



Optimal Kanban Number: An Integrated Lean and Simulation Modelling Approach

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Abstract: Kanban is credited as a major means to controlling the inventory within a manufacturing system. Determining the optimum number of Kanban is of great interest for manufacturing industries. To fulfill this aim, an integrated modelling approach using discrete-event simulation technique and Kanban Lean tool is developed for a pull system ensuring an optimum Kanban number. This research has developed a base-case simulation model which was statistically validated using ANOVA. Initial Kanban number obtained from the mathematical model of Toyota motor company is used to obtain initial results. A Kanban integrated simulation model is developed that employed the idea of pull system that required the arrival of a customer for a product and Kanban pair to proceed through the production steps. The Kanban-Simulation integrated model is further used to test the effect of different Kanban numbers to obtain the best value of Kanban which is selected as 275. This approach has been applied on a case company involved in the manufacturing of agricultural and construction metal hand tools. The optimum Kanban number is selected by simulating the model about three performance indicators: customer waiting time, weekly throughput, and Work-in-progress. The analysis of the results obtained from the proposed integrated Kanban-simulation model showed a 76.7% reduction in the inventory level. The integrated Kanban-simulation model has also given a minimum customer waiting time of 0.84 Hrs. and a maximum throughput value of 737 Pcs of shovels. The integrated Kanban-simulation model is useful for manufacturing industries working to avoid overproduction waste and greatly reduce inventory costs.

Keywords: Kanban, Discrete-Event Simulation, Optimization, Production Performance

1. Introduction

Just-in-time (JIT) is probably one of the renowned contributions of Toyota Production Systems (TPS) that has captured the attention of organizations. It relates to the removal of inventory wastes which in turn affect all other wastes in the production system [1]. The Kanban system is one of the major means to realize the philosophy of JIT by initiating production or retrieving the necessary items in the required amount at the right time [2]. Kanban as a sub system of JIT serves to control inventory levels, production and supply of raw materials with the objective of minimizing work-in-progress (WIP) and total cost of inventory [3]. Kanban system requires containers to be associated with

Kanban cards containing production/supply of parts information at each stage. The level of inventory for each part at each station is decided by the Kanban number [4].

The implementation of Kanban is accompanied by the important consideration that calls for detailed design of processes, standardization of the operations and smooth production [1]. Within the main objective of maximizing the productivity of a manufacturing facility, reducing the idle time of a process receives much emphasis [5]. The possibility of enhancing Kanban system by integrating it with other tools such as discrete-event simulation (DES) and optimization tools is a burgeoning field of interest [1, 2, 6, 7].

In this research work, simulation modeling techniques are used to analyze the optimal Kanban numbers for a metal tools factory and select the option that projects improved

efficiency through decrement in customer waiting times, decrement in WIP and increment in throughput of a manufacturing facility. Output data from the simulation model runs are tested using the analysis of variance (ANOVA) to verify and validate the simulation model against the base-case scenario. The research investigated how simulation modeling technique can be integrated with Kanban system to improve the productivity of the system. The research work addressed the following points.

- a) To collect and analyze data.
- b) To build the base-case simulation model, verify it and validate it using ANOVA by testing the null hypothesis.
- c) To create an integrated Kanban-based simulation model.
- d) To investigate and select the best model projecting the best Kanban number.
- e) To examine the performance improvement of the upgraded system.

The remainder of this paper is structured as follows: section 2 presents review of related literature, section 3 describes the methodology used for integrating simulation tool and Kanban, section 4 analyzes the simulation model and selects optimum Kanban numbers for the case under consideration, section 5 evaluates the performance improvement achieved in the integrated approach, and finally section 6 presents the conclusion.

This research would be beneficial for manufacturing facilities and decision-makers who are interested in reducing inventory cost through the design and implementation of the integrated Kanban and simulation modeling approach.

2. Literature Review and Hypothesis

The objective of this research is to use an integrated simulation and Kanban-based approach to determine the most suitable model that leads to improved efficiency of the case company. The research work analyzed the effect of Kanban decisions on customer waiting times, WIP and throughput of the manufacturing facility.

2.1. Kanban-based Manufacturing

The Kanban system through utilization of cards for withdrawal, store and different signs, creates a smoother flow of the processes in a production system limiting work-in-process inventory and ultimately reducing overload in manufacturing systems [8]. Naufal uses a two-card Kanban system, which are (the Production instruction Kanban (PIK) and the Production withdrawal Kanban (PWK)) to design a Kanban system with the aim to improve Lead time, WIP, finished goods inventory of a manufacturing industry [9]. The PIK contains the work instructions indicating the type of product and quantity to manufacture while the PWK specifies the quantity of product that is required to identify what the next process must withdraw [3]. Triana and Beatrix use a Kanban system for sports shoe manufacturing company and have used master production schedule diagrams in the methodology to show information flow and material flow [10].

2.2. Tools to Determining Optimum Container Sizes and Kanban Numbers

Control cards (Kanban cards, Conwip cards, etc...) in a pull driven system, are major parameters that must be taken into account when considering efficient production flow [11]. To model behavior of production systems and determine optimum number of Kanban cards, simulation tools, mathematical programming, stochastic modeling tools and Markov process are often used [8].

Naufal analyzes optimum number of Kanban and its effect on manufacturing performance using customized mathematical model of Toyota to attain the reduction of product lead time by 36% and inventory on the floor by 81% [12]. Dimitrescu [13] and Adnana [14] analyze implementation of Kanban system for manufacturing process in a bicycle manufacturing company and a real case manufacturing plant respectively by using mathematical model.

Yousefi applies DES with optimization software to optimize the number of Kanban for each respective workstations to arrive at minimum work-in-progress inventory [15]. Ezema analyses the design of a single card Kanban system in a drug manufacturing plant assisted by a simulation tool and iso-curve mapping method to determine the loop variants, which optimize total inventory levels [16]. Azadeh applies integrated computer simulation tool to develop a practical optimum JIT dynamic modeling. Analysis of variance (ANOVA) was utilized to investigate the behavior of the production line against the simulation model for verification and validation purposes. A practical optimum JIT simulation model is set utilizing Kanban-based production modelling technique for non-JIT systems. Bottleneck analysis and line balancing techniques are used for JIT systems [17].

According to Azadeh, conventional JIT approach is mostly applicable to static production systems. A dynamic production system requires Kanban and a more integrated approach of applying simulation modeling [17].

2.3. Integrated Simulation- Kanban Tools

Many researchers have investigated the possibility of integrating Kanban systems with DES to enhance the benefits obtained from Kanban system to improve on production efficiency. Golchev uses simulation model to simulate different production scenarios and select optimum capacity of Kanban container that gives improved throughput [1]. Schindlerova applies simulation tool to a production process to obtain optimum number of Kanban circuits using production time and size of inter-operational supplies as KPIs (key performance indicators) [18]. Tosanovic utilizes simulation tool towards comparing the performance of different pull control mechanisms which includes Conwip, Kanban, Hybrid Kanban/Conwip, Drum Buffer Rope (DBR) and their effect on lead time in different production conditions [11]. According to Hao [19], Kanban researches are divided into areas: synthesis and analysis. The synthesis

approach aims at designing new Kanban system that fulfills predefined conditions using analytical mathematical models. The analysis approach which deals with performance analysis of Kanban systems, looks at structural deviations using typical measurements such as throughput, WIP, buffer size and average flow time. Since the system is complex and dynamic, simulation is by far the methodology of choice for studying the analysis aspect.

Hence, this research paper investigates the combined use of mathematical model and simulation tool integrated with Kanban pull control mechanism for designing and analysis of Kanban for dynamic systems. This research aims to bridging the gap and hence focuses on the application of simulation tool to capture the dynamics of the production system, and to create pull instigated Kanban models to select optimum Kanban number. The simulation part has further projected the improvements obtained from the designed Kanban system. The analysis of variance (ANOVA) is presented thereafter to verify and validate the simulation model. The commercial package Arena was used in this research.

3. Research Methodology

This research investigates the integrated use of simulation tool with Kanban models towards attaining improved production performance. ANOVA is employed to verify and validate the simulation models. The research methodology is outlined in the following paragraphs and summarized in Figure 1 below.

Study the process flow and Value stream map: The research carefully considers the value stream map (VSM) of the case company's selected product for the study. Data such as cycle times, work-in-progress between workstations, and respective workstation uptimes are obtained from the value stream map. Weekly throughput is collected from production records.

Develop conceptual model of the system: The conceptual model of the existing system is constructed by carefully observing the material flow sequence as shown in the process flow chart in Figure 2.

Develop simulation model: The simulation model is developed following the system logic. Data collected from the production process are entered into Arena input analyzer to determine the best fitting probability distribution.

Verify and validate the simulation model: The behavior of the production line was examined against the simulation model by applying ANOVA, considering a 95% confidence level for the t-test. Results obtained are used to ascertain that the simulation model is representative of the actual production system. Weekly throughput is selected as performance measure to validate the simulation models.

Develop integrated Kanban-based simulation model: The base-case simulation model is transformed to integrated Kanban-based simulation model. The model considered the random distribution of customer arrivals and subsequent pull system for the movement of materials through the processes.

Determine optimum Kanban number: The effect of

varying Kanban number against selected performance measures such as customer waiting time in the system, WIP and weekly throughput are tabulated to decide on the optimum Kanban number.

Result analysis: The production performance from the optimum Kanban model is analyzed and improvements are discussed.

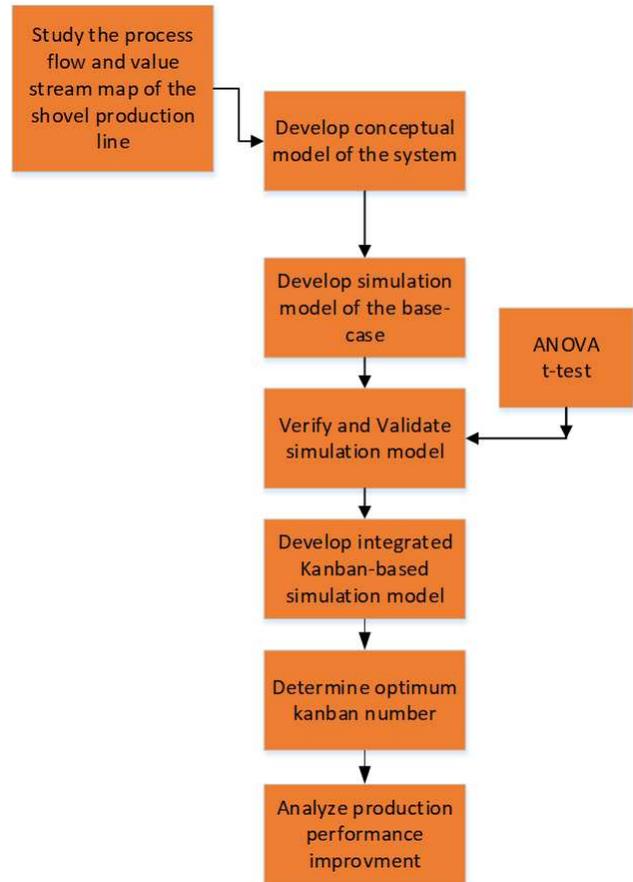


Figure 1. Research methodology.

4. Case Study

4.1. Profile of the Case Company

The research was conducted in a metal tools factory located in Ethiopia. The case company in consideration is engaged in manufacturing of construction and agricultural metal hand tools. Decline in profitability and market position has induced the company to adopt improvements in the production processes. The research focused on determining the optimum number of Kanban by the application of simulation tools to attain reduction in WIP and other inventories. One of strategic product line identified by the case company, namely the Shovel production line that accounts for 63.04% output by volume of sales, is considered in this research work.

4.2. Shovel Production Process

The shovel production process has its own dedicated

machines in the hot forging department of the company. The process starts by cutting sheet metal rolls into parallelogram shapes using the shearing machine. Each cut piece yields two shovels. The cut pieces are passed to a blanking machine that cuts the shovel profiles off the sheets. These parts are passed to a punching machine where three identical holes are punched to install the wooden handle later to the shovel. These cut shovel profiles are placed in batches of 200 pieces (Pcs) in the heating furnace. The heated pieces are removed

three to four pieces at a time from the furnace and passed to the forming press that gives it the basic form of shovel. The curling machine then curls the fixture for the handle. Finally, the company logo is stamped, and 200 pieces of shovel are collected and passed to a rambling step that removes soot and scabs that have formed from the heating furnace step. The last step is dip painting of each piece and hanging them to dry and transferring them to the finished product store. The simplified process flow is shown in the below Figure 2.

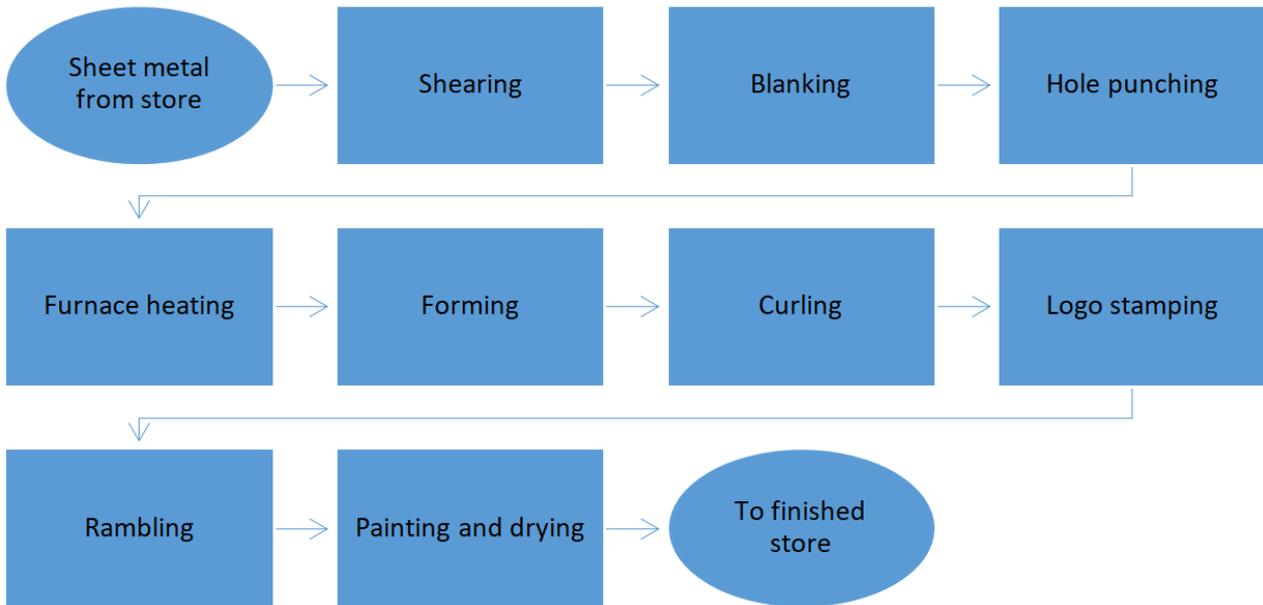


Figure 2. Process flow of shovel production.

4.3. Base-case Simulation Model Design and Validation

4.3.1. Simulation Model

The simulation model is constructed using Arena software 14.00.000001. The model has the following assumptions:

- a) The production line operates 8 hours a day in a single shift, 6 days a week.

- b) Scheduled stoppage of machines for programmed maintenance is not considered.
 - c) The transportation time between any two neighboring stations is assumed negligible in comparison to the process times.
 - d) Number of rejected products is considered negligible.
- The base-case simulation model is shown in Figure 3.

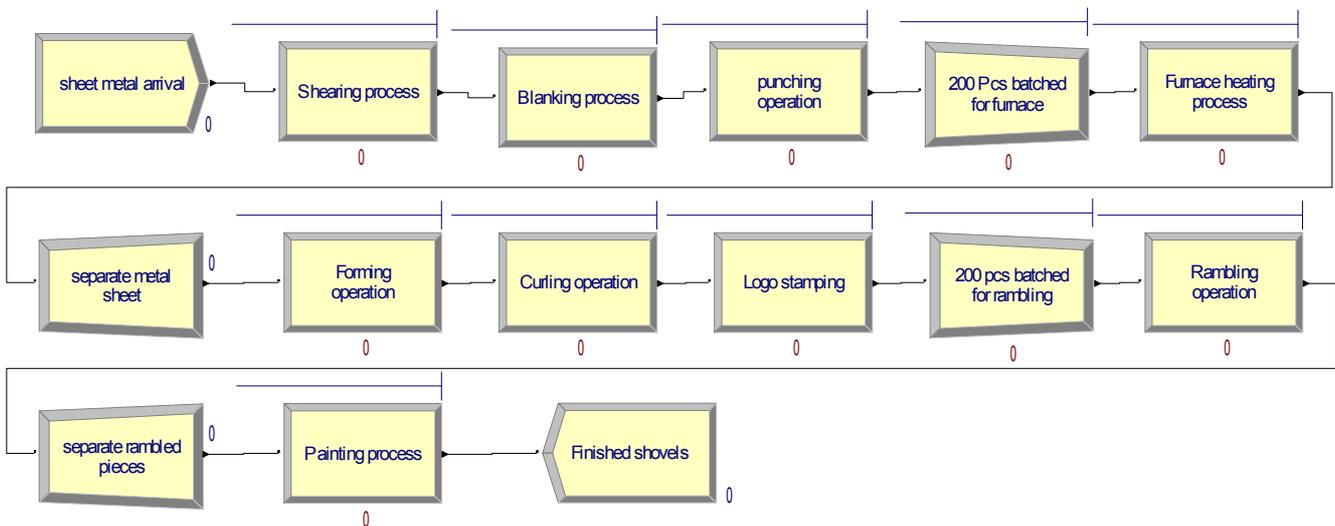


Figure 3. Base-case simulation model.

4.3.2. Processing Times

Arena input analyzer has been utilized to determine the distribution functions for processing times, machinery downtimes, machinery uptimes and raw material arrival times. The distribution functions and expressions are given in Table 1. Raw material inter-arrival times for shovel production follow an exponential distribution with mean 60 (Expo (60)) minutes. Run length is 48 hours and number of replications is 15.

Table 1. Distribution functions.

Process	Base-case model expression (minutes)
Shearing	5 + EXPO (7.5)
Blanking	10 + LOGN (15.5, 3.15)
Punching	TRIA (10, 12, 12.5)
Furnace heating	TRIA (34.5, 35, 36)
Forming	TRIA (7.26, 12.4, 17.8)
Curling	5 + WEIB (7.09, 1.67)
Logo Stamping	5 + 5.58 * BETA (7.01, 1.41)
Rambling	TRIA (55, 60, 65)
Painting	10 + 9 * BETA (14.5, 2.49)
Machine failure	0.999 + EXPO (19.8) (Hours)
Machine uptime	TRIA (125, 184, 191) (Hours)

Determining the warmup period for a simulation model is important to remove the initial bias because of the transient

state and to consider steady-state results [20, 21]. Based on the method given by Kelton [22], a single overall output measure is established. In this case, total WIP is tracked overtime as time- persistent data. The WIP curve is tracked during the simulation run and Arena's output analyzer is used to indicate when the curve is stable. The transient state is clearly discerned from the steady state in 4 hours from start of the simulation and hence taken as the value for the warmup period.

4.3.3. Simulation Model Verification and Validation

Logical connection between components, namely create entity, setting processing stations and batching stations of the model is made closely representing the product flow chart. The Arena software is used to debug the model making sure that the logical connection is implemented, and mistakes are amended. To validate the model, one way ANOVA test is conducted using SPSS 16.0 software. Throughput values collected from the existing shovel production line and output data from simulation model are taken as a dependent variable. The method that generates the output data is taken as a Factor that causes variation in the dependent variable. Hence in this case, the simulation model is tested against the existing shovel production line for significant difference. The output from the ANOVA test is shown in Table 2.

Table 2. ANOVA result table.

ANOVA					
Throughput	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	68640.833	1	68640.833	.089	.768
Within Groups	2.164E7	28	772735.376		
Total	2.171E7	29			

The test shows that there is no significant difference between the current production line and the simulation model at 0.768; i.e., significantly greater than $\alpha = 0.05$. Hence, the null hypothesis is accepted, and the simulation model is deemed representative of the current state production line. Improvements in the base-case are added to the simulation model and final Kanban-integrated simulation model is developed as described below.

4.4. Kanban-integrated Simulation Model

4.4.1. Method for Kanban Development

Golchev, Naufal and Triana have used the following steps to develop the Kanban model for manufacturing systems [1, 9, 10].

- Gathering relevant parameters
- Calculating temporary number of Kanban.
- Establishing the pull mechanism and rule

Relevant parameters such as cycle times, replenishment times, weekly demand and production output data were utilized to calculate the temporary number of Kanban. The data is collected from the production floors and by referring to production records. A single card Kanban system is considered to be adequate for the case being studied since the distance between workstations is reduced in the modified

layout to allow a single buffer to serve all the workstations. According to Kumar [23] the formula developed by Toyota Motor Company for determining the Kanban number is used to calculate the temporary Kanban number as shown in Equation (1).

$$K \geq \frac{DL(1+\alpha)}{C} \quad (1)$$

Where

K is the number of Kanban

D is the demand per unit time

L is the Lead time

α is the safety factor

C is the container capacity

In calculating the temporary Kanban number, the average demand is taken as 674 Pcs/week. The lead time considered consists of production time, waiting time, planning time and delivery time. As part of the effort to remove batch operations, induction heater is introduced that instantaneously heats up single pieces to prepare for the forming operation without the accumulation of 200 pieces to conduct this process step. Similarly, it has been recommended that the rambling process be replaced with mechanical polishers to remove soot and scabs on

individual shovels. These recommendations help remove the batch movement of work pieces and hence the

accumulation of WIP. Accordingly, the adjusted Lead time is given in Table 3.

Table 3. Shovel production Lead Time.

Production time	Waiting time	Planning time	Delivery time	Total Lead time
14.0 Hrs.	2.00 Hrs.	6.0Hrs.	1.0Hr.	23.0Hrs.

Considering a safety factor of 5% and container capacity of 1 shovel, the temporary Kanban is calculated as 340 Kanban. Once the temporary Kanban number is set, the pull mechanism is established, and an integrated Kanban based simulation model is developed based on the validated base-case model that gives differing performance outputs for different Kanban values.

4.4.2. Modified Kanban-integrated Simulation Model

The Kanban integrated model as seen in Figure 4 uses the Match module to integrate the raw material arriving to the free Kanban cards originally introduced into the system at a fixed number. The model generates pull system fulfilling the requirement that a customer must arrive at the system for a product and Kanban pair to be matched to a newly arriving customer and proceed to the next step. This leads to the

Kanban cards to be freed and routed back to Kanban collection station to start the process again. If no customer is introduced into the system, the process proceeds and accumulates at the second Match module until all the originally introduced Kanban cards are exhausted. In this experiment, Kanban numbers varying from 50 to 400 are inserted and the simulation model is run in 15 replications with a replication length of 48 Hrs. and warmup time of 4 Hrs. Customer waiting time is selected as the primary performance indicator of the model to select the optimum Kanban number. This is based on the organizational policy of the company that gives higher priority to customer satisfaction. As a secondary and tertiary performance indicators, weekly throughput of the model and WIP is used to evaluate which Kanban number leads to optimum result.

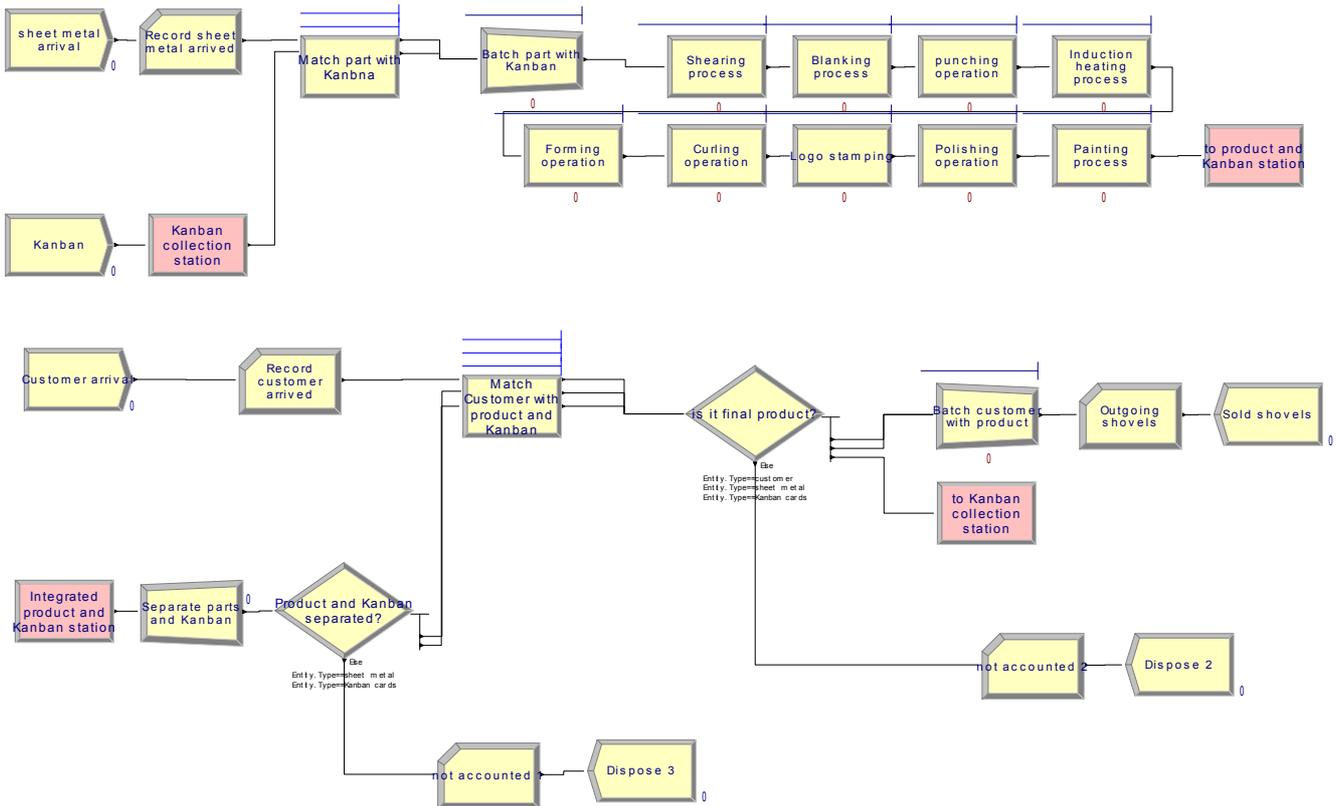


Figure 4. Kanban-integrated simulation model.

Customer waiting time, weekly throughput and WIP are plotted against varying Kanban numbers in Figure 5. The results from the Customer waiting time plot against the Kanban number shows both 275 and 300 Kanban number give the minimum customer waiting time of 0.84Hrs. The

throughput plot gives maximum throughput value of 737 Pcs for both 275 and 300 Kanban number. 275 Kanban gives a slightly lesser value of 323 Pcs for WIP while 300 Kanban gives 344 Pcs.

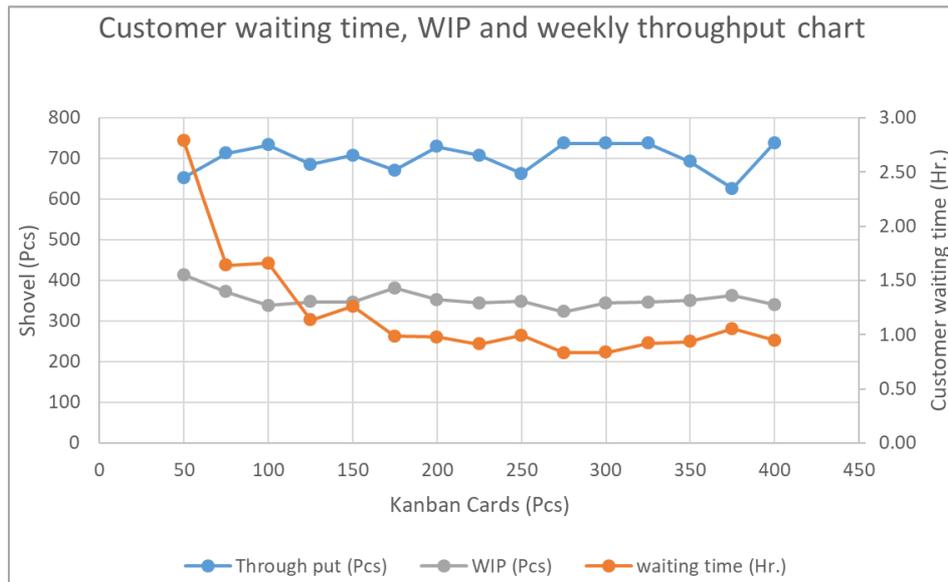


Figure 5. Customer waiting time, WIP and weekly throughput chart.

Many of the Kanban cards number show closer performance output results. But, since 275 Kanban number gives the lowest value of customer waiting time and WIP, and the highest value of throughput, it is taken as an optimum value for Kanban cards number.

5. Performance Improvement Achieved

The introduction of Kanban- simulation integrated system has a major advantage in the reduction of overproduction waste. In the base-case model, production started and proceeded to making finished products without the arrival of customers. What was produced was stored to wait for a customer. Hence the system was operating in a push mode. In the Kanban-simulation integrated model, the arrival of a customer is a key aspect for the product to proceed to the finished store. The amount of product produced is exactly set by the number of customers arriving at the system. This feature makes it to be a pull system. If the same number of customers arrive to the two models, the inventories accumulated in the base-case model and in the Kanban-integrated simulation model (operating with 275) Kanban are compared and is shown in Table 4 below.

Table 4. Performance comparison of the simulation models.

	Base-case model	Kanban-simulation integrated model
Throughput	2060 Pcs	737 Pcs
Customer demand	687 Pcs	687 Pcs
Over production	1373 Pcs	50 Pcs
WIP	227 Pcs	323 Pcs

From table 4, the Kanban-simulation integrated model has lesser inventory in the system giving a 76.7% reduction in inventory from the base-case situation. The result shows fewer parts are produced that are not currently demanded by the customer termed as overproduction waste and hence a

much lesser cost from unnecessary inventory present in the system. The WIP observed in the Kanban-simulation integrated model is due to completed parts waiting for the arrival of customer at the last Match module. Originally inserted Kanban numbers into the system leads to the production of the WIP. Hence, the finished products produced wait for customers to be matched with until the Kanban introduced are exhausted.

6. Conclusion

In this research work, the use of simulation tool towards identifying an optimum Kanban number for the manufacturing case company was investigated. Customer waiting times, throughput rates and WIP were considered as main performance indicators following closely with the interest of the case company. Hence, primarily a base-case simulation model was prepared and statistically validated for conformance. Secondly, suitable Kanban pull system was integrated into a simulation model to attain future state simulation model that removed the major wastage of overproduction from the system. Lastly, by using the temporary Kanban number obtained from the mathematical model of Toyota motor company as a starting point, the effect of different Kanban numbers on the key selected performance indicators were analyzed. Hence, 275 Kanban is selected as an optimum value for this system assuring minimum customer waiting time, minimum WIP and maximum Throughput. The performance improvement from the upgraded system removes the creation of overproduction wastage but at the same time, guarantees enough parts waiting in the system to handle any spikes that can regularly occur in real world situations. The research work has endeavored to show the significant performance benefits that can be attained through the integrated use of simulation with Lean tools, in this case the Kanban tool.

The Kanban-simulation integrated model can be readily adapted to fit different manufacturing situations and assist managers to implement pull mechanism for the efficient movement of inventories. Once the initial Kanban value is calculated from the mathematical model, different values of Kanban can be inserted into the simulation model and the best Kanban number selected that would lead to reduced inventories in manufacturing facilities.

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