the day specifies demand and cycle time.

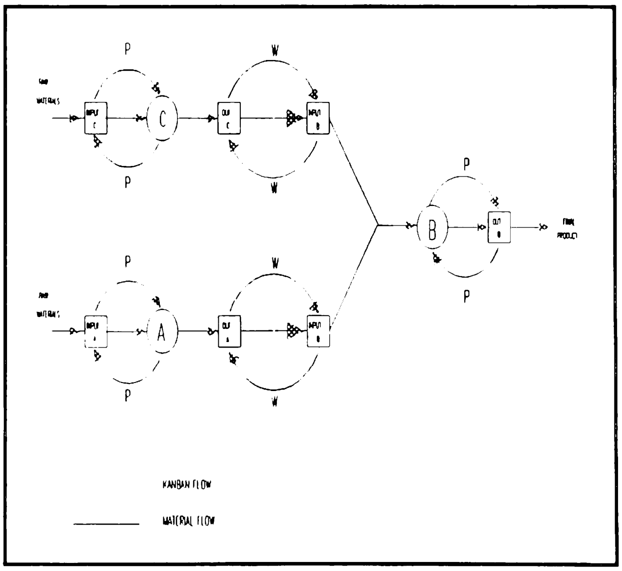

Figure 1: Kanban Production Flow

If the production rate drops at the subsequent process (B), the number of containers withdrawn from the preceding process will decrease accordingly. This causes delay at both processes A and C. On the other hand, if the production rate increases at the subsequent process, the number of Kanbans must be increased to meet the additional demand or process B will starve. Therefore, if the production rate at process B is less than the required demand, the actual number of withdrawals will be calculated based on the production rate rather than demand rate.

## 3 SIMULATION MODEL

The flow of entities from one process to another on the production floor is simulated and the model has been tested to capacity. A flow chart of the model is shown in Figure 2. The entities in the system represent containers. There are two queues associated with the Kanbans at each station. A queue holding the production Kanban cards is associated with the input containers, and a queue holding the withdrawal Kanban cards is associated with the output containers.

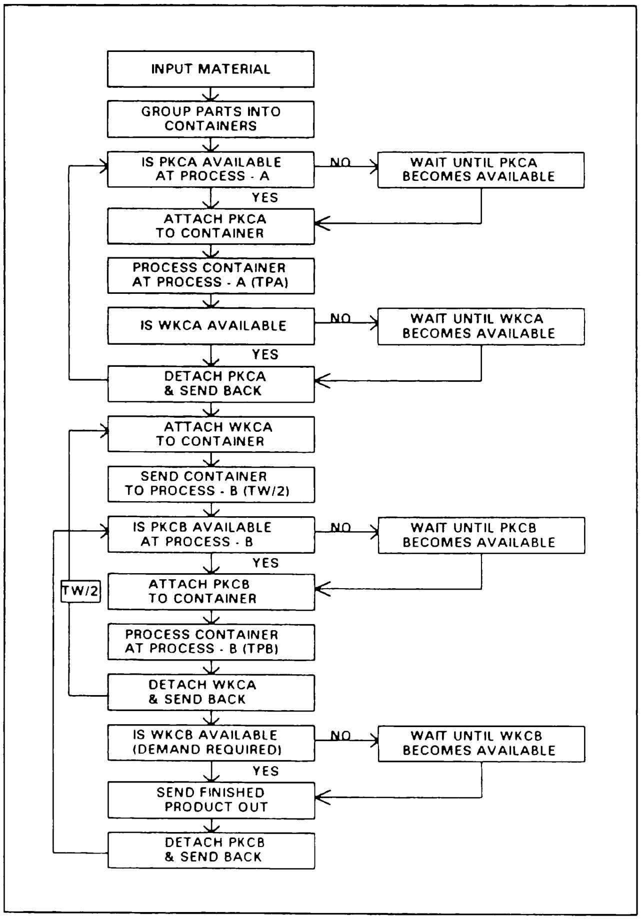


Figure 2: Flow Diagram of the Production Model

The demand is issued into the system in the form of withdrawal Kanban cards at the last stage of the production system. The maximum capacity of this demand input queue is set at 400 orders. This number forms a limit on the system when the system is operating in an inefficient manner.

The introduction of demand generates a withdrawal Kanban at process B (WKBB). The withdrawal Kanban is matched with the material and generates a production Kanban at process A (PKBA). The production Kanban is then attached to an empty container and produced at process A. The process time at A is marked as TPA. At the end of this production statistics are collected and a withdrawal Kanban card for process A is generated.

The demand is introduced into the system in the form of orders created at specified time intervals. For the sake of consistency whenever Poisson distribution was used in the simulation program, the random number stream was seeded. The same seed value were used for the different number of Kanban cards simulated to ensure repeatability and comparability of the results.

### 3.1 Production Parameters

This section contains the definition of the parameteres used in the simulation and the range of values investigated for each parameter.

#### 3.1.1 Percent Loading

Percent loading is the ratio of the demand rate to the actual production capacity of the system. The system that is loaded 100% is said to be fully capacitized. The production processes at this study were rated at 24 minutes per part. This is equivalent to 120 minutes per container, operating at 100% capacity. The percent loading on the system was reduced by decreasing the demand rate. The demand rates used in this study were 120, 126, 132, 138, and 144 minutes per container.

#### 3.1.2 Percent Availability

Machine availability is measured by how much the machines are utilized. This is characterized by machine breakdowns and production stoppage for any reason. Percent availability is a function of demand and production up time. Machine up time is referred to the productive period of the machine. As demand increases, utilization also increases. The same relationship also holds for the production up time. This study did not include the effect of breakdowns on the system's performance.

### 3.1.3 Yield

The philosophy of JIT/Kanban calls for zero defects in the production process. However, the fact remains that defects and defective products will always exist. Yield is defined as in equations (1) ans (2).

$$\text{Yield} = 1 - (\text{\# of defects} / 100) \quad (1)$$

$$\text{Yield} = \text{Probability of success} \quad (2)$$

No previous attempts has been made to look at the effects on the JIT/Kanban model as a result of producing defective products. The effect of producing defectives on the performance of the model is left for future studies.

### 3.1.4 Lead Time

Lead time or throughput time is defined as the total time required to produce a product from ordering raw materials to the completion of the final product. However, the time from when the order is placed until it is filled is considered the inventory lead time. Therefore, manufacturing lead time is the sum of setup time, process time, Kanban time, conveyance time, and the waiting time. Again, assuming that the setup time is minimized and the time to issue the Kanbans are negligible, the effect of variable lead time on the system's performance is investigated. Inventory lead times are also determined as a function of manufacturing lead times.

### 3.1.5 Batch Time

Batch time is defined as the total time required to produce the entire batch or container of products. Lot-sizes are directly proportional to batch times, as the lot-size increases, the batch time also increases. However, by reducing the setup time, smaller lot-sizes may become feasible. This increases the number of setups per production period, but reduces the batch time.

Given a batch or container of size (C), and a process time per unit of TP minutes, then the batch time is calculated as shown in equation (3).

$$TB = C \times TP \quad (3)$$

The batch cycle time (TCB) is the sum of setup time and the process time for each part in the batch or container.

$$TBC = TS + (C \times TP) \quad (4)$$

This dissertation examined the effects of the variable batch time on the performance of the Kanban system.

### 3.1.6 Cycle Time

Production cycle time is the duration of time required to process a single part for a given process or machine. This duration also includes a portion of the production setup time. Therefore, cycle time for a given operation is the sum of setup time and process time for one unit of production.

$$TC = TS/Q + TP \quad (5)$$

This study examines cycle time only through investigating batch time.

## 4 DISCUSSION OF RESULTS

The results of the study are presented and evaluated in this section. The approach taken to evaluate the simulation results of the production model and their significance is described. The main objective is to show the behavior of the inventory, in a given JIT/Kanban production system, when exposed to variation in demand and throughput. The efficiency and throughput of the system is measured and compared for various demand rates using a range of values for process times, withdrawal times, and number of Kanbans. The performance parameters measured during the study are discussed and the data is plotted.

This study examines the effect on the dependent variable as a function of two independent variables is shown using the three dimensional graphs. Three different types of graphs are presented in this paper. The three independent variables include number of Kanbans (N), time to process a container at the using machine (TPB), and the time between order arrivals (TBC). From the listed objectives for this entire study, only the results for order completion time and the average time in the system, average withdrawal time, and the number of containers completed are presented in this paper.

### 4.1 Order Completion Time

Order completion time is the average system time required to fill an order. This is an important parameter which reflects the time required to satisfy a demand for the various system configurations. It could be used to measure production rates and the ability to meet delivery schedules.

Figure 3 shows the order completion time plotted as a function of number of Kanbans and withdrawal times. This is the data for a Poisson run using TBC of 120, and TPB of 30. As shown by Figure 3, for the number of

Kanbans equal to 1, the completion time increases in an exponential fashion as a result of an increase in withdrawal time. The increase in the average times to complete an order becomes less significant as the number of Kanbans are increased. This is due to the fact that the system has more capacity, and the orders are satisfied quicker at the higher number of Kanbans.

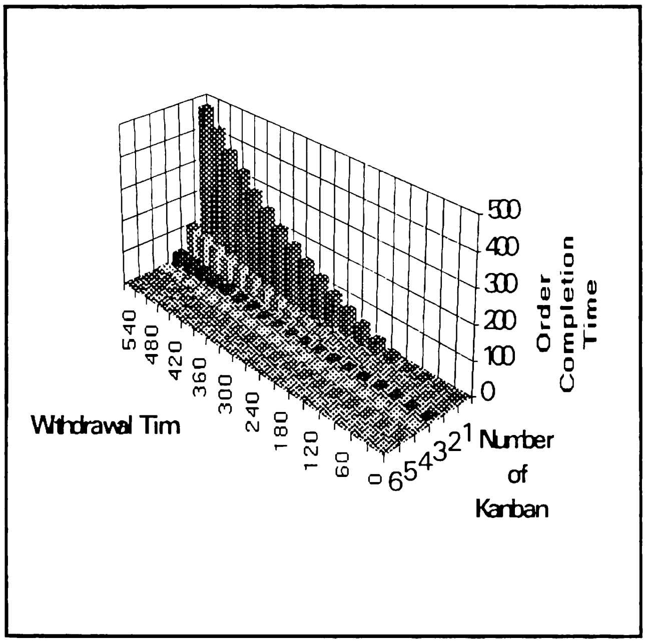


Figure 3: Order Completion Time, RUN=P, TBC=120, TPB=30

relationship of the number of Kanbans times TBC. For the values of lead time less than or equal to $(N \times TBC)$, the demand is satisfied and the order completion times are zero. However, for the lead time values greater than $(N \times TBC)$, the demand is no longer satisfied, and the average time to complete the orders increase in an exponential fashion.

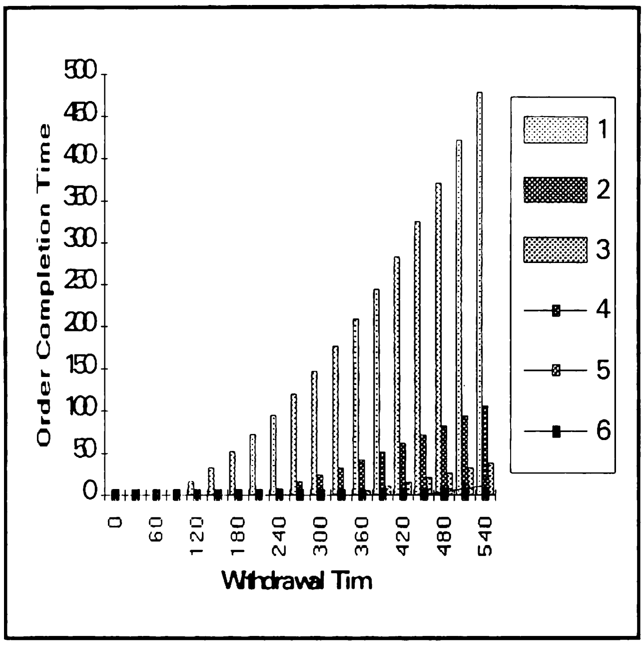


Figure 4: A Two Dimensional View of Order completion Times

For the same data, from a two dimensional point of view, the significant changes that occur by increasing the number of Kanbans are easily noted in Figure 4. Figure 4 shows the growth in completion time as a function of withdrawal time. It becomes obvious that increasing the withdrawal time has a significant influence on delivery time of the orders, especially at lower Kanban values.

Looking at Figure 3, the demand is satisfied at all the points where the completion time is zero. However, the order completion time increases exponentially for all other locations. In fact, there exist a relationship between order completion time and the independent variables involved. The points at which the demand is no longer satisfied and the order completion times start to increase, fall on a straight line represented by the Equation (6).

$$TBC + TW = N \times TBC \qquad (6)$$

The left side of above equation represents the production lead time and the right side represents the linear

This relationship between the production lead time, demand, and the number of Kanbans could be utilized to determine the allowable withdrawal times between two processes or transit times between any two locations. For example, using the production parameters specified for Figure 3 to be TBC = 120 and TPB = 30 and solving for the withdrawal time:

$$TW = N \times TBC - TPB \qquad (7)$$

The following results are obtained:

| | |
|---|---|
| N = 1 | TW = 90 |
| N = 2 | TW = 210 |
| N = 3 | TW = 330 |
| N = 4 | TW = 450 |

The above values of TW are the withdrawal times at which the increase in the order completion times have occurred in Figure 3. This relationship can also be utilized to calculate the number of Kanbans required to satisfy the demand. For example, for a demand rate of one container every 120 minutes, a process time of 30 minutes, and a withdrawal time of 420 minutes, the number of Kanbans required to fill the orders and satisfy the demand without any delay can be calculated using the following equation.

$$N = {TPB + TW}/{TBC} \quad (8)$$

Equation(8) is somewhat different than the equations used by Monden (1983, 1986) to calculate the number of Kanbnas. It allows the process time and withdrawal time to be independent of production lead time. This change in the Equation(8) is required, since the number of Kanbans needed is not only a function of demand but also a function of withdrawal time and process time.

Figure 5 shows the number of Kanbans required as a function of the process withdrawal time. By increasing the number of Kanbans one can increase the capacity of the system dramatically. Comparing Figures 6 and 7, the average time to complete the orders reduced significantly by increasing the number of Kanbans to 2. However, an increase in WIP is experienced whenever the number of Kanbans are increased.

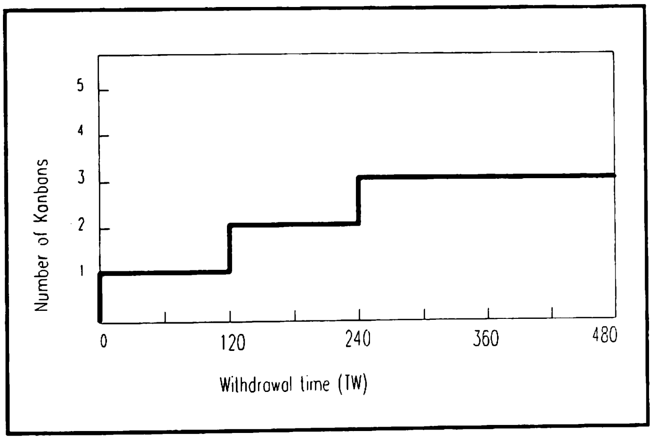


Figure 5: Number of Kanbans Required to Satisfy Demand

## 4.2 The Average Time of Parts in System

The average time of parts in the system provide us with the actual time that parts spend in the system. The results show the effects of increasing the lead time and

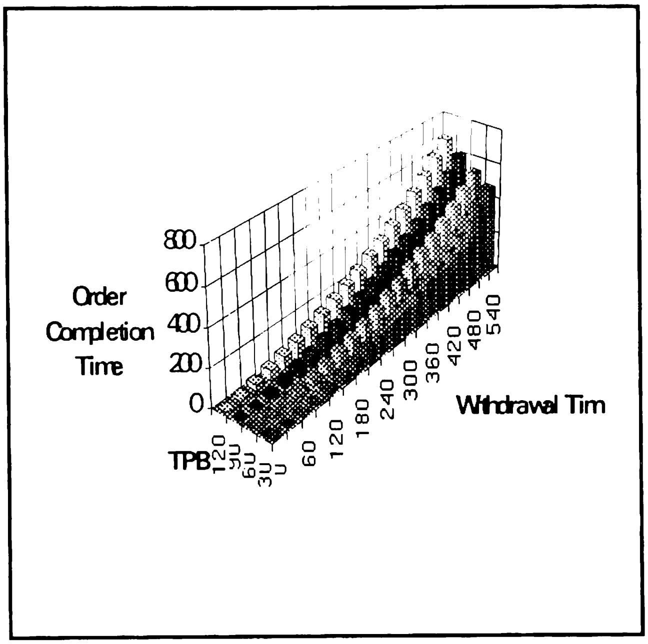


Figure 6: Order Completion Times, RUN=P, TBC=120, N=1

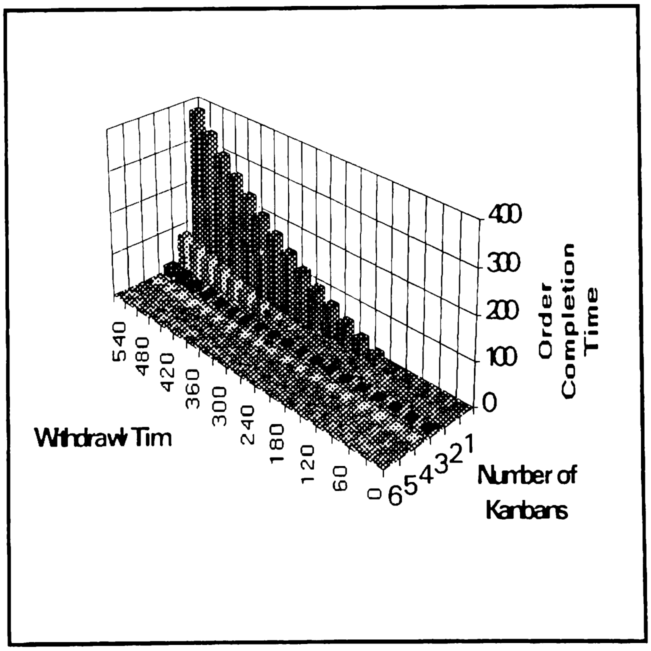


Figure 7: Order Completion Times, RUN=P, TBC=144, TPB=30

the number of Kanbans on the performance of the system. This value is important due to the direct relationship to the production WIP. The results obtained provide a tool to optimize the time parts spend in the system. Figure 8 shows the average time of parts in the system as a function of the two independent variables TW and TPB.

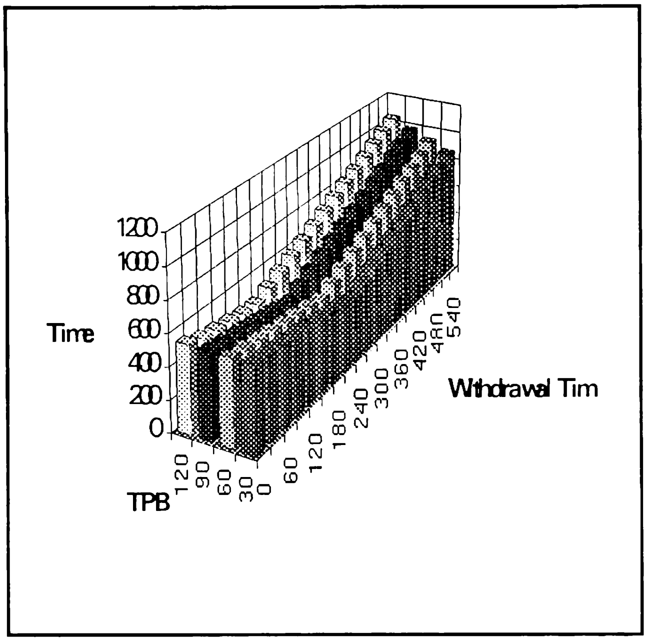


Figure 8. Average Time of Parts in System, RUN=P, TBC=132, N=2

The saddle shape curve consists of two different portions. The first portion at the lower values of withdrawal time shows the initial decrease in the time the containers spend in the system as TW increases. The second portion of the curve with increasing time values is formed as a result of an increase in the production lead times past the point of optimum capacity. The increase in either process time or withdrawal time forces an increase in the time spend in the system.

At small values of lead time the model is satisfying the demand. The point of inflection is where the lead time values are equal to the factor ($N \times TBC$). After the lead time increases above this factor for each run, the orders will accumulate in the WKBB queue. This is consistent with our previous findings about the behavior of the system in this region. The penalty for too many parts in the system at the early portion of this curve is much smaller than the penalty for too few parts.

Figure 9 shows the average time of parts in the system for N=3, as a function of processing time. Comparing the two Figures 8 and 9, all the parameters are kept the same except the number of Kanbans in the system. As the number of Kanbans are increased from 2 to 3 respectively, the point of inflection shifted further down the axis to higher values of withdrawal time. This is due to the fact that increasing the number of Kanbans resulted in an increase in the system capacity.

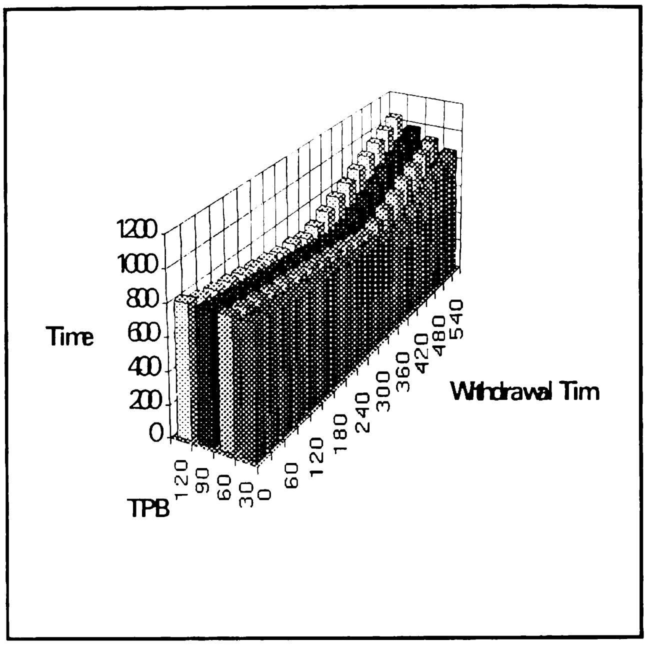


Figure 9. Average Time of Parts in the System, RUN=P, TBC=132, N=3

Figure 10 shows the effects of increasing the number of Kanbans on the time the containers spend in system. The machine process time is kept constant and equal to 30 minutes for process B. It is obvious that the increase in the time values as a result of changing N, is more significant than the increase as a result of changing the withdrawal time. At lower values of withdrawal time, the increase in the number of Kanbans will produce a sharp and linear increase in the time spent in the system. However, at higher values of withdrawal time, the increase in time spent in the system is gradual.

An increase in the process time at B from 30 to 120 has little or no effect on the model at higher values of N. But at small values of N, the model was affected by changing the process time. There exists a minimum time of parts in the system for various numbers of Kanbans and processing time at B. One can determine the optimum process time and number of Kanbans required to maintain a minimum number of parts in the system, using Equation (6). The results presented in Figure 9, can also be utilized to determine the optimum capacity required to maximize the efficiency of the system.

values increase since the model is satisfying the demand in a less and less efficient manner.

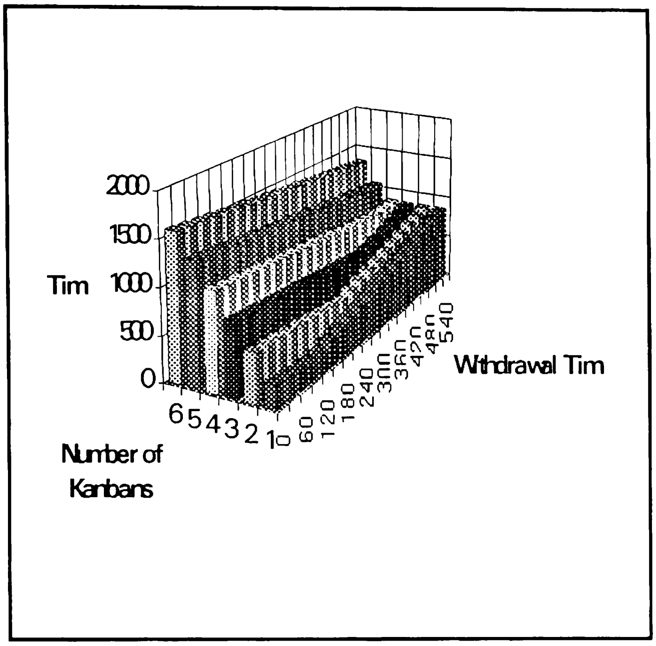


Figure 10: Average Time of Parts in the System, RUN=P, TBC=132, TPB=30

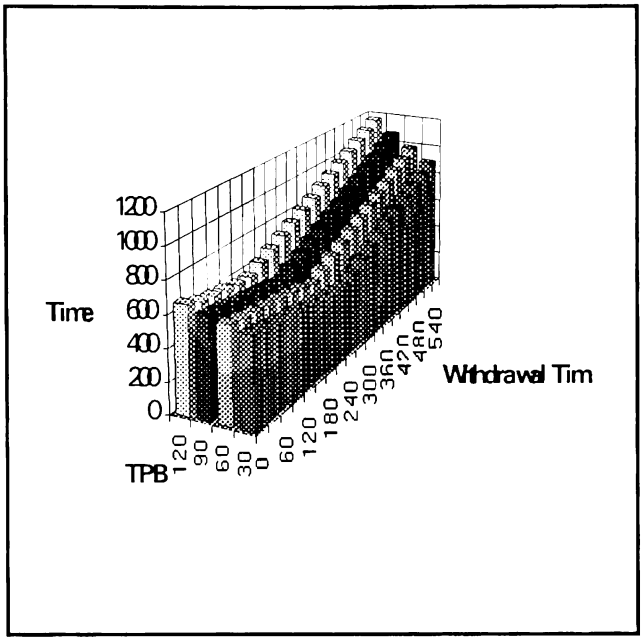


Figure 11: Average Withdrawal Time, TYPE=2, RUN=P, TBC=132, N=2

### 4.3 The Average Withdrawal Time

This section contains the data representing the time from when machine A starts processing a container until that container is ready to be processed at B. The results show the performance of the system without the order processing time, and the time variability at machine B. By eliminating the processing time variability of machine B, the values represent the average time required for parts withdrawal from one process to another.

The results are used to confirm that there exists a minimum time that parts spend in the system. This optimum value is a function of the production lead time. The optimum time value is the lowest point of the saddle in Figure 11. This Figure shows the average withdrawal times for a Poisson run. The time values presented here are a function of lead time.

$$T = f(TPB + TW) \times DemandRate \qquad (9)$$

As the lead time increases, the average withdrawal time decreases. This relationship holds true for values of lead time less than the factor $(N \times TBC)$, given in the Equation (6). However, when the lead time values are greater than $(N \times TBC)$, the average withdrawal time values increase since the model is satisfying the demand in a less and less efficient manner.

The process time at machine B has the same effect on either side of the curve in Figure 11. As TPB increases, average withdrawal times also increases. However, it is apparent that the withdrawal times between the two processes has two opposite effects on the model, on either side of the limiting factor given by Equation (6). For lead time values less than (N * TBC), as TW decreases the system capacity decreases to a point of maximum efficiency. But for the values of lead time greater than $(N \times TBC)$, as TW increases, the system capacity still decreases which decreases the overall efficiency of the Kanban process. Also, as it is shown in Figure 11, the penalty for running the system at higher values of TW is much greater than the penalty encountered at lower values of TW.

### 4.4 The Number of Containers Completed

The results describe the total count for the containers that have left the system before termination of the simulation run. The results should explain the effect on production efficiency as a function of number of Kanbans. They also provide a guide line on the number of Kanbans required to avoid exponential growth of entities in the system. The actual number of containers completed as a function of withdrawal time and number of Kanbans are shown in

Figure 12. As the number of Kanbans increases, the capacity of the system also increases. This means that more orders are processed through the system, which in turn will increase the WIP.

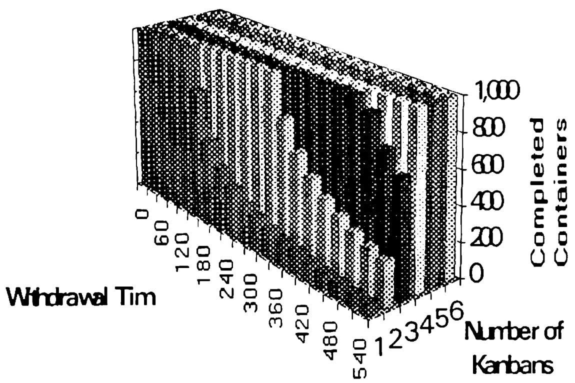


Figure 12: Number of Containers Completed, TYPE=1, RUN=C, TBC=120, TPB=30

Therefore, for lower values of Kanban, the orders are not processed as rapidly as for the larger values, due to lack of availability of containers for withdrawal from machine A. This leads to a faster build up of orders in WKBB queue. This, in turn, will terminate the simulation sooner than desired due to the third simulation stopping rule.

Less orders were completed before the maximum queue length for the WKBB was reached. This occurred as a direct result of an increase in the system time. In the case, for TW=540, increasing the process time by a factor of 4, from 30 to 120, only reduced the number of orders completed by 26%. Where as the increase in TW from 120 to 540 which is a factor of 4.5, reduced the number of orders filled by 93%.

## 5 CONCLUSION

It is concluded that increasing the number of Kanbans, increases the capacity of the system which in turn increases the number of containers completed. This approach can be used to reduce the overall floor inventory. When the number of Kanbans exceeds 4, all the orders generated are processed through the system in this simulation. For smaller number of Kanbans, the simulation is sometimes terminated when the capacity on WKBB is achieved. The termination point shows an exponential type of growth in the queue length WKBB, as the system becomes more constrained.

This paper identifies the relationship that exists between completion time of an order, the number of Kanbans, and the production process time. A point where the production system operates most effectively is also recognizes and described. This is shown by the point of inflection on the saddle shape curves presented in this study. Production Kanban withdrawal time and process time are shown to have a dominant effect on the system throughput. The deciding factor on the optimum values of throughput time for a given model is shown to be the product of time between order arrivals and the number of Kanbans. An equation is developed for calculate the number of Kanbans required, as a function of process time and withdrawal time, to meet the production demand and minimize floor inventory as well.

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