Increasing Line Efficiency By Using Line Balancing In A Steel Manufacturing Company

Ứng dụng cân bằng chuyển để nâng cao hiệu quả dây chuyển sản xuất: nghiên cứu tại công ty sản xuất thép

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Abstract: Line balancing using the Takt Time method is recognized as a modern tool for assisting businesses in reducing costs and increasing profits. It is possible for the enterprise to smoothly produce the most optimal number of products by rational calculation and resource arrangement. This paper presents a case study on the application of line balancing by the Takt Time method in a steel factory in Vietnam. The methods selected for the study include describing the current situation of the factory, applying Lean Manufacturing improvement tools, applying modern equipment technology, and rearranging factory resources, finally calculating Line Balancing metrics and implementing them in practice. According to the findings of the research, using the Takt Time line balancing method provides numerous benefits to the factory. The number of operators decreased by 9 people. The percentage of line balance increased by 22% from 77% to 99% and the efficiency of line balance increased by 6% from 93% to 99%. In addition, the study also helps Vietnamese businesses have a more objective view of the application of Takt Time line balancing in the future.

Keywords: Industry 4.0; lean manufacturing; line balancing; steel industry; technology

Tóm tắt: Cân bằng chuyên theo phương pháp Takt Time là công cụ giúp doanh nghiệp giảm chi phí và tăng lợi nhuận. Doanh nghiệp có thể sản xuất với số lượng sản phẩm tối ưu nhất bằng cách tính toán và bố trí nguồn lực hợp lý. Bài báo này trình bày một trường hợp nghiên cứu về ứng dụng cân bằng dây chuyển theo phương pháp Takt Time tại một nhà máy sản xuất thép tại Việt Nam. Phương pháp nghiên cứu bao gồm mô tả hiện trạng nhà máy, áp dụng các công cụ cải tiến Lean Manufacturing, áp dụng công nghệ thiết bị hiện đại, sắp xếp lại nguồn lực nhà máy, cuối cùng là tính toán các chỉ số Line Balancing và triển khai chúng vào thực tế. Theo kết quả nghiên cứu, việc sử dụng phương pháp cân bằng dây chuyển Takt Time mang lại nhiều lợi ích cho nhà máy. Số lượng người điều hành giảm 9 người. Ty lệ cân bằng dây chuyển tăng 22% từ 77% lên 99% và hiệu quả cân bằng dây chuyển tăng 6% từ 93% lên 99%. Ngoài ra, nghiên cứu còn giúp các doanh nghiệp Việt Nam có cái nhìn khách quan hơn về việc ứng dụng cân bằng dây chuyển Takt Time trong tương lai.

Từ khóa: Cân bằng dây chuyển; công nghệ; công nghệ 4.0; ngành thép; sản xuất tính gọn

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1. Introduction
According to the Ministry of Industry and Trade, in 10 years (2011-2020), the industry has the highest growth rate of all economic sectors, contributing approximately 30% to GDP. It helps Vietnam from the 50th position (in 2010) to the 22nd position (in 2019) among the world's largest exporting countries [1].

The industry's average growth rate of value added (VA) is expected to be 7.16% from 2016 to 2020. It was 810.438 trillion VND in 2015 and is expected to be 1,145,437 trillion VND in 2020 [2]. As a result, the number of industrial plants in Vietnam has increased dramatically.

With the advancement of industry and modern tools and techniques in Industry 4.0, Vietnamese businesses are constantly looking for ways to reduce costs, increase profits, and improve customer satisfaction. The Takt Time line balancing method is one method for keeping the factory running smoothly. Using this method will help the factory allocate resources more effectively, such as machines, people, and equipment. Furthermore, it aids in the elimination of waste and production problems, as well as the removal of bottlenecks and the increase of worker satisfaction. This paper presents a case study of the Takt Time line balancing method in a steel factory in Vietnam.

The paper is divided into five sections: the first introduces the topic; the second and third sections are a literature review and the article's method; Part 4 describes the process of implementing Takt Time line balancing in businesses, which includes two tasks: describing the situation and implementing improvements. Part 5 concludes the paper.

2. Literature review
2.1. Lean manufacturing
Nowadays, Lean Manufacturing is developed and applied all over the world, bringing many breakthrough results, it helps businesses develop effectively and sustainably, especially for developing countries [3].

Lean Manufacturing is a model that includes principles and tools to improve by eliminating waste and increasing customer satisfaction [4].

Lean Manufacturing implementation brings many benefits including Improved productivity and quality of products and services; Reduced processing time and cycle time; Reduced waste; Improved equipment efficiency; Improved employee morale, effective communication, job satisfaction, and standardized housekeeping [5].

Lean Manufacturing includes many tools such as Value Stream Mapping (VSM), U-line system, Inventory control, Cellular Manufacturing (CM), Single Minute Exchange of Dies (SMED), Kanban, Pull System, and Production Levelling... Line balancing using the Takt Time method is one of the tools that bring many benefits when deploying to businesses [6].

2.2. Line Balancing
Line balancing is the process of allocating the appropriate number of
workers and machines in the manufacturing process. The main goal is to increase line production speed, eliminate bottlenecks, and reduce waste [7].

A well-balanced production line provides numerous benefits, including the following: Fast production speed; Low per-unit cost; Labor specialization, reducing costs, and reducing training time; High production process control; Quickly arrange the flow of materials, machines, and equipment [8].

A balanced production line must meet the following requirements: The workload is evenly distributed; No bottlenecks; No waiting; No WIP; The product produced by the previous station is the same as the product required by the following station [9].

Each worker will have a different capacity and working speed. As a result, when balancing the line, the following guidelines must be followed: Maximize the expertise of workers for each stage; Work steps should be carried out by workers who are equally qualified; Job requirements correspond to worker capabilities; Stick to standard operating procedures; Care about the health of workers and the condition of the factory's machinery; If the worker is ill and the machinery is damaged, the number of workers tends to round up in the division of labor; in the opposite case, the number of workers tends to round down [8].

2.3. Some Line Balancing Research
Farida Pulansari describes Line Balancing Techniques for Efficiency Improvement in Construction Steel companies in 2020. According to the research findings, the production line efficiency is 92.2%, the balance delay is 7.8%, and the smoothness index is 14.6 with 11 operators [10].

The study, which used U-shaped line balancing to increase line efficiency and meet production goals, was published in 2022 in a paper by Rainisa Maini Heryanto and others. The maximum ranked positional weight method produced the highest line efficiency of 84.08%, representing a 24.37% improvement over the actual method. In addition, the required number of operators was reduced from 15 to 10, with a 12-week production capacity of 76,688 [11].

A more detailed example of the application of this tool is cited in a paper that appeared in 2020 at XYZ company. According to the findings, the Largest Candidates Rules method is the best because the efficiency increased by 13.93%, the balance delay decreased by 3.93%, and the smoothness index decreased by 1.285 seconds from the starting line [12].

In addition, Fansuri presented Productivity Improvement Through Line Balancing at an Electronic Company in 2018. The purpose of this study is to improve the productivity of Electronics Manufacturing Service Company (EMSC) production assembly. It also aims to eliminate non-value-added activities in the body in order to reduce waste and propose a leaner line [13].

As reported by Mishan and others in 2015, Line balancing can increase the
productivity and efficiency of a food processing line. Line balance loss is reduced from 69% to 23% and line efficiency is increased from 30% to 76% as a result of the proposed improvements [14].

Furthermore, other studies by Hidayat [15], Damayanti [16], Suhardi [17], Sriwana [18], Saurabh [19], Shukla [20] all show that using line balancing improves plant efficiency.

3. Methodology
After collecting data at the steel company, the research methodology consists of two steps (Figure 1).

Step 1 has 3 tasks including: Calculate the current Takt time based on the collected data, Description of current line balance by visual graph and Calculate the line balance/efficiency ratio of the plant.

The purpose of step 2 is to apply advanced tools to improve Calculate the line balance/efficiency ratio of the plant, including 3 tasks: Reduce waste by Lean manufacturing tools, Rearrange work to be reasonable and smooth and the Update calculations for the new index.

4. Case study
4.1. The production process of steel fiber (style: bead fiber)
This research paper demonstrates the manufacturing process of steel bead fiber products. Table 1 describes the six-step procedure.
Step 1. Dip material into the chemical bath: the material is dipped through the HCL bath to remove the rust layer.

Step 2. Straightening steel fiber by MD machine: the steel fiber needs to be straightened before the next steps.

Step 3. Spinning by tractor 1: pull the steel thread from 5.5 \( \phi \) to 3.2 \( \phi \).

Step 4. Patenting: heating, copper plating, and lead plating to make the steel thread durable and the product of better quality before taking the following steps.

Step 5. Spinning by tractor 2: pull the steel thread from 3.2 \( \phi \) to 1.3 \( \phi \).

Step 6. Plating & packing: plating some chemicals on the outside of the steel and packing the product

### 4.2. Calculate the current Takt time

\[
Takt\ Time = \frac{\text{Working time}}{\text{Demand}}\quad(1)
\]

Working time is the total working time of the factory. Currently, a factory works 4 weeks a month, a week works 5 days and a day works 8 hours. So the total working time is calculated:

\[
\text{Total working time} = 8\text{ hours/day} \times 5\text{ days/week} \times 4\text{ weeks/month} = 160\text{ hours/month} = 576000\text{ sec/month}
\]

The demand per month for steel fiber is about 4600 ton. Therefore using equation (1), Takt time is calculated as follows:

\[
Takt\ Time = \frac{\text{Working time}}{\text{demand}} = \frac{576000}{4600} = 125\text{ sec/ton}
\]

The time taken for 1 ton of steel to move from the first step to the last step at each station is 125 seconds. If the factory has 1 station for more than 125 seconds, it will not provide enough products.

### 4.3. Description of current line balance

Following the calculation of Takt Time, the study determines the number of operators and machines at each factory process (Table 2).

<table>
<thead>
<tr>
<th>No</th>
<th>Process Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dip material into the chemical bath</td>
</tr>
<tr>
<td>2</td>
<td>Straightening steel fiber by MD machine</td>
</tr>
<tr>
<td>3</td>
<td>Spinning by tractor 1</td>
</tr>
<tr>
<td>4</td>
<td>Patenting</td>
</tr>
<tr>
<td>5</td>
<td>Spinning by tractor 2</td>
</tr>
<tr>
<td>6</td>
<td>Plating &amp; packing</td>
</tr>
</tbody>
</table>

**Table 2.** Operators and machines at each process
The cycle time of each process was measured using a stopwatch in the study. Each process is researched five times. Then take the average of these 5 times. Table 3 displays the cycle time results for each process:

Table 3. Cycle time of each process

<table>
<thead>
<tr>
<th>No</th>
<th>Process</th>
<th>Machine</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dip material into the chemical bath</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Straightening steel fiber by MD machine</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Spinning by tractor 1</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Patenting</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Spinning by tractor 2</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Plating &amp; packing</td>
<td>54</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>123</td>
<td>42</td>
</tr>
</tbody>
</table>

Figure 2 depicts the current status of the plant's line balance in relation to takt time.

Figure 2. Current Line Balancing

There are two processes with a higher Cycle time/Machine than Takt Time included in the current line balancing: spinning by tractor 1 and spinning by tractor 2. If the current line balance is not improved, the factory will be unable to meet customer demand.

4.4. Calculate the line balance/efficiency ratio

The minimum number of workstations is determined using the following formula:

\[
\text{Minimum workstations} = \frac{\text{Total Cycle Time}}{\text{Takt time}}
\]

Minimum workstations = \(\frac{14274}{125} = 114\)

The factory's Percentage of Line Balance is calculated using formula 3 as follows:

\[
\text{Percentage of Line Balance} = \frac{\text{Total Cycle Time}}{\text{Total Machine} \times \text{Highest(Cycle time/Machine)}}
\]

Percentage of Line Balance = \(\frac{14274}{123 \times 150} = 77\%

The efficiency of Line Balance is calculated according to the following formula:

\[
\text{Efficiency} = \frac{\text{Total Cycle Time}}{\text{Total Machine} \times \text{Takt time}}
\]

Efficiency = \(\frac{14274}{123 \times 125} = 93\%\)
After calculating three indicators, including Minimum Workstations, Percentage of Line Balance, and Efficient, the results show that the factory's efficiency is not good.

4.5. Reduce waste

The plant's performance indicators are not impressive. As a result, the research used innovative tools to improve the plant's efficiency.

There are four processes in the manufacturing process that have an index Cycle time/Machine greater than or less than Takt Time, so the research has concentrated on improving these four processes (Table 5).

**Table 5. Factory enhancement projects**

<table>
<thead>
<tr>
<th>No</th>
<th>Process</th>
<th>Enhancement activities</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Spinning by tractor 1</td>
<td>- Reduce wire break rate</td>
<td>Cycle time Before 1650</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Scheduled machine maintenance</td>
<td>Cycle time After 1600</td>
</tr>
<tr>
<td>2</td>
<td>Patenting</td>
<td>- Replace expired parts</td>
<td>Cycle time 4600</td>
</tr>
<tr>
<td>3</td>
<td>Spinning by tractor 2</td>
<td>- Reduce wire break rate</td>
<td>Cycle time 1650</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Scheduled machine maintenance</td>
<td>Cycle time 1600</td>
</tr>
<tr>
<td>4</td>
<td>Plating &amp; packing</td>
<td>- Application of automatic packaging machine</td>
<td>Cycle time 5500</td>
</tr>
</tbody>
</table>

Spinning by tractor 1 and spinning by tractor 2: Quality inspection of machinery has reduced the rate of wire breakage during this process. Furthermore, the plant intends to perform weekly maintenance. As a result, the machine runs smoothly, the machine stop rate is low, product quality is improved, and the cycle time is reduced from 1650 seconds to 1600 seconds.

Patenting: All expired components have been inspected and replaced by factory maintenance. After replacing the parts, the cycle time was reduced from 4600 seconds to 4300 seconds.

Plating & packing: The successful research and deployment of automatic packaging technology by factory engineers has reduced the Cycle Time index from 5500 seconds to 3200 seconds.

4.6. Rearrange work

Following the implementation of the improvement activities, the Cycle Time of the processes: spinning by tractor 1, patenting, spinning by tractor 2, plating and packing are 1600 s, 4300 s, 1600 s, and 3200 s respectively. Figure 3 depicts Line Balancing after improvement activities are implemented.

![Figure 3. Line Balancing After implementing improvement activities](image)

The number of machines and operators are rearranged in Tables 6 and 7 using the Takt time line balancing method.

**Table 6. Number of machines after balancing line by Takt Time method**

<table>
<thead>
<tr>
<th>Process</th>
<th>No. of Machines</th>
<th>No. of Operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinning by tractor 1</td>
<td>124</td>
<td>145</td>
</tr>
<tr>
<td>Patenting</td>
<td>125</td>
<td>108</td>
</tr>
<tr>
<td>Spinning by tractor 2</td>
<td>145</td>
<td>108</td>
</tr>
<tr>
<td>Plating &amp; packing</td>
<td>59</td>
<td>125</td>
</tr>
</tbody>
</table>

141
The total number of machines at the factory decreased by 29 machines, with “Spinning by tractor 1” increasing by 2 machines, stage Patenting decreasing by 5 machines, “Spinning by tractor 2” increasing by 2 machines, and Plating & packing decreasing by 28 machines.

Table 7. Number of Operators after balancing line by Takt Time method

<table>
<thead>
<tr>
<th>No</th>
<th>Process</th>
<th>Operator</th>
<th>Rearrange Operator</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dip material into the chemical bath</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Straightening steel fiber by MD machine</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Spinning by tractor 1</td>
<td>11</td>
<td>13</td>
<td>-2</td>
</tr>
<tr>
<td>4</td>
<td>Patenting</td>
<td>40</td>
<td>35</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>Spinning by tractor 2</td>
<td>11</td>
<td>13</td>
<td>-2</td>
</tr>
<tr>
<td>6</td>
<td>Plating &amp; packing</td>
<td>54</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>123</td>
<td>94</td>
<td>29</td>
</tr>
</tbody>
</table>

The total number of operators has decreased by 9 people, in which Dip material into the chemical bath and Straightening steel fiber by MD machine remain unchanged, "Spinning by tractor 1" increases by 1 operator, Patenting decreases by 1 operator, "Spinning by tractor 2" increases by one operator and stage Plating & packing decreases by 10 operators.

4.7. Update calculations

The study is based on cycle time after improvement activities and the number of machines after the line balancing Takt time method is implemented.

Table 8 recalculates the cycle time/Machine index.

Table 8. Cycle time/Machine ratio after balancing line by Takt Time method

<table>
<thead>
<tr>
<th>No</th>
<th>Process</th>
<th>Cycle time/Machine (s)</th>
<th>Takt Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dip material into the chemical bath</td>
<td>124</td>
<td>125</td>
</tr>
<tr>
<td>2</td>
<td>Straightening steel fiber by MD machine</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>3</td>
<td>Spinning by tractor 1</td>
<td>123</td>
<td>125</td>
</tr>
<tr>
<td>4</td>
<td>Patenting</td>
<td>123</td>
<td>125</td>
</tr>
<tr>
<td>5</td>
<td>Spinning by tractor 2</td>
<td>123</td>
<td>125</td>
</tr>
<tr>
<td>6</td>
<td>Plating &amp; packing</td>
<td>123</td>
<td>125</td>
</tr>
</tbody>
</table>

Figure 4 depicts the factory line balancing by comparing the Cycle time/Machine index and Takt Time

Figure 4. Line Balancing after balancing line by Takt Time method

All stages have a Cycle time/Machine index of less than 125. As a result, the factory will fulfill enough orders for customers.

Based on formula 3, the factory's Percentage of Line Balance is recalculated as follows:

\[
\text{Percentage of Line Balance} = \frac{\text{Total Cycle Time}}{\text{Total Machine} \times \text{Highest(Cycle time/Machine)}}
\]

\[
\text{Percentage of Line Balance} = \frac{11574}{94 \times 125} = 99\%
\]

The efficiency of line balancing is also recalculated based on the formula 4.
Efficiency = \frac{\text{Total Cycle Time}}{\text{Total Machine \times Takt time}}

Efficiency = \frac{11574}{94 \times 125} = 99% 

The factory's Percentage of Line Balance and Efficiency of Line Balance have been improved following a recalculation.

5. Results and discussion

For each manufacturing enterprise, the balance factor plays a vital role in creating stability in factories. The Takt Time line balancing method is one of the most important methods for achieving production balance in businesses. It is a method of arranging a consistent production flow over time in order to minimize workload spikes at each stage of production as customer requirements change. The main goal of this method is to improve production speed, eliminate bottlenecks, and cut down on wasted time.

Almost all manufacturing businesses use this method. The author mentions Takt Time line balancing at a steel factory in this study. According to the study's findings, using this method has resulted in many benefits for businesses, including a reduction of 9 workers, an increase in the percentage of line balance from 77% to 99%, and an increase in the efficiency of line balance from 93% to 99%. It also contributes to greater customer satisfaction.

However, in order to use this method successfully, the factory must also invest in the necessary equipment, machinery, and resources. As a result, before implementing Takt Time line balancing method in your factory, you must carefully consider the cost and profit.

Tài liệu tham khảo


