Lean Manufacturing Design for Fishing Net Production System

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Abstract
The application of lean manufacturing has been successfully proved that can reduce the work in process, increase service level and shorten cycle time simultaneously. Many guidelines are proposed for traditional production systems to achieving lean manufacturing. However, there is no evidence of work applying lean manufacturing principles to fishing net production. This research follows some guidelines of achieving lean manufacturing on a fishing net manufacturing system and then selects some factors which can be changed simple and without any investment. Finally these factors are optimized. According to the results of simulation experiments, both service level and WIP are improved.

Keywords
Lean manufacturing, simulation, fishing net, experimental design.

1. Introduction
The common challenges of companies are market competition, increased pressure on inventory, increased service levels, and reduced work in process (WIP). Lean manufacturing is one of the approaches that can help companies respond appropriately to these challenges [7]. The focus of the approach is on cost reduction, by eliminating activities that do not add value by linking and balancing work stages, so that products from one stage are consumed directly but the next stage, until the end of the production line is reached [3].

Applications of lean manufacturing have spanned many sectors, including the automotive industry, electronics, white goods and consumer goods [1]. However, there is no evidence of work applying lean manufacturing principles to fishing net production. Fishing net manufacturing is a high make-to-order (MTO) environment, because net size and type change according to the ocean environment, fish kinds and ship size. Higher WIP and longer cycle time (CT) always result in a lower service level and produce lower customer satisfaction. This provides the motivation for this research, to design a lean manufacturing system for this industry.

There are various fishing nets, such as gill nets, lift nets, drag nets, surrounding nets (purse seine nets), set nets (trap nets), covering nets, and fish breeding nets. Each kind of net has a unique application which is based on the ocean environment, fish type and ship size. The raw materials for fishing nets include nylon, trawl, nylon filament, nylon multi-filament and polyester. Twine size is the composition of a rope as shown in Figure 1 [4]. Raw material filaments are twisted into yarn, then twined yarns are made into strands. Strands are twisted into twine, and then braided twines into rope. Mesh size is a special unit of a net; different mesh depth and mesh length will result in a different shape and area of fishing net. The relationship between mesh size, mesh depth and mesh length is show in Figure 2 [4].
Net cage is one kind of fishing net which is the main product of the case study company. The main function of the net cage is to be fixed under the sea and cultivate salt water fish in it. According to the size and type of the cultivated fish, the corresponding specifications of net cages are also different. The general diameter varies from 10 meters to 30 meters, depth varies from 4 meters to 10 meters, while mesh varies from 2 mm to 30 mm.

In the case study company there are six workstations for net cage manufacturing. They are 1) Twisting, 2) Braiding, 3) Net knitting, 4) Dyeing, 5) Heating and 6) Suturing. All manufactured net cages follow the sequence of workstation above, from 1 to 6.

Rother and Shook [8] proposed seven guidelines to design lean manufacturing systems. According to the seven guidelines there are several factors that should be considered. Different combinations of the factors would result different production performance. However, the implementation of the recommendations is likely to be risky. The simulation is a useful tool for evaluating the performance of a new design but it cannot provide the optimal design. Combining simulation with experimental design or intelligent search has been successfully adopted for simulation optimization.

This research aims to use a case study of fishing net manufacturing to demonstrate how the guidelines proposed by Rother and Shook [8] can help the design of lean manufacturing. Follows the guidelines several production factors are selected. Finally, the factors are optimized by an experimental design.

The remaining sections of this paper are organized as follows. In Section 2 the seven guidelines proposed by Rother and Shook [8] are introduced, and a number of decision factors highlighted. Then an experimental design is adopted for optimizing the decision factors in Section 3. A summary of results and concluding remarks are presented in Section 4.

2. The Guidelines proposed by Rother and Shook
Rother and Shook [8] propose a five phase implementation of VSM. The phases are 1) selection of product family; 2) current state mapping; 3) future state mapping; 4) definition of working plan; and 5) achievement of working plan.
The lean techniques to be used are defined in the third phase which contains seven guidelines to design the lean manufacturing system. The seven guidelines are summarized below:

Guideline #1: Produce to your takt time.

“Takt time” is used to synchronize the pace of production with the pace of sales. In general, it can be calculated by equation (1)

\[
\text{Takt time} = \frac{\text{available working time per day}}{\text{customer demand rate per day}}
\]

Guideline #2: Develop continuous flow where possible

Continuous flow refers to producing one piece at a time to reduce the inventory of WIP and production CT. However, continuous flow requires a great deal of creativity to achieve and sometimes it requires plant layout redistribution [7]. In this research, this guideline is not taken into consideration in the case study.

Guideline #3: Use a supermarket to control production where continuous flow does not extend upstream

A “supermarket” is nothing more than a buffer or storage area located at the end of the production process for products that are ready to be shipped [1]. When continuous flow is not possible and batching is necessary, a supermarket can smooth the whole manufacturing process. Supermarkets use a kanban system to fix the inventory level. If the number of kanban in a supermarket is too high, it causes higher inventory cost. On the other hand, the downstream production process will be subject to delays if the number of kanban in the supermarket is too low.

Guideline #4: Try to send customer scheduling to only one production process

In guideline Number 1, for calculating the takt time, the customer demand rate is based on customer scheduling. The process time is set by one of the production processes. That process is called the “pacemaker process”. The pacemaker process synchronizes the pace of the entire manufacturing process and there are no supermarkets downstream of the pacemaker process. Therefore, select different workstations as the pacemaker process will have an important influence on the performance of the entire manufacturing system.

Guideline #5: Level the production mix

Leveling the product mix means dividing the volume of all the product types based on their kanban size, and then producing them evenly over a time period. The more level the product mix is, the greater is the ability to respond to different customer requirements with a short lead time. For the example above, the production sequence can be A-A-A-A-BB-BB-BB-BB-BB or A-BB-A-BB-A-BB-A-BB. The latter is more level and allows the process to proceed smoothly with smaller supermarkets, but it would cause more changeovers. The use of a larger number of batches with fewer products in each batch results in a more level process. Therefore, the number of batches is also an important factor in designing lean manufacturing system. Moreover, the production sequence also influences the performance of the manufacturing system. That means the managers have to decide between A-BB-A-BB-A-BB-A-BB and BB-A-BB-A-BB-A-BB in the example of the production sequence above.

Guideline #6: Level the production volume

Leveling the production volume is related to the guideline Number 1. It means that production should be based on a fixed pace, the takt time.

Guideline #7: Develop the ability to make “every part every day” (then every shift, then every hour or pallet or pitch) in fabrication processes upstream of the pacemaker process.

This guideline is related to guideline Number 5. In order to divide the volume of all product types into more batches, some production methods have to be changed, such as reducing the changeover time, decreasing the production unit and so on.
3. Lean manufacturing design optimization

In this research, a simulation model of the net cage manufacturing system is developed for evaluating the performance of the future state map. According to the guidelines introduced in Section 2, five factors are importation for the net cage manufacturing process. They are 1) the production unit; 2) the pacemaker process; 3) the number of batches; 4) the production sequence; and 5) supermarket size. The design levels of each factor are shown in Table 1. As regards the supermarket size, this research uses OptQuest as the optimization tool which embeds scatter search in a simulation model to optimize the supermarket size for all lean manufacturing strategies. Glover et al. [2], Laguna and Martí [6], and Laguna [5] give details of scatter search and the OptQuest algorithms. Thus, four factors (production unit, pacemaker process, number of batches, and production sequence) are taken into consideration in experimental design for designing future state map. For each scenario, OptQuest is used for finding the best supermarket size and the corresponding performances are viewed as the performance of the scenarios.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Description (Unit)</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Pacemaker process</td>
<td>10m x 1m</td>
<td>10m x 2m</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Production unit (m)</td>
<td>Suture workstation</td>
<td>Knitting workstation</td>
<td>Dyeing workstation</td>
</tr>
<tr>
<td>C</td>
<td>Production sequence</td>
<td>Earliest due date (EDD)</td>
<td>First in first out (FIFO)</td>
<td>Shortest process time (SPT)</td>
</tr>
<tr>
<td>D</td>
<td>Number of batches</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

An $L_{18}(21\times37)$ orthogonal array has the least number of treatments to account for one two-level and more than three three-level control factors. Therefore, an $L_{18}(21\times37)$ orthogonal array was used to collect the experimental data. The experimental scenarios are shown in Columns 2-5 of Table 2. The two levels and three levels of all factors were denoted as 1-2 or 1-3 (the lower, the middle and the upper levels). For each scenario, OptQuest was used to search for the best supermarket size to maximize the service level. The service level and WIP for each scenario with the best supermarket size are shown in Columns 6 and 7 of Table 2. Service level is to be maximized, and the WIP is to be minimized. Let $\eta_j$ be the S/N ratio of scenario $j$ and let $v_{jk}$ be the simulation result for scenario $j$, in the $k$th replication. $r$ is the total number of replications. Equations (2) and (3) respectively are used for calculating the signal to noise ratio (S/N) of service level and WIP. The S/N ratios of all scenarios are shown in Columns 8 and 9 of Table 2.

$$\eta_j = -10 \times \log \left( \frac{1}{r} \sum_{k=1}^{r} \frac{1}{v_{jk}} \right)$$

(2)

$$\eta_j = -10 \times \log \left( \frac{1}{r} \sum_{k=1}^{r} v_{jk}^2 \right)$$

(3)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>$L_{18}$</th>
<th>Service Level</th>
<th>WIP</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>1 1 1 1</td>
<td>19.99</td>
<td>-89.94</td>
</tr>
<tr>
<td>2</td>
<td>1 1 2 2</td>
<td>20.23</td>
<td>-88.64</td>
</tr>
<tr>
<td>3</td>
<td>1 1 3 3</td>
<td>19.71</td>
<td>-91.08</td>
</tr>
<tr>
<td>4</td>
<td>1 2 1 1</td>
<td>19.91</td>
<td>-90.59</td>
</tr>
<tr>
<td>5</td>
<td>1 2 2 2</td>
<td>19.90</td>
<td>-89.84</td>
</tr>
<tr>
<td>6</td>
<td>1 2 3 3</td>
<td>19.39</td>
<td>-91.21</td>
</tr>
<tr>
<td>7</td>
<td>1 3 1 2</td>
<td>19.74</td>
<td>-91.11</td>
</tr>
<tr>
<td>8</td>
<td>1 3 2 3</td>
<td>19.41</td>
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</tr>
<tr>
<td>9</td>
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<td>20.06</td>
<td>-90.03</td>
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<tr>
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<td>11</td>
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<td>12</td>
<td>2 1 3 2</td>
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</tr>
<tr>
<td>13</td>
<td>2 2 1 2</td>
<td>19.92</td>
<td>-89.78</td>
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<tr>
<td>14</td>
<td>2 2 2 3</td>
<td>20.10</td>
<td>-90.19</td>
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</table>
According to the S/N ratios in Table 2, the effect of each factor level on service level and WIP are calculated and shown in Figures 3 and 4. Figure 3 shows that A₂B₁C₂D₂ is the best design for the lean manufacturing system to maximize the service level. Figure 4 shows that A₁B₁C₂D₂ is the best design for the lean manufacturing system to minimize the WIP.

The performances are shown in Table 3. The current service level and WIP of the fishing net manufacturing system are 68% and 63,971 kg respectively. It can be seen that the design of A₂B₁C₂D₂ increases service level from 68% to 90% and reduces WIP from 63,971 kg to 42,269.31 kg. The improvements from the current state map are 32.35% and 33.92%, respectively. The design of A₁B₁C₂D₂ increases service level from 68% to 88% and reduces WIP from 63,971 kg to 33,762.75 kg. The improvements from the current state map are 29.41% and 47.22%, respectively.

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<table>
<thead>
<tr>
<th>Lean manufacturing system design</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A₂B₁C₂D₂</td>
<td>0.90</td>
</tr>
<tr>
<td>A₁B₁C₂D₂</td>
<td>0.88</td>
</tr>
</tbody>
</table>

5. Conclusions

Lean manufacturing has been applied successfully in many kinds of manufacturing industry. It focuses on cost reduction by eliminating non-value adding activity. In this research, a net cage manufacturing system is proposed as the case study. Based on the guidelines for achieving lean manufacturing, some important production factors are selected for optimizing the manufacturing system. Using experimental design and a simulation optimization tool, these factors are optimized. According to the simulation results, both service level and WIP can be improved. Moreover, the selected factors can be changed to any level without extra investment. That means the case company can implement the future state map to achieve lean manufacturing without any financial pressure. Therefore, it can be the first step to achieving lean manufacturing.

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Acknowledgements
The authors thank the anonymous company for providing the case study. This work was supported, in part, by the National Science Council of Taiwan, Republic of China, under grant NSC-100-2221-E-432-003- and NSC-98-2221-E-006-100-MY3.

References