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Manufacturing system optimization using computer-based control kanban loops

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Abstract

The study assessed manufacturing system optimization using computer-based control kanban loops. The study assessed JIT's effect on average throughput-time, demand fill rate, net operating income for a certain product mix complexity and manufacturing overhead level. ARENA/SIMAN and WITNESS simulation tools were used to study implementation. The Drug Process Plant's JIT system reduced end buffer inventory, shortened customer lead time, and improved visual control. The mean response of the simulated new physical system in terms of NOI was 85.54 but gave a mean response of 85.30 when implemented on the shop floor. The mean response of the simulated new physical system in terms of cycle time was 617 but gave a mean response of 634 when implemented on the shop floor. Simulated new physical system in terms of DFR gave a mean response of 93.11 when implemented on the shop floor. Overwhelmingly, the new JIT system outperformed the old physical system.

Keywords: Code generation; Kanban rule; Arena interface; System performance; JIT system model

Introduction

Johel Drug Manufacturing Process Plant makes many products. This cause longer wait times and more scheduling and resource allocation work at manufacturing facilities. Most items spend 76% of their throughput time waiting or queuing. Due of limited space, WIP is on conveyors. This makes checking item status and quantity difficult. No permanent placement for conveyors also reduces inventory awareness (Deming and Edwards, 2016). To improve inventory status and location, a more visual system should be implemented.

The production process in the Drug Process Plant was conducted by the MRP system. This caused the Drug Process Plant to hold surplus completed goods. The Drug Process Plant must implement JIT to solve this problem. Due to uncertainty in customer order timing, processing time, rework, and scrap rate, inaccuracy in demand forecasts, and equipment failure, manufacturing activities are deemed stochastic (Agrawal, 2010; Crandall and Timothy, 2013; Ahmadi *et al.* 2020). All organizational units and levels, especially the Drug Process Plant, are affected.

In the evaluated studies on JIT production systems, the constant demand optimization model is inadequate when the supply chain system confronts time-varying demand (Ezema *et al.* 2017a).

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If the supply chain system is optimized for average demand, it may encounter significant shortages during the peak season or excessive inventories during the low season (Ezema *et al.* 2017b; Ezema *et al.* 2016). Severe shortages result in lost sales and client loyalty. Overstocked products from one season may be outmoded the next. To better modify ordering, satisfy demand, and maintain a cost-efficient supply chain and manufacturing system, a more appropriate policy is needed.

Most historical modeling and optimization of supply chain manufacturing systems have examined JIT delivery, time-varying demand, integrated inventory encompassing raw materials, WIP and finished products, and flexible production capacity individually. Adding these aspects to modeling has received little attention. This study closes the gap. It proposes an effective and economical operational technique for a multi-stage production system with JIT deliveries and time-varying demand under flexible production capacity. This research provides analytical results to solve production system operating problems optimally. This study blends industrial engineering and operations management. This study also examined the interactions between MAS options and operations management parameters. Existing research ignored key interrelationships.

The motivation of the study is hinged on the need to model an optimal Common Frequency Routing (CFR) for a Just in Time (JIT) manufacturing system with time-varying demand and flexible production capacities. The objectives of the research among others are to design computer-based production control systems using kanban loops which integrate information flow with material flow. The study also intends to deduce the effect of trigger point and number of kanbans on cycle time, Work in Process (WIP) level, flow time and orders satisfied The effect of JIT manufacturing system alternative on average throughput- time, demand fill rate, net operating income for a given level of product mix complexity and manufacturing overhead level in the drug manufacturing/process plant will also be deduced.

Materials and methods

The scope of this research focuses on manufacturing system optimization using computer-based control kanban loops. This research work among other things designed and developed an enhanced algorithm that control production systems using kanban loops which integrate information flows with material flows. Existing algorithms, such as the Pure pull put out by Sparks (2011), were only compatible with multi-stage single product systems. A product sequencing technique called Network Map Algorithm was also created by Henninger (2009). In contrast to the proposed JIT System algorithm which is multi-stage multi-product, the algorithm was only capable of handling a three-product system. Our suggested method may establish a product sequence for a production system based on system factors such as setup times, buffer levels, consumption rates, output rates, etc. It is all-inclusive, just-in-time, and can be applied to any production system. Due to their particular restrictions and limitations, most dynamic systems may not be able to use most current algorithms since they do not fulfill the JIT requirements of the researched manufacturing plant. Therefore, a JIT design strategy that is more relevant and consistent with the constraints of dynamic systems is needed, such as the one we suggest in our research.

Aside from that, the models of Blackburn and Millen (2010) and Nance (2011) are constrained to level demand and an indefinite planning horizon. Their models solely took into account fixed-interval and fixed-size shipments as a form of shipping mechanism. The issues of raw material, WIP, and finished product inventories were taken into consideration separately by some researchers (Suzaki, 2021; Wemmerlow, 2022; Svensson, 2020; Palas and Bunduchi, 2021; Ibrahim, 2022; Jamshidi and Osanloo, 2018) during the model development; however, it makes more sense to analyze all of these issues concurrently. Blackburn and Millen (2010) proposed an exact solution procedure for time-varying demand models that took into account two-stage and multi-stage manufacturing systems, but they did not take into account the manufacturing situation where the production capacity is flexible. Instead, they assumed that the production rate of a manufacturing system is fixed and unchangeable. Because the issue was so difficult, earlier academics disregarded this kind of model. Nevertheless, machine production rates are readily adjustable, and production costs are influenced by production rates (Abhijeet *at el.* 2022; Fry, 2019; Johnson, 2021). In our study, a model for a more diverse category of supply chain manufacturing systems—one with flexible production capabilities as decision variables—is established.

The design step determines all system technical features. Implementation includes new system execution and preparation. The evaluation measures the new system's effectiveness. This step involves making improvements. Simulation is also utilized to improve the performance of the new system after implementation. ARENA/ SIMAN and WITNESS were used. This study established a discrete event simulation model for JIT supply delivery (JSS). Real-time linkages between JSS and manufacturing are examined. The study identifies inventory dynamics and contributing factors. JIT implementation involves improvements in setup time, vendor relationships, and production leveling (Johnson, 2021; Kane *et al.* 2015). This research doesn't cover them. Simulation modeling has its own benefits and limits, as do any research methods. The model can be quickly extended and upgraded to include more information because it is essentially infinitely changeable. No simulation model can capture the infinite extraneous variables in real systems (Jaouen and Neumann, 2014).

Thus, the outcomes of any simulation study are heavily influenced by the model's assumptions (Nance, 2011; Neely, 1999). Simulation modeling's main benefit is the ability to monitor performance measurements under the same environmental parameters, which can guide future study. The simulation software is correct. The generated model helps understand the system's behavior (Schroer *et al.* 1984; Selvaraj, 2008).

Model development procedure/ code generation

Code generation in this research work was done using ARENA/SIMAN software and WITNESS simulation software. JIT Manufacturing System Model was developed alongside six sub-models namely: Supplier Sub Model, Route Sub-Model, Kanban Sub Model, Production Sub Model, Consumption Sub Model and Plant Sub Model. Animations were used to verify the logic of the simulation.

Arena simulation software

ARENA /SIMAN is used to simulate this model during code generation. Arena, a commercial discrete-event simulation application, using SIMAN/Cinema simulation language and a Windows-based interface. Arena turned user actions into SIMAN code. Stochastic systems use random-number generators, therefore simulation output estimates system behavior (Spear, 2014; Stalk, 2008). Multiple runs were utilized to sample system behavior, hence a confidence interval was employed to describe the output.

JIT manufacturing system model was executed using ARENA/SIMAN. The model included animation and sophisticated factors. Arena estimates the confidence interval using these variables and formulae:

n = the number of samples
$\bar{X}(n)$ = the sample mean
$S^2(n)$ = the variance of the sample

$t_{n-1,1-\alpha/2}$ = the critical value from a t distribution with n-1 degrees of freedom

$$\bar{X}(\mathrm{n}) = \frac{1}{\mathrm{n}}\sum_{i-1}^{n} X_i \quad (1)$$

$$S^2(n) = \frac{1}{\mathrm{n}-1}\sum_{i=1}^{n}[X_i - \bar{X}(\mathrm{n})]^2 \quad (2)$$

Then the 100 (1-α) % confidence interval is:

$$\bar{X}(\mathrm{n}) \pm t_{n-1,1-\alpha/2}\sqrt{\frac{S^2(\mathrm{n})}{\mathrm{n}}}$$

Figure 1 shows the interface used to construct and run the model. Arena users click and drag icons to make or alter models. A pop-up window let the user change icon behavior. The user developed a model, ran it, and the program produced a report. Arena symbols symbolize conveyors, equipment, operators, etc. In cases when there is no preprogrammed icon, the user created Arena logic blocks. The user examined possibilities by adjusting resources, variables, attributes, etc. and conducting simulations.

Simulation using "SIMAN" and "WITNESS" simulation software

A Visual Interactive Simulation system known as WITNESS simulation software was used in executing and constructing the conceptual model. This program was used to conduct simulation experiments, construct and test models, and meet the study's objectives. Input parameters included setup time, machine alteration, and shift alteration. This work is based on the Drug Process Plant's single-card pull mechanism.

JIT system design considerations

Main issues and problem in the manufacturing plant was identified by collecting relevant information and understanding the actual operating system. The range of information included manufacturing processes, operating procedures for executing orders, plant layout and items produced by the Plant. To implement the mechanisms of the proposed JIT system, the following factors were considered in the design: number and location of buffers, batch size and operating procedures or mechanisms for running the system/ information flow of the orders. The implementation involved activities to achieve model design specification. This step included training since training was considered the dominant factor for successful implementation of the system.

Figure 3 depicts the ARENA-modeled existing system. If a customer knows the item number, scientific name, and dosage, he can order a drug item. The customer would walk to the corridor to look for drugs. When the terminal is busy, the customer uses a folder and Kanban cards to find a title.

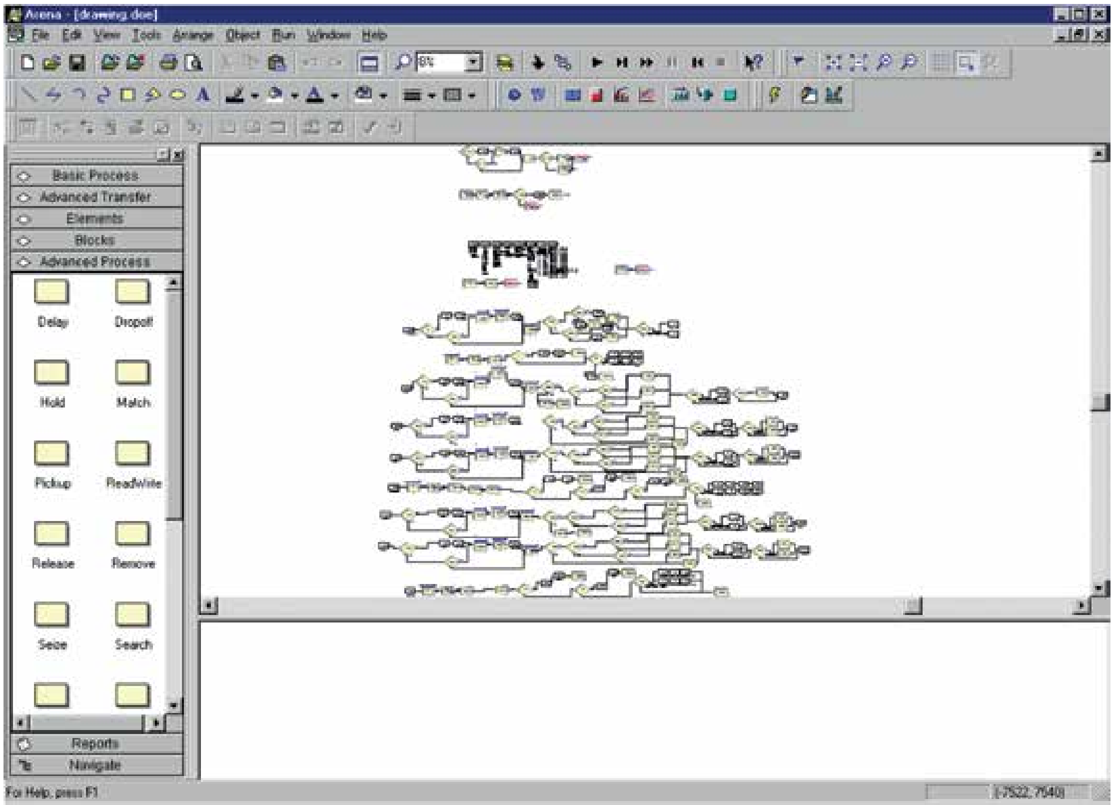

Fig. 1. The arena interface

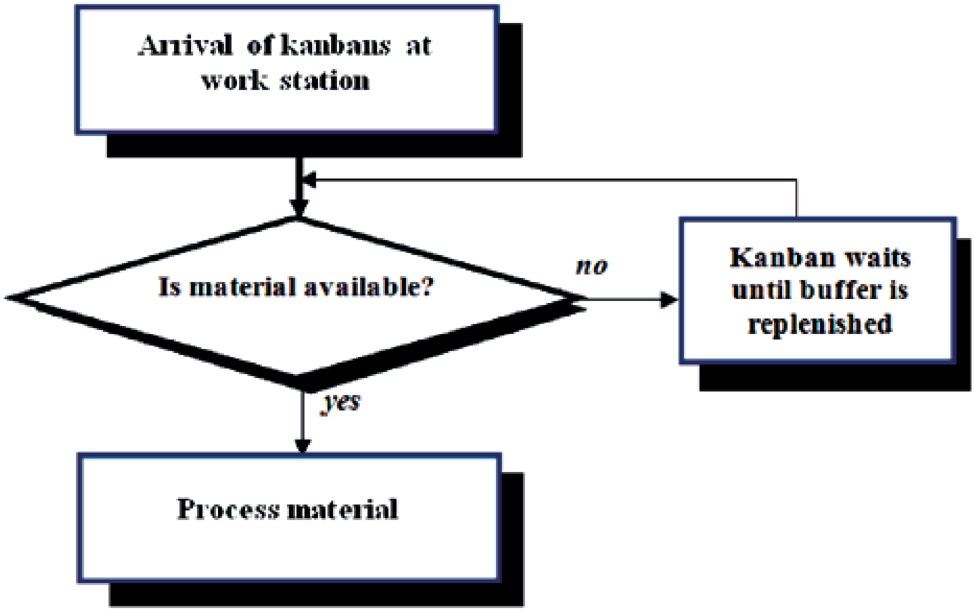

Fig. 2. Movement of materials based on kanban rule

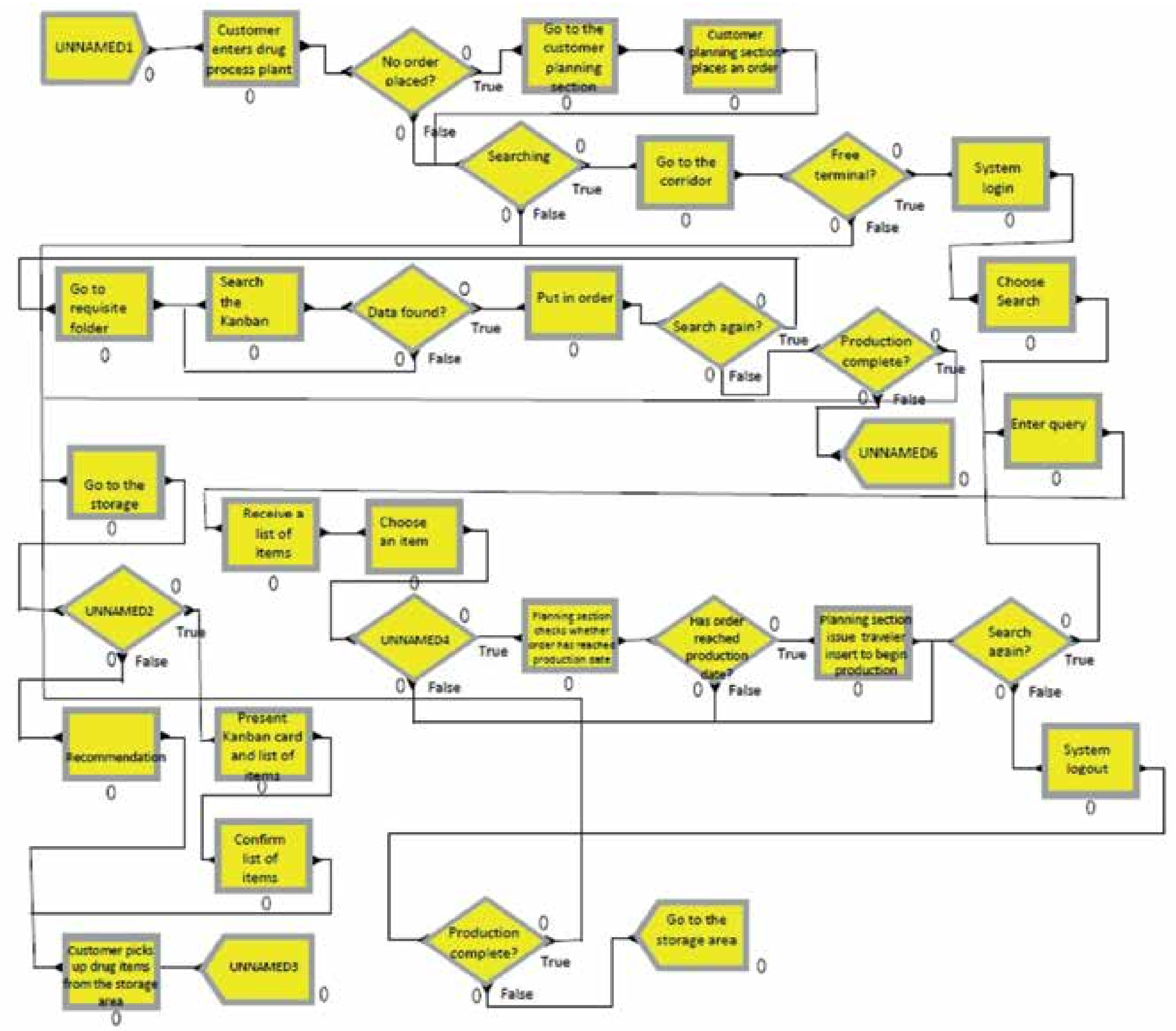

Fig. 3. JIT system model

After that, the consumer can select as many drug items as needed utilizing folders. After selecting, the buyer can buy drugs and depart the plant. Searching via medicine plant terminal is comparable. The customer can log in, select the search menu, and input search criteria if the terminal is available. The list includes available drugs. Revisions and printing are available. Customer can search till all needed drugs are found. Again, customers might choose to buy the selected drugs. When a list of drug items is not available, the customer is channeled to the storage area of the drug process plant, otherwise the process goes to finish. At the storage area of the drug process plant, the customer can ask for recommendations or annotations. And finally, the customer presents kaban card and list of items to be purchased which after confirmation the customer picks up the drug items from the storage area and leaves.

Results and discussion

System performance in terms of Cycle Time (Lead Time), Flow Time, Demand Fulfillment Rate, Throughput Time, Inventory Level, Net Operating Income, Work in Progress Level were extracted from the old physical system, simulated old physical system, simulated new physical system and the new physical system after implementation on shop floor as shown in Table I.

Table I is a description of the system response in terms of Cycle Time /Lead Time, Flow Time, Demand Fulfillment Rate, Throughput Time, Inventory Level, Net Operating Income and Work in Progress Level in ten observations. As shown in Table I, the mean response of the old physical system in terms of NOI was 67.34 while a mean response of 67.75 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of NOI was 85.54 but gave a mean response of 85.30 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of NOI. Table I show that the mean response of the old physical system in terms of cycle time was 785 while a mean response of 781 was recorded when simulated. Also, the mean response of the

Table I. Analysis of system performance after implementation

(a) NOI (Millions)

Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
Old Physical System	79.45	65.38	66.44	67.31	64.06	66.08	65.30	65.70	65.09	68.59	**67.34**
Simulated Old Physical System	79.13	65.87	66.48	66.92	65.27	65.25	66.34	68.19	65.04	69.00	67.75
Simulated New Physical System	84.33	89.64	81.40	94.63	91.210	88.70	81.50	76.10	82.10	83.82	85.54
New Physical System after Implementation on Shop Floor	82.20	89.30	79.80	97.50	93.00	89.80	81.50	76.90	79.90	83.10	85.30

(b) Cycle Time (Minutes)

Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
Old Physical System	783	722	781	872	781	746	731	789	851	789	785
Simulated Old Physical System	761	823	737	806	818	746	735	743	854	791	781
Simulated New Physical System	612	617	607	609	618	612	621	645	607	618	617
New Physical System after Implementation on Shop Floor	616	627	654	643	623	635	639	644	617	637	634

(c) DFR (%)

Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
Old Physical System	66.00	68.00	61.00	71.00	63.00	66.00	64.00	72.00	73.00	64.00	66.80
Simulated Old Physical System	66.10	69.00	61.00	73.00	65.00	68.00	67.00	73.00	72.00	65.00	67.91
Simulated New Physical System	94.60	93.00	92.50	95.60	93.00	98.10	94.00	91.20	91.00	94.10	93.71
New Physical System after Implementation on Shop Floor	94.00	93.00	92.00	94.00	92.00	98.00	92.00	91.00	91.00	94.10	93.11

(d) Inventory Turnover (units on a scale of 20)

Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
Old Physical System	8.00	11.00	14.90	- 1.00	13.00	12.00	7.00	12.00	10.4	12.00	9.93
Simulated Old Physical System	9.00	12.00	15.00	1.00	13.00	12.60	8.00	13.50	10.2	12.8.00	10.48
Simulated New Physical System	11.00	13.00	15.00	13.00	15.50	12.00	17.00	14.70	16.43	17.00	14.46
New Physical System after Implementation on Shop Floor	10.40	13.90	14.00	11.00	15.20	11.90	17.40	14.20	13.53	17.00	13.85

(e) WIP (units)

Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
Old Physical System	680	730	670	610	670	720	650	720	630	770	685
Simulated Old Physical System	680	720	690	710	710	723	654	740	630	775	703
Simulated New Physical System	890	930	970	910	970	920	966	920	950	977	940
New Physical System after Implementation on Shop Floor	887	929	971	910	968	920	960	910	950	965	937

(f) Throughput Time (Minutes)

Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
Old Physical System	345	456	314	354	312	306	332	355	375	374	352
Simulated Old Physical System	339	445	306	354	311	306	330	335	335	363	342
Simulated New Physical System	213	210	248	200	369	209	239	250	280	209	243
New Physical System after Implementation on Shop Floor	220	212	260	204	274	212	240	253	281	212	237

(g) Flow Time (Minutes)

Observ.	1	2	3	4	5	6	7	8	9	10	MEAN
Old Physical System	126	136	139	194	191	155	166	185	115	125	153
Simulated Old Physical System	125	130	137	174	176	156	159	183	115	121	148
Simulated New Physical System	112	109	103	117	143	112	134	126	112	115	118
New Physical System after Implementation on Shop Floor	113	111	103	130	142	113	135	132	113	120	121

simulated new physical system in terms of cycle time was 617 but gave a mean response of 634 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of cycle time.

As revealed in Table I, the mean response of the old physical system in terms of DFR was 66.80 while a mean response of 67.91 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of DFR was 93.71 but gave a mean response of 93.11 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of DFR.

Table I also indicated that the mean response of the old physical system in terms of Inventory Turn-over was 9.93 while a mean response of 10.48 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of Inventory Turn-over was 14.46 but gave a mean response of 13.85 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of Inventory. As shown in Table I, the mean response of the old physical system in terms of WIP was 685 while a mean response of 703 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of WIP was 940 but gave a mean response of 937 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of WIP. Table I equally reveal that the mean response of the old physical system in terms of Throughput Time was 352 while a mean response of 342 was recorded when simulated.

Also, the mean response of the simulated new physical system in terms of Throughput Time was 243 but gave a mean response of 237 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of Throughput Time. Table I further indicate that the mean response of the old physical system in terms of Flow Time was 153 while a mean response of 148 was recorded when simulated. Also, the mean response of the simulated new physical system in terms of Flow Time was 118 but gave a mean response of 121 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system in terms of Flow Time.

Conclusion

This work introduced a framework for manufacturing system optimization using computer-based control kanban loops. The framework was applied and tested for a JIT production line (Johel Drug Process Plant). Problems encountered by the Drug Process Plant include long lead time to customers, no visual method to observe the work in process and extra storage held to anticipate rapid changes of demand. The new physical system gave a mean response of 634 when implemented on the shop floor. However, the simulated new physical system in terms of DFR gave a mean response of 93.11 when implemented on the shop floor. Also, the mean response of the simulated new physical system in terms of Inventory Turn-over was 14.46 but gave a mean response of 13.85 when implemented on the shop floor. This indicates that the new JIT system outperformed the old physical system.

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