

Line Balancing in Assembly Line Automotive Carrosserie (Body of a Car) Production Process at PT. XYZ

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Abstract

PT. XYZ wants to increase production efficiency, achieve optimal production capacity, and calculate the right amount of operator at the work station, so line balancing analysis is carried out. Line balancing method used is Rank Positional Weight, Largest Candidate Rules, Kilbridge-Wester, and Moodie Young, and identify performance line before and after the line balancing are carried out using the software ProModel. The data collection technique used is a time study using a stopwatch. The beginning balance efficiency is 42.79%, 6 work station and smoothness index 115.15 minutes, with Rank Positional Weight, Largest Candidate Rules, Kilbridge-Wester, and Moodie Young method, the balance efficiency is 82.98%, 3 work station, and smoothness index 77.02 minutes. The final result of the simulation using ProModel is a product output of 7 units, which indicates that the simulation results on the new planning line exceed the specified target of 3 units in 8 hours without the need for overtime work. There was a reduction of operators from 4 to 3 people.

Keywords

Line Balancing, Rank Positional Weight, Largest Candidate Rules, Kilbridge-Wester, Moodie Young

1. Introduction

In this 4.0 industrial era, many companies are growing rapidly, one of which is a manufacturing company, namely PT. XYZ. PT. XYZ is a company engaged in manufacturing and producing cargo boxes, flatbeds, and tubs of transportation according to the needs and desires of consumers. PT. XYZ also offers for maintenance and repair of cargo boxes for the PT. XYZ brand itself and other brands. PT. XYZ implements a make to order system in which to produce cargo boxes according to consumer desires.

PT. XYZ wants to increase production efficiency, achieve optimal production capacity and calculate the right amount of operator at the work station. Therefore, this research is needed to solve this problem. To produce a balanced production line and improve workstation efficiency, the line balancing method can analyze the problem. This method is expected to provide a solution as an alternative to improve the balance performance of the production line by minimizing the balance delay, optimizing the balance efficiency, smoothness index, and optimizing the number of work stations.

Production PT. XYZ in the last year was 862 units, due to the pandemic, PT. XYZ uses only 2 production lines. The time-motion study data for this research use a stopwatch on the assembly line.

2. Literature Review

2.1 Cycle Time

Cycle time measurement using a stopwatch to calculate the time of each movement that occurs. Each operator can produce a different time in each movement so that here can be seen the standard cycle time performed by operators who have good abilities (Wignjosoebroto, 2003). The Cycle time is measured from the average time tested.

$$W_s = \frac{\sum x}{n} \dots \dots \dots (1)$$

Where

W_s = Cycle Time

x = Observational Data

n = Number of Observations

2.2 Adjustment Factor

The adjustment is made by multiplying the average cycle time or the average element time by a price P called the adjustment factor. The method of adjustment used is the Westinghouse method. The value of the adjustment factor (rating factor) can be determined by the Westing House System's Rating method, which is a determination of the rating on skills, effort, working conditions, and consistency (Sutalaksana, et, al.,2006).

Each factor is then subdivided into super skill, excellent, good, average, fair and poor. Each sub-factors are attached with numeric values. The average time obtained from time study is normalized by applying the sum of the ratings of the four factors.

2.3 Normal Time

The Normal time is the time used by a worker to work fairly without excessive effort throughout the working day, in a system and working environment conditions that are reasonable and naturally relatively the easiest to work on, with general procedures and the worker shows seriousness in carrying out his job.

$$W_n = W_s x (1 + \Sigma \text{Westing house rating}) \dots\dots\dots(2)$$

Where

W_n = Normal Time

W_s = Cycle Time

2.4 Allowance

Allowances consist of: first, allowances for personal needs, including personal needs such as drinking, toilets, and work. The amount of allowance granted for such personal needs varies. Second, looseness to relieve fatigue. Third, allowance for obstacles is inevitable (Sutalaksana, et, al.,2006).

2.5 Standard Time

Standard time is when a normal worker takes to complete a job carried out in the best work system. (Sutalaksana, et, al.,2006).

$$W_b = W_n x (1 + i) \dots\dots\dots(3)$$

Where

W_b = Standard Time

W_n = Normal Time

i = Allowance

2.6 Line Balancing

Line balancing is a balancing method for assigning task elements from an assembly line to a work station to minimize the number of work stations and minimize the total idle time at all stations for a specific output level (Gaspersz, 2004). In balancing these tasks, the time requirements per unit of product specified for each task and sequential relationships must be considered. There are procedures to apply the line balancing method. The procedures that should be performed include:

a. Make the Precedence Diagram

The precedence diagram illustrates the sequence of work operations to facilitate the control and planning of activities related to it (Dilworth, 2013). Precedence diagram is made with:

- i. Circle symbol (node) with letters or numbers in it; facilitate the identification of an operating process that distinguishes work elements in a production line.
- ii. Arrow; show the sequence and direction of the sequence of operations. Operations at the base of the arrow mean to precede the work operations at the arrow's tip.
- iii. Standard time (W_b); is above the circle symbol (node), which is the time needed to complete each operation.

b. Cycle Time

Cycle time is the average completion time in an operational process. The cycle time here is only to count the number of work stations.

$$Cycle\ Time = \frac{production\ time}{target\ production} \dots\dots\dots(4)$$

c. Theoretical Minimum Number of Work Station (TM)

This calculation shows theoretically the minimum number of work stations needed on a production line.

$$TM = \frac{Total\ of\ task\ time}{Cycle\ Time} \dots\dots\dots(5)$$

d. Balance Efficiency (BE)

The calculation of line balancing efficiency is intended as a parameter of the success of the line balancing method.

$$BE = \left(\frac{Total\ Work\ Station\ Time}{TM(Cycle\ Time)} \right) \times 100\% \dots\dots\dots(6)$$

e. Balance Delay (BD)

Balance delay is the percentage of idle time in a production line because the distribution of operations between stations is uneven.

$$BD = 100\% - BE \dots\dots\dots(7)$$

f. Smoothness Index (SI)

Smoothness index is a way to measure the relative idle time of a production line. The minimum value of the smoothness index is zero (perfect balance). If the smoothness index value is getting closer to zero, then the production line is getting more balanced.

$$SI = \sqrt{\frac{\sum(Sti_{max} - Sti)^2}{n}} \dots\dots\dots(8)$$

Where

Sti_{max} : Largest Work Station Time, and

Sti : Time of Each Work Station (i=1, 2, ..., n)

2.7 Rank Positional Weight

This method is a combined method between the Large Candidate Ruler method and the region approach method. The rank positional weight value is a calculation between the work element and the position of each work element in the precedence diagram (Heizer and Render, 2006). The steps of the rank positional weight method are as follows:

- a. Make a precedence diagram or network diagram from the operation process chart.
- b. Calculate cycle times.
- c. Creating a path matrix based on precedence diagrams.
- d. Calculating the position weight of each operation is calculated based on the number of times the operation and the operations that follow it.
- e. Sort operations from the largest to the smallest operating weight.
- f. Calculate the minimum number of work stations.
- g. Make a flow diagram for the minimum work station, then load the operation on the work station starting from the largest to the smallest operating weight. The criteria that the total operating time is smaller than the desired cycle time.
- h. Conduct trial and error to get the highest track efficiency.
- i. Calculate the balance delay.

2.8 Largest Candidate Rules

The basic principle of the largest candidate rules method is to combine processes based on sequencing the largest operation processing time to the shortest operation time. Before combining, it must first be determined how many cycle times will be used. This cycle time will be used as a limiter in combining operations in one work station. The steps of the largest candidate rules method are as follows:

- a. Make a precedence diagram of the production line.
- b. Sort the work elements from the largest to the shortest completion time.
- c. Work elements at the first work station are taken from the order that has the largest turnaround time. The work element moves to the next work station when the number of work elements has exceeded the cycle time.
- d. Repeat the third step for the other stations until all work elements have been placed in the work station and the work station time does not exceed the cycle time and meets the requirements for the precedence diagram

sequence.

2.9 Kilbridge-Wester

The Kilbridge-Wester method is a heuristic procedure that selects work elements for assignment to a work station according to their position in the preferred precedence diagram (regarding work station time and work elements). The steps of the the Kilbridge-Wester method are as follows:

- a. Make a precedence diagram of the production line.
- b. Divide the work elements in the precedence diagram into columns from left to right.
- c. Sort the work elements from the largest operating time to the shortest operating time.
- d. Grouping work elements starts from the first column by prioritizing the work elements with the largest completion time in that column.
- e. If the work elements in the first column have all been grouped into work stations, then move on to the next column.
- f. If the workstation time exceeds the cycle time, replace the workstation's existing workstation with the following work station as long as it does not violate the precedence diagram.
- g. Repeat steps e and f until all work elements have been placed into the work station.

2.10 Moodie Young

According to Baroto (2002), the Moodie Young method is a line balancing method that has two phases (stages) of analysis. Phase one is to group work stations based on a matrix of relationships between elements. Phase two was revised on the results of phase one. In phase one, a precedence diagram is made for the matrix P and the matrix (which depicts the predecessor work elements and the following work elements. For example, the F matrix shows the relationship between the predecessor work elements and the matrix (shows the relationship between the work elements that follow. Then the work elements are placed on the work station. Which is sequential in the production line with the rule, if two work elements can be selected, then the work element which has the largest time is placed first. Phase two is carried out to distribute idle time evenly for each station resulting from phase one. Step in phase two:

- a. Identifies the time of the largest work station time and the shortest work station time.
- b. Determine half of the difference between the two-goal values (GOAL) with the formula:
$$GOAL = \frac{Tsi(max) - Tsi(min)}{2} \dots\dots\dots(9)$$
- c. Specifies a work element (station time) max that is smaller than the GOAL value and which work element is moved to the work station with the minimum time but does not violate the precedence diagram rules.
- d. Move the work element to a workstation with more minimum time if there is a work element at the maximum work station that is smaller than the GOAL value.
- e. Perform steps d and e until there are no work elements that can be moved.

2.11 Promodel

Promodel is an application program that is used to simulate a system and analyze the production system. Promodel is a discrete simulation software that sees a production system as a location process arrangement, such as a machine or workstation where entities are processed according to the applied process logic.

3. Methods

The flowchart applied in this research can be seen in Figure 1 below.

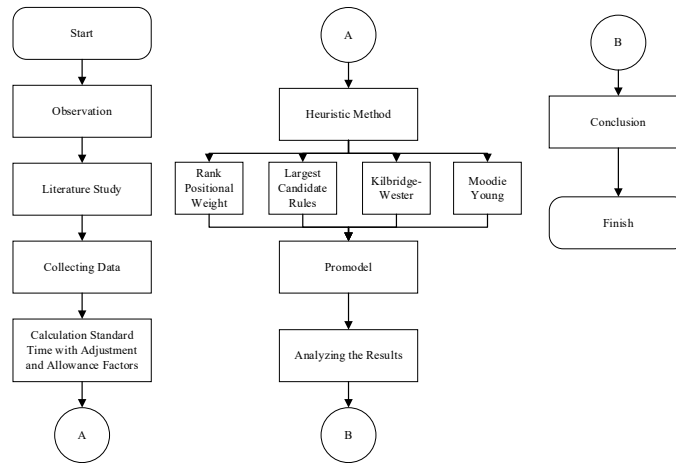


Figure 1. Research Methodology

4. Data Collection

Here are some data of time for each task elements in the assembly line at PT. XYZ can be seen in Table 1 below.

Table 1. Data of Standard Time

No	Task Element	Cycle Time (min)	Normal Time (min)	Standard Time (min)
1	Assembly Base	15.49	18.1233	23.83
2	Assembly Wall	51.6275	58.339075	74.67
3	Assembly Roof	23.0725	25.610475	32.78
4	Assembly Door	14.03	16.1345	20.41
5	Assembly to Framework	13.3075	15.303625	20.35
6	Assembly to Truck	12.835	15.1453	19.69
Total Time (min)		130.3625	148.656275	191.7404173

5. Results and Discussion

5.1 Line Condition Before Line Balancing

The precedence diagram of the assembly process in the assembly line can be seen in Figure 2 below.

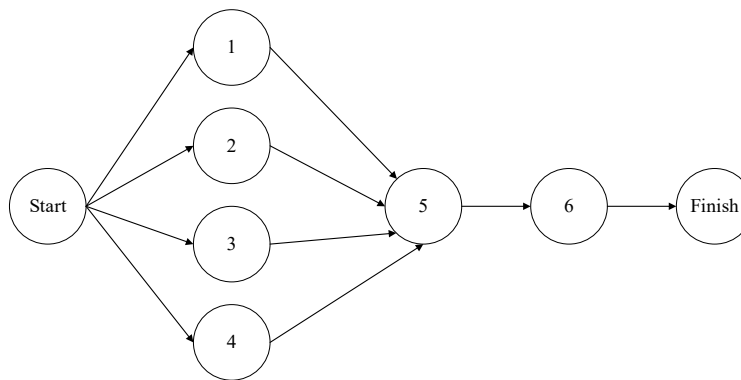


Figure 2. Precedence Diagram of Line Condition Before Line Balancing

It is known that the cargo box assembly has a cycle time which is assumed to use the longest processing time on the assembly line. It is 74.67 minutes on the wall assembly work element with 6 work stations. Then it can calculate the balance efficiency and balance delay.

$$BE = \left(\frac{191.74}{6 \times 74.67} \right) \times 100\% = 42.79\%$$

$$Balance\ Delay = 100\% - 42.79\% = 57.21\%$$

$$SI = \sqrt{(74.67 - 74.67)^2 + (74.67 - 23.83)^2 + \dots + (74.67 - 19.69)^2} = 115.15\ min$$

After that, an initial calculation will be performed to determine the cycle time and minimum theoretical number of work stations.

$$Cycle\ Time = \frac{8 \frac{hours}{shift} \times 60 \frac{minutes}{hours}}{3\ unit/shift} = 160\ minutes/unit$$

The total processing time obtained from observations and the previous standard time calculation was 191.74 minutes/unit. Then the minimum theoretical calculation is:

$$TM = \frac{191.74\ minutes}{160\ minutes} = 1.20\ station = 2\ station$$

5.2 Comparison of the Results of Each Method

The calculation result using the Rank Positional Weight method, Kilbridge-Wester method, Largest Candidates Rules, and Moodie Young method (Alexandra and Gozali, 2020) can be seen in Figure 3 and Table 2 below.

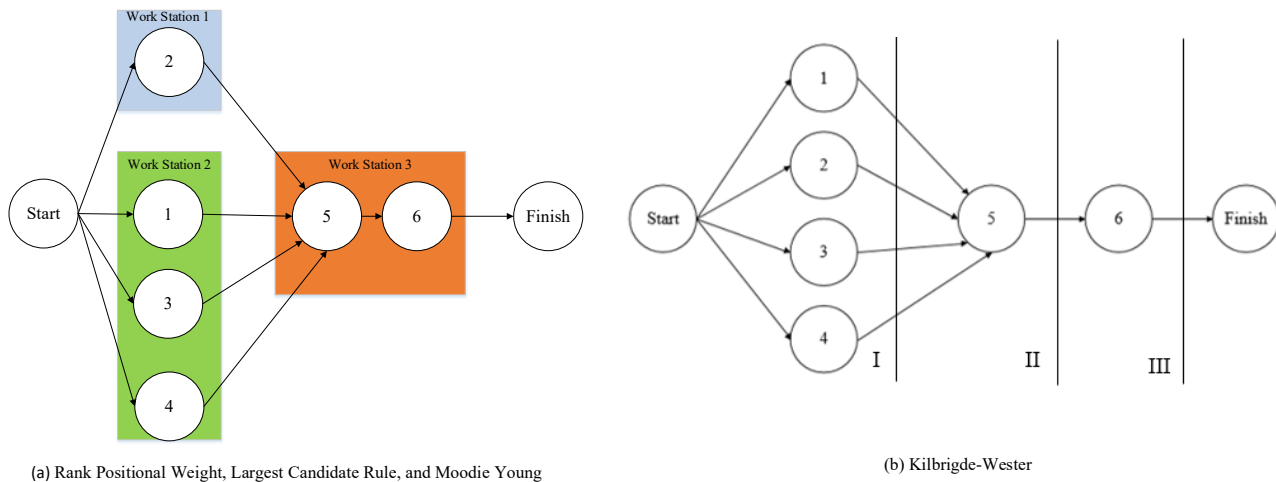


Figure 3. Precedence Diagram of Each Method

Table 2. Comparison of the Results of Each Method

	Before Line Balancing	Rank Positional Weight	Largest Candidate Rule	Kilbridge-Wester	Moodie Young
Work Station	6	3	3	3	3
Balance Efficiency (%)	42.79	82.98	82.98	82.98	82.98
Balance Delay (%)	57.21	17.02	17.02	17.02	17.02
Smoothness Index (Minutes)	115.15	37.06	37.06	37.06	37.06
Longest Cycle Time (Minutes)	37.34	77.02	77.02	77.02	77.02

5.3 ProModel

Simulation with promodel (Harrell, et.al., 2004) can be seen in Figure 4 to Figure 9.

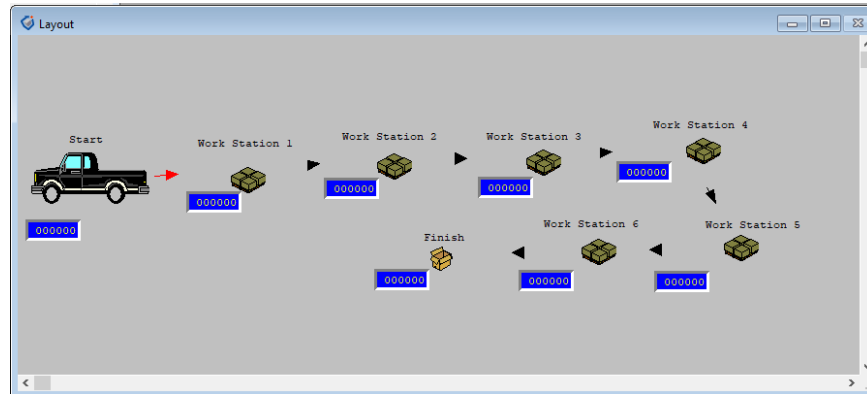


Figure 4. Layout Before Line Balancing

promodel sebelum line balancing.rdb - Output Viewer 3DR

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General Report (Normal Run - Rep. 1)

General Locations Location States Multi Location States Single Entity Activity Entity States

promodel sebelum line balancing.mod (Normal Run - Rep. 1)

Name	Scheduled Time (HR)	Capacity	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Maximum Contents	Current Contents	% Utilization
Start	8,00	999999,00	481,00	236,03	236,52	474,00	474,00	0,02
Work Station 1	8,00	1,00	7,00	58,57	0,85	1,00	1,00	85,42
Work Station 2	8,00	1,00	6,00	64,74	0,81	1,00	1,00	80,93
Work Station 3	8,00	1,00	5,00	29,15	0,30	1,00	1,00	30,37
Work Station 4	8,00	1,00	4,00	20,12	0,17	1,00	0,00	16,77
Work Station 5	8,00	1,00	4,00	20,47	0,17	1,00	0,00	17,06
Work Station 6	8,00	1,00	4,00	15,25	0,13	1,00	1,00	12,71
Finish	8,00	999999,00	3,00	0,00	0,00	1,00	0,00	0,00

Figure 5. Output for Each Work Station Before Line Balancing

promodel sebelum line balancing.rdb - Output Viewer 3DR

File View Tools Window Help

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General Report (Normal Run - Rep. 1)

General Locations Location States Multi Location States Single Entity Activity Entity States

promodel sebelum line balancing.mod (Normal Run - Rep. 1)

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)	Avg Time Waiting (MIN)	Avg Time In Operation (MIN)	Avg Time Blocked (MIN)
Raw Material	0,00	475,00	0,00	0,00	0,00	0,00	0,00
WIP	0,00	2,00	0,00	0,00	0,00	0,00	0,00
Cargo Box	3,00	1,00	341,09	70,00	9,85	188,19	73,06

Figure 6. Result of Simulation Before Line Balancing

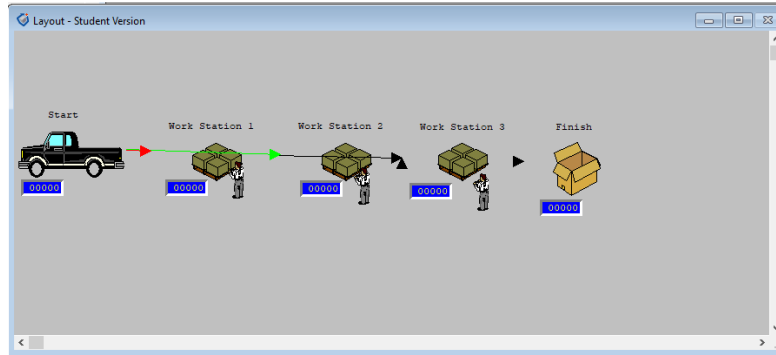


Figure 7. Layout After Line Balancing

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General Report (Normal Run - Rep. 1)

General | Locations | Location States Multi | Location States Single | Entity Activity | Entity States

Promodel Line Balancing.MOD (Normal Run - Rep. 1)

Name	Scheduled Time (HR)	Capacity	Total Entries	Avg Time Per Entry (MIN)	Avg Contents	Maximum Contents	Current Contents	% Utilization
Start	8,00	999999,00	481,00	234,29	234,78	470,00	470,00	0,02
Work Station 1	8,00	1,00	5,00	85,97	0,90	1,00	0,00	89,55
Work Station 2	8,00	1,00	5,00	85,80	0,89	1,00	1,00	89,38
Work Station 3	8,00	1,00	8,00	39,66	0,66	1,00	0,00	66,10
Finish	8,00	999999,00	7,00	0,00	0,00	1,00	0,00	0,00

Figure 8. Output for Each Work Station After Line Balancing

File View Tools Window Help

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General Report (Normal Run - Rep. 1)

General | Locations | Location States Multi | Location States Single | Entity Activity | Entity States

Promodel Line Balancing.MOD (Normal Run - Rep. 1)

Name	Total Exits	Current Qty In System	Avg Time In System (MIN)	Avg Time In Move Logic (MIN)	Avg Time Waiting (MIN)	Avg Time In Operation (MIN)	Avg Time Blocked (MIN)
Raw Material	0,00	472,00	0,00	0,00	0,00	0,00	0,00
WIP	0,00	1,00	0,00	0,00	0,00	0,00	0,00
Box	7,00	1,00	288,37	30,00	86,94	114,91	56,53

Figure 9. Result of Simulation After Line Balancing

The final result of the simulation (Gozali, et. al.,2020) is a product output of 7 units, which indicates that the simulation results on the new planning line exceed the specified target of 3 units in 8 hours without the need to overtime work.

6. Conclusions

Based on the calculations and analysis of the research carried out on the assembly line at PT. XYZ, there is a change in the number of work stations from 6 work stations to 3 work stations. The balance efficiency also increased from 42.79% to 82.98%. The balance delay decreased from 57.21% to 17.02%, the smoothness index in the four methods had the same value, namely 77.02 minutes. So it can be concluded that the four methods provide the best solution, and by applying the heuristic method, the problems faced by the company will be resolved. The company can exceed the target they set from the discussion results, which is 6 units in 1 line. There was a reduction of operators from 4 to 3 people. In addition, the company will use more productive work time to increase the number of products it produces.

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Biographies

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Lina Gozali is a Lecturer in the Industrial Engineering Department of Universitas Tarumangara since 2006 and a freelance lecturer at Universitas Trisakti since 1995. She graduated with her Bachelor's degree at Trisakti University, Jakarta - Indonesia, then she got her Master's Degree at STIE IBII, Jakarta – Indonesia, and she recently got her Ph.D. at Universiti Teknologi Malaysia, Kuala Lumpur – Malaysia in 2018. Her apprentice college experience was in paper industry at Kertas Bekasi Teguh, shoes industry at PT Jaya Harapan Barutama, and automotive chain drive industry at Federal Superior Chain Manufacturing. She teaches Production System and Supply Chain Management Subjects. She did a research about Indonesian Business Incubator for her Ph.D. She has written almost 70 publications since 2008 in the Industrial Engineering research sector, such as Production Scheduling, Plant Layout, Maintenance, Line Balancing, Supply Chain Management, Production Planning, and Inventory Control. She had worked at PT. Astra Otoparts Tbk before she became a lecturer.