A Performance Comparison between the Extended Kanban Control System (EKCS) and the Traditional Kanban Control System (TKCS)

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Abstract – **This paper studies the performance difference of the Extended Kanban Control System (EKCS) versus the Traditional Kanban Control System (TKCS). Simulations were run using Arena version 12 for different initial parameter settings and a performance conclusion done for the Key Performance Indicators (KPI), such as fill rate and total average inventory.**

Keywords - **Traditional Kanban Control System (TKCS), Extended Kanban Control System (EKCS), Simulation**

I. INTRODUCTION

A kanban system is a production mechanism which uses "production authorization cards" (kanbans) to control the work-in-process at each stage. A kanban is attached to every finished part. Once a customer demand arrives, the kanban that was attached to the finished part is removed and sent back to re-initiate the manufacturing production process while the finished part is shipped to the customer.

In this paper, two significant pull systems–Traditional Kanban Control System (TKCS) and Extended Kanban Control System (EKCS) are investigated. By far, studies have only been conducted on the qualitative aspect of the differences of both systems. The purpose of this research is to study the performance difference of both systems quantitatively and to validate if performance of EKCS is superior to TKCS. In this study, simulations were run using Arena version 12 for different initial parameter settings and performance conclusion done for the Key Performance Indicators (KPI), such as fill rate and total average inventory.

Three key observations were made. Firstly, in terms of performance results via KPIs, the initial parameter settings affect only EKCS but not TKCS. Secondly, under specific initial parameter values, EKCS outperforms TKCS in along KPIs, however only slightly. Thirdly, under identical initial settings of all kanbans attached to the parts in the output buffers, and all other queues (e.g. demand queues, kanban queues) being empty, performance of EKCS and TKCS becomes identical.

II. MODEL OF A TWO-STAGE TKCS AND EKCS

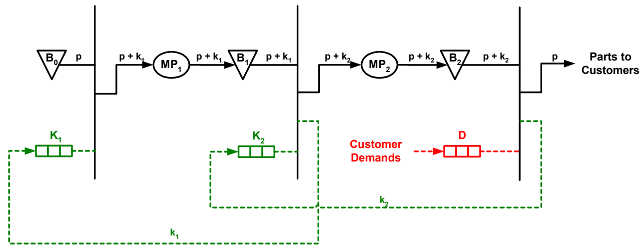

Fig. 1. A Two-Stage Traditional Kanban Control System (TKCS) (Sugimori et. al. [1])

The TKCS was first proposed by Sugimori et. al. [1] and has been heavily applied in the industry ever since – for example the global car manufacturer Toyota adopts this kind of manufacturing strategy.

Referring to Fig. 1, the Traditional Kanban System (TKCS) operates as follows: When a customer demand arrives at the system it joins Queue D requesting the release of a finished product from B_2 to the customer. At that time there are two possibilities: If a part is available in B_2 (which is initially the case), it is released to the customer after detaching the stage 2 kanban that was attached to it. This kanban is transferred upstream to queue K_2, carrying with it a demand signal for the production of a new stage 2 finished part. If no part is available in B_2, the demand is backordered and waits in Queue D until a new part is completed and arrives in B_2. The newly finished part will be released to the customer instantly and the detached kanban will transfer to Queue K_2 instantly too.

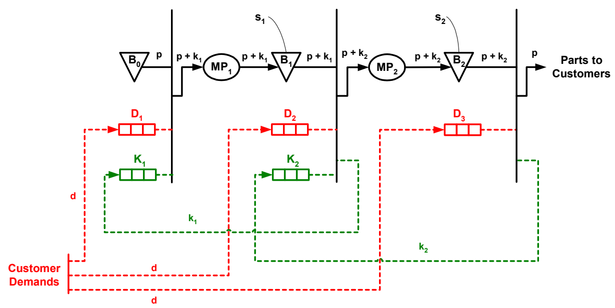

Fig. 2. A Two-Stage Extended Kanban Control System (EKCS) (Dallery [2])

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On the other hand, the EKCS, first proposed by Dallery [2], is a hybrid of both the TKCS and Base Stock (BS) mechanism – also another popular pull system.

Referring to Fig. 2, the Extended Kanban Control System (EKCS) operates as follows: When a customer demand arrives at the system, it is instantaneously split into N + 1 demands (equal to three in this two stages system). The first demand joins Queue D_3, requesting the release of a finished product from buffer B_2 to the customer. If a part is available in B_2, it is released to the customer after detaching the stage 2 kanban. This kanban is then transferred upstream to K_2. Otherwise the demand is backordered.

The other N (=2) demands will join the input demand Queue D_i of each stage i, i = 1, 2. If a part is presently attached with a stage i-1 kanban in B_{i-1} and a stage i kanban in Queue K_i, the stage i-1 kanban is immediately detached from the part and transferred upstream to K_{i-1}. At the same time, stage i kanban is removed from K_i and attached to the part. This pair is then released into MP_i. If there is either no part in B_{i-1} or no stage i kanban in K_i, the demand is backordered and has to wait in D_i.

III. LITERATURE REVIEW

The true advantages of EKCS over TKCS are still not properly addressed in the research literature. In this section, the literatures that compare different types of Kanban Control Systems are reviewed.

Karaesmen & Dallery [3] used an optimal control framework to study the Base Stock (BS), Traditional Kanban Control System (TKCS) and Generalized Kanban Control System (GKCS). They have used a two-stage production system where demands arrive according to a Poisson process with rate λ and their Manufacturing Processes (MP) have exponentially distributed service times with rate μ_i (i=1,2). However, their modeling approach has made it difficult for the analyses of inventory levels in the two separate stages because they have used X_1 as a random variable to represent a combination of stage 1 output buffer and stage 2 MP. Usually, in literature, X_1 should denote the Work-In-Process (WIP) of the first MP plus the first output buffer while X_2 denote the WIP of the second MP plus the second output buffer. Also, they did not use EKCS in their comparison because under the state space representation approach, the EKCS is a special case of the GKCS. Hence, scenarios which EKCS outperforms TKCS are not clearly highlighted. Moreover, they did not compare their performances in terms of Key Performance Indicators (KPI).

The latest comparison of pull control policies was done by Korugan & Cadirci [4]. They studied the four most common pull control systems: Base Stock (BS), Traditional Kanban Control System (TKCS), Generalized Kanban Control System (GKCS) and Extended Kanban Control System (EKCS), using a Markov Chain model to develop each of the four policies. These models were then analyzed using a cost function, which was then minimized with respect to the control parameters of each control mechanism. Finally, results are obtained from numerical experiments and conclusions drawn. Even though the authors explicitly mentioned that hybrid pull systems such as the EKCS and GKCS display better performance than simple systems i.e. BS and TKCS, their analysis is based on a cost function. The method used has not clearly shown how the EKCS outperforms the TKCS based on KPIs. Also, the pull models are not of standard tandem process lines. They included an additional remanufacturing process on top of the usual Manufacturing Process (MP), which makes their analysis more complex.

Khuller [5] used simulation to compare two types of kanban control systems in different manufacturing environments. Although KPIs such as Fill Rate, Work-In-Process (WIP) and order fulfillment time were used as a gauge, he did not use the standard EKCS. Instead, he used the Extended Information Kanban Control System (EiKCS) i.e. EKCS with the Base Stock level equal to the maximum WIP capacity at each stage.

Deokar [6] also used simulation to compare the TKCS, GKCS and EKCS. She assumed a multi-product system where the kanbans are either dedicated or shared. By assuming a multi-product system, she increased the complexity of the analysis. Even so, she has not specifically mentioned why, and in what scenarios, does the EKCS outperform the TKCS.

This shows that there is insufficient analysis on how the EKCS outperforms the TKCS. A clear and well defined comparison in terms of the KPIs between the EKCS and TKCS is needed.

IV. SIMULATION EXPERIMENTS AND RESULTS

A. Simulation Model

In order to verify whether the Extended Kanban Control System (EKCS) outperforms the Traditional Kanban Control System (TKCS) in terms of KPIs, the TKCS and EKCS were simulated using Arena Version 12. Figure 3 and Figure 4 shows a screenshot of a two-stage TKCS and EKCS system modeled in Arena, respectively.

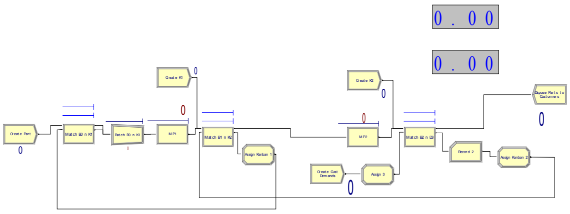

Fig. 3. The Traditional Kanban Control System (TKCS) in Arena

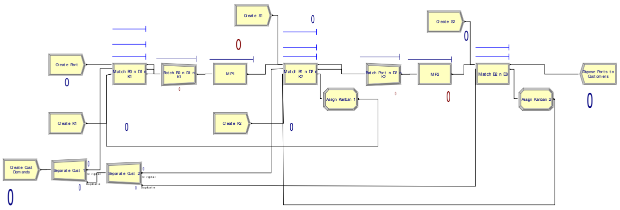

Fig. 4. The Extended Kanban Control System (EKCS) in Arena

B. Simulation Assumptions

The assumptions made while modeling the KCS are as follows:

- Both systems make only a single part type.
- They adopt the One-Card kanban system.
- They do not produce defective parts.
- Both systems adopt only two stages each i.e. only two MPs.
- Each Manufacturing Process (MP) contains only one machine.
- There are no setup times at each machine.
- There are no machine failures.
- Each machine can only process one part per unit time.
- Parts are transported with negligible transfer time.
- Demand signals and kanbans flow instantaneously.
- Parts authorized for loading follow a First In First Out (FIFO) dispatching policy at all machines and buffers.
- The raw materials buffer has infinite supply of raw parts.
- Both systems assume customer demand arrival rates follow a Poisson process with mean arrivals of five per day.
- All MPs assume processing times to be exponentially distributed with a mean of 1/6 day.
- Each simulation was replicated 10 times
- Each replication was run for half a year (182.5 days)

C. Simulation Parameters and Results

Five sets of data were simulated with the objective of determining the conditions under which EKCS outperforms TKCS as well as verifying if initial conditions affect the two kanban controlled systems.

k_i, i = 1, 2, represents the initial total number of kanbans for each stage. s_i, i = 1, 2 represents the initial number of base stock in the output buffers with each part having a kanban attached to it. $k_i - s_i$, i = 1, 2, represents the number of kanbans in the kanban queues k_i, i = 1, 2. TKCS has only one parameter per stage: the number of kanbans k_i whereas EKCS relies on two parameters per stage: the number of kanbans k_i, and the number of base stock s_i. The main condition for EKCS is $ki \geq si$, i = 1, 2, because the number of kanbans in the kanban queues cannot be negative for $ki - si$, i = 1, 2.

The first data set (refer Table I) tested TKCS with increasing levels of k_i, since it only relies on one parameter k_i. The second data set (refer Table II) tested EKCS with initial condition $k_i = s_i$, i = 1, 2. This means that there are initially k_i, numbers of parts (each attached a kanban) in the output buffers B_1 and B_2 respectively. All other queues are empty. This scenario tests the condition where there is only base stock in the EKCS but no kanbans in the kanban queues initially.

TABLE I
PERFORMANCE MEASURES OF TKCS WITH INCREASING k_i

Variables			TKCS		
Customer Demand Arrival Rate (per day)	MP Proces-sing Rate (per day)	No. of initial kanbans per stage (k_i)	Fill Rate (Total no. of parts out / Total no. of demand arrivals)	Total Average Inventory in the system ($B_1 + B_2$)	Average Cycle Time for Customer (hours)
5 parts	6 parts	1	0.86	0	290.84
		2	0.97	0	107.96
		4	1	2	8.4
		6	1	5	4.17
		8	1	8	3.59

TABLE II
PERFORMANCE MEASURES OF EKCS WHEN $k_i = s_i$

Variables				EKCS		
Demand Arrival Rate (per day)	MP Rate (per day)	No. of initial kanbans per stage (k_i)	No. of initial Base Stock per stage (s_i)	Fill Rate	Total Average Inventory	Average Cycle Time for Customer (hours)
5 parts	6 parts	1	1	0.86	0	290.84
		2	2	0.97	0	107.96
		4	4	1	2	8.4
		6	6	1	5	4.17
		8	8	1	8	3.59

TABLE III
PERFORMANCE MEASURES OF EKCS WHEN $s_i = 0$

Variables				EKCS		
Demand Arrival Rate (per day)	MP Rate (per day)	No. of initial kanbans per stage (k_i)	No. of initial Base Stock per stage (s_i)	Fill Rate	Total Average Inventory	Average Cycle Time for Customer (hours)
5 parts	6 parts	1	0	0.83	0	348.92
		2	0	0.92	0	139.4
		4	0	0.99	0	27.44
		6	0	0.99	0	34.33
		8	0	0.98	0	43.73

The third data set (refer Table III) tested EKCS with initial condition $s_i = 0$. This means that there are initially k_i of kanbans in the kanban queues. All other queues are empty. This scenario tests the condition of no base stock in EKCS but only kanbans in the kanban queues, initially.

The fourth data set (refer Table IV) tested EKCS with initial condition of $k_i - s_i = 1$. This means that there is only 1 kanban in each respective kanban queue, while the rest are attached to the base stock parts in the respective output buffers initially. This scenario tests that the condition when there is both base stock and kanbans in the kanban queues in the EKCS, initially.

The fifth data set (refer Table V) tested EKCS with initial condition of $s_i = 1$. This means that there is only 1 base stock in the output buffers initially, while the rest of the kanbans wait in the kanban queues.

TABLE IV
PERFORMANCE MEASURES OF EKCS WHEN $k_i - s_i = 1$

Variables				EKCS		
Demand Arrival Rate (per day)	MP Rate (per day)	No. of initial kanbans per stage (k_i)	No. of initial Base Stock per stage (s_i)	Fill Rate	Total Average Inventory	Average Cycle Time for Customer (hours)
5 parts	6 parts	1	0	0.83	0	348.92
		2	1	0.94	0	134.6
		4	3	1	1	19.82
		6	5	1	4	3.62
		8	7	1	7	1.78

TABLE V
PERFORMANCE MEASURES OF EKCS WHEN $s_i = 1$

Variables				EKCS		
Demand Arrival Rate (per day)	MP Rate (per day)	No. of initial kanbans per stage (k_i)	No. of initial Base Stock per stage (s_i)	Fill Rate	Total Average Inventory	Average Cycle Time for Customer (hours)
5 parts	6 parts	1	1	0.86	0	290.84
		2	1	0.94	0	134.6
		4	1	0.99	0	44.36
		6	1	0.99	0	26.91
		8	1	1	0	24.39

V. DISCUSSION OF RESULTS

Table I results show no difference from Table II i.e. between the TKCS and the EKCS in terms of all KPIs. The KPIs are namely the fill rate, total average inventory in system and average cycle time for customers. This is because setting $k_i = s_i$ in a two stage EKCS leads to an equivalent two stage TKCS. The demand queues D_i, play no role in the synchronization station they belong to, as they do not block the passage of parts through that synchronization station and can be eliminated. Once demand queues D_i, $i = 1, 2$, are eliminated from the EKCS queuing network, the remaining network is the same as the queuing network model of the TKCS.

In the case of initial condition $s_i = 0$, Table III shows that EKCS contains lower inventory than the TKCS (Table I) at every kanban level other than k_i, because it has been forced, from the start, not to carry any stock in its output buffers. Intuitively, as it does not carry any base stock in its output buffers, customer demands will have to suffer longer average waiting times. This can be seen as the TKCS (Table I) has shorter average cycle time for customers as compared to the EKCS (Table III). The reason TKCS has higher inventory levels is because it does not have the base stock element to enforce a low number of stock in the output buffers. It allows the MP to begin production once there is a kanban in the kanban queue, regardless of incoming customer demand. This results in higher stock at the output buffers.

In the TKCS, parts from preceding stages are authorized for production without waiting for customer demand arrivals; hence they enter the MP for processing much quicker than the EKCS. But in the case of EKCS, parts from preceding stages are allowed to enter into the MP for processing only if both a kanban and demand is present. This results in an incoming customer having to wait for the entire production line to process the part starting from a raw part, from the first to the last stage.

That is why the TKCS is able to satisfy incoming demands faster than the EKCS.

Table IV values show that the EKCS responds similarly to the TKCS at higher levels of k_i. This is obvious as already mentioned that setting $k_i = s_i$ in a two stage EKCS leads to an equivalent two stage TKCS. Hence referring to Table IV, as k_i progresses to higher levels, the EKCS progressively responds like the TKCS. However, EKCS seems to outperform the TKCS in all KPI aspects at levels $k_i > 4$. At $k_i = 4$ the EKCS has a lower total average inventory as the TKCS, but it has a higher average cycle time. As k_i, increases to levels above 4, the EKCS has both lower total average inventory as well as lower average cycle time as compared to the TKCS. This shows that there are certain values of the parameters k_i and s_i, which enable EKCS to outperform the TKCS.

Table V shows, as expected, that the EKCS has a lower total average inventory than the TKCS because the base stock element forces it to maintain, at most, only 1 part in its output buffers. However, in terms of total average cycle time for a customer, it remains relatively constant for the EKCS while it decreases, as k_i increases, for the TKCS. This is also expected as, in the TKCS, parts from preceding stages are authorized for production without needing to wait for customer demand arrivals unlike the EKCS.

VI. CONCLUSION AND FUTURE WORK

In this paper, two significant pull systems, the Traditional Kanban Control System (TKCS) and the Extended Kanban Control System (EKCS), were simulated using Arena version 12. The two systems were simulated under four different initial parameter conditions: $k_i = s_i$, $s_i = 0$, $k_i - s_i = 1$ and $s_i = 1$. Through the simulation results, the following important observations were made:

1. Initial parameter conditions affect the EKCS but not the TKCS.
2. Only under certain initial parameter values does EKCS outperform the TKCS in terms of all KPIs. (Table III at levels $k_i \geq 4$).
3. Setting $k_i = s_i$ in the EKCS leads to an equivalent TKCS. (Table I).
4. Base stock element in the EKCS ensures a minimal number of parts in the output buffer, regardless of the number of kanbans in the kanban queues.
5. In TKCS the number of kanbans stored in the kanban queues will eventually end up attached to parts in the output buffers. In TKCS, if there are kanbans in the kanban queues, the MPs need not wait for customer demands before starting processing.
6. In EKCS, a tradeoff exists between carrying base stocks in the output buffers vs. carrying kanbans in the kanban queues. Having all inventories stored as base stock, the total average inventory in the system is high but the average cycle time low, (Table I). Having all kanbans in kanban queues and no base stocks, the average cycle time for a customer is high but the total average inventory in the system is low, (Table II).

The next phase of research will address the following research gaps:

1. Since the simulation results demonstrated that EKCS outperforms TKCS only under certain initial parameter values, the next step would be to identify a method to search for a set of optimal control parameters for EKCS.
2. Lastly, presuming that a set of optimal control parameters could be found, the performance difference might still not be significant. By far, this entire research was based on a single product environment assumption. By relaxing this assumption to a multiple product environment, it is the hope that significant differences in the performance of the various systems under study may be uncovered.

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