Analysis of Single Flow Line Multi Stage Multi-Product Pull Control Systems

G G Sastry and R Garg

1,2Department of Mechanical Engineering University of petroleum and Energy Studies, Dehradun 248006, Uttarakhand, India

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The production control systems in industries become a significant pre-requisite for its success. The pull control systems could be a systematic approach for the effectiveness of production systems. This paper covers the investigation and performance analysis of Constant Work in Process (CONWIP), Kanban Control System (KCS) and Extended Kanban Control System (EKCS) using real time industrial problem. The industry manufactures two gears of different diameters and the demand for each is 20 per day. The CONWIP, KCS and EKCS are modeled as network diagrams in MATLAB-SIMULINK and simulated. The performance of EKCS is optimal as compared to KCS and CONWIP. The EKCS was implemented for one month and the production is increased by 54%.

Keywords: CONWIP, KCS, EKCS, Kanban, WIP, Average Waiting Time, Utilization, Demand Rate

Introduction

The modernized manufacturing sectors find a competitive environment for producing the products of distinguished quality and high perish ability. The competitiveness is the key requirement for the country’s growth and employment opportunities. The industries follow make-to-order approach based on the customer demand as compared to make-to-stock approach which yields high inventory cost. The multi-product pull control system works on dedicated and shared type of kanban system. The kanban is attached to each product independently in dedicated system whereas kanban is shared between the product types in shared system. However, the determination of lot size and set up time is an important parameter for the selection of multi-product systems. The shared kanban system shows superior performance as compared to dedicated kanban system. The multi-product KCS processed on single manufacturing facility using decomposition method. It depends upon number of kanbans for computing the steady-state performance. The performance of hybrid system, which is the combination of pure push and pure pull system, was analyzed. The pure push system was more significant as compared to pure pull system. Also, the kanban systems are reviewed for design and operational systems and analyzed for other sequencing rules for the performance measurement.

Problem statement

The objective is to analyze the performance of the three pull production control systems; CONWIP, KCS and EKCS for single flow line multi stage multi-product system using industrial case study. The model is developed and simulated by using technical computing software as specified. The performance is
analyzed for number of kanbans and breakdown to achieve optimized output. A small scale industry located at Ghaziabad India, with work force strength 15, is selected for investigation. The industry manufactures two Gears of different diameters, Gear A and Gear B, with sequence of operations viz. turning and generation; profiling; cleaning/ burnishing. The processing mean time for Gear A is 17 minutes, 10 minutes and 22 minutes and for Gear B is 20 minutes, 13 minutes and 18 minutes respectively. The expected demand for each gear type is 20 per day. The industry works for 6 days per week @ 16 hours per day.

Multi product system –model generation

Figure 1 illustrates the manufacturing system with two product types in three manufacturing stages MP_i, where i=1, 2, 3,... Queue q_p^r_i is the output buffer of product type r, and stage i where r =1, 2 and i=1, 2, 3. The finished product for each type is stored in the respective output queue. It synchronizes with the customer demand of the respective product type. The CONWIP, KCS and EKCS have three dynamic elements viz., product, demand and kanban (product authorization). The raw material or semi-finished product moves from upstream to downstream stage after processing and wait at the buffer of each stage. The demand moves from the output of downstream stage to the input of upstream stage. Product authorization is the kanban fixed for each stage along with product type associated with it. The kanban moves with the part or demand or alone in each stage. The dedicated kanban for stage i is synchronized with type ‘r’ product. The allocation of the product type for each manufacturing stage is by specific rules depending on the batch size and availability of products in the buffer. The invariants of CONWIP system for one product consisting of kanban path are:

\[ M(D_i) \cdot M(P_rA_i) = 0 \]
\[ M(D_iA_i) + (MP_1 + MP_2 + MP_3) + P_rA_i = K \]
\[ 0 \leq D_iA_i \leq K \]
\[ 0 \leq (MP_1 + MP_2 + MP_3) + P_rA_i \leq K \]

The KCS consisting of kanban in each stage imply the invariants for one product are:

\[ M(D_iA_{i+1}) \cdot M(P_rA_i) = 0 \text{ where } i = 1, 2, 3,... \]
\[ M(D_iA_i) + M(MP_i) + M(P_rA_i) = K_i \text{, where } i = 1, 2, 3,.. \]
\[ 0 \leq MP_i \leq K_i \text{, where } i = 1, 2, 3,... \]
\[ 0 \leq (MP_i + P_rA_i) \leq K_i \text{, where } i = 1, 2, 3... \]
\[ 0 \leq P_rA_i \leq S_i \text{, where } i = 1, 2, 3, ... \]

The invariants and characteristics of EKCS in each stage for one product are:

\[ M(A_{i+1}) \cdot M(P_rA_i) \cdot M(D_i) = 0 \text{ where } i = 1, 2, 3,... \]
\[ M(A_i) + M(P_rA_i) + M(MP_i) = K_i \text{ where } i = 1, 2, 3,... \]
\[ M(A_i) = K_i - S_i \text{, where } i = 1, 2, 3, ... \]
\[ 0 \leq M(A_i) \leq K_i \text{, where } i = 1, 2, 3, ... \]
\[ 0 \leq MP_i \leq K_i \text{, where } i = 1, 2, 3, ... \]
\[ 0 \leq (MP_i + P_rA_i) \leq K_i \text{, where } i = 1, 2, 3, ... \]
\[ M(P_rA_i) - D_i \leq S_i \text{, where } i = 1, 2, 3, ... \]

Results and Discussions

The developed models of CONWIP, KCS and EKCS are simulated for 5760 minutes (i.e. six days @ 16 hours) for demand rate of 2.5 to 3 parts per day.

Fig.1—Queuing Network diagram of single flow line multi stage multi-product system
The mean time between failures is 480 minutes and mean time to repair is 30 minutes. The performance is analyzed and compared for two, three and four kanbans per stage with and without considering the machine breakdown. The simulation results of Gear A and Gear B for 4 kanbans per stage are given in table 1. The production in CONWIP is less as compared to KCS and EKCS for the given input parameters. Hence, it was not considered for further analysis. However, the values of production and utilization in KCS and EKCS are similar at a demand rate of 2.72 parts per hour (i.e. demand mean time 22 min) for four kanbans per stage. Further, the WIP in EKCS is equal to or less than KCS. The average waiting time in EKCS is less as compared to KCS. Hence, for the given input parameters and customer demand, the performance of EKCS is optimal as compared to KCS considering production, average waiting time, WIP and utilization.

### Implementation of KCS and EKCS in Industry

The KCS and EKCS were implemented on the shop floor for two days each on experimental basis. The data was recorded in real time considering the warm up time and breakdown. The same input data was used in the network model developed as discussed earlier and simulated for 1920 minutes for each system. Table 2 gives the comparative performance based on the results obtained from simulation and shop floor. The production in EKCS was high as compared to KCS. The machine utilization and WIP in KCS was high as compared to EKCS. However, the WIP in KCS and EKCS shows similar variation between simulation and actual results. Therefore, considering production, WIP and machine utilization, the performance of EKCS is optimum at demand mean time 22 minutes. Henceforth, EKCS was implemented for longer duration to analyze the performance.

### Performance of EKCS in Industry

The EKCS was implemented in industry for one month and the results are recorded on weekly basis for optimum demand mean time 22 min i.e. 2.72 parts/hour. The batch size for each gear type is 21. Simultaneously, with the same input data, the system was simulated for one month i.e. four weeks (24 days @16 hours =23040 minutes). The simulation results and the real time output obtained after four weeks are

<table>
<thead>
<tr>
<th>Demand Rate Parts/hour</th>
<th>Constant Work in process (CONWIP)</th>
<th>Kanban Control System (KCS)</th>
<th>Extended Kanban Control system (EKCS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production A W T (min)</td>
<td>WIP Utilization (%age)</td>
<td>Production A W T (Min)</td>
<td>WIP Utilization (%age)</td>
</tr>
<tr>
<td>3</td>
<td>98</td>
<td>94</td>
<td>102</td>
</tr>
<tr>
<td>2.85</td>
<td>123</td>
<td>82</td>
<td>73</td>
</tr>
<tr>
<td>2.72</td>
<td>123</td>
<td>82</td>
<td>73</td>
</tr>
<tr>
<td>2.61</td>
<td>123</td>
<td>82</td>
<td>105</td>
</tr>
</tbody>
</table>

### Table 2—Performance comparison of KCS and EKCS with simulation results and actual results

<table>
<thead>
<tr>
<th>PRODUCTION</th>
<th>KCS Simulation</th>
<th>KCS Actual</th>
<th>EKCS Simulation</th>
<th>EKCS Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand mean time 22 min. 4 Kanban/stage</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>44</td>
<td>40</td>
<td>36</td>
<td>34</td>
<td>43</td>
</tr>
</tbody>
</table>
given in Table 3. The performance comparison of production, utilization and WIP respectively obtained by simulation, actuals before implementing the pull control system and actuals after implementation of EKCS are shown in figures 2 and 3.

**Conclusions**

The performance of CONWIP system, KCS and EKCS for single flow line multi stage multi-product system has been analyzed. Initially, the system was analyzed on the basis of simulation results which indicate that the performance of KCS and EKCS is sensitive to part complexity, breakdown, average waiting time and WIP. The KCS and EKCS were implemented on the shop floor to evaluate the relative performance. The EKCS emerged best as compared to KCS on the basis of production, WIP and utilization.

Earlier, the industry was producing 12-13 gears of each type per day. After implementation of EKCS for one month, the production has increased from 20 to 21 gears of each type per day. Thus, the production has increased by approximately 54%. The WIP has decreased and machine utilization has shown significant improvement.

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**References**


