A COMPARATIVE STUDY OF POLCA AND GENERIC CONWIP PRODUCTION CONTROL SYSTEMS IN ERRATIC DEMAND CONDITIONS

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Abstract
The design and analysis of Toyota production systems (namely Lean production) has received great attention of both academia and industry for over 20 years. As one of the most important elements of the lean production, the traditional Kanban production control system has been widely investigated. Kanban systems are mainly suitable for certain repetitive manufacturing environments with low demand variability and low product variation. In order to overcome this downside of Kanban, CONWIP (Spearman et al., 1990) and POLCA (Suri, 1998) were proposed as alternative systems. In this paper, the optimal settings of operating parameters for POLCA and Generic CONWIP systems are determined under different hypothetical scenarios. The performances of the two production control systems are compared using simulation and the results are discussed in detail.

Keywords: Lean manufacturing, POLCA, CONWIP, Simulation

1. Introduction
Lean manufacturing became a cornerstone for the manufacturing world after Toyota gained an enormous market power by inventing and applying it. Companies all over the world have been implementing lean techniques to gain competitive advantage. Lean production has various tools, such as pull production control systems, cellular manufacturing, and 5S. Among them, pull production control systems have been receiving great attention by both academia and practitioners. Implementation and selection of appropriate pull production control mechanism have vital importance in achieving an effective production system. In particular, the Kanban production control system is the most widely known aspect of lean production. Although Kanban and its comparisons with other production control mechanisms are abundant in academic literature, the alternative pull mechanisms of Kanban have not been investigated with such detail.

As stated in Monden (1983), traditional Kanban system has some drawbacks. First of all, it requires that demand must be almost constant (demand variability is low) and the product variation (product types related to a Kanban card) must be low. To ensure pull with high product variation environments, Spearman, Woodruff, and Hopp (1990) proposed another pull production control mechanism called CONWIP (Constant work in process). This mechanism allows for operating pull control for a line having different products, with higher flexibility. In addition, for engineered-to-order manufacturing
environments (erratic demand conditions) Suri (1998) proposed a different production control systems: POLCA (*Paired-cell Overlapping Loops of Cards with Authorization*) production control system.

The rest of the paper is organized as follows: section 2 explains the problem and the motivation. Section 3 gives information about experimental settings and methodology, Section 4 summarizes the results, and Section 5 presents concluding remarks and identifies future work.

2. Motivation and Problem Definition

Although both CONWIP and POLCA are hybrid pull production control mechanisms and have superior advantages over Kanban in high demand variability environments, their operating characteristics are different and therefore their parameters must be set different levels to achieve maximum performance.

In literature, optimal operational settings are identified by plenty of studies related to Kanban. Similarly, CONWIP systems have been investigated with a great detail. Additionally, there are plenty of studies related to the comparison of Kanban and CONWIP systems in various scenarios. On the other hand, POLCA system is a rather new subject. Suri and Krishnamurthy (2003) published a technical report for implementing issues for POLCA systems. Riezebos (2006) conducted a simulation analysis of a unidirectional flow system which uses POLCA. Fernandes and Carmo-Silva (2006) proposed an enhanced version of POLCA named G-POLCA (Generic POLCA). Baysan, Kabadurmus, and Durmusoglu (2007) analyzed POLCA for a real life case and conducted an economic analysis using simulation. Most recently, Vandaele, et al. (2008) investigated POLCA for multi-product, multi-machine job shops. Since the literature of POLCA is not very rich, it is a promising area for academia.

The aim of this paper is to compare POLCA and CONWIP. As stated by Suri (1998), POLCA is particularly suitable for engineered-to-order production environments. It can also be shown that CONWIP system can be used as an alternative. Especially under certain scenarios, selection of the appropriate alternative is crucial.

To begin with, the main features of Suri (1998) layout are used and hypothetical manufacturing system is constructed (Figure 1 and Figure 2).
As seen from the Figure 1, for any product, a route sheet is necessary, as parts are moved according to their routes. For the sake of illustration, part family 4 is selected and its route is A1-B3-C2 (Table 1). In order to start processing at A1, any of the A1/B3 POLCA cards must be available. Otherwise, the next job in the A1 queue starts processing at A1, for instance A1/B1 POLCA card is available and part 1 starts processing as it is the next item in the queue of A1. For the B cells, the authorization rule for a part is that there must be two different POLCA cards available, related to the route of the part. For instance, at B3 cell, the A1/B3 POLCA card (already moved from upstream cell with the part) and B3/C2 POLCA card must be ready. Otherwise, the next item (or the first item that has the explained qualifications to process) in the queue is processed, as long as it has the two POLCA cards. Similar to the A cells, for the C cells; there must be one POLCA card. Obviously, the card is already attached to the part when it arrives to the destination C cell. For example, B3/C2 POLCA card is already attached when the part arrived to the C2 cell. The operating systematization of POLCA cards are the same for other POLCA loops.
Table 1. Processing Times and Routes of Identified Part Families

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Part 1</td>
<td>10</td>
<td></td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part 2</td>
<td></td>
<td>12</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>Part 3</td>
<td></td>
<td></td>
<td>17</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Part 4</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
<td>32</td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Part 5</td>
<td>15</td>
<td>19</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td>19</td>
<td></td>
<td></td>
<td>16</td>
</tr>
</tbody>
</table>

(All numbers are the means of normal distributions of individual parts families and given in minutes)

Figure 2 summarizes the CONWIP operations. As noticed, CONWIP system is operated for the whole line. In that, CONWIP is employed to operate many cells. In particular, this aspect of generic CONWIP systems was investigated by academia. For example, Golany, Dar-El, and Zeev (1999) studied to optimize backlog list of generic CONWIP controlled multi-family, multi-cell manufacturing system. In our paper, the parts are queued according to FIFO rule at the beginning of the line; their authorization decision depends on available CONWIP cards in the line. More precisely, if there is an available CONWIP card at the beginning of the line, the job is released to the system, otherwise it waits. When processing of a part is completed and part is leaved the system, the CONWIP card is detached from the exiting part, and sent back to the beginning of the line. By this routine, it signals the authorization to release for the next item in the queue, which was previously waiting for a CONWIP card to enter the system.

Five different product families are identified for this production system, and the routes and processing times of each part type is given in the Table 1. For POLCA loops, the system parameters are estimated using the formulas given by Suri (1998) and for CONWIP system, the necessary parameters are calculated from the formulas proposed by Hopp and Spearman (2001). In order to see the effect of individual manufacturing system’s (POLCA or CONWIP) to the performance measure, operating parameters of the production control system is selected optimally for each scenario.

3. Experimental Settings

For the comparison of CONWIP and POLCA, the traditional design of experiments methodology is used. The various input parameters are set to certain levels to achieve maximum performance of responses (Table 2). Full factorial design is used and two responses are selected: “manufacturing lead time (or time in system)” and “work in process inventory”.

As input parameters, variability of the processes are planned to be accounted by coefficient of variation. In order to account demand variability, exponentially distributed interarrival times (IAT) are used. Batch size is changed in different scenarios to identify its effect on system performance. Down time ratio is used for modeling machine failures. Down time ratio is defined in this paper as “Down time ratio = Down time / Up time”. For product variation, 5 different product types are used; however, their percentages vary differently among scenarios. The complete summary of input settings is given in Table 2.

The scenarios are modeled in Arena Simulation Software and the results are obtained by simulation length of 5 days with warm-up period of 2 hours.
Table 2. Summary of Experimental Settings

<table>
<thead>
<tr>
<th></th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of variation</td>
<td>0.3</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Interarrival Times (minutes)</td>
<td>Expo(9)</td>
<td>Expo(8)</td>
<td>Expo(7)</td>
</tr>
<tr>
<td>Batch Size</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Down time ratio</td>
<td>0.0</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Product Variation</td>
<td>(20%, 15%, 30%, 15%, 20%)</td>
<td>(25%, 20%, 20%, 20%, 15%)</td>
<td>(15%, 25%, 10%, 25%, 25%)</td>
</tr>
</tbody>
</table>

4. Results

The average performance values of POLCA and CONWIP are given in Table 3. As noticed, POLCA outperforms the CONWIP controlled system according to both performance metrics. Nevertheless, this rough cut analysis does not show performance deviations for each factor level. Hence, in this paper, POLCA and CONWIP are compared for each input parameter in a great detail.

Table 3. Summary of Experimental Settings

<table>
<thead>
<tr>
<th></th>
<th>Time in System(mins)</th>
<th>Average WIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>POLCA</td>
<td>466.311</td>
<td>11.475</td>
</tr>
<tr>
<td>CONWIP</td>
<td>552.161</td>
<td>15.430</td>
</tr>
</tbody>
</table>

As a first comparison, POLCA and CONWIP are compared in terms of interarrival times. As seen from the Figure 3, CONWIP has a poor performance in comparison to POLCA, since POLCA system has lower average WIP and lower average time in system values. In addition, as a general trend, the reduction in the demand rate reduces the differences in two systems.

Figure 3. The comparison of POLCA and CONWIP – Interarrival times

Coefficient of variation (of the processing times), obviously decreases the system performance (Figure 4). Again, POLCA performs better than CONWIP.
A comparative study of POLCA and generic CONWIP production control systems in erratic demand conditions
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As the batch size increasing, the average time in system values are increasing for both production control systems (Figure 5). In addition, as a general trend, the performance difference of POLCA and CONWIP is diminishing as the batch size is increasing. Obviously, POLCA outperforms CONWIP for each batch size scenario.

Figure 5. The comparison of POLCA and CONWIP – Batch size

Figure 6 shows that high machine failure times lead to poor system performance. Once again, POLCA has a better performance over CONWIP in terms of different down time ratios. Interestingly, small down time ratios (or even zero) makes the performance gap of two systems small.

Figure 6. The comparison of POLCA and CONWIP – Downtime ratio
A comparative study of POLCA and generic CONWIP production control systems in erratic demand conditions
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Figure 7. The comparison of POLCA and CONWIP – Product mix

For different product mixes, POLCA outperforms CONWIP although their performances are quite same for product mix 1 (where CONWIP performs better in terms of time in system). Note that, the performance of CONWIP is more unstable than POLCA for different product mixes (Figure 7).

5. Conclusions and Future Studies

Lean production methodology has been taking great attention of both practitioners and academia for over 20 years. This methodology has its own tools and pull production control system is one of the most important and popular subject among these. The most well known implementation tool for pull production control is Kanban system. It has been investigated in a great detail by academia for decades and implemented by practitioners from all over the world. Nevertheless, Kanban system has some deficiencies in some manufacturing environments having erratic demand conditions.

For high demand variability and high product variation environments, traditional Kanban system is not a valid alternative (Monden, 1983). For this reason, CONWIP and POLCA systems are proposed. On the other hand, although there are numerous studies for CONWIP, studies related to POLCA are rare. In addition, comparison of POLCA with other production mechanisms has not been investigated in detail yet. The lack of such comparative analyses motivates this paper.

In this paper, POLCA and CONWIP systems are compared in erratic demand conditions. For a hypothetical system, various factors are investigated using different scenarios. The main performance criteria are given as total time in system (manufacturing lead time) and work in process inventory. The factors are demand variability, product variation, processing time variability, batch size, and down time ratio.

For given scenarios, POLCA outperformed CONWIP. In addition, it is revealed that CONWIP does not fit well certain environments having erratic demand (both demand rate and product mix changes unexpectedly), high machine failures and high process variability. Therefore, it is observed that the performance gap of POLCA and CONWIP tends to reduce for low downtime ratios, large batch sizes, and lower demand rates. As a concluding remark, POLCA system works with high performance and therefore is an appropriate choice to ensure pull in erratic conditions, whereas CONWIP is prone to perform poorly with these unstable conditions.
For the future study, the problem can be enriched by different factors, such as transfer times. In addition, different pull production control systems can be tested. Another interesting extension of this problem would be modeling complex systems and using real life data.

6. References


