IMPLEMENTATION OF A MULTI-TRIANGULAR KANBAN SYSTEM
IN AN ELECTRONIC CONNECTOR PLANT

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Abstract. The implementation of a new Kanban system in an electronic connector plant is described in this paper. The plant was characterized by relatively long setup time of machines, high variety of products and multiple machines to multiple assembly lines in job assignment. It’s verified that the traditional Kanban system is not suitable for the plant’s production system under study. A multi-triangular Kanban system was developed to avoid the potential negative effects caused by long setup time and high variety of product types. For the job assignment problem, Kanban allocation was modeled and solved using integer programming. Simulation was run to determine optimal parameter values, including batch size and low control limit, as well as to compare the multi-triangular Kanban system with the single triangular Kanban system. The results show that the multi-triangular Kanban system is superior to the single one in reducing the WIP of the system.

Keywords: Kanban, Multi-triangular, WIP, Simulation

1. Introduction

Lean production aims at incorporating multiple management practices to create a streamlined, high quality system that produces finished products at the pace of customer demand with little or no waste (Shah et al. 2002). One important dimension of lean manufacturing is Kanban system. Despite its successful implementation, particularly in Japan, Kanban systems have been criticized for its compatibility limited applicable situations. Kanban system requires the production process to behave as a nearly frictionless pipe, which is hard to achieve in actual production situations. Scrap loss, significant set-ups and expediting are not tolerated (Spearman et al. 1990).

In this paper, we describe our promotion of a multi-triangular Kanban system in a manufacturing plant of electronic connectors. We have to modify the traditional Kanban system to make it more suitable to the specific manufacturing situation, which is characterized by long setup time of machines, high variety of products and multiple machines to multiple assembly lines in job assignment.

The remaining of this paper is organized as follows: In the second section, previous researches on Kanban system and pull approach are presented; In the third section, the characteristics of the manufacturing process in the electronic connector plant are described, which forms the fundamental of our analysis; In the fourth section, we discuss the reasons for the implementing of Kanban system in the plant; In section five, different aspects of the multi-triangular Kanban system are described. In section six, the simulation model is presented. The model was used to set the system parameters and evaluate the multi-triangular Kanban system. Finally, issues requiring further considerations are discussed in section seven.

2. Literature review

Push and pull systems were compared in different aspects by many researchers. LP Rees et al. (1989) compare MRP lot-for-lot with Kanban. And they concluded that more money may be saved by staying
with a MRP system if the time bucket can be reduced than converting to Kanban. Some methodologies were developed by combining pull and push approaches to achieve effective production. For example, the theory of constraints or ‘drum-buffer-rope’ approach developed by Goldratt (1984). Similar to this approach is CONWIP (Spearman et al. 1990) in which production is pulled by the demand but the pull signal is delivered to the beginning of production process and pushed downstream. By using Markova model, Deleersnyder et al. (1992) found that hybrid push/pull approach appeared to be superior to pure pull control in several aspects. We also incorporated the idea of push approach with pure pull approach to make it more applicable in the electronic connector plant. Batch production is maintained as well as the implement of Kanban system. And the schedule of operations on the shop level is optimized using integer programming.

Analytical methods have also been developed to evaluate the performance of the Kanban system. Maria Di Mascolo et al. (1996) developed a general purpose analytical method consisting stages in series. Each stage contains one subsystem. The Kanban system is modeled as a queuing network with synchronization mechanisms. In our case, a simulation model based on the queuing theory is used to evaluate the performance.

3. Problem description

The product has two essential components. One is housing, produced in molding workshop from plastic grains. The other is pin jack. The pin metal needs to be processed through punching and plating workshops. The two components are assembled in the final stage as shown in the Fig. 1. We generally focused on the process from molding to the final assembly

The characteristics of the process have a large impact on implementation of Kanban system. We analyzed the process and found out those relative ones as a fundamental of our analysis.

1) Multiple machines in each stage

The assembly lines are short and equipped with automated or semi-automated machines. For such assembly lines, workers are only required for replenishment of components and checking. Thus, one assembly line can be treated as a single machine in this plant. Manufacturing in other workshops are held on discrete machines. As a result, the overall process can be modeled as a system which contains limited stages, each containing multiple machines. Because the capacity of one molding machine is smaller than the requirement of an assembly line, it is impossible for one machine to serve one assembly line. It is inapplicable for several molding machines to serve one particular assembly line as well. $M$ machines have to work together to meet the demand of $N$ assembly lines ($M, N>1$). This brought the problem of Kanban allocation, which will be further analyzed.

2) Long set-up time and high set-up cost

The molding machines need a relatively long setup time. Moreover, warm-up period is required since initial components produced at the beginning are useless due to instability, leading to the increase of setup cost. As mentioned above, long setup time and high setup cost are usually not tolerable for Kanban system.

3) High variety of products

The manufacturer produces a large variety of product types. Each type is produced for duration varying from several hours to several days. The time is decided by the order size.

4) The existence of bottleneck

Molding workshop is the bottleneck of the whole process. Considering that the pace of the production is actually decided by the pace of molding workshop, it seems that we just need to make a good production
schedule and then push it down the process. But we will discuss later that a tailored Kanban system can bring some benefit to the system.

Kanban is inapplicable in many situations. Monden (1983) has indicated that Kanban is difficult or impossible to use when there are:
1) Job orders with short production runs, or
2) Significant set-ups, or
3) Scrap, or
4) Large, unpredictable fluctuations in demand

Comparing these to the characteristics of the plant, it can be concluded that the system is not that suitable to the traditional Kanban system. In contrast, MRP, which the plant already has, can be applied in most production systems. The plant already has a MRP system. Then why we choose to implement a Kanban approach?

4. Reasons for the implement of Kanban approach

4.1 Controls over WIP
Since the withdrawal Kanban is released as the production going on, the WIP in the assembly workshop is bounded by the number of Kanban, in other words, the production capacity of assembly lines.

The inventory bounded by the low control limit and batch size in molding workshop is a part of WIP. We may have to set the low control limit higher and the batch size larger than optimal values at the beginning, however, we can gradually reduce them as the production process is improved.

What’s more, according to little’s law:
Average flow time = Average WIP/Average throughput

The average throughput is bounded by the capacity of plant in peak demand period. Thus, the average flow time can be reduced if the average WIP is reduced.

4.2 Environment effects
Krejewski et al. (1987) indicated that environmental considerations may be the main cause for differences in the performance of push and pull production systems. The implementation of Kanban requires the environment amelioration. With the reduced WIP level, existing problems of the system can be highlighted. Thus, cues are given to solve these problems.

In our practice, the implementation of Kanban stimulated the effort to reduce setup time and scrap loss. The improvement of environment condition will make the performance of Kanban system better.

4.3 Against the fluctuations of demand
The electronic connector is a part of mainboard, which is a part of desktops or laptop computers. The manufacturer of electronic connector is far from end users, thus, suffers more from the change of demand. This makes the forecasting difficult. There is a risk the products will fail to be sold out due to the change of market demand. On one hand, integration of the supply chain is required to reduce uncertainty; on the other hand, the plant has to reduce the WIP level and flow time in order to achieve quicker response to demand. That is why a Kanban system desired in the plant.

In order to gain the benefits of pull approach, the traditional Kanban system should be tailored to better accommodate to the situation. Long setup time and high variety of products are the mainly focuses to employ changes to Kanban system.

5. Solution
Due to the characteristics of production, we designed a multi-triangular Kanban system. For operations schedule under this Kanban-controlled system, integer programming is used to allocate Kanban to specified machine. The parameter values of the system were set using simulated experiment design. We also used the simulation model to evaluate the performance of the system.

Since the process requires a relatively long setup time and a warm up period, batch production is applicable. Withdrawal Kanban is used to withdraw parts from molding workshop. The inventory in molding workshop is controlled with a triangular Kanban. As soon as the inventory decreases to the low control limit indicated by the triangular Kanban, the production starts under the authorization of triangular Kanban.

Problem appears since one triangular Kanban can only be allocated to one machine, and the molding
machine has a lower production rate than the demand rate of the assembly line. The inventory will keep on decreasing during the production. In this case, we can set a high low control limit to ensure the continuous production. However, since it manufactures a large variety type of products, maintaining a large inventory for every type of components is not economical. Therefore, we developed a multi-triangular Kanban system.

5.1 Deciding the system parameter values
1) Deciding the number of triangular Kanban
Each kind of part produced in molding workshop has multiple number of triangular Kanban. The number is decided roughly by the demand rate of assembly line.

\[ n = \frac{\text{total demand rate}}{\text{production rate of single machine}} \]

In reality, we can often find an approximate relationship expressed as how many machines are necessary for one assembly line, how many for two, etc. Thus the decision process for \( n \) can be simplified. If the production state of assembly lines changes, \( n \) should be updated.

2) Deciding and updating the low control limit
We implemented a fixed frequency material withdrawal policy. It was chosen to avoid the potential operational complexity of continuous inventory review.

The low control limit was set based on the demand of assembly lines between two withdrawal time points. Whenever the kind of parts assembled changes, the low control limit should be reset. The optimal value of the low control limit was decided using simulation.

3) The economical batch size
Whenever the production starts as indicated by the triangular Kanban, an economical batch size should be produced. The value of this parameter is optimized using simulation.

5.2 The procedure
When one container of components is used in the assembly line, the withdrawal Kanban attached to it is put off and collected. At the beginning of every fixed time period, the withdrawal Kanban is sent to the upstream production workshop, which is molding workshop in this case. The required components are transported to assembly lines with withdrawal Kanban attached to their containers. At the same time, if the inventory of the particular type of components reaches its low control limit and triangular Kanban is available, the Kanban is allocated to one machine to start production and a card indicates the machine ID is put on the shelf of the particular type of components.

![Fig. 2. Procedure of Kanban between molding and assembly workshops](image)

5.3 Allocation of Kanban
Since a long setup time exists in molding workshop, and the changeover time between different types of components has large differences, the cost will increase if we just allocate the Kanban randomly.

We try to use integer programming to solve this problem. Let \( i \in \{1, 2, \ldots, m\} \) be index different kinds of components. Let \( j \in \{1, 2, \ldots, n + 1\} \) index different machines. We set machine \( n+1 \) as a dummy. It has an unlimited capacity and a very large changeover cost.

**Parameter:**
- \( e_{ij} \) = the changeover time \( i \) type of component needed on machine \( j \)
- \( p_j \) = the production rate of machine \( j \)
- \( r_{ij} \) = the remaining components to be processed indicated by the previous Kanban.

**Decision Variable:**
- \( x_{ij} = 1 \), if type \( i \) component should be produced on machine \( j \);
- \( = 0 \), otherwise

**Model:**
\[
\begin{align*}
\min & \sum_{i=1}^{m} \sum_{j=1}^{n-1} (c_{i,j} + r_{i,j} / p_{i,j})x_{i,j} \\
\text{s.t.} & \quad \sum_{j=1}^{n} x_{i,j} = 1 \quad \text{For all } i \\
& \quad \sum_{i=1}^{m} x_{i,j} \leq 1 \quad \text{For } j = 1, 2 \ldots n \\
& \quad \sum_{i=1}^{m} x_{i,n+1} = M \\
& \quad x_{i,j} = 0 \text{ or } 1 \text{ for all } i, j
\end{align*}
\]

The objective of the model is to minimize the overall waiting time of production order indicated by Kanban to be processed on machine. It composes of two parts, the waiting time when the machine is blocked by another Kanban and the exchange time of dies. The constraints are every Kanban can only be allocated to one machine and every machine can only take one production task. The third constraint is to allocate all the Kanban that exceed the capacity to the dummy machine. If \(x_{i,j}=1\), the i type of component should be allocated to machine j. If \(x_{i,j}=0\), it should not.

5.4 Supporting approaches
In order to make the system run smoothly, supporting approaches need to be implemented. These approaches include 5S, rapid exchange of dies, and training of personnel. Specific departments in the plant were assigned to perform these tasks respectively.

6. Analysis of the multi-triangular Kanban system using simulation
To validate our solution, a simulation model was developed. We used the model to identify the key factors that influenced the performance of the system, set the parameter values and compared the multi-triangular Kanban system with the single triangular Kanban system.

6.1 The simulation model
We built the simulation model of molding workshop and the assembly lines. Input distribution includes:
1) Capacity of machines in molding workshop and assembly lines;
2) MTBF (Mean Time between Failures) and MTTR (Mean Time to Repair) of machines and assembly lines;
3) Required changeover time of machines.

The distributions used in simulation are fitted based on actual data of historical production. All the parameter values related to time are in minute. The distributions used are listed in Table 1. Orders in the next several days of the plant are used as demand in simulation. The orders assigned to three of the assembly lines are presented in Table 2. The data was slightly changed here to not reveal the business secret, while the result of the simulation would not be significantly affected.

<table>
<thead>
<tr>
<th>Parameter name</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity of assembly lines</td>
<td>35kpc</td>
</tr>
<tr>
<td>MTBF of assembly lines</td>
<td>20 * 60 / (Uniform(1, 9) / 8)</td>
</tr>
<tr>
<td>MTTR of assembly lines</td>
<td>Exponential(0, 99.7843)</td>
</tr>
<tr>
<td>Changeover time of assembly lines</td>
<td>Normal(15, 1)</td>
</tr>
<tr>
<td>Capacity of molding machine</td>
<td>27kpc</td>
</tr>
<tr>
<td>MTBF of molding machines</td>
<td>Exponential(0, 900)</td>
</tr>
<tr>
<td>MTTR of molding machines</td>
<td>Exponential(0, 90)</td>
</tr>
<tr>
<td>Change over time of molding machines</td>
<td>Normal(37, 2): 40%</td>
</tr>
<tr>
<td></td>
<td>Normal(60, 3): 60%</td>
</tr>
</tbody>
</table>
Table 2. Demand in the next week for three assembly lines

<table>
<thead>
<tr>
<th>Line ID</th>
<th>Product ID</th>
<th>Housing ID</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
<th>7th</th>
</tr>
</thead>
<tbody>
<tr>
<td>J</td>
<td>3TOY-4F</td>
<td>0082</td>
<td>30000</td>
<td>30100</td>
<td>30100</td>
<td>27400</td>
<td>1650</td>
<td>30900</td>
<td>0</td>
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<tr>
<td></td>
<td>3TOE-5F</td>
<td>0084</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2700</td>
<td>28450</td>
<td>0</td>
<td>29750</td>
</tr>
<tr>
<td>K</td>
<td>V-63BL</td>
<td>2012</td>
<td>15050</td>
<td>29400</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>V-63DL</td>
<td>1012</td>
<td>700</td>
<td>0</td>
<td>29400</td>
<td>29400</td>
<td>29400</td>
<td>29400</td>
<td>14700</td>
</tr>
<tr>
<td>L</td>
<td>7-H3B-4F</td>
<td>1032</td>
<td>2800</td>
<td>19250</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10150</td>
</tr>
<tr>
<td></td>
<td>V-H3B</td>
<td>1042</td>
<td>3000</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>10150</td>
<td>48650</td>
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<td>V-63DL</td>
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<td>10150</td>
<td>29400</td>
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<td>19250</td>
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<tr>
<td></td>
<td>3TE-5F</td>
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<tr>
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<td>V-63BL</td>
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<td>0</td>
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<td>0</td>
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<tr>
<td></td>
<td>H3L-4F</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6750</td>
<td>24400</td>
</tr>
</tbody>
</table>

6.2 Use simulation to set system parameter

We first run several pilot simulation experiments to see how the factors would influence the performance of the system. The four factors are:

1) If the triangular Kanban is allocated randomly or under the policy we designed as in section three;
2) The low control limit of inventory in molding workshop;
3) The batch size of production in molding workshop;
4) The maximum temporary inventory allowed before assembly line.

BJ Berkley, AS Kiran (1991) compared the different local sequencing rules in a Kanban controlled flow shop. Lateness and tardiness can not be used because there were no due dates. As a result, job blocking was used. With similar consideration, one of our dimensions to evaluate the performance of the system is related to job blocking, which is the waiting time of Kanban.

Together with other dimensions, we evaluated the influence of the factors on the system through the following aspects:

1) The maximum and average waiting time for available machine of a production order indicated by the Kanban;
2) The times of exchange of dies in molding workshop;
3) The average inventory in molding workshop;
4) The average inventory before assembly lines;
5) The average waiting time of the assembly lines for required components.

The results showed that reduce the batch size and low control limit can decrease the inventory in molding workshop and the waiting time of production order. The Kanban allocation policy is effective in reducing the required number of times to exchange dies.

More detailed experiments were developed to further evaluate the system parameters. Different levels of parameter values were compared based on the changeover times of machines and the time of the assembly line waiting for components. Fig. 3 is the comparison of different levels of batch size; the result shows 19 as the optimal among the four levels. Fig. 4 is the comparison of different levels of low control limit; the result shows 4 as the optimal among the three. 19 and 4 here is the number of standard containers of components. These parameters were checked to the technologic aspects of the process. The parameters are applicable.
The work of Krajewski et al. (1987) showed that reducing lot sizes was the single most effective way to reduce inventory investment. But he also indicated that it appeared affordable only when setup times were small. The result of our simulation shows that the discontinuous time decreases as the batch size decreases from 25 containers to 19 containers. The discontinuous time here has the same meaning with the queuing delay time for available components. Our result is consistent with that of Krajewski et al. While on the other side, an increase of discontinuous time occurs if the batch size decreased below a specified value. This is due to the long setup time of molding machines.

In this case, another parameter should also be considered. That is the temporary inventory before the assembly line waiting to be processed in the next time period. We also designed an experiment to evaluate the impact of different levels of this parameter on the production. The result shows that if the sum of the low control limit and the maximum temporary inventory before assembly line is approximately the demand of the assembly line in two time periods, the discontinuity of production is tolerable.

### 6.4 Comparison with single triangular Kanban system

In order to compare the efficiency of our approach with the one-triangular Kanban system, we used the data from the manufacturer to simulate.

We set the low control limit of multi-triangular system as 4 containers, which was got from previous simulation result as an optimal parameter value. And we set the level of low control limit of single triangular system varying from 4 to 12 containers. The cooperation of the number of times the assembly line waiting for parts is summarized in Fig. 5. And the total time of waiting is summarized in Fig. 6.
We can conclude that to maintain the same level of production, the multi-triangular Kanban system can reduce WIP by approximately 50%-60%. This result shows that the multi-triangular Kanban system is superior to the single one in this specific situation. Further analysis is needed to explore its applicability in other situations.

7. Conclusion

During our practice in the plant, the benefits of Kanban system appeared gradually. The WIP was controlled and other aspects of production were improved. The multi-triangular Kanban system is superior to the single one as it reduced the WIP by approximately 50%-60%. But limitations exist in our analysis. The simulation should be run over a longer time period. And more complex model can be developed to observe the effectiveness of the approach in the whole plant.

The multi-triangular Kanban system is suitable in this specified plant, but it remains to be seen whether it can be applied to other similar situations. Analysis based on Markova Model and queuing theory can be conducted to reveal more underlying nature of the system.

Alternative operations schedule policies under this Kanban system may be explored. Although integer programming can be used, less complex method is necessary especially for those plants where information platform is not well developed.

It is not always economical to implement the Kanban system. For those plants where setup cost must be considered seriously, it is meaningful to investigate to what extent the setup cost must be reduced to achieve an economical convert to Kanban system. This is useful for those plants that already have a MRP system to make decisions.

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