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IJIEM (Indonesian Journal of Industrial Engineering & Management)

ISSN (Print) : 2614-7327 ISSN (Online) : 2745-9063

Measurement of Line Balancing in the Production Process Copper Cathode at PT. Smelting Using Ranked Positional Weight (RPW) Method

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ARTICLE INFORMATION

Article history:

Received: 29 September 2023
Revised: 12 November 2023
Accepted: 12 February 2024

Category: Research paper

Keywords:
Line
Balancing
Rank positional weight
Workstation

DOI: 10.22441/ijiem.v5i3.23322

A B S T R A C T

Line balancing is required in the production process. Without a balanced production line at work stations, the production process is less effective and efficient. Refinery at PT. Smelting has a type of mass production process, so it is planned to determine the optimal production line so that the loading on each work station will be more evenly distributed and reduce idle time. The method used is the measurement of working time with a stop watch. the data used is the work element and the time needed by the operator to complete the copper cathode production process which is from the anode arriving at the Anode Preparation Machine (APM) until the copper cathode is finished strapping at the Cathode Washing & Stripping Machine (CWSM). There are two results of the analysis,based on the first analysis that by using the line balancing method, the company can achieve a line efficiency of 78.10% and reduce the balance delay by 15.11% which is from 37.01% to 21.90%.

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1. INTRODUCTION

In this global era, it is undeniable that every aspect of activity requires developments in industrial technology to deal with problems and production activity Sumasto (2023). With the current era of industrialization, The operational activities of a company can run effectively and efficiently if the company implements quality control to reduce product failures or damages, aiming to achieve the required quality standards (Fenny, 2023). In order to satisfy consumers, these industries must create quality products and meet consumer needs, to achieve company success. The company's success can be seen from the implementation of the production system implemented. A production system is a series of several elements that are interconnected and mutually support each other to achieve a certain goal. The production system implemented by a company will influence all aspects of creating quality products. The purpose of this research is to examine the measurement results of the Ranked Positional Weight method for the balance of production lines on waiting time (balance delay), line efficiency and smoothness of the production process (smoothes index). Line balancing is needed to plan and control a production process so that it can run smoothly and produce products on time, maximize work efficiency and minimize workload imbalances between existing work stations. The Ranked Positional Weight method can group work operations into regions, making it easier to sort work operations based on work operation time priority and work operations that have the largest work operation time are carried out first. This research uses the Ranked Positional Weight method because this method measures weighting which is in line with the sequential production system implemented at PT Smelting.

Production process line for making copper cathodes at PT. Smelting begins with copper anodes originating from the smelter site arriving at the refinery site and placed on the APM (Anode Preparation Machine) machine. In this APM machine the anode which initially comes in a horizontal condition is changed to a vertical position and is given the same distance. After the anodes are in a vertical position and are spaced apart, then the gap between each copper anode will be filled with SS Blank (Stainless Steel Blank). After the copper anode and SS Blank have become 1 cell, the two objects are lifted and moved using a crane to a liquid electrolyte to produce a copper cathode that sticks to the SS blank. After producing the copper cathode, the SS blank and the remaining anode are lifted using a crane and moved to the ASWM (Anode Scrap Washing Machine) machine to place the remaining anode and after that the crane will lift the SS blank to the CWSM (Cathode Washing and Strapping Machine) machine to separate the cathode. The copper attached to the SS blank is followed by the binding of the copper cathode after it consists of several stacks into 1 bundle. At PT Smelting there has never been any detailed research on this matter so the company does not yet know the level of efficiency in their copper cathode production process and there is also a bottleneck at one of the work stations in the production process, so this research needs to be carried out.

In the copper cathode production process, it is necessary to make an analysis or balance calculation of the production process so that the production process can run smoothly. This aims to ensure that the company can produce more optimal quantities and according to the company's capacity in order to obtain maximum profits. The rank positional weight method of line balancing is expected to provide an optimal solution quickly and easily to this problem. So that later results will be obtained that can be used as evaluation material for the company. And can be used as a basis for planning copper cathode production at PT Smelting.

2. LITERATURE REVIEW

The production process is an activity or series that is interrelated to provide value or add useful value to an item. A production process that aims to provide value to an item can be seen in the production process which processes raw materials into semi-finished or finished goods. Meanwhile, the production process which aims to add value or usefulness to a good or service can be seen in the production process which changes semi-finished goods into finished goods. Production process activities do not only involve the processing of manufacturing various goods, of course it is true that many production activities are carried out in companies. (Fitriana, 2020). According to Agustina (2020), a workstation is a work space that is oriented towards work related to physical human interaction with equipment. Workstation design from an ergonomic perspective can significantly increase employee productivity and minimize stress caused by an unsupportive work space. Workstation design can influence physiological and psychological reactions both directly and indirectly.

Time measurement is the work of observing and recording work times for each element or cycle using prepared tools. The purpose of measuring this time is to obtain various kinds of work system designs so that the best work design can be obtained. Measuring working time is related to efforts to determine the standard time required to complete a job. Measuring working time can be done directly and indirectly. What is meant by direct measurement is that the observer directly measures and records the time required by the operator to carry out his work at the place where the operator works, while by indirect measurement the observer does not always have to observe work directly at the place where the operator works because it has been conditioned (Rahayu, 2020). According to Rahma (2019) cycle time is the time needed by a machine operator or anything else to complete one cycle of the work he is doing, including carrying out manual and ongoing work. Normal time is working time that has taken into account the adjustment factor, namely the average cycle time multiplied by the adjustment factor. Normal time for an element of work operations is an indication that a well-qualified operator will work to complete the work at the proper work tempo or in other words normal. Normal time is obtained by multiplying the cycle time of each operation by the existing allowance. (Trenggonowati. 2019)

Standard time is the standard amount of time for each element of work. Standard time is the time used to complete one cycle of work carried out according to a certain work method at normal speed taking into account the performance rating and allowance. Standard time can be determined after first finding the normal time, as well as determining the allowances given to workers for various things. To simplify the standard time for completing a work operation, normal time must be added to allowance time (which is a percentage of normal time). (Kusuma, 2019). According to Mustofa (2021) Performance Rating is an activity to evaluate the operator's work speed or tempo during work measurements. Effort speed, tempo and work performance all indicate the operator's movement speed while working. The purpose of implementing the performance rating is to show the operator's work ability while working so that the normal time for a work operation can be determined. According Cahyawati (2019) Performance Rating is a comparison of the operator's actual performance with a defined concept under normal performance conditions. According to Matiro (2021), in actual conditions in the field an operator will not be able to work continuously. Therefore, an allowance factor value is needed, which is a special time for needs such as personal needs, the need to unwind, and other needs that are beyond the operator's control. Delays can be caused by various factors that are difficult to avoid or can be called unavoidable delays, but sometimes there are also factors that can actually be avoided. According to Meyers (2002) Allowance is divided into 3 categories, namely: (1) personal allowance, (2) fatigue allowance, and (3) unavoidable delay.

According to Aripin (2019) Line balancing is a production path where material moves continuously at the same average rate through a number of work stations, where assembly work is carried out. Basuki (2019) stated that path balance emphasizes the assignment of individual work elements to work stations so that all human resources have the same quantity of work. Ranked Positional Weight (RPW) is a line balancing method developed by Helgeson and Birnie by ranking each job according to how important it is in completing all the work that depends on that job. This method assigns work elements to stations optimally by taking into account the priority relationships and processing time of all jobs. (Hapid, 2021)

Previous research was conducted by Dharmayanti (2021) who used the same method in different places. in his research to produce output from the calculation results, it was discovered that the efficiency that occurred in the initial trajectory of the production floor for product x was quite low. This is shown through the calculation of Line Efficiency (LE) before line balancing is 33%. Meanwhile, the Balance Delay (BD) is 77%. The line balance method used in calculating track efficiency is the Killbridge & Wester method and the Ranked Positioned Weight method, where by using these two methods the Line Efficiency (LE) value is 76.08%, with a Balance Delay (BD) of 23.92%. So the proposed number of work stations is four, a reduction of three work stations from the previous seven work stations. This aims to balance the workload between each existing work station so as to increase efficiency and effectiveness on the production line.

3. RESEARCH METHOD

This research was conducted by PT. Smelting. The research will be carried out in March 2023 until the required data is sufficient. Data collection was carried out in the production division. A variable is an object that is the focus of research. Referring to the title of this research problem, related variables can be identified, namely:

1. Dependent Variable

The dependent variable is the variable that is influenced or is the result of the existence of the independent variable. The dependent variable in this research is the level of line efficiency in good line balance in the copper cathode production process.

2. Independent Variable

Independent variables are variables that influence the value of the dependent variable. The independent variables in this research are: (a) Production capacity data, (b) Available work element data, (c) Time data for each work element, (d) Production process flow diagram

Data processing is an analytical technique used in the basic processing of data and theories related to problems. The methods used in processing data in this research is ranked positional weight method. Problem solving steps are carried out to clarify the sequence of solving the problem from the beginning to getting the final result or research solution. The problem solving structure in this research is

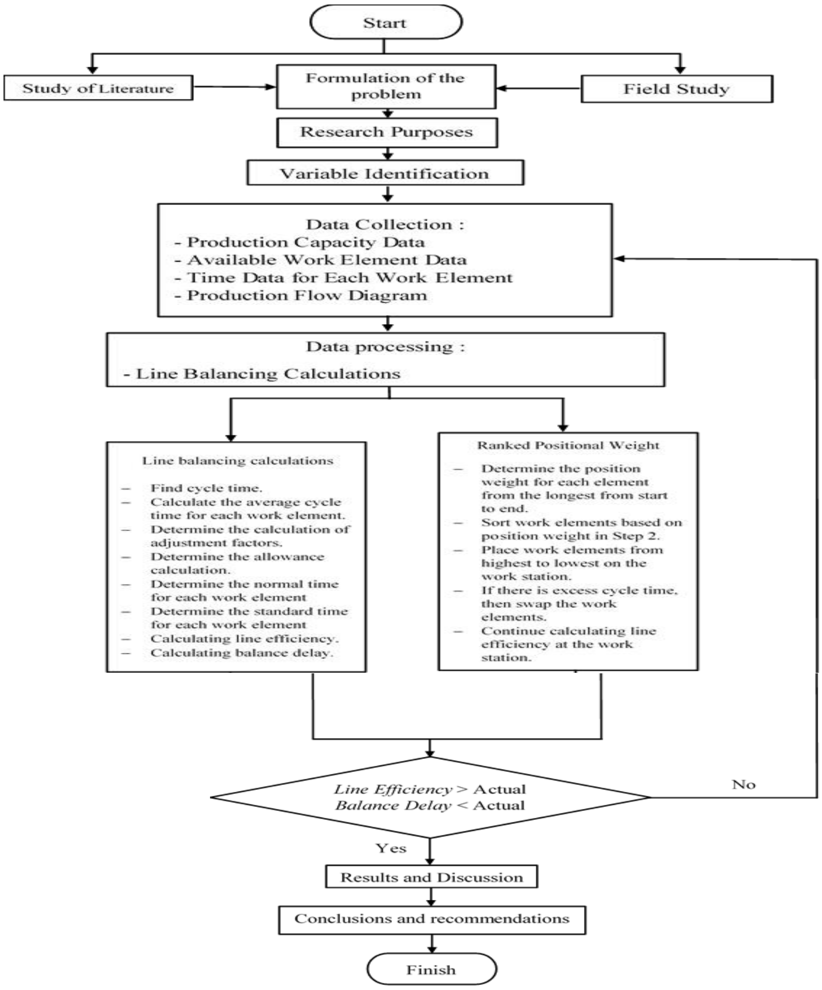

Figure 1. Flowchart of study

4. RESULT AND DISCUSSION

The data obtained was based on interviews with supervisors in the field. The data required is raw material data, production capacity data, machine data used, and cycle time for each work element, and precedence diagram data.

The average target production capacity for copper cathodes at PT. Smelting in one month is 300,000 tons with effective working hours of 8 hours per day.Some of the machines used in production include: (1) Anode preparation machine-APM, (2) Cranes, (3) Anode scrap and washing machine-ASWM, (4) Cathode washing and stripping machine-CWSM. Companies can take advantage of the results of this research by considering decision making for work stations that experience bottlenecks so that their line efficiency can be recalculated. and industry can use this research as a procedure to measure the line efficiency of a production process. Ranked Positional Weight method for line balancing, a standard time for each work operation is required. For this reason, observations and measurements of working time are carried out. Data collection was carried out by observing the working time of the working elements for making copper cathodes in the following table (Table 1).

Table 1. Available work elements

No	Work Element	No	Work Element
1	Tilting 1	15	Loading Cathode
2	Receiving 1	16	ASWM To CWSM
3	Transfer Device 1	17	Unload Cathode To CWSM
4	Spacing 1	18	Charging Trolley
5	Trolley 1	19	Receiving c/v
6	N&S Discharge Beam 1	20	Transfer Device 1
7	Unload SS Blank	21	Washing c/v
8	Loading Anode+SS Blank	22	Transfer Device 2
9	Anode+SS Blank To Cell	23	Flexing
10	Unload Anode+SS Blank To Cell	24	N&S Stacking (Chiseling)
11	Taking Anode Scrap+Cathode	25	Weighting
12	Loading Anode Scrap+Cathode	26	Strapping
13	Cell To ASWM	27	Discharge c/v
14	Unload Anode Scrap to ASWM		

Table 2. Operation time for all working elements for making copper cathode

	Work Element	**Observation**			**Average**
		1	2	3	
APM	1	00:00:24	00:00:25	00:00:25	00:00:24
	2	00:00:37	00:00:31	00:00:40	00:00:36
	3	00:00:07	00:00:7	00:00:08	00:00:07
	4	00:00:08	00:00:08	00:00:07	00:00:08
	5	00:00:49	00:00:51	00:00:50	00:00:50
	6	00:00:06	00:00:08	00:00:07	00:00:07
Plant & Cropping	7	00:01:11	00:01:04	00:00:51	00:01:02
	8	00:00:24	00:00:27	00:00:22	00:00:24
	9	00:00:49	00:00:44	00:00:51	00:00:48
	10	00:01:06	00:01:17	00:01:06	00:01:09
	11	00:00:44	00:00:40	00:00:42	00:00:42
	12	00:00:23	00:00:24	00:00:24	00:00:24
	13	00:00:50	00:00:48	00:00:49	00:00:49
	14	00:00:59	00:01:52	00:01:01	00:01:17
	15	00:00:37	00:00:22	00:00:22	00:00:27
	16	00:00:13	00:00:12	00:00:14	00:00:13
	17	00:00:38	00:00:37	00:00:33	00:00:36
CWSM	18	00:00:36	00:00:37	00:00:36	00:00:36
	19	00:00:34	00:00:29	00:00:30	00:00:31
	20	00:00:06	00:00:06	00:00:07	00:00:06
	21	00:00:20	00:00:19	00:00:22	00:00:20
	22	00:00:06	00:00:07	00:00:08	00:00:07
	23	00:00:06	00:00:06	00:00:07	00:00:06
	24	00:00:06	00:00:06	00:00:06	00:00:06
	25	00:00:46	00:00:46	00:00:54	00:00:48
	26	00:01:02	00:01:06	00:01:01	00:01:03
	27	00:00:56	00:00:55	00:00;54	00:00:55

To find out the normal time, the value of the adjustment factor (p) must first be determined. This aims to normalize working time obtained from measuring employee work when observed due to changes in employee work speed, skill level, environment and so on. Adjustment factors are analyzed based on observations before the research takes place and are subjective depending on the research, but at least efforts are made to be close to reality.

Table 3. Westinghouse performance rating calculation

Factor	Class	Initials	Adjustment
Skill	Excelent	B1	+0,11
Effort	Good	C1	+0,05
Working Conditions	Good	C	+0,02
Consistency	Excelent	B	+0,03
TOTAL			**+0,23**
Work Under Normal Circumstances			+1,00
Performance Rating			+1,21

From the westinghouse performance rating calculation above, the P value obtained using the Westinghouse method is 1.21. Meanwhile, in calculating standard time or standard time, we must calculate the allowance value first. This allowance is the time when employees interrupt the ongoing process because certain things cannot be avoided. The time required to interrupt the ongoing process can be calculated by paying attention to several aspects, including the calculation of allowances for working conditions in the field.

Table 4. Allowance calculation

No	Factor	Score
1	Power Released: Light	8%
2	Work Attitude: Standing on Two Feet	2%
3	Work Movement: Somewhat Limited	2%
4	Eyestrain : Almost Continuous Viewing	6%
5	Temperature Condition: Normal	5%
6	Atmospheric Conditions: Fair	2,5%
7	Working Environment: Very Noisy	2,5%
8	Men's Personal Needs	2%
9	Inevitable Looseness	5%
	TOTAL	35%

Based on the table above, the allowance value is 35% which will be used to find the standard time. After obtaining the required data, the next step will be data processing to solve the line balancing problem. After knowing the value of the allowance factor (P) and allowance, the next step is to calculate the normal time from the cycle time multiplied by the adjustment factor, and the standard time from the normal time multiplied by the allowance in the following table (Table 5).

Table 5. Cycle time, normal time and standard time

Work Element	Cycle Time	Normal Time	Standard Time (Minute)
1	00:00:24	00:00:28	0,65
2	00:00:36	00:00:43	0,98
3	00:00:07	00:00:07	0,18
4	00:00:08	00:00:09	0,21
5	00:00:50	00:01:00	1,36
6	00:00:07	00:00:07	0,18
7	00:01:02	00:01:15	1,68
8	00:00:24	00:00:28	0,65
9	00:00:48	00:00:58	1,31
10	00:01:09	00:01:23	1,88
11	00:00:42	00:00:51	1,14
12	00:00:24	00:00:28	0,65
13	00:00:49	00:00:58	1,32
14	00:01:17	00:01:19	1,80
15	00:00:27	00:00:32	0,74
16	00:00:13	00:00:16	0,36
17	00:00:36	00:00:43	0,98
18	00:00:36	00:00:43	0,98
19	00:00:31	00:00:37	0,85
20	00:00:06	00:00:07	0,16
21	00:00:20	00:00:24	0,54
22	00:00:07	00:00:07	0,18
23	00:00:06	00:00:07	0,16
24	00:00:06	00:00:07	0,16
25	00:00:48	00:00:58	1,31
26	00:01:03	00:01:16	1,72
27	00:00:55	00:01:06	1,50

Calculating Normal Time, For example in Strapping Process No. 26 requires a cycle time of 00:01:03 or 1.05 minutes, then the Normal Time value is :

$$Wn = Ws\ x\ p$$

$$Wn = 1{,}05 \text{ x } 1{,}21$$

$$Wn = 1{,}27 \text{ Minutes}$$

So, the normal time required for the Strapping No. 26 is 1.27 minutes or 00:01:16.

Calculating Standard Time: For example in Strapping Process No. 26 requires a Normal time of 00:01:16 or 1.27 minutes, then the Standard Time value is:

$$Wb = Wn + (Wn \text{ x Allowance})$$

$$Wb = 1{,}27 + (1{,}27 \text{ x } 35\%)$$

$$Wb = 1{,}72 \text{ Minutes}$$

So, the standard time required for the Painting No. 26 is 1.72 minutes or 00:01:43. And from the table above, it can be seen that the largest total standard time is at station 2 with a total standard time of 12.51 minutes.

Line Balancing Analysis, Number of working hours at PT. Smelting is 8 hours or 480 minutes per day, while Takt Time is the effective working hours per demand. Production targets based on requests at PT. Smelting is 38 units for each day. With that, then :

$$\text{Takt Time (TT)} = \frac{480\ minutes}{38\ unit/day}$$

$$= 12{,}63 \text{ minutes/unit}$$

The total Takt Time for copper cathode production is 12.63 minutes per unit, this means that production of each unit is not allowed to exceed 12.63 minutes, which is the maximum time limit in the work process. From the calculation, it can be seen that the line efficiency in the copper cathode production process is currently 62.99% with the calculation details as follows:

$$\text{LE} = \frac{Twc}{n.Tc}\, x\ 100\%$$

$$\text{LE} = \frac{23{,}64}{3 \times 12{,}51} \times\ 100\%$$

$$\text{LE} = 62{,}99\ \%$$

Actual Balance Delay in the Copper Cathode Production Process: From the calculation above, it can be seen that the balance delay in the copper cathode production process is currently 37.01% with the calculation details as follows:

$$\text{BD} = 100\% - LE$$

$$\text{BD} = 100\% - 62{,}99\%$$

$$\text{BD} = 37{,}01\ \%$$

Initial Idle Time in the Copper Cathode Production Process: From the calculation above, it can be seen that the idle time in the copper cathode production process is currently 13.89 minutes with the calculation details as follows :

$$\text{IT} = n.Tc - Twc$$

$$\text{IT} = 3\ \times\ 12{,}51 - 23{,}64$$

$$\text{IT} = 13{,}89 \text{ Menit}$$

For the application of line balancing using the ranked positional weight method, the first step in applying this method is to draw a precedence diagram according to the actual, then determine the position weight for each work element of an operational process that has the longest completion time from the start of the work to the end of the work element that has lowest completion time.

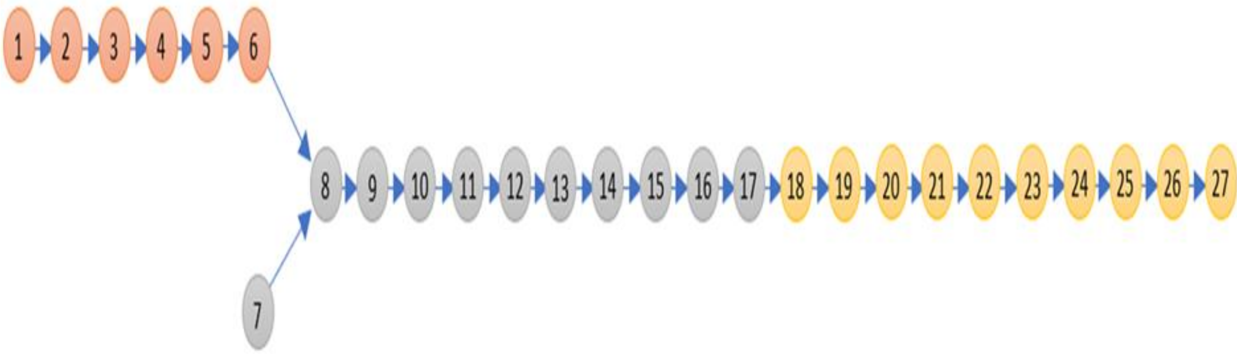

Figure 2. Precedence diagrams PT Smelting Copper Cathode production process

Table 6. Working time weighting using the ranked positional weight method

Element	Weight	Element	Weight	Element	Weight
1	23,64	10	16,44	19	6,59
2	22,99	11	14,56	20	5,74
3	22,01	12	13,42	21	5,58
4	21,83	13	12,77	22	5,04
5	21,62	14	11,45	23	4,86
6	20,26	15	9.65	24	4,7
7	20,08	16	8,91	25	4,54
8	18,4	17	8,55	26	3,23
9	17,75	18	7,57	27	1,51

Details of the weight calculation are as follows
First position weight = total standard time

2nd position weight =(1st position weight)-
Wb work element 1
=23,64-0,65
=22,99 menit

The weight of the 3rd position and so on is reduced as was done for the weight of the 2nd position and the weight reduction continues to be carried out as much as the number of working elements, namely 27 times. After completing the sorting, the next step is to group several work elements into work stations by paying attention to precedence constraints and Takt Time, meaning that there should be no grouping of work by preceding processes that are earlier and exceed 12.63 minutes for each work station. Determining the Minimum Number of Work Stations. Before continuing to group work elements, we must determine the minimum number of work stations, to find out the minimum number of work stations that are allowed.

$$n\ min = \frac{Twc}{Tt} = \frac{23,64}{12,63} = 1,87 \sim 2$$

So the minimum number of work stations required is 2 work stations for all work elements. Grouping RPW Work Stations, After determining the minimum number of work stations, the next step is to group work stations based on the RPW method in order to calculate line efficiency and balance delay. The grouping of RPW work stations is as follows (Table 7).

Table 7. Working time weighting using the ranked positional weight method

Work Element	Standard Time	Positional Weight	Total Time (Minute)	Takt Time (Minute)
1	0,65	23,64	3,56	12,63
2	0,98	22,99		
3	0,18	22,01		
4	0,21	21,83		
5	1,36	21,62		
6	0,18	20,26		
7	1,68	20,08	5,52	
8	0,65	18,4		
9	1,31	17,75		
10	1,88	16,44		
11	1,14	14,56	6,99	
12	0,65	13,42		
13	1,32	12,77		
14	1,80	11,45		
15	0,74	9.65		
16	0,36	8,91		
17	0,98	8,55		
18	0,98	7,57	7,56	
19	0,85	6,59		
20	0,16	5,74		
21	0,54	5,58		
22	0,18	5,04		
23	0,16	4,86		
24	0,16	4,7		
25	1,31	4,54		
26	1,72	3,23		
27	1,50	1,51		

Line Efficiency After Implementing the Ranked Positional Weight Method, From the grouping of work elements above, it can be seen that the line efficiency in the copper cathode production process is currently 78.1% with the calculation details as follows :

$$LE = \frac{Twc}{n.Tc} x\ 100\%$$

$$LE = \frac{23{,}64}{4 \times 7{,}56} \times\ 100\%$$

$$LE = 78{,}1\ \%$$

Balance Delay After Implementing the Ranked Positional Weight Method, From the above calculations it can be seen that the balance delay in the copper cathode production process is currently 21.9% with the calculation details as follows :

$$BD = 100\% - LE$$

$$BD = 100\% - 78{,}1\%$$

$$BD = 21{,}9\%$$

Idle Time After Implementing the Ranked Positional Weight Method, From the above calculations it can be seen that the idle time in the copper cathode production process is currently 6.6 minutes with the calculation details as follows :

$$IT = n.Tc - Twc$$

$$IT = 4 \times 7{,}56 - 23{,}64$$

$$IT = 6{,}6\ \text{Menit}$$

Comparison with previous research, Line Efficiency (LE) before line balancing is 33%. Meanwhile, the Balance Delay (BD) is 77%. The line balance method used in calculating track efficiency is the Killbridge & Wester method and the Ranked Positioned Weight method, where by using these two methods the Line Efficiency (LE) value is 76.08%, with a Balance Delay (BD) of 23.92%. So the proposed number of work stations is four, a reduction of three work stations from the previous seven work stations. while in this research In the actual conditions of the copper cathode production process at PT Smelting, a line efficiency of 62.99% and a balance delay of 13.22% were obtained. The results obtained after calculating using the Rank Positional Weight method showed that the line efficiency was 78.1% and the balance delay was 21.9%. and the number of workstations previously three has now increased to four.

5. CONCLUSION

In the actual conditions of the copper cathode production process at PT Smelting, a line efficiency of 62.99% and a balance delay of 13.22% were obtained. The results obtained after calculating using the Rank Positional Weight method showed that the line efficiency was 78.1% and the balance delay was 21.9%. Based on the data obtained, there is a work station that experiences a bottleneck, namely the charge and crop work station with a cycle time of 7.66 minutes. For further research, the author suggests using a method that has not yet been implemented, namely the Region Approach method to compare the results of line efficiency calculations with the Rank Positional Weight method.

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