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Simulation modeling and analysis of single line multi stage manufacturing system

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Present study compares performance of proposed model [Hybrid Extended Kanban Control System (HEKCS)], with Extended Kanban Control System (EKCS) and Constant Work In Process (CONWIP) in a single line and multi stage manufacturing system with or without effect of machine breakdown. It was observed that, when demand rate increases, throughput, average WIP and utilization% also gradually increases for all three-control mechanisms. When manufacturing system is operated with or without machine breakdown, HEKCS shows better performance than EKCS and CONWIP.

Keywords: CONWIP, EKCS, HEKCS, Promodel

Introduction

Japanese technique, Just In Time (JIT) manufacturing system, has been in use in production management. JIT technique is implemented with Kanban control system (KCS), which cannot be used in large, unpredictable fluctuations in demands, job orders with short production runs, presence of scrap, significant setup time, transportation time, job shop manufacturing, machine break down, etc. Hence, alternative pull production control systems like Constant Work In Process (CONWIP), periodic pull system, Generalized Kanban Control System (GKCS), Extended Kanban Control System (EKCS), Local Control System (LCS), Hedging Point Control System (HPCS), Base Stock Control System (BSCS), hybrid pull system etc. have been developed. CONWIP[1] provides safety stock to reduce effect of variation and demand fluctuations in JIT environment. EKCS[2,3] combines base stock and kanban control for the production coordination. Two variants[4] of EKCS [Independent Extended Kanban Control System (IEKCS) and Simultaneous Extended Kanban Control System (SEKCS)] have been found to be more productive in extending to industrial applications. Sastry *et al*[5] studied comparison of SEKCS and IEKCS for multi line multi stage assembly manufacturing system using Simulation Language for Alternative Modeling (SLAM). Selvaraj *et al*[6] combined variants of EKCS and CONWIP and proposed a hybrid control system. Gupta *et al*[7] studied impact of sudden breakdown of material handling system on the performance of traditional kanban system (TKS) and compared results with flexible kanban system (FKS). Wang & Wang[8] applied queuing concept and Markov process approach to decide number of kanban for a production system, in which unreliable machines exist. So & Pinault[9] proposed a method of estimating the amount of safety stock needed at each station of a production line to take care of variations in processing times, machine breakdowns and demand fluctuations in order to meet predetermined desired level of performance. Villeda *et al*[10] highlighted processing time variations and its unbalancing to increase production rate in JIT system.

Present study compares performance of proposed model [Hybrid Extended Kanban Control System (HEKCS)] with EKCS and CONWIP in a single line and multi stage manufacturing system with or without effect of machine breakdown. Performance measures, like throughput, average Work in Process (WIP) and utilization% were computed and compared.

Proposed Hybrid Extented Kanban Control System (HEKCS)

Proposed HEKCS, a hybrid of EKCS and CONWIP, has combined advantages of EKCS and CONWIP. HEKCS (Fig. 1) is considered a single line multi stage

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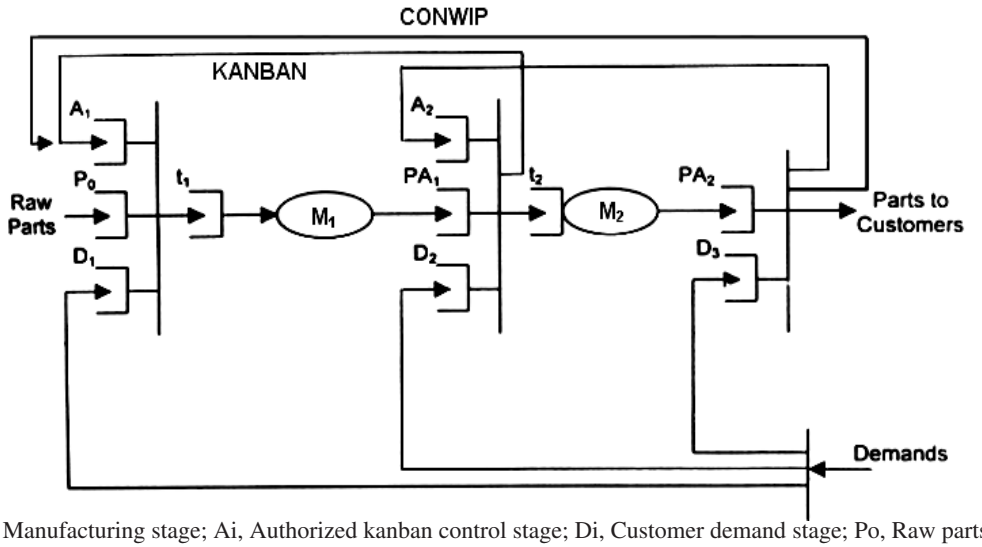


Mi, Manufacturing stage; Ai, Authorized kanban control stage; Di, Customer demand stage; Po, Raw parts; ti, Buffer stage; and Pai, Kanbans card with part stage; i = 1, 2, 3 …

Fig. 1—Schematic diagram of HEKCS

manufacturing system, which comprises of three stages (M1, M2 and M3). Each stage may comprise of a single machine or a set of machines. The parts are processed in M1, M2 and M3 stages respectively where value addition takes place from raw material stage to the finished products.

Average processing times of each manufacturing stage is assumed to be exponential distribution of mean 15 min. The demand rate varies from 60 to 20 min with equal interval of 10 min. Number of kanbans have been chosen 3 per stage. Mean Time Between Failure (MTBF) is varied with exponential distribution of 3000, 4500 and 6000 min of manufacturing stage M1, M2 and M3 respectively and Mean Time To Repair (MTTR) is an exponential distribution of 120 min for all three stages. HEKCS is modeled by Promodel 12, Windows-based simulation and animation tool for simulating and analyzing production systems of all types and sizes quickly and accurately. Whole manufacturing line is simulated with 4000 h, which include warm-up of 6 h with 5 replications. In this model, warm up is estimated to be 6 h by using law and Kelton method 11 to reach steady state.

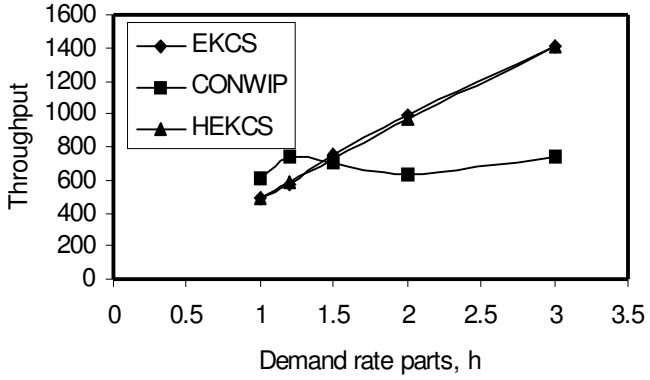
Results And Discussion

Simulation of Manufacturing Line without Machine Breakdowns

A single line multi stage manufacturing system with simulation model for CONWIP, EKCS and HEKCS have been studied without machine breakdown. When demand rate is low, throughput, average WIP and utilization% are almost equal for the three pull control mechanisms (Fig. 2). As the demand rate increased (0-3 parts/h), performance measures throughput, average WIP and utilization% of the pull control systems increased. Whereas HEKCS shows slight improvement than other two control mechanisms. Average WIP is showing a typical behavior like throughput with change in demand rate. Average WIP increases with demand rate in all three control mechanisms, whereas HEKCS shows less average WIP than EKCS and CONWIP. Since kanban, demand and finished part synchronize equally in each stage, it would result in the reduction of average WIP. Similarly, HEKCS shows more utilization% increase with demand rates than EKCS and CONWIP.

Simulation of Manufacturing Line with Machine Breakdowns

Performance measures of the pull systems have been studied earlier assuming machines are available full time (availability=1). However, realistic systems are imperfect, machines suffer breakdown obstructing the flow of material in manufacturing (availability<1). Other unscheduled downtimes may result from shortages caused by human failure, resulting in the machine being inactive. Machines may fail during a production run, which stops production immediately. Thus manufacturing systems are prone to suffer machine breakdowns, operation at delays and variable demands. The downtimes that occur independently for individual machines, are assumed to be preemptive, i.e., if a downtime occurs the machine goes off line immediately, regardless of whether a lot is currently being processed or not. Once downtime is over, machine continues processing immediately. MTBF and MTTR can be used



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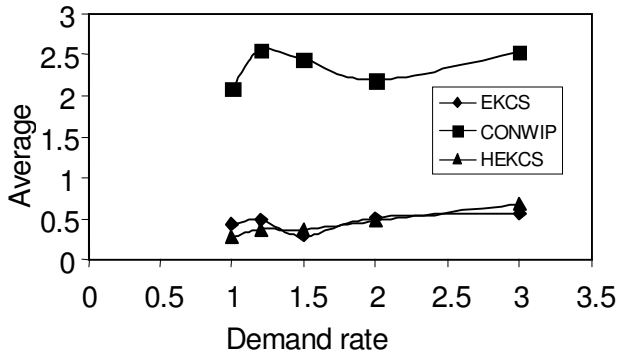

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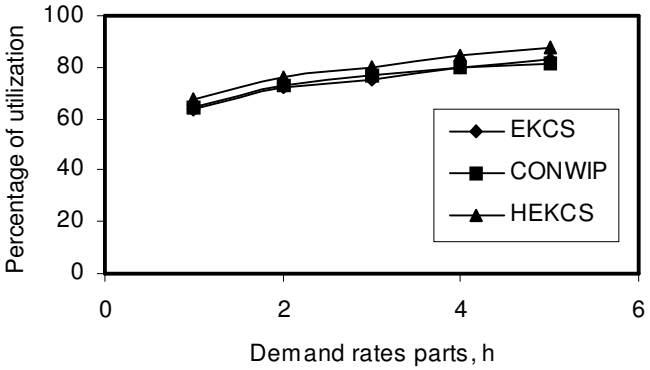
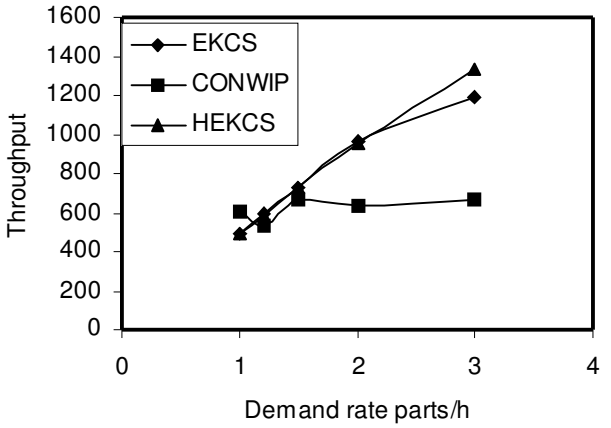


(c)

Fig.2—Performance measures for CONWIP, EKCS and HEKCS without machine breakdown: a) Throughput; b) Average WIP; and c) Utilization %



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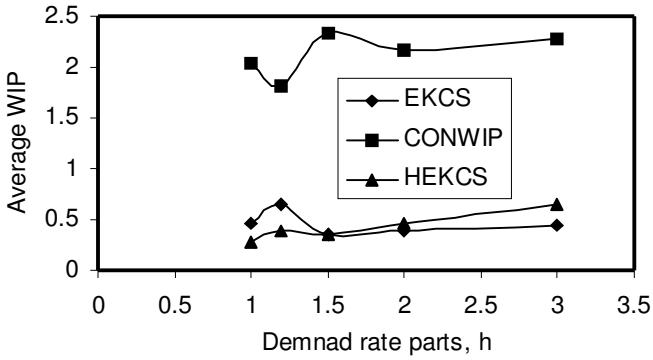

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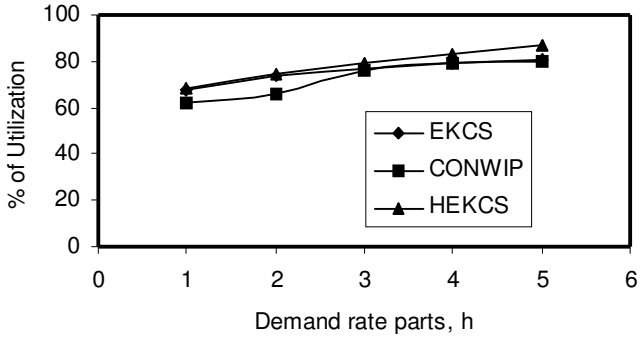

(c)

Fig.3—Performance measures for CONWIP, EKCS and HEKCS with machine breakdown: a) Throughput; b) Average WIP; and c) Utilization %

to compute the availability. The time between two successive downtimes (MTBF and MTTR) are assumed to be exponentially distributed. The term failure is used to indicate unavailability of a machine. Availability of machine can be calculated as

$$\text{Availability: } \mathbf{a} = 1 - \frac{t_{repair}}{t_{repair} + t_{intfail}} \Leftrightarrow$$

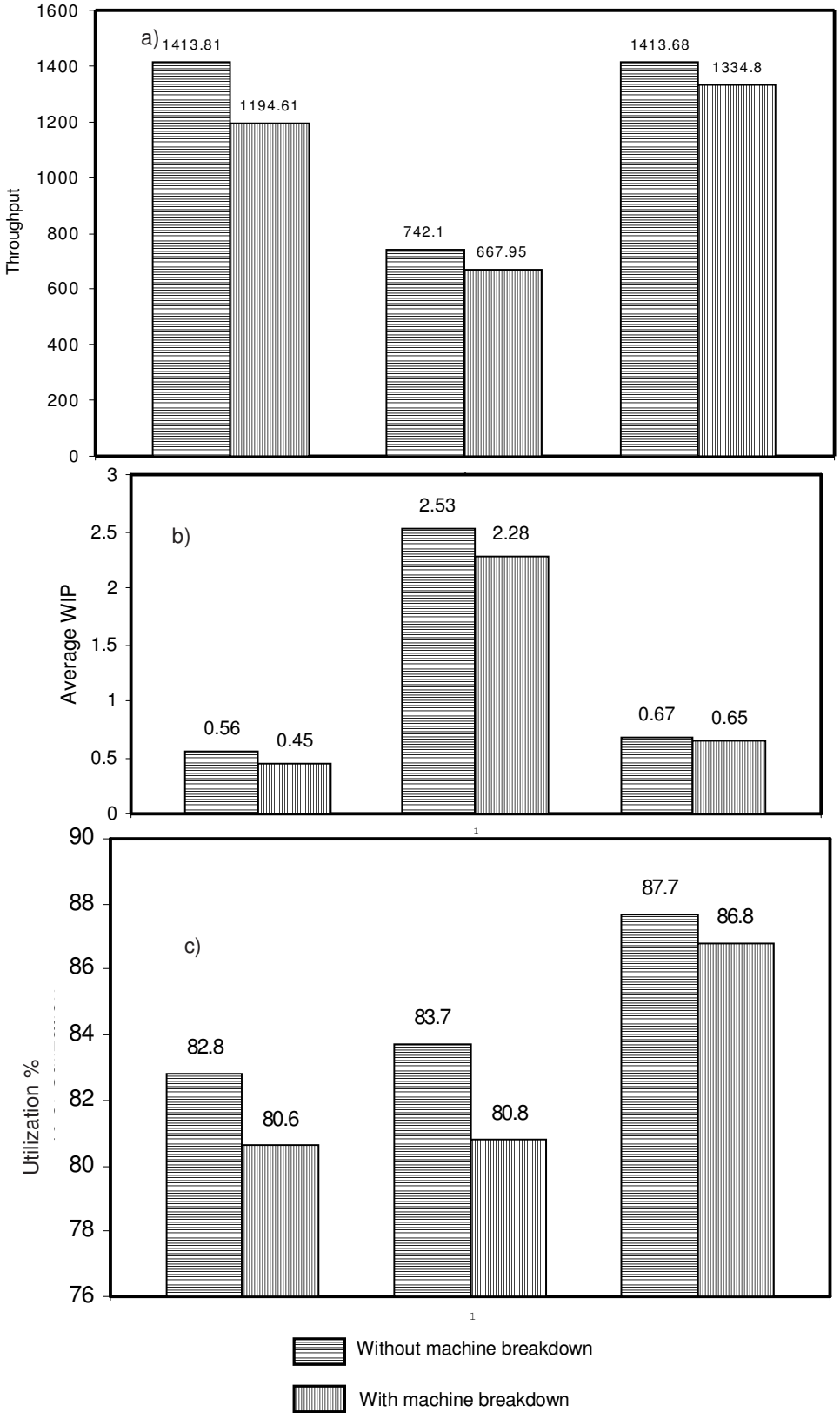

Fig. 4—Effects of simulation results on performance measures for CONWIP, EKCS and HEKCS with and without machine breakdown: a) Throughput; b) Average WIP; and c) Utilization %

$$a = \frac{t\ intfail}{t\ repair + t\ intfail}$$

where $t_{repair,}$ repair duration; and $t_{infail,}$ interfailure time.

Simulation experiments were conducted with machine breakdowns at different MTBF and MTTR values. Performance measures (throughput, average WIP and utilization%) are computed from simulation runs for each control mechanisms (Fig. 3). When demand rate is low, throughput, average WIP and utilization% are almost equal for three pull control mechanisms. As demand rate increased (0-3 parts/h), all performance measures of the pull control systems increased. Whereas HEKCS shows slight improvement than other two control mechanisms. Average WIP is showing a typical behavior like the throughput with the demand rate. Average WIP increase with demand rate in all three control mechanisms, whereas HEKCS shows less value than EKCS and CONWIP. Since kanban, demand and finished part synchronize equally in each stage, it would result in the reduction of average WIP. Similarly, HEKCS shows more utilization% increase with demand rates than EKCS and CONWIP.

Comparative Analysis

Performance measures of single line multistage manufacturing system with three control policies are changing at demand rate. Fig. 4 presents comparison of simulations results at demand rate of 3 parts/h. It is well known that throughput, average WIP and utilization% decrease with machine breakdowns for all EKCS, CONWIP and HEKCS. Proposed HEKCS shows better performance than the other control mechanisms in the case of machine breakdown situation too.

Conclusions

Control mechanisms (EKCS, CONWIP and HEKCS) were compared for a pull production system with and without machine breakdown. Machine breakdown affect the overall performance of typical manufacturing system like throughput, average WIP and utilization% for all three-control mechanisms. In the case of with or without machine breakdown, proposed HEKCS shows superior performance than EKCS and CONWIP in all performance measures.

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