EFFECT OF KANBANS IN THE PERFORMANCE OF CONWIP, KCS AND EKCS

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Abstract - The manufacturing station, input and output buffers are the logical areas, which respond to kanban to change its status to distinct areas in the flow line manufacturing system. The paper is focused to study the effect of number of kanbans in each manufacturing stage, for Constant work in process (CONWIP), Kanban Control system (KCS) and Extended Kanban Control system (EKCS) for the performance analysis using single flow line manufacturing systems. The configuration of the single flow line is considered to have three manufacturing stages. The Single flow line manufacturing system is modeled as network diagram using technical computing software MATLAB SIMULINK. Simulation studies were performed to determine the optimum number of kanbans per stage. The optimal selection of number of kanbans is based on high values of production and low values of work in process (WIP) and average waiting time (AWT). The customer demand mean time, 20, 25 and 30 minutes, and the processing mean time of 20 minutes for the three manufacturing stages are considered for the study respectively. The performance results obtained by single flow line are compared, analyzed for CONWIP, KCS and EKCS to determine the optimal number of kanbans per stage..

Keywords: CONWIP, KCS, EKCS, Kanban, Performance, production, WIP, AWT, Utilization

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1. INTRODUCTION

Just in time (JIT) manufacturing technique, the application of kanban control system (KCS), used in Toyota in mid seventies, is a popular pull control system is widely used as a managing tool in industries. The importance of just in time manufacturing system emerged with effective coordination of manufacturing stages to react with demands to control the production rather than forecasting. The other pull control systems include Base stock control system (BSCS), Generalized kanban control system (GKCS) and Extended kanban control system (EKCS). The customer demand, kanban (production authorization) and the component are integral elements of the pull system and become crucial in production management. In other words, the component processing management is based on customer requirement and manufacturing capability. Determining the number of kanbans for each manufacturing stage is a crucial factor, affecting the desired performance level. This decision will reduce backorders at each stage and results in keeping the work in process (WIP) at the minimum possible level. For optimizing the number of kanbans, several alternative approaches are being proposed like analytical, heuristic and simulation etc., but each approach has its own demerits and limitations. In this paper, the author has made an attempt to determine the number of kanbans for -

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single flow line manufacturing systems by comparing the performance parameters using the simulation model. The paper proceedings and its outline are as follows. In section two, the brief review of the research efforts to determine the number of optimized kanban per stage is presented. Section three covers the objective of study and research. The section four covers the working description of KCS, CONWIP and EKCS and provides qualitative comparison based on control space description of the mechanisms. The numerical results and analysis to explore the comparative performance of KCS, CONWIP and EKCS and the tradeoff between numbers of kanbans vs. performance parameters are covered in section five. Finally,the section six presents the conclusions of main results of the simulation and research in this paper.

2. LITERATURE REVIEW

There are many contributions where an attempt is made to determine the number of kanbans with reference to different types of pull control mechanisms. Some of the contributions related to the paper are as follows.

[1] discussed the various pull control mechanisms viz., Base stock control system (BSCS), Kanban control system (KCS), Generalised kanban control system (GKCS) and Extended Kanban control system (EKCS) for multi stage manufacturing system. They have elaborated the coordinating mechanism for the release of parts into each manufacturing stage by synchronizing with customer demand. [2] Introduced new mechanism called Extended kanban control system (EKCS). It is a combination of BSCS and KCS. The properties of the system are exhaustively discussed and concluded that EKCS has a stronger coordination compared to KCS. [3] discussed about the influence of number of kanbans in KCS and CONWIP. The performance of the system is more dependent once the kanbans are optimally set. The simulation studies about the number of kanbans by varying demand mean time for EKCS [4] and GKCS [5] concluded that number of kanbans

has larger influence on demand and processing time with resulting effect on work in process (WIP), production and utilization. Also [6] , explored the review concepts of pull control systems and suggested meta heuristics techniques like simulation annealing, genetic algorithm to determine the number of kanbans and other measures. [7] discussed simulation studies over small supply chains and presented that the fixed work in process (WIP) shortens the lead time whether it is pull or push system.[8] presented the review and theoretical concepts of multi product kanban system and focused about the shared and dedicated system for each type of product. [9] presented a case study of six work station automotive industry with simulation analysis. A mathematical model was developed for optimizing number of kanbans with few assumptions resulted with increases in the production rate. [10] discussed a case study of kanban system applied to reduce work in process (WIP) in chipper assembly for lawn mower industry. The system was analysed with simulation studies and the company achieved tremendous benefits with high production rates and reduction of WIP, labor cost, and assembly time.

Hence, in spite of intense research studies to determine the number of kanbans per stage for KCS and EKCS, still the study to determine the optimal number of kanbans on the basis of comparative performance of different pull control systems and combined optimization has not been deeply studied and still in its development stage.

3. STATEMENT OF THE PROBLEM

The objective of the problem is to determine the combined optimal number of kanbans in CONWIP, KCS, and EKCS for single flow line manufacturing system. The single flow line system with three manufacturing stages is considered for the analysis. The average mean processing time for each manufacturing stage is assumed to be 20 minutes. The maximum numbers of kanbans per stage are 10. The customer demand follows exponential distribution with mean time of 20 minutes, 25 minutes and 30 minutes. The single flow line model for CONWIP, KCS and EKCS is formulated as a network diagram using technical computing software MATLAB-SIMULINK. The manufacturing flow lines are simulated for the time period of 43200 minutes with the following assumptions:-

1. The setting time at each manufacturing stage is included in the respective processing times
2. Inter arrival of products follows stochastic distribution.
3. The transportation time, material handling time between production stages is negligible
4. Each part type follows the same process routing in each line sequentially.
5. The failure rate is assumed to be zero, i.e. the product will not be damaged or scrapped.

The objective is to study, compare and analyze with the performance parameters like production rate, Work in process (WIP), average waiting time (AWT) and server

utilization for the flow lines in order to compute the optimum number of kanbans per stage.

4. NETWORK MODELS OF PULL CONTROL SYSTEM

The pull control systems i.e. CONWIP, KCS and EKCS, are modeled as queuing networks with synchronization stations. Each system depends on different philosophy on how demand flows through the system and is used for the production control.

4.1 Constant Work in Process (CONWIP)

The constant work in process (CONWIP) is equivalent to single stage kanban control system (KCS) that uses kanban to control the manufacturing system. As the finished part leaves the system, new part enters the flow line manufacturing system. Thus, the total work in process (WIP) in the system including the finished part is constant, hence the name CONWIP, shown as network diagram in Fig 1.
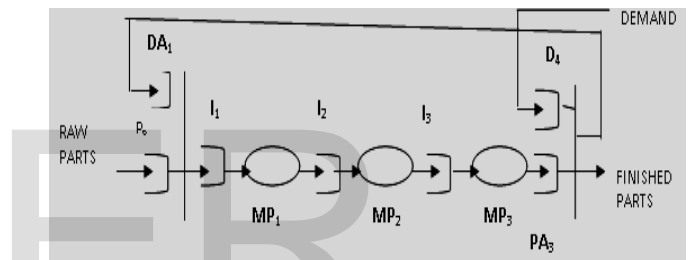

Fig 1 : Three Stage Queuing Network Diagram of CONWIP

Queue P0 contains raw parts. The flow line manufacturing system consists of three manufacturing stages MPi , and an input buffer Ii, where i =1,2,3. The output of the flow line is queue PA3 consist of kanban and finished part. The customer demand arrives at the queue D4 synchronizes with finished part with kanban at PA3. The finished part is released to the customer and the kanban is transferred to upstream queue DA1 which contains ki -Si kanbans. The kanban in queue DA1 and raw parts in queue P0 are synchronized and released into manufacturing stages.

4.2 Kanban Control System (KCS)

The most popular pull control system is the kanban control system (KCS) works on single parameter per stage and is often used to exemplify just in time manufacturing system. fig 2 shows the queuing network model of kanban control system with three stages in series with production authorization or kanban Ki, i=1..
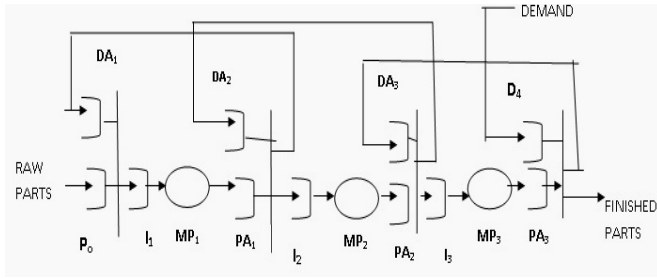
Fig 2: A Three Stage Queuing Network Diagram of KCS

Queue PAi is output buffer of stage i contains pair of finished parts and product authorization. Queue Ii is the input buffer of stage i for manufacturing stages MPi, where i=1, 2, 3. Queue P0 represents the raw parts buffer and queue D4 represents the customer demand. In the initial state, queue P0 contains the raw part and DAi contains kanban. When customer demand arrives, it joins queue D4 synchronize with PA3 and releases the finish part to the customer. Also, the kanban is transferred upstream from from PA3 to DA3. The queue containing ki-Si kanbans in DAi synchronize with Pi-1 to release part to MPi for processing, where i=1, 2, 3…. The philosophy depends upon customer demand transferred upstream by synchronizing with finished part.

4.3 Extended Kanban Control System (EKCS)

Extended kanban control system (EKCS) depends on two parameters per stage, and is a combination of BSCS and KCS depends upon number of kanbans and inventory of raw/semi finished parts. Fig 3 shows the queuing model of EKCS with three stages Si, i=1, 2, 3.
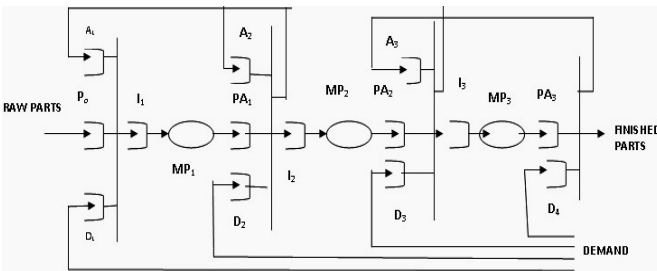

Fig 3: A Three stage Queuing Network Diagram for EKCS.

A stage consists of input buffer Ii, manufacturing stage MPi and output queue PAi. PAi represents output buffer containing finished parts and product authorization. Di+1 represents the customer demand at stage i, i=3. Queue Ai contains free stage kanban, i =1, 2, 3. Queue Di contains customer demand for the production of new stage i finished parts. Queue P0 is the buffer of raw parts. Queue Ii is the input buffer of manufacturing stages. PAi contain finish parts at stage i with a kanban attached to it. Ai

contains Ki-Si kanbans per stage. It is assumed that Ki ≥ Si for all i.

When Customer demand arrives to the system, it is split into n +1 stage i.e four queues in three stage manufacturing system. The customer demand joins queue D4 and synchronizes with PA3, releases finished part to customer, and also transfers the kanban to upstream queue A3. At stage 3, A3, PA2 and D3 synchronizes and release the part to downstream and transfers the kanban to the upstream stage and so on.

5. RESULTS AND DISCUSSIONS

The simulation studies the effect of number of kanbans per stage for demand mean time of 20, 25 and 30 minutes with manufacturing processing time of 20 minutes at each stage.

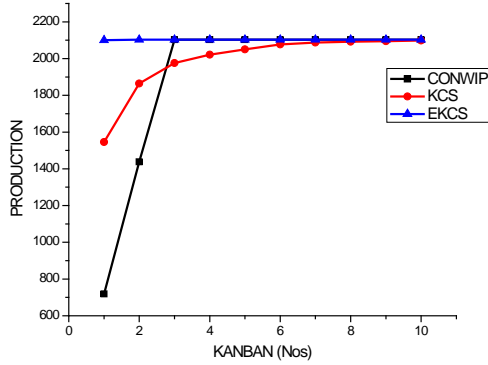### 5.1 Effect of number of kanbans for demand mean time 20 minutes

Simulation experiments for customer demand mean time of 20 minutes were conducted. The results are shown in Table 1 and are plotted in fig 4 for production, utilization, Average waiting time (AWT) and Work in process (WIP) respectively.

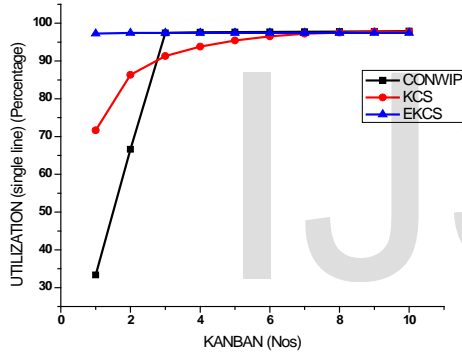TABLE 1 : SIMULATION RESULTS FOR DEMAND MEAN TIME 20 MINUTES

No of kanbans per stage	CONWIP				KCS				EKCS			
	Production	AWT	WIP	Utilization	Production	AWT	WIP	Utilization	Production	AWT	WIP	Utilization
1	719	0	1	33.3	1546	0	3	71.7	2100	0	3	97.3
2	1438	0.02	2	66.6	1864	14.8	4	86.3	2103	18.8	4	97.4
3	2103	0.18	3	97.4	1970	30.3	8	91.3	2103	36.1	5	97.4
4	2107	18.4	4	97.6	2021	46.6	10	93.8	2103	52.1	6	97.4
5	2108	35.9	5	97.7	2050	63.5	12	95.4	2103	66.7	7	97.4
6	2109	52.2	6	97.7	2077	82.1	12	96.5	2103	79.9	8	97.4
7	2110	67.3	7	97.7	2087	102	11	97.2	2103	91.6	8	97.4
8	2111	81.1	8	97.8	2092	123	12	97.5	2103	102	8	97.4
9	2112	97	9	97.8	2095	140	13	97.8	2103	110	8	97.4
10	2113	114	10	97.9	2098	155	13	97.8	2103	118	8	97.4

When the numbers of kanbans per stage are high, the production and machine utilization is similar in CONWIP, KCS and EKCS. The average waiting time, work in process in EKCS is less compared to KCS and CONWIP but the CONWIP has higher average waiting time. When the kanbans per stage are three and less, the CONWIP has least production, average waiting time and work in process. The average waiting time in KCS and EKCS are similar and increases linearly till 6 kanbans per stage. Beyond 6 kanbans per stage in EKCS the average waiting time has the least value compared with other systems. Furthur, the WIP also increases linearly till 6 kanbans per stage and then become constant for high number of kanbans. The WIP in KCS is higher and varies in range from 20% to 60%. But in CONWIP, the average waiting time and WIP is less for least number of kanbans, and increases linearly for the
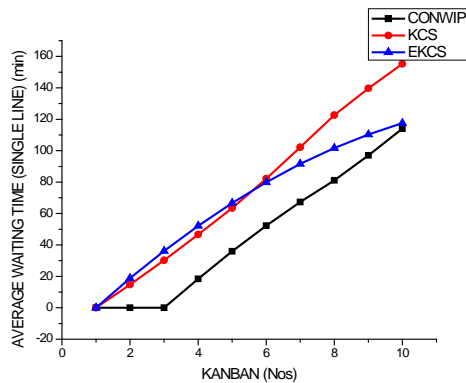
increment in number of kanbans per stage. When number of kanban per stage exceeds 10, the average waiting time and WIP in CONWIP may be higher compared to KCS and EKCS.
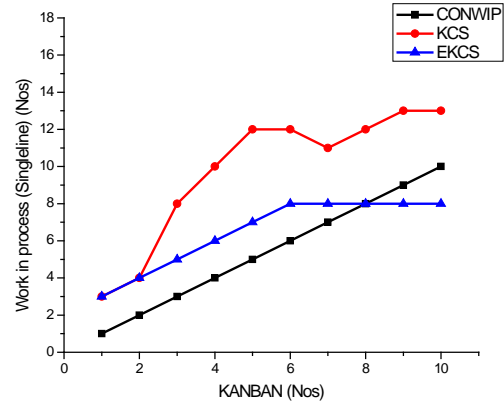

(a)

(b)

(c)

(d)

Fig 4: Effect of Number of Kanbans on performance for Demand Mean time 20 minutes (a) Production (b) Utilisation (c) Average Waiting Time (d) Work in Process (WIP)
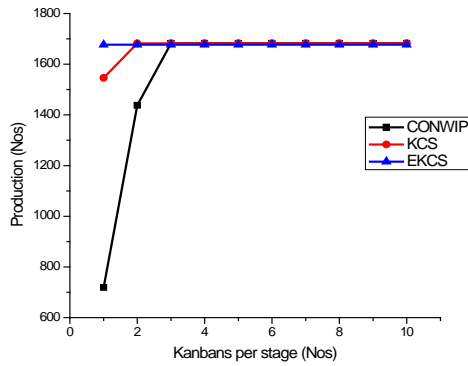
5.2 Effect of number of kanbans for demand mean time 25 minutes

The simulation results for the demand mean time of 25 minutes are shown in table 2 and are plotted in fig 5 for the performance parameters like, production, average waiting time (AWT), work in process (WIP) and utilization.
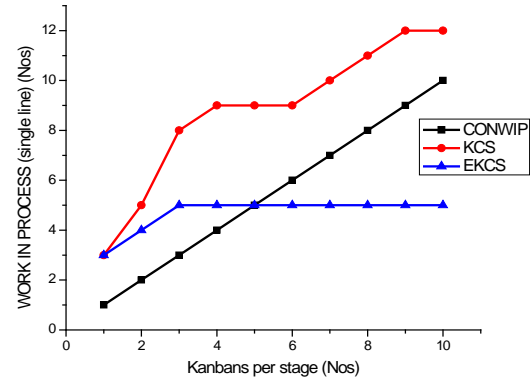
TABLE 2 : SIMULATION RESULTS FOR DEMAND MEAN TIME 25 MINUTES

No. of KANBANS per Stage	CONWIP				KCS				EKCS			
	Production	AWT	WIP	Utilization	Production	AWT	WIP	Utilization	Production	AWT	WIP	Utilization
1	719	0	1	33.3	1546	0	3	71.7	1677	0	3	77.7
2	1438	0.02	2	66.7	1682	12.6	5	77.9	1677	13	4	77.7
3	1680	14.4	3	77.8	1682	21.7	8	78	1677	20.9	5	77.7
4	1687	28.7	4	77.8	1680	28.5	9	78.1	1677	25.3	5	77.7
5	1682	46.8	5	77.9	1682	33.3	9	78.2	1677	27.6	5	77.7
6	1682	67.9	6	77.9	1682	38.3	9	78.3	1677	28.7	5	77.7
7	1682	90.9	7	78	1682	42.1	10	78.4	1677	29.2	5	77.7
8	1682	115	8	78	1682	44.3	11	78.5	1677	29.3	5	77.7
9	1682	140	9	78.1	1682	46.7	12	78.6	1677	29.4	5	77.7
10	1682	165	10	78.5	1682	50.2	12	78.7	1677	29.3	5	77.7

When the number of kanbans per stage is three or more, the production is same in EKCS, KCS and CONWIP. The production is less in KCS and CONWIP when number of kanbans per stage. The average waiting time for CONWIP, KCS and EKCS is nearly same for three kanbans per stage. But the number of kanban increases, average waiting time in CONWIP increases linearly and has higher value, whereas in EKCS the value becomes constant and is comparatively lesser than KCS. The work in process (WIP) is same for KCS and EKCS for single kanban per stage whereas it is least in CONWIP. As the number of kanbans per stage increases, the WIP in CONWIP increases linearly, whereas in EKCS increases linearly upto 3 kanbans and becomes constant. In case of KCS, the WIP increases with increase in number of kanbans per stage for the defined configuration and may become lesser than CONWIP.
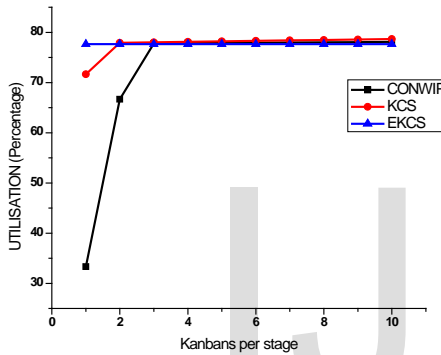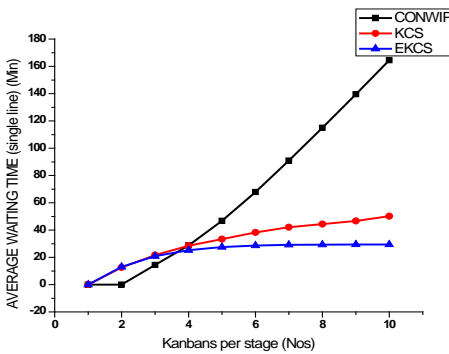
(a)

(d)

Fig 5: Effect of Number of Kanbans on performance for Demand Mean time 25 minutes   (a) Production (b) Utilisation (c) Average waiting time (d) Work in Process (WIP)


(b)

(c)

5.3 Effect of number of kanbans for demand mean time 30 minutes

The results for demand mean time of 30 minutes are shown in Table 3 and the performances of the system are plotted in fig 6.

TABLE 3 : SIMULATION RESULTS FOR DEMAND MEAN TIME 30 MINUTES

No. of KANBANS per Stage	CONWIP				KCS				EKCS			
	Production	AWT	WIP	Utilization	Production	AWT	WIP	Utilization	Production	AWT	WIP	Utilization
1	719	0	1	33.3	1400	0	3	64.9	1397	0	3	64.7
2	1399	1.59	2	64.8	1401	11	5	65	1397	0	3	64.7
3	1400	29	3	64.8	1401	18.6	6	65.1	1397	15.1	4	64.7
4	1401	51.8	4	64.9	1401	23.1	6	65.2	1397	17.1	4	64.7
5	1401	78.3	5	64.9	1401	26.1	6	65.3	1397	17.9	4	64.7
6	1401	107	6	65	1401	29.2	7	65.4	1397	18.1	4	64.7
7	1401	137	7	65	1401	31.3	6	65.4	1397	18.1	4	64.7
8	1401	166	7	65.1	1401	31.5	6	65.5	1397	18.1	4	64.7
9	1401	198	10	67.1	1401	33	4	65.6	1397	18.1	4	64.7
10	1401	120	10	65.2	1401	35.8	5	65.7	1397	18.1	4	64.7

The KCS and EKCS has the same production and machine utilization for the number of kanbans per stage. The average waiting time in CONWIP, KCS and EKCS is same for two kanbans per stage. The average waiting time (AWT) in KCS and EKCS is similar with increase in number of kanbans per stage and the KCS is 10-15% higher compared to EKCS. But the average waiting time in CONWIP is higher compared to KCS and EKCS. The Work in process (WIP) varies between 2 to 4 for KCS, EKCS and CONWIP for two kanbans per stage. The WIP in CONWIP increases linearly for increase in number of kanbans per stage and possess high value. The EKCS maintains constant WIP compared to KCS and there is a fluctuation of 10 to 15% in comparison to EKCS.
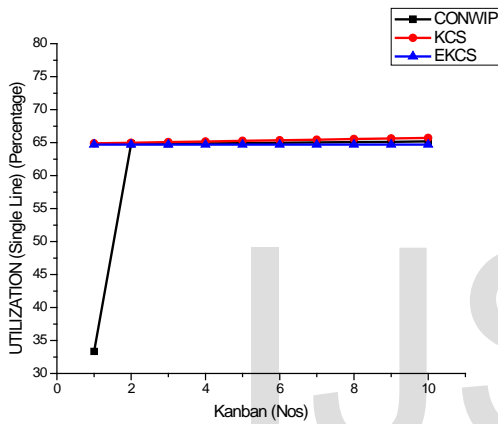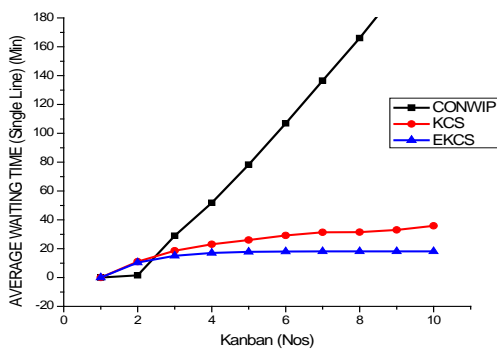
(a)

(b)

(c)
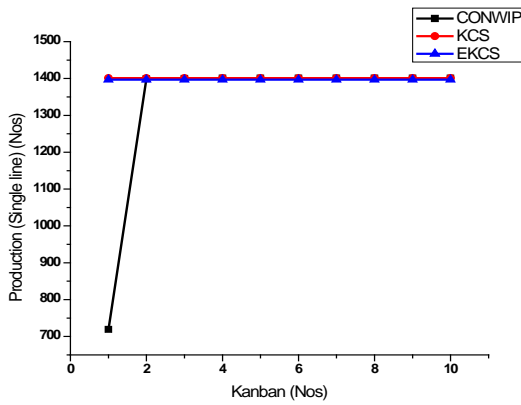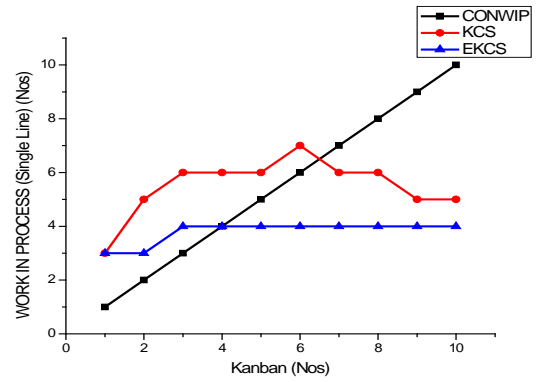
(d)

Fig 6:Effect of Number of Kanbans on performance for Demand Mean time 30 minutes   [A] Production [B] Utilisation [C]Average Waiting Time [D]Work in process (WIP)

5.4. Comparison

The performance of the flow line manufacturing system for the number of kanbans per stage with processing time of 20 minutes and demand mean time of 20 min, 25 min and 30 min respectively and is compared in terms of production, average waiting time (AWT), work in process (WIP) and utilization. It is observed that EKCS has constant production for the number of kanbans per stage whereas KCS and CONWIP has less production for less number of kanbans with reference to demand mean time. The average waiting time in CONWIP increases with increase in number of kanbans per stage whereas for KCS and EKCS, the average waiting time depends on demand mean time. Therefore for lower demand mean time, the optimum numbers of kanbans per stage is high .As the demand mean time increases the optimum number of kanbans per stage decreases and become least. That means, for the demand mean time of 20 min, the optimum number of kanbans are 6 as shown in fig 4(c) for demand mean time of 25 min, the optimum number of kanban are 4 as shown in fig 5(c), and for demand mean time of 30 min, the optimum number of kanbans are 2 as shown in fig 6(c). The Work in process (WIP) for CONWIP increases with increase in number of kanbans per stage, but for KCS and EKCS it depends upon demand mean time and processing time of manufacturing stages. For less number of kanbans, the WIP in CONWIP is least. As the number of kanban per stage increases, WIP in KCS has marginal variation compared to EKCS and it depends upon demand mean time. From fig 4(d), 5(d) and 6(d), it is seen that for demand mean time of 20 min, the optimum number of kanban per stage is 6, for demand mean time of 25 min, the optimum number of kanbans per stage are 4, and for optimum demand mean time of 30 min,

the optimum number of kanbans per stage are 2, respectively.

6. CONCLUSIONS

Simulation experiments were conducted in a typical single line three stage manufacturing systems. The author concluded that the determination of optimum number of kanbans per stage for CONWIP, KCS and EKCS considering the processing mean time of 20 min and demand mean times of 20 min 25 min and 30 min respectively. The optimum number of kanbans per stage ranges from 3 to 5. The production and machine utilization are same in CONWIP, KCS and EKCS for the optimum number of kanbans and its value depends upon the demand mean time. For less number of kanbans per stage, the production in EKCS has higher production compared to CONWIP and KCS. The average waiting time in CONWIP varies linearly with number of kanbans per stage, whereas in KCS and EKCS, the average waiting time depends on demand mean time and changes till the optimized number of kanbans. Furthur, there is a marginal variation of 10-20% in average waiting time between KCS and EKCS. The effect of WIP is also very similar like average waiting time.

Hence, the optimum number of kanbans per stage depends upon customer demand mean time, processing mean time and is based on maximum production with minimum average waiting time and work in process.

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