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Analysis of Line Balancing to Increase Production Line Efficiency in the Car Battery Industry

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A B S T R A C T

The automotive industry, in the form of electric cars, has entered Indonesia, making competition in automotive companies increasingly competitive, including the companies in this study that have had a positive impact, namely increasing demand for car batteries. In line with the development of electric cars, the company also developed new products, so the company installed an assembly line. but after the assembly line was running, productivity from production capacity and efficiency could not reach an average output of 823 units/day, the actual average output produced was only 622 units per day. There is a problem with line balancing on the assembly line which causes quite high waiting times at several stations, does not achieve production targets, and makes line efficiency less than optimal. Therefore the purpose of this study is to make improvements with the right Line Balancing method to be applied to achieve a suitable line balance and to find the Line Efficiency value that can be gained from the application of Line Balancing and how much the production capacity increases. The results of the research show that the Largest Candidate Rule method is the best method because it can increase the Line Efficiency value by 91.03%, the percentage of idle time or Balance Delay has improved, which has decreased to 8.97% and the total idle time is 21.3 seconds compared to the initial conditions. And can increase production capacity per day by 35.7%. This will be achieved consistently if the company can continue to improve employee skills by conducting training and increasing operators' motivation.

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1. INTRODUCTION

The entry of the automotive industry in the form of electric cars that have been rapidly entering Indonesia has made competition in automotive companies increasingly competitive. With the existence of electric car factories that have started to build factories in Indonesia such as Tesla, Nyundai, Wuling, and so on, there has been a lot of demand and consumer interest in these electric cars.

Therefore, the increasing demand for electric cars consumers is in line with the increasing demand for batteries for electric cars. The automotive industry can make a significant contribution to the national economy, with a total capacity of production in the automotive industry reaching 2.35 million units per year and can absorb a workforce of 38 thousand people and as many as 1.5 million people who work along the value chain in the industry (Kementrian Perindustrian Republik Indonesia, 2021).

This research was conducted at an automotive company that manufactures car batteries, which at the end of 2021 the company will add an assembly line due to consumer demand to make a new type of battery product and the assembly line will start operating in 2022. However, the output produced so far has not met the company's expectations, namely with an average daily output value of 622 units/day. Even though the company's target is to produce 823 units per day, the line has not been able to achieve the line capacity target. Increasing efficiency in production by paying attention to line balance, is an important part of ensuring production activities run well, minimizing total costs due to lost production and idle time that affects line balance. (Fitri et al., 2022); (Liu et al., 2022).

From previous research line balancing has several main objectives including increasing line efficiency and standardization (Srijayasari et al., 2018);(Addis, 2020); (Rocha & Lopes, 2022), increased production and productivity (Pathak et al., 2021);(Gofur et al., 2023). In the process of making batteries or car batteries in the automotive industry, in this study, 9 workstations were passed. To get the ideal process, we must first find the cycle time of each workstation by measuring the working time. The measurement of working time is in the form of direct observation techniques in the area or object being observed (Kartika et al., 2022). There is a goal achieved in this study is to make improvements with the appropriate Line Balancing method to be applied to achieve a suitable line balance and to find the Line Efficiency value that can be achieved from the implementation of Line Balancing and how much the production capacity increases. In increasing production capacity, one of the corrective actions is needed by utilizing the available resources optimally to produce maximum products without reducing the quality of these products.(Siregar & Yasid, 2018). Using the line balancing method, you can also find out how much the performance of each workstation is and how many workstations are needed so that the efficiency and effectiveness of the line can be achieved (Febriani et al., 2020); (Pilati et al., 2020).

2. LITERATURE REVIEW

Before analyzing and balancing the track, a measurement of work time is needed, which is a very important element in designing or repairing a working system. There are several objectives in analyzing work systems, namely to get the best way of working, this can be done by: (Erliana, 2015): (a) Improving work movements, (b) Improving workspace layout and design, (c) Utilizing human resources and reducing unnecessary activities, (d) Improving the use of alternative materials, machines, and labor, ada (e) Developing a good working environment.

Balancing assembly lines can be achieved through several different methods or approaches, all aiming to optimize the line for the best possible use of labor and facilities. There are three common methods used in line balancing problem-solving: (1) Heuristic Method: This method relies on experience, intuition, or empirical rules to find solutions better than previous ones (Nahmias, 2009). (a) Ranked Positional Weight/Hegelson and Birine Method (Positional Weight Ranking), (b) Kilbridge's and Waste/Region Approach (Region Method), (c) Large Candidate Rule (Longest Operation Time Method). (2) Analytic or Mathematical Method: This approach uses mathematical symbols such as equations and inequalities to represent real-world scenarios, (Branch and Bound Method) (Cormen et al., 2022). (3) Simulation Method: This method replicates the behavior of a system by studying the interactions between its components. Simulation models do not require explicit mathematical functions to relate system variables, making them suitable for solving complex systems that cannot be easily addressed mathematically (Law, 2015).

In this research, the improvement is carried out using the Heuristic method.The imbalance in assembly lines can be addressed through 10 steps, namely (Widyantoro et al., 2020): identify tasks and activities, determine the time required for completion, perform precedence constraints with precedence this diagram is a graphical description used to facilitate control and planning of activities (Baroto, 2001), determine output, assembly line, determine total time in producing output, calculate cycle time, assign machines and workers, determine minimum work stations according to desired output results, assess effectiveness and efficiency, carry out continuous improvement processes.

3. RESEARCH METHOD

The data collection method used in the preparation of this study is as follows

1. Direct Observation
   This activity is a direct observation by looking at the production process in as much detail as possible and then pouring it into a note sheet as supporting material for the data to be processed.
2. Indirect Observation
   This activity is an observation made indirectly or not at the location of the production process, observations are made by describing the production process in a simulation to compare actual conditions and ideal conditions and can more easily analyze the entire production process.
3. Documentation
   Data collection originates from documents or data in the company that are considered important and relevant to the object under study, such as production layouts, records of previous time measurements, and others.
   - Data processing and analysis are carried out using 3 methods in designing track balance, namely: Ranked Positional Weight/Hegelson and Birine
   - Kilbridge`s and Waste/Region Approach
   - Large Candidate Rule

From the calculations using the above method, the value of line performance is measured by calculating the value of Line Efficiency with formula 1, Balance Delay with formula 2 and Idle Time with formula 3.

$LE = TWC/(n.Tc) \times 100\%$..............................(1)

Information :

LE = line efficiency
Twc = total cycle time
Tc = highest cycle time
n = number of work stations

$BD = (n.Tc - Twc)/(n.Tc) \times 100\%$...................(2)

Information :

BD = balance delay
Twc = total cycle time
Tc = highest cycle time
n = number of work stations

$IT = ST\ maks - \sum STk$…………………...(3)

Information :

IT = idle time
ST maks = target time/ longest cycle time
∑STk = total cycle time for each station

4. RESULT AND DISCUSSION

a. Initial Conditions

Workstation Layout

The initial layout of the workstations on the assembly line consists of a total of 9 workstations, each operated by 9 operators. The initial condition of the workstation layout can be seen in Fig. 1.

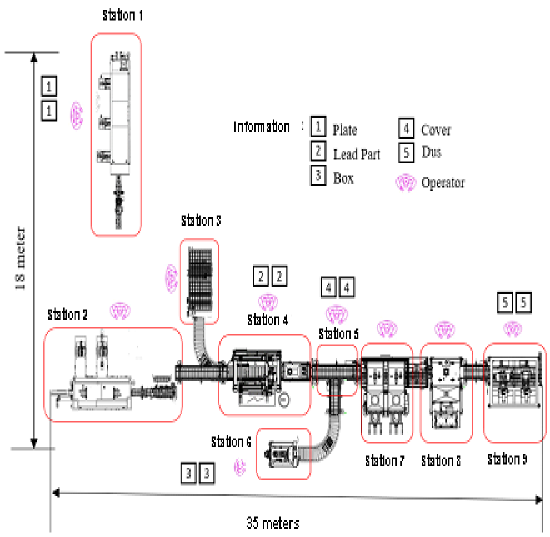


Fig. 1. Initial condition work station layout

In the initial condition, there are a total of 9 stations, and from each operator, the basic time for each job element performed by the operator is obtained by measuring their working time using a stopwatch. The total workstation time can be seen in Table 1.

Table 1. Total station operating time

Work Station	No	Work Element	Standard Time/Wb (Second)	Total Station Time (Second)
Station 1 Plate Cutting Process	1	Loading Plate	9.2	23.8
	2	Unloading Plate	10.5	
	3	Arrange Plates	4.1	
Station 2 Enveloping Process	4	Take Plate	5.9	24.7
	5	Loading Plate Positive	7.0	
	6	Unloading Plate Positive	4.2	
	7	Arrage Plate Positive	7.6	
Station3 Mearing Process	8	Take Plate Negative	4.1	27.0
	9	Cleaning Lug Plate	4.1	
	10	Arrange Plate	18.9	
Station4 Welding Process	11	Take the Arrangement Plate	6.0	46.3
	12	Install Lead Part	13.4	
	13	Welding	21.5	
	14	Cooling	5.4	
Station 5 InsertingProcess	15	Visual Check Elements	7.2	24.9
	16	Inserting Elements	13.5	
	17	Move Box	4.2	
Station 6 Punch Process	18	Take Box	5.8	19.0
	19	Punch Box	7.5	
	20	Move Box	5.7	
Station 7 Insert Cover Process	21	Take Cover	2.9	13.7
	22	Install Cover	6.8	
	23	Move Battery	4.1	
Station 8 Burning terminal Process	24	Install the Cup	6.9	21.6
	25	Burning Terminal	10.7	
	26	Move Battery	3.9	
Station 9 Packing Process	27	Take Dus	3.9	16.3
	28	Install Dus	8.0	
	29	Move Battery	4.4	
∑Total Operating Time				217.3

From the table above, it is known that the total condition of each process at each station and also the overall time value of each 1 series of operations on 1 product can be a value of 217.3 seconds. Pictures of each workstation with precedence diagrams can be seen in Fig. 2.

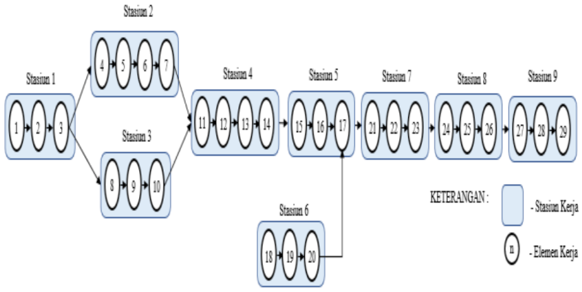


Fig. 2. Initial condition of work elements on the assembly line

Line performance in initial conditions by calculating the value of line efficiency, Balance Delay, and Idle Time.
The efficiency value is obtained by using the formula 1
Line Efficiency (LE) = 217,3/(9 x 46,3) x 100% = 52%
Balanced Delay using formula 2
Balance Delay (BD) = (9 x (46,3)-(217,3))/(9 x (46,3)) x100% = 48%
Then Calculate Idle Time using formula 3, can be seen in Table 2.

Table 2. Initial condition idle time

Number of Station	Total Cycle Time for each station (STk)	Target Time/ Longest cycle time (STmax)	Idle Time
Station 1	23.8	46.3	22.5
Station 2	24.7	46.3	21.6
Station 3	27	46.3	19.3
Station 4	46.3	46.3	0
Station 5	24.9	46.3	21.4
Station 6	19	46.3	27.3
Station 7	13.7	46.3	32.6
Station 8	21.6	46.3	24.7
Station 9	16.3	46.3	30
Total Idle Time			**199.4**

From the table above it can be seen that there is an imbalance of the trajectories of each station, as seen from the results of calculating the inequality value of the work, which is still very high, which is around 48%. The waiting time or idle time of each station is still quite high, namely 199.4 seconds. For Takt Time based on an effective working time of 8 hours or 28,800 seconds with an output target of 823 units, the takt time value is obtained using the following formula:

Takt Time = (Effective Working Time)/(Production Target Per day)………(4)

Then the exact takt time is **35 seconds/unit**

b. Line Balancing Ranked Position Weight Method

In the sequential weighting method, by looking at the work chain, the results of the largest weight will prioritize the work elements. The results of weighting and grouping can be seen in Table 3

Table 3. Results of theweighting and grouping of work elements

Work Elemen	Operation Time (Second)	Work Element Weight	Operating Time for each station (Second)
1	9.2	198.4	33.8
2	10.5	189.2	
3	4.1	178.7	
8	4.1	149.9	
4	5.9	147.5	
5	7.0	141.6	32.1
6	4.2	134.6	
7	7.6	130.4	
18	5.8	70.6	
19	7.5	64.8	
9	4.1	145.8	34.7
10	18.9	141.7	
11	6.0	122.8	
20	5.7	57.3	
12	13.4	116.8	34.9
13	21.5	103.4	
14	5.4	81.9	30.3
15	7.2	76.5	
16	13.5	69.3	
17	4.2	55.8	
21	2.9	51.6	31.4
22	6.8	48.7	
23	4.1	41.9	
24	6.9	37.8	
25	10.7	30.9	
26	3.9	20.2	20.2
27	3.9	16.3	
28	8.0	12.4	
29	4.4	4.4	

Hours of operation for each station from the results of weighting and grouping, the results of the precedence diagram obtained from the use of the Ranked Position Weight method can be seen in Fig. 3.

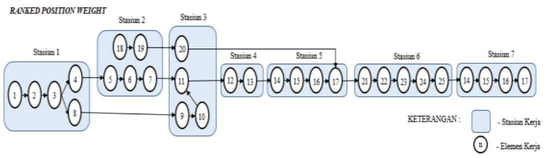


Fig. 3. Elements of work on the assembly line with the ranked position weight method

The results of line efficiency values in this method by calculating Line Efficiency, Balanced Delay, and Idle Time with the previous formula, the results are obtained: for a line efficiency of 88.95%, an inequality value of 11.05%, and for a total waiting time of 26.9 seconds, can be seen in the Table 4.

Table 4. Idle time with ranked position weight method

Number of Station	Total Cycle Time for each station (STk)	Target Time/ Longest cycle time (STmax)	Idle Time
Station 1	33.8	34.9	1.1
Station 2	32.1	34.9	2.8
Station 3	34.7	34.9	0.2
Station 4	34.9	34.9	0
Station 5	30.3	34.9	4.6
Station 6	31.4	34.9	3.5
Station 7	20.2	34.9	14.7
Total Idle Time			**26.9**

c. Line Balancing Largest Candidate Rule Method

The next method uses the line balancing method based on its placement in the workstation based on operating time. This method is carried out by grouping work elements based on initial conditions with a total of 9 workstations by describing each work element preceding and previous work elements and the processing time required for each element by making Precedence Constraints. Then, sort the work elements based on the longest operating time. sequencingof operations can be seen in Table 5.

Table 5. Sort oldest to fastest operating time

Work elemen	Operation time (second)	Work elemen	Operation time (second)
11	21.5	4	5.9
19	18.9	15	5.8
13	13.5	17	5.7
10	13.4	20	5.4
25	10.7	29	4.4
2	10.5	5	4.2
1	9.2	14	4.2
28	8.0	3	4.1
6	7.6	7	4.1
16	7.5	18	4.1
12	7.2	23	4.1
8	7.0	26	3.9
24	6.9	27	3.9
22	6.8	21	2.9
9	6.0		

After that, grouping the new work elements into Grouping work elements into 7 stations with the operating time limit for each station not exceeding the takt time, which is 35 seconds, and the sequence of work elements does not precede the previous process, can be seen in Table 6.

Table 6. Operating time of work element largest candidate rule

Preceding Work Elements	Previous Work Element	Process Time	Operating Time for Each Station (Second)
1	0	9.2	
2	1	10.5	
3	1,2	4.1	32.0
8	1,2,3	4.1	
9	1,2,3,8	4.1	
4	1,2,3	5.9	
5	1,2,3,4	7.0	31.8
10	1,2,3,8,9	18.9	
6	1,2,3,4,5	4.2	
7	1,2,3,4,5,6	7.6	31.2
11	1,2,3,4,5,6,7,8,9,10	6.0	
12	1,2,3,4,5,6,7,8,9,10,11	13.4	
13	1,2,3,4,5,6,7,8,9,10,11,12	21.5	34.1
14	1,2,3,4,5,6,7,8,9,10,11,12,13	5.4	
15	1,2,3,4,5,6,7,8,9,10,11,12, 13,14	7.2	
16	1,2,3,4,5,6,7,8,9,10,11,12 ,13,14,15	13.5	
18	0	5.8	32.5
19	0,18	7.5	
20	0,18,19	5.7	
17	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16	4.2	
21	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20	2.9	
22	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20,21	6.8	24.9
23	1,2,3,4,5,6,7,8,9,10,11,12,13 , 14,15,16,17,18,19,20,21,22	4.1	
24	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20,21, 22,23	6.9	
25	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20,21, 22, 23,24	10.7	
26	1,2,3,4,5,6,7,8,9,10,11,12,13 , 14,15,16,17,18,19,20,21,22, 23, 24,25	3.9	
27	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20,21, 22,23,24,25,26	3.9	30.9
28	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20,21, 22,23,24,25,26,27	8.0	
29	1,2,3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20,21, 22,23,24,25,26,27,28	4.4	

From the results of weighting and grouping, the results of the precedence diagram obtained from the use of the Largest Candidate Rule method can be seen in Fig. 4.

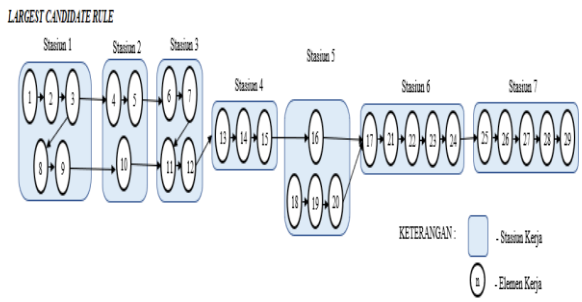


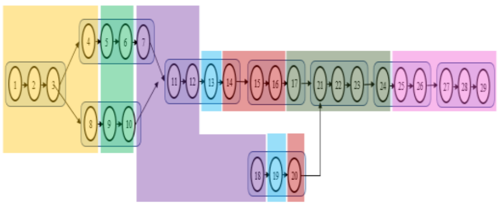
Fig. 4. Working elements on the assembly line using the largest candidate rule

The results of the line efficiency values in this method by calculating Line Efficiency, Balanced Delay, and Idle Time with the previous formula, the results are obtained: for a line efficiency of 91.03%, an inequality value of 8.97%, and for a total waiting time of 21.3 seconds, can be seen in Table 7.

Table 7. Idle time with largest candidate rule method

Number of Station	Total Cycle Time for each station (STk)	Target Time/ Longest cycle time (STmax)	Idle Time
Station 1	32.0	34.1	2.1
Station 2	31.8	34.1	2.3
Station 3	31.2	34.1	2.9
Station 4	34.1	34.1	0
Station 5	32.5	34.1	1.6
Station 6	24.9	34.1	9.2
Station 7	30.9	34.1	3.2
Total Idle Time			**21.3**

d. Line Balancing Region Approach Method
The next balance method uses the area approach method. This method is a division of work elements based on the earlier placement of areas concerning using the description of the precedence diagram. The grouping of these regions can be seen in Fig. 5.



Color of region information:

Fig.5. Grouping workstation areas by region

Next, calculate how much operating time from grouping by region.

Table 8. Region approach work element operating time

Work Element	Region	Operation Time (second)	Operating Time for Each Station (second)
1	1	9.2	
2	1	10.5	
3	1	4.1	33.8
4	1	5.9	
8	1	4.1	
5	2	7.0	
6	2	4.2	34.2
9	2	4.1	
10	2	18.9	
7	3	7.6	
11	3	6.0	32.8
12	3	13.4	
18	3	5.8	
13	4	21.5	29.0
19	4	7.5	
14	5	5.4	
15	5	7.2	31.8
16	5	13.5	
20	5	5.7	
17	6	4.2	
21	6	2.9	
22	6	6.8	24.9
23	6	4.1	
24	6	6.9	
25	7	10.7	
26	7	3.9	
27	7	3.9	30.9
28	7	8.0	
29	7	4.4	

From the results of regional grouping, theresults of the precedence diagram can beseen in Fig. 6.

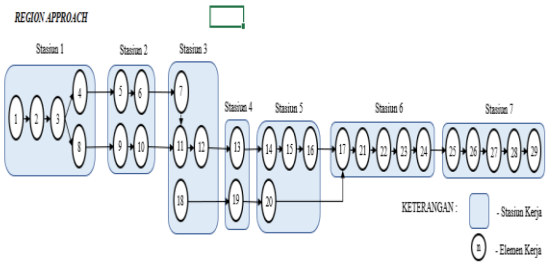


Fig. 6. Work elements on the assembly line with the regional approach method

The results of the line efficiency value in this method by calculating line efficiency, balanced delay, and idle time with the previous formula, the results are obtained: for a line efficiency of 90.7%, an inequality value of 9.23%, and for a total waiting time of 22 seconds, can be seen in Table 9.

Table 9. Idle Time wihRegion Approach Method

Number of Station	Total Cycle Time for each station (STk)	Target Time/ Longest cycle time (STmax)	Idle Time
Station 1	33.8	34.2	0.4
Station 2	34.2	34.2	0
Station 3	32.8	34.2	1.4
Station 4	29	34.2	5.2
Station 5	31.8	34.2	2.4
Station 6	24.9	34.2	9.3
Station 7	30.9	34.2	3.3
Total Idle Time			**22**

From the results of using the above methods, there is a comparison of the efficiency values of the line repairs which can be seen in Table 10.

Table 10. Comparison of the results of the methods

Methods	Line Efficiency	Balance Delay	Idle Time
Starting condition	52%	48%	199.4 Second
Ranked Position Weight	88.95%	11.05%	26.9 Second
Largest Candidate Rule	91.03%	8.97%	21.3 Second
Region Approach	90.77%	9.23%	22.0 Second

Comparison of line efficiency, balance delay and idle time shows that the best line arrangement method uses the largest candidate rule. With a line efficiency value of 91.03%, where the greater the value of effectiveness, the better the performance and effectiveness and the balance of idle time or balance delay has improved by 8.97%, this indicates that the weighting in each job is experiencing a good balance with a total idle time of 21.3 seconds compared to the initial conditions.

The results of these improvements can be increase productivity from the line there by reducing the occurrence of bottle necks. Where this makes activities on the line less effective, efficient and forms of waste in the line. With this application, the company can also increase its production capacity where the working time in the initial conditions with 8 working hours is only able to produce 622 units, while with this improvement it is able to increase the output or yield of the product to 844 units.This is profitable for the company because the production capacity produced per day increases by 35.7%.

From these results, a layout design for improvements can be made in accordance with the calculations with reference to the layout using precedence diagrams with the best method produced using the Largest Candidate Rule

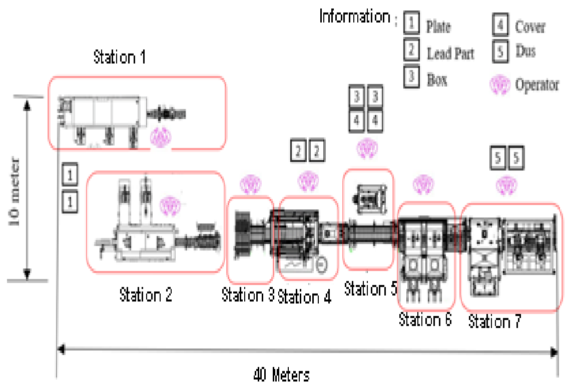


Fig. 6. Reapair layout withlargest candidate rule method

5. CONCLUSION

Of the three Line Balancing methods, the best method for line repair is using the Largest Candidate Rule method. The Line Efficiency value is 91.03%, where the greater the effectiveness value, the better the performance and effectiveness, and the balance of idle time or Balance Delay has improved by 8.97%, this indicates that the weighting in each job is experiencing a good balance with a total idle time of 21.3 seconds compared to the initial conditions. With an increase in production capacity per day of 35.7%.

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