Determining Optimum Number of Kanbans for Workstations in a Kanban-based Manufacturing Line using Discrete-Event Simulation: A Case Study

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Abstract

In this article, a mathematical model is provided for optimizing the number of Kanbans allocated to each workstation of a pull-production system while maintaining a desired service level and minimum total work-in-process inventory. Discrete-event simulation is applied for solving this model. A production line with 6 workstations of a firm which is a supplier for large manufacturing companies in Iranian automotive industry is simulated. The number of Kanbans allocated to each station is set as response variables for optimization. Arena Simulation software was employed and using OptQuest tool, optimum solutions for the response values was found through meta-heuristic algorithms.

Keywords

Just in time, Kanban, Simulation, Optimization, Kanban allocation problem

1. Introduction

Just in time (JIT) production system, is one of the up-to-date planning and controlling production systems that increasingly drew the attention of engineers and managers and other relative authorities. This system can be implemented as a useful tool to reduce costs and maintain competitive advantage in the market product. One of the important aspects of this general approach is, to reduce the level of inventories and overt and hidden costs associated with them. The use of pull production system rather than the push system can be a suitable approach to implement this aspect of just in time strategy.

In the pull production system, in order to reduce inventories of the final product and inventories in the manufacturing line, the production rate will be based on the elasticity of demand at the end of the final product line. Aytug.H and A.Dogan believe that to implement the just in time philosophy, one needs to use a pull production system in which customer demand will determine the production rate (Aytug.H and A.Dogan 1998).

Successful implementation of pull production system requires an appropriate control mechanism. One of the most effective and widely used ones is the Kanban method that is also known as Kanban production Control System. The main purpose of Kanban is the same as pull production system theory that any production and shift of goods through the manufacturing line should be based on their need and use. So Kanban restrict the maximum level of Work in process (WIP) and can adjust the flow of information and materials in the production line. In this method some cards which named Kanban cards are used as a tool for transmitting information about the production and transportation products between workstations in a production line or between suppliers, producers and customers in a supply chain. Each Kanban card represents a container or a pallet of products. Controlling production process with Kanbans decreases the amount of inventory in all stages of production. In addition to calculating the required Kanbans for factories and production lines in order to implement the JIT system, the need to specify the number of Kanbans for each workstation is necessary since the impact of factors such as process times, equipment failures and etc, lead to lack of coordination between different stages of the process and shortages in stored inventory. In this paper, work in process means the number of required Kanban for each station.

Effective factors in this study are the failure of production equipments and maintenance programs, rate of waste at each station and imbalance of the production line. For example, a high failure rate or high time to repair of an equipment at a workstation, can lead to lack of semi-manufactured materials for the next station. Given the factors mentioned above, in order to achieve desired goals in JIT like inventory decline and on time demand response, the optimal number of Kanbans required for each station should be computed.

This article is trying to calculate the optimum number of work in process of a discrete line Kanban-based system with the aid of computer simulation, according to just in time philosophy. The aim is to determine the number of stored Kanbans for each workstation so that semi-manufactured materials or total Kanbans used in the production line get to the minimum amount while the service level and on time respond to the demand being maximized or maintained at a certain level. The software package used for simulation was Arena and to calculate the optimal number of Kanban OptQuest tool is applied.

2. Literature Review of the Study

In recent years some effort is done on analyzing the Kanban system and its behavior in different modes and on investigating factors affecting its performance. In a four-station production line with fix order rate, Berkley (1993) showed that the order point has a significant impact on the average inventory and production rates. Berkley (1996) has simulated a two-card kanban system with multiple part types to survey the effect of container size on average inventory and customer service levels in tandem so that total in process capacity remains that constant. Results indicate that smaller containers lead to smaller average inventories. He has also observed that smaller containers will not always lead to poor customer service levels. Wormgoor O.S. (2000) has offered an analytical model using network queuing theory for the performance of Generalized Kanban Control System and has used it for improving Kanban system in manufacturing units. A combined simulation approach (discrete event and agent-based simulation) by Qi Hao and Weiming Shen (2008) is provided to model complex systems of material handling process based on Kanban production system. Cassandras and Panayiotou (1999) have presented an algorithm that maximized output of a production line with constant demand rate, the desired process times and fixed work in process. They could determine the number of stored Kanban for each workstation. In a research which was done by N.Salvaraj (2009) in Generalized Kanban Control System (GKCS) and Extended Kanban Control System (EKCS) in a hypothetical production line with three workstations, the optimal number of Kanbans has been calculated considering three different demand rates and the average time of the whole process to be constant, with the aid of simulation and the Promodel software. Simulation is done in 2 cases, with and without failure of equipments and the number of optimimum Kanbans has been calculated in a condition that the output of production line and the utilization percentage of equipments are maximized and the work in process is minimized. In another study that was conducted by M.Sreenivasa Rao et al. (2008) a hypothetical two-stage Kanban production system was modeled which considers the demand rate and probable process time, with the help of the Continues Time Markov Chain (CTMC) and the statistical distribution of the performance measures were calculated analytically .The performance measures of considered system were included in the average output line, the average work in process and the level of service. With the help of numerical calculations and different allocation of stored Kanban for each of the two workstations, in distributions obtained from Markov chain, the amount of performance measures were calculated in different states and the obtained conclusions with the results of computer simulation were validated in the confidence level of 95%. In addition to determining the optimal number of Kanbans for each workstation, the available number of products in each Kanban (the size of each product palette) will also affect the production line ability and the respond time of the demand based on various condition. F. T. S. Chan (2001) conducted a study that surveyed the impact of Kanban size on two types of Kanban system, pull and mixed, according to the standards of production ability and work in process. P-Shahabudeen et al. (2002) have tried to offer a model based on a single-card Kanban system, with the dual objective function (bi-criteria objective function) for determining the number of Kanbans for each workstation. Furthermore, two types of simulated annealing algorithm are used in this study to find the optimum solution. A. Azadeh et al. (2005) have designed a practical model for dynamic systems in the form of just in time system. By using a case study on a production line, they have demonstrated that the actual system must be modeled and being validated with analysis of variance test, the just in time model should be designed and optimal number of Kanbans will be determined considering system's constraints. Terrence J. Moran and John Stevens (2011) used simulation to evaluate setup time effect on average WIP inventory costs comparing EPQ and Kanban system. The expected finding for the research question was that when setup times are high (greater than 30 minutes), Kanban will have lower average WIP inventory costs. It was expected that EPQ will have lower average WIP inventory cost at some setup time of less than 15 minutes. After running the simulations, they observed that Kanban outperforms EPQ at setup times greater than 12 minutes. More importantly the research gives practitioner a tool to evaluate their situation. It demonstrates the importance of kanban container size and setup time on the WIP inventory cost, which was the performance metric.

3. Kanban Allocation Problem

3.1 Review of kanban allocation problem

As mentioned earlier, one of the major objectives of the JIT theory is to minimize inventory and storage of the final products. However, its purpose to reduce the lead time should be put into consideration. In other words, these two goals are in conflict with each other since we can never eliminate the lead time and due to the importance of on time response to customer demand, the inventory cannot be considered zero. However, there are some methods for calculating the minimum amount of stored inventory. One of the main methods is the analytical formula for calculating the number of required palettes in the Kanban system. This formula which its main foundation is achieved from the theory of economic order quantity is calculated as follows:

$$N = \frac{D_{ave}(T+\alpha)}{C} \qquad (1)$$

Consider that in a manufacturing plant, lead time is equal to T and mean rate of demand for the product is equal to D_{ave} for one unit of time, then if C is considered the number of product in a pallet, the required number of pallets of product in plant, N comes from the following equation where α is the factor of certainty. The value of α is considered quite arbitrary, since it changes depending on factory conditions and management opinion of the influence of possible parameters on lead time such as equipments failure, possible process times and etc (Wormgoor O.S, 2000).

It is a naive opinion to consider that the problem of minimum determination of work in process will end here. In addition to calculating the optimum number of Kanbans in a production line, the required number of Kanbans behind each workstation of a discrete production line, should be optimized since it is clear that process times for different steps of a procedure may not be the same and constant so this can lead to shortage of inventory or much congested inventory, behind workstations. The result is lack of final product and delays in delivery to the customer or hidden costs of excess work in process. Considering these facts, we can set a new problem that is to determine the number of stored Kanbans for each workstation while minimizing the deficiency of final product and work in process.

As it was mentioned (Panayiotou and Cassandras 1999) insisted that one of the most important issues associated with Kanban system, is to determine the number of kanbans for each workstation, (Peter Kochl and Ulf Neilender 2002) have emphasized the importance of Kanban Allocation Problem (KAP) and defined it as follows:

> “ *The problem to allocate a given total number of Kanbans among the stages of a multi-stage system such that a given criterion will be optimized.”*

Many factors influence the efficiency of a production line. Some of these factors which are more important include:

- The output rate of workstations
- The capacity of the pallet
- The rate of wastage

- The logistic of factory
- The Maintenance system
- Level of maintenance inventory

Due to stochastic behavior of these factors, such as equipment failure rates, wastage rates and output rates of equipments and workstations, the need to determine optimum Kanban for each workstation is inevitable.

The intended conceptual model to solve the kanabn allocation problem is explained in next section.

3.2 Modeling

Assume SL as summation of responded demand per total demand. Equation (2) shows this variable and it is between 0 and 1. It can be named the Service Level. Lower bound of Service level is determined based on organizational policy by production management.

$$SL = \frac{\sum_{j=1}^{m} AD_j}{\sum_{j=1}^{m} TD_j} \qquad j=1,\ldots,m \tag{2}$$

Set AD_j the responded demand and TD_j the amount of demand for *j*th order, also m the total number of orders during the simulation period. In this model, the decision variable is the number of allocated Kanbans to each workstation so it is defined $WIP = [wip_1, wip_2, \ldots, wip_n]$ where n is the number of workstations. $V = [v_1, v_2, \ldots, v_n]$ is the vector that is defined in this model for representing the maximum amount of space behind the station i for accumulating Kanbans (pallets). For such a problem, different models can be defined, here we point to two specific models.

MODEL I

$$Maximize\ Z = SL \tag{3}$$

S.T:

$$wip_i \leq v_i \tag{4}$$

$$\sum_{i=1}^{n} wip_i \leq K_{total} \tag{5}$$

$$wip_i \geq 1 \tag{6}$$

Model 1 is for maximizing the service level considering the given constraints. In equation (4) v_i represents the maximum space available on each workstation. This equation makes the number of Kanbans allocated to the all stations not to exceed from that amount of space. Equation (5) limits the sum of Kanbans allocated to all work stations by total number of kanbans in the corresponding production line which is named K_{total} and can be calculated by the management and other authorities of the manufacturing plant with the aid of equation (1). For all buffers, WIP_i should be greater than or equal to 1 which is modeled in equation (6).

MODEL II

$$Minimize\ Z = \sum_{i=1}^{n} wip_i \tag{7}$$

S.T:

$$wip_i \leq v_i \tag{8}$$

$$SL \geq 1 - \alpha \tag{9}$$

$$wip_i \geq 1 \tag{10}$$

In this model focus is on the main aim of Kanban system which is reducing the work in process. The difference between this model and model I is that the objective function of model I is now a constraint in the new one. Hence according to equation (7) total kanbans assigned to workstations are minimized. Furthermore, it is easy to reach to any desired service level by setting the desired value for variable α in equation (9). Equation (8) is the same as equation (4) in the model 1.

The second model is more acceptable because the main objective of this study is to determine the optimum number of pallets stored in each workstation and it is clear that in Kanban system, as the work in process levels are reduced, we get closer to the point of just in time concept. Hence, Model II is used as prime model in this study.

Considering the effect of contingency factors on the output of the production line and the variable SL defined above, it is difficult to provide a mathematical function or equation showing the relation of decision variables (i.e. WIP's) and SL. Consequently, the Models I and II cannot be solved with analytical methods. Therefore using simulation with an optimization tool is a better approach to find the optimum solutions under such a circumstance.

4. Case Study

This research is done as a case study on one of the production lines of an automotive part supplier. The product line includes 6 workstations. The final product consists of two pieces that are assembled at the beginning of the manufacturing procedure. Factors affecting the number of stored Kanban which are considered in the research include equipment failures and the time of production process at different stations. Incoming demand from customer to the production system is contingent and has a determined statistical distribution. Customer prefers 70% of its demands to be responded on time since it can obtain 30% of the remains from other suppliers. Figure (1) shows the considered production line.

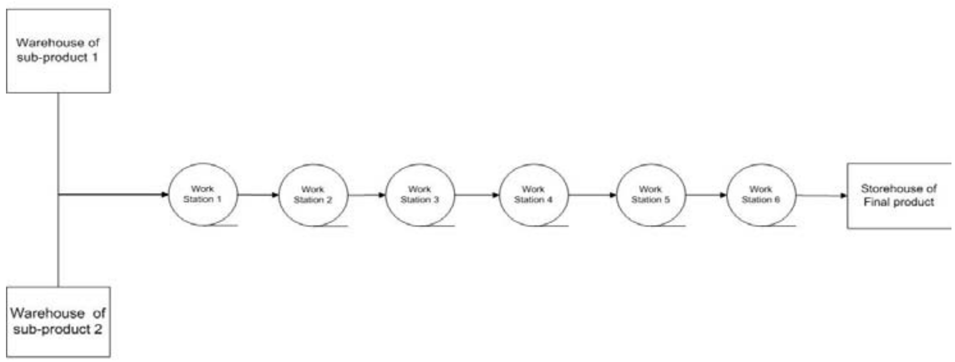

Figure 1: Production line considered for simulation

Considering the purpose of just in time system, which means less work in process, all workstations should have stock equal to one Kanban but the influence of factors such as equipment failures or bottlenecks lead to inability of production line in responding all the demands on time. It is better for workstations to have stored inventory which in Kanban system, it will be the pallets or Kanbans of semi-manufactured products, according to their need and impact they get from various factors. After simulating the production line, the impact of various production line factors on Kanban system is studied and required number of Kanbans for each workstation is calculated.

Assumptions for simulating and solving the problem of KAP in this case are:

- Inputs of assembly line, assumed always available and never faced with shortages.
- Failures in equipments have occurred only accidentally.
- Scheduled down time have not considered because they are short and negligible enough to be omitted.
- Assembly line works only from 6 am to 6 pm.
- In the system, the rate of wastage is considered zero.
- The percent of parts that needs reworking after process at some workstations is considered to be constant.
- Incoming demands to system are supposed to be always supplied completely and there are no partial responses to any demand.
- Travelling time of WIP's between stations in comparison with process time is negligible.
- The time of all processes and the amount of customer demand is determined based on the statistical distribution.

- Due date for each demand is known and has a specific statistical distribution.

In the simulation model, which is shown in figure 2, the production line is represented with 6 workstations and each of them has its time of process which follows from specific statistical distribution. The statistical distributions have been derived from data of stop-watch timing of each station using data fitting method. Raw materials which consist of 2 semi-manufactured pieces are entered to the first workstation as two distinct entities in the model and are assembled together. From this stage these two entities become into one entity. After passing all later stages, the final product is transferred to the storehouse.

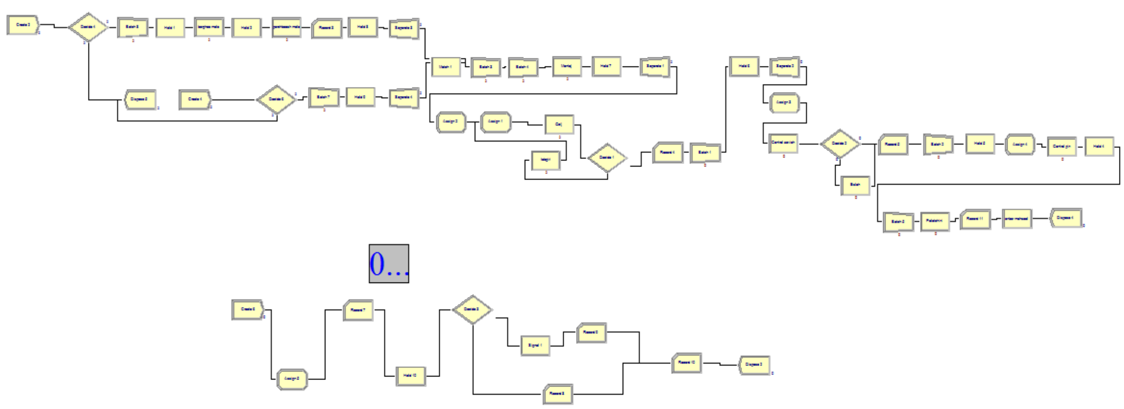

Figure 2: Simulation Model of the Kanban production line

Another part was added to this model and it is supposed to represents the demand responding procedure. Each demand possessing its own quantity and due date enters to model as an entity and after responding to it, exits from the system.

During making the structure of the model, the Kanban logic should be implemented in it. According to assumptions mentioned earlier, the condition of transferring signal from a station to another must be created. For this purpose, when the number of pallets before station *i+1* is less than it's determined number of Kanbans, then station *i* immediately starts working to compensate the amount of deficit in station *i+1*. When the stored amount of station *i+1* was completed, the station *i* stops producing until the station *i+1* again picks up specific amount of pallets from its store. This reduce in the number of pallets at each station is like a signal for the previous station and force it to start working. This logic can precisely simulate the behavior of the Kanban system.

After simulating the Kanban system in the production line, it is time to solve the allocation problem of Kanbans. In order to optimize the number of Kanbans in each workstation, there are several methods. By technological developments, different tools are presented to market to optimize mathematical models using simulation results. These tools intelligently, attempt to get the optimal solution for the model by using innovative or heuristic methods and at the same time, benefit from the simplicity of their use. Example of these applications is the OptQuest tool that will solve conceptual models which are made from variables in the simulation, by using scatter search and Tabu search algorithms, replicating the simulation a lot of times. This tool has considered variables used in the simulation model as input and output and the user can create its desired model. It optimizes any specific function of the corresponding variables subject to desired constraints.

According to this choice, OptQuest as the optimization tool that analyzes the results of the simulation runs, first the decision variables or controller for the system are selected and then the types of variables and constraints on the decision variables and the response variables are determined and finally, the type of objective function that will be minimized or maximized is specified with mathematically set of variables. An optimization by OptQuest might take a long time (several days or weeks), so the correct analysis of the simulation model and accurate selection of variables can play an important role in speeding up the optimization. Furthermore computers with high processing speed can help to accelerate the process of getting optimum results.

In designed model, the control variables are the number of pallets (i.e. Kanbans) that are stored as a buffer behind each station and the number of pallets of final product in the storehouse. Response variables are total number of demands that are placed to system and number of them which are responded on time. The only constraint that is applied in this model is the lower limit for the service level which is considered 70% here.

The objective function is the minimum of total kanbans allocated to each work station and storehouse of final product. After the model fully defined, the simulation has been runned and the OptQuest tool started to provide solutions. As mentioned earlier, this tool can provide good results, but not an optimum ones since it applies heuristic and meta-heuristic methods like Tabu search.

5. Computational Results

The model simulates 1 year of the plant and warm up period has been considered 5 days. For optimization, 1550 different combinations, each with 8 replications, have been performed, and took 72 hours. Initial value for summation of WIPs has been determined 60 and after optimization the value reduced to 43. Results can be found in Table 1.It illustrates five best solutions of the number of Kanbans for each workstation and storehouse, ranked based on their total number of Kanbans from 1 to 3. Optimal convergence diagram for this optimization is illustrated in figure 3. This diagram is displayed by Optquest tool during the simulation runs and optimization. The horizontal axes represents the number of combinations that are checked by Optquest while the vertical one shows the best answer for total number of kanbans calculated, after checking corresponding number of combinations.

Table 1: five answers of the best solutions offered by OptQuest

	Ranked solutions	Rank 1	Rank 2		Rank 3	
Number of Buffered Kanbans for each Station and Storehouse	Station 1	1	2	1	2	1
	Station 2	1	1	1	2	1
	Station 3	3	3	4	2	3
	Station 4	2	2	2	2	2
	Station 5	1	1	1	1	1
	Station 6	3	3	3	3	5
	Storehouse	32	32	32	33	32
Total Number of Kanbans		43	44	44	45	45

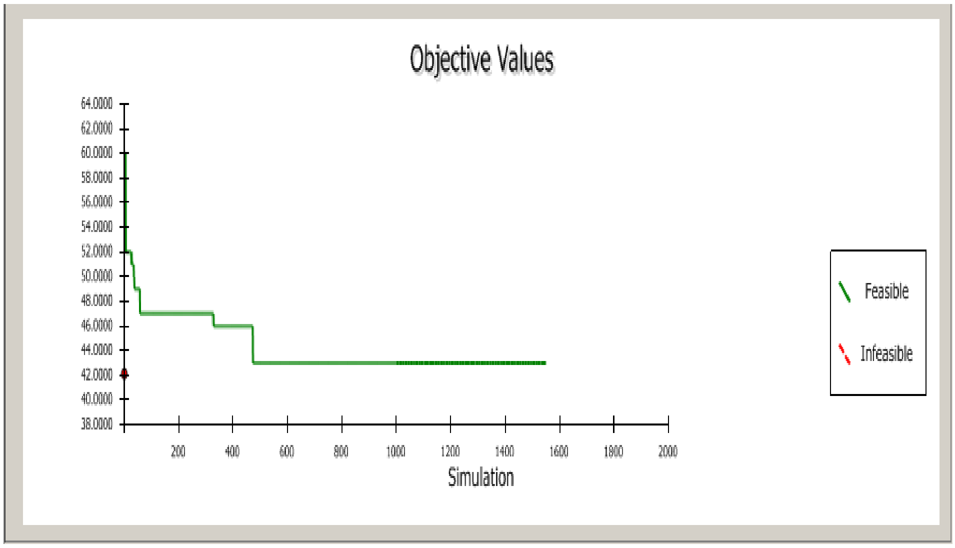

Figure 3: optimal convergence diagram from implementation of Optquest

6. Conclusion and Suggestions

Since the just in time theory is considered one of the most practical methods of producing, paying attention to how it is implemented and a detailed look into the structure and methodology of it, is very important. We can point to Kanban as one of the implementing tools for JIT that its main purpose is to reduce work in process and to maintain the desired service level that can be obtained, by exact estimation of the number of allocated kanbans stored behind each workstation. For this purpose, there are many methods for estimating the optimal number of stored inventory at each workstation.

In this study, a conceptual model was developed for Optimizing the optimal number of Kanbans allocated to each station. In order to test and implement this model in the real world, an automotive part manufacturer was considered as the case study. The company's Kanban system was modeled with Arena simulation software and by Using OptQuest tool we found that total number of Kanbans can be reduced from 60 to 43 subject to considered constraints. The obtained solutions indicated the ability of this method to solve KAP problem.

Given this complexity, the use of simulation to reduce work in process, is an appropriate approach in Kanban system. Using designed models in Optquest tools, we can calculate the lowest amount of work in process and also compute the optimal allocation of inventory behind each workstation with maintaining the desired service level and help to smooth the flow of materials in the production line while other variables such as service level and restrictions like storage space and space allocated to storehouse can be considered in different conditions. The obtained answers implies the possibility of optimizing the real world problems or more broadly in the supply chain between suppliers and customers and providing an optimum Kanban system in a production line or a firm and it is a good contribution. However, due to the low-speed personal computers and increasing complexity of designed model, there are still significant limitations to perform a comprehensive simulation and optimization for industrial authorities.

In this paper, we have provided a model to calculate the lowest inventory with regard to the service level and semi-manufactured material storage limitations, by using simulation and optimization tools. However, it is possible to do further analysis by other models that obtained from the production line. For example, in the model we can also consider the wastage rate of machines and do the optimization on this basis. The effect of shortages of raw materials and their input rates into the system can also be investigated further in Kanban model and supply chain. Another analysis can survey the effect of pallet size, in a Kanban system and work in process because by decreasing this variable, the output rate of production line is increased.

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