

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

Ứng dụng cân bằng chuyền để nâng cao hiệu quả dây chuyền 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 chuyền 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 chuyền 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 chuyền Takt Time mang lại nhiều lợi ích cho nhà máy. Số lượng người điều hành giảm 9 người. Tỷ lệ cân bằng dây chuyền tăng 22% từ 77% lên 99% và hiệu quả cân bằng dây chuyền 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 chuyền Takt Time trong tương lai.

Từ khóa: *Cân bằng dây chuyền; công nghệ; công nghệ 4.0; ngành thép; sản xuất tinh gọn*

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.

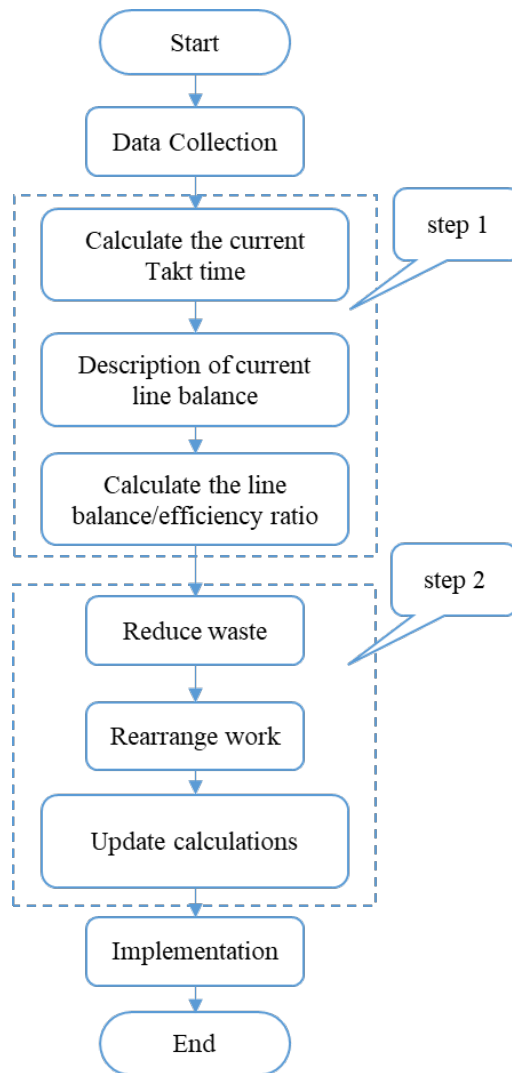


Figure 1. Research methodology







Finally, the study will assign workers tasks based on the new line.

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.

Table 1. Production process

No	Process	Description
1	Dip material into the chemical bath	
2	Straightening steel fiber by MD machine	
3	Spinning by tractor 1	
4	Patenting	
5	Spinning by tractor 2	
6	Plating & packing	

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 Ø to 3.2 Ø .

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 Ø to 1.3 Ø .

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

4.2. Calculate the current Takt time

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

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:

$$\begin{aligned} \text{Total working time} &= 8 \text{ hours/day} \times 5 \text{ days /week} \times 4 \text{ weeks/month} \\ &= 160 \text{ hours/month} \\ &= 576000 \text{ sec/month} \end{aligned}$$

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

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

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 2. Operators and machines at each process

No	Process	Machine	Operator
1	Dip material into the chemical bath	1	2
2	Straightening steel fiber by MD machine	6	2
3	Spinning by tractor 1	11	4
4	Patenting	40	10
5	Spinning by tractor 2	11	4
6	Plating & packing	54	20
Total		123	42

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

No	Process	Precedence	Cycle time (s)
1	Dip material into the chemical bath	-	124
2	Straightening steel fiber by MD machine	1	750
3	Spinning by tractor 1	2	1650
4	Patenting	3	4600
5	Spinning by tractor 2	4	1650
6	Plating & packing	5	5500

The Cycle time/Machine ratio is calculated using the data from tables 2 and 3. This ratio shows how long it takes one ton of steel to go through each process (see Table 4).

Table 4. Cycle time/Machine ratio

No	Process	Cycle time/Machine (s)	Takt Time (s)
1	Dip material into the chemical bath	124	125
2	Straightening steel fiber by MD machine	125	125
3	Spinning by tractor 1	150	125
4	Patenting	115	125
5	Spinning by tractor 2	150	125
6	Plating & packing	102	125

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

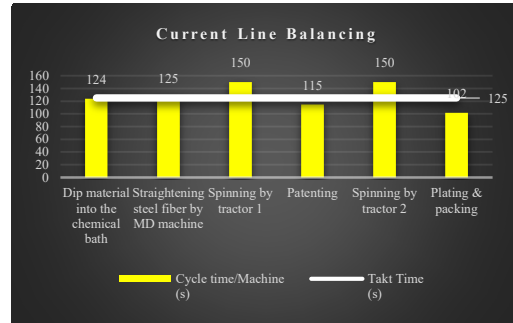


Figure 2. Current Line Balancing

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:

$$\text{Minimum workstations} = \frac{\text{Total Cycle Time}}{\text{Takt time}} \quad (2)$$

$$\text{Minimum workstations} = \frac{14274}{125} = 114$$

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

$$\text{Percentage of Line Balance} = \frac{\text{Total Cycle Time}}{\text{Total Machine} * \text{Highest}(\text{Cycle time/Machine})} \quad (3)$$

$$\text{Percentage of Line Balance} = \frac{14274}{123 * 150} = 77\%$$

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

$$\text{Efficiency} = \frac{\text{Total Cycle Time}}{\text{Total Machine} * \text{Takt time}} \quad (4)$$

$$\text{Efficiency} = \frac{14274}{123 * 125} = 93\%$$

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

No	Process	Enhancement activities	Result	
			Cycle time Before	Cycle time After
1	Spinning by tractor 1	- Reduce wire break rate - Scheduled machine maintenance	1650	1600
2	Patenting	- Replace expired parts	4600	4300
3	Spinning by tractor 2	- Reduce wire break rate - Scheduled machine maintenance	1650	1600
4	Plating & packing	- Application of automatic packaging machine	5500	3200

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 3200s respectively. Figure 3 depicts Line Balancing after improvement activities are implemented.

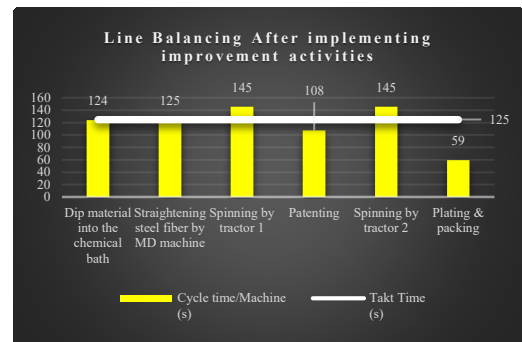


Figure 3. Line Balancing After implementing improvement activities

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

No	Process	Machine	Rearrange Machine	Difference
1	Dip material into the chemical bath	1	1	0
2	Straightening steel fiber by MD machine	6	6	0
3	Spinning by tractor 1	11	13	-2
4	Patenting	40	35	5
5	Spinning by tractor 2	11	13	-2
6	Plating & packing	54	26	28
Total		123	94	29

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

No	Process	Operator	Rearrange Operator	Difference
1	Dip material into the chemical bath	2	2	0
2	Straightening steel fiber by MD machine	2	2	0
3	Spinning by tractor 1	4	5	-1
4	Patenting	10	9	1
5	Spinning by tractor 2	4	5	-1
6	Plating & packing	20	10	10
Total		42	33	9

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

No	Process	Cycle time/Machine (s)	Takt Time (s)
1	Dip material into the chemical bath	124	125
2	Straightening steel fiber by MD machine	125	125
3	Spinning by tractor 1	123	125
4	Patenting	123	125
5	Spinning by tractor 2	123	125
6	Plating & packing	123	125

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

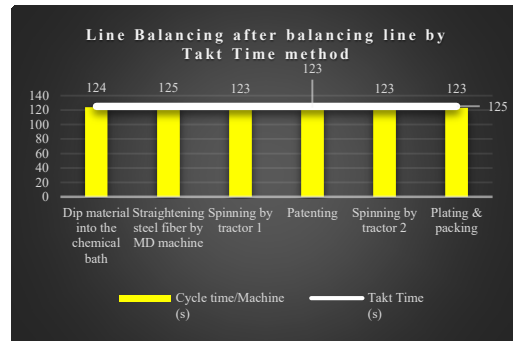


Figure 4. Line Balancing after balancing line by Takt Time method

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:

$$\text{Percentage of Line Balance} = \frac{\text{Total Cycle Time}}{\text{Total Machine} * \text{Highest(Cycle time/Machine)}}$$

$$\text{Percentage of Line Balance} = \frac{11574}{94 * 125} = 99\%$$

The efficiency of line balancing is also recalculated based on the formula 4.

$$\text{Efficiency} = \frac{\text{Total Cycle Time}}{\text{Total Machine} * \text{Takt time}}$$

$$\text{Efficiency} = \frac{11574}{94 * 125} = 99\%$$

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

- [1] Viet Anh, “Ngành công nghiệp: Những dấu ấn nổi bật,” Bộ Công Thương, 2022. <https://congthuong.vn/nganh-cong-nghiep-nhung-dau-an-noi-bat-177439.html> (accessed Dec. 19, 2022).
- [2] Do Thi Bich Thuy, “Công nghiệp Việt Nam năm 2020 và 5 năm 2016 - 2020,” Bộ Công Thương, 2021. <https://vioit.org.vn/vn/chien-luoc-chinh-sach/cong-nghiep-viet-nam-nam-2020-va-5-nam-2016---2020-4291.4050.html> (accessed Dec. 19, 2022).
- [3] C. Maware, M. O. Okwu, and O. Adetunji, “A systematic literature review of lean manufacturing implementation in manufacturing-based sectors of the developing and developed countries,” *International Journal of Lean Six Sigma*, vol. 13, no. 3. Emerald Group Holdings Ltd., pp. 521–556, May 16, 2022. doi: 10.1108/IJLSS-12-2020-0223.
- [4] S. V. Buer, J. O. Strandhagen, and F. T. S. Chan, “The link between industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda,” *Int J Prod Res*, vol. 56, no. 8, pp. 2924–2940, Mar. 2018, doi: 10.1080/00207543.2018.1442945.
- [5] J. Bhamu and K. S. Sangwan, “Lean manufacturing: Literature review and research issues,” *International Journal of Operations and Production Management*, vol. 34, no. 7. Emerald Group Publishing Ltd., pp. 876–940, 2014. doi: 10.1108/IJOPM-08-2012-0315.
- [6] R. Sundar, A. N. Balaji, and R. M. Satheesh Kumar, “A review on lean manufacturing implementation techniques,” in *Procedia Engineering*, Elsevier Ltd, 2014, pp. 1875–1885. doi: 10.1016/j.proeng.2014.12.341.
- [7] R. Iwan, “Analysis of productivity improvement using line balancing method (study case assembling line in PT XYZ),” in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics

Publishing, Nov. 2018. doi: 10.1088/1757-899X/453/1/012055.

[8] J. S. Germanes, M. F. Puga, R. B. Sabio, E. M. Sanchez, and J. C. Hugo, "Improving Efficiency of Shoe Manufacturer through the Use of Time and Motion Study and Line Balancing," *Journal of Industrial and Intelligent Information*, 2017, doi: 10.18178/jiii.5.1.16-22.

[9] M. H. Kharuddin and M. F. Ramli, "A Review on Methods to Improve and Balance the Assembly Line," in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Mar. 2020. doi: 10.1088/1757-899X/767/1/012022.

[10] S. Farida Pulansari, "Line Balancing Techniques for Efficiency Improvement in Construction Steel Company," *NSTproceeding*, 2020.

[11] R. Maini Heryanto, D. Try Liputra, and A. Sugiatna, "The Application of U-shaped Line Balancing at Furniture Manufacturing," vol. 2, pp. 155–165, 2022, doi: 10.31098/bmss.v2i1.528.

[12] S. Alexandra and L. Gozali, "Line balancing analysis on finishing line dabbing soap at PT. XYZ," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing Ltd, Dec. 2020. doi: 10.1088/1757-899X/1007/1/012030.

[13] A. F. H. Fansuri, A. N. M. Rose, M. F. F. Ab Rashid, N. M. Z. Mohamed Nik, and H. Ahmad, "Productivity Improvement Through Line Balancing at Electronic Company - Case Study," in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Nov. 2018. doi: 10.1088/1757-899X/409/1/012015.

[14] N. N. Mishan and M. M. Tap, "INCREASING LINE EFFICIENCY BY USING TIMESTUDY AND LINE BALANCING IN A FOOD MANUFACTURING COMPANY," 2015.

[15] R. Hidayat, S. fitrotis Salimah, Moh. Jufriyanto, and M. F. Khaqiqi, "Line Balancing Analysis of Hollow Dakota 1730 Manufacturing Process in PT XYZ," *E3S Web of Conferences*, vol. 328, p. 05012, 2021, doi: 10.1051/e3sconf/202132805012.

[16] D. D. Damayanti, M. D. Astuti, E. B. Setyawan, and A. F. Ramdani, "Assembly line balancing using genetic algorithm method to minimize number of working stations: A case study in car manufacturing," in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing Ltd, Dec. 2020. doi: 10.1088/1757-899X/1007/1/012099.

[17] Suhardi et al., 2016 International Conference on Information Technology Systems and Innovation (ICITSI): proceedings: October 24-27, 2016, Bandung - Bali, Indonesia.

[18] I. K. Sriwana, I. A. Marie, and D. Mangala, "The recommendation of line-balancing improvement on MCM product line 1 using genetics algorithm and moodie young at XYZ Company, Co.," in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Dec. 2017. doi: 10.1088/1757-899X/277/1/012053.

[19] P. Saurabh Jha and M. Salman Khan, "Article ID: IJMET_08_03_003 Cite this Article: P Saurabh Jha and Mohd Salman Khan. An Experimental Study on the Automotive Production Line Using Assembly Line Balancing Techniques," *International Journal of Mechanical Engineering and Technology*, vol. 8, no. 3, pp. 22–33, 2017, [Online]. Available: <http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=8&IType=3http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=8&IType=3>

[20] P. Shukla, S. Malviya, S. Jain, Mt. Student, and A. Professor, "Improvement of Production Rate by Line Balancing for Small Scale Industry: A Case Study," 2018. [Online]. Available: www.ijrsrd.com

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