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Line Balancing Application Analysis of Generator Manufacturing Process in DPG Inc.

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Abstract. Every company always try to fulfill their customers' demand in order to gain maximum profit with minimum cost. To achieve that, company needs to pay attention to all aspects of the industry from upstream to downstream and create an integrated system so all processes can run effectively and efficiently. One important aspect that needs to be considered closely is production time. Company have to ensure that the production activity can be done within the time target so customers can get the right product in the right time. In the production floor, the balance of production lines is effecting the efficiency of production process. This research measures the efficiency of a manufacturing process in a generator company (DPG Inc.) based on its production time. Then, line balancing is applied to the generator manufacture line using RPW, J-Wagon, and LCR method to know the comparison of efficiency before and after line balancing applied. Based on the line efficiency, smoothness index and balance delay obtained, the best line balancing method to use in the generator manufacture line is LCR. The result is the generator manufacture line is more efficient after line balancing applied, especially using LCR method.
Keywords: Line Balancing, Line Efficiency, Smoothness Index, Balance Delay, Ranked Positional Weight Method(RPW), J-Wagon Method, Largest Candidate Rule Method(LCR)

1. Introduction

Electricity is one of human needs that is very important to Indonesian society, whether in urban or rural areas. People's needs toward electricity can be categorized as a primary need because this time, almost every household appliances uses electricity as its energy source. Even so, along with the growth of population rate and economic rate in each region, the electricity provided by the State Electricity Company (PLN) sometimes cannot meet the needs of the community. This results in frequent power outages that are quite disruptive to community activities. To address this, people can use electricity generators. Electric generators convert mechanical energy into electrical energy that is suitable for lighting and electricity reserve use.

Just like any other industries, DPG Inc. always try to fulfill their customers' demand on time in order to get maximum profit with minimum cost. But in reality, often production target that has been scheduled cannot be done on time. This might happen because of some factors that occur during the manufacturing process. One of those factors came from the company's production floor, that the manufacturing process is not yet efficient.

Line balancing is a way that can be applied in production floor, in order to balance the work element weight on each workstation. These balanced work element weight will prevent the production line from 'bottleneck effect' or in other words, too many stacked product or semi-finished product in one workstation. Moreover, line balancing can also be an alternative solution that can be applied to smoothen out the production stream and to increase line production efficiency. Therefore, in this research, researcher applied line balancing to know how much efficiency can DPG Inc. get after the line balancing applied in its production line. The line balancing itself, in this research, is done using three different methods; ranked positional weight (RPW) method, J-Wagon Method, and Largest Candidate Rule Method (LCR).

RPW Method prioritizes work element with the largest weight, followed by work elements with smaller weight. Different from RPW, J-Wagon Method prioritizes work element with most work included followed by fewer work included. While LCR method sorts work element with the longest time to the shortest time. For this research, researcher uses three indicators to measure a production line efficiency for each method. Those indicators are; line efficiency, smoothness index, and balance delay.

2. Methods

Figure 1. Flowchart

The first step taken in this research is to observe generator production process flow. This step is important to understand step-by-step of creating a unit of generator. After that, researcher created a precedence diagram to visualize the production process flow. The third step is to collect generator cycle time which is a sum of time needed in every work elements presented in minutes. This cycle

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time is obtained from the sum of the work elements average time. The next step is to calculate line efficiency, smoothness index, and balance delay of current generator production process. Meanwhile, line balancing approach is applied using three methods; RPW, J-Wagon, and LCR so that line efficiency, smoothness index, and balance delay of every methods can be calculated. After line balancing using the three methods been calculated, researcher compare and elect one method that has the best result among the others. Then, the results of the current generator manufacturing process indicators are being compared with the results of the chosen line balancing method indicators. Finally, researcher analyze those results to know which one of those calculation shows the most efficient among the other.

3. Result and Discussion

3.1. Precedence Diagram

Precedence diagram is a graphic visualization of work operation order and relationship between one operation to others in order to support control and planning activity for each operation [1]. DPG Inc. has 12 workstations in its generator production line which consist 24 work elements. The generator manufacturing flow is being visualized into a precedence diagram to to describe the sequence of work elements, each nodes represents work elements.

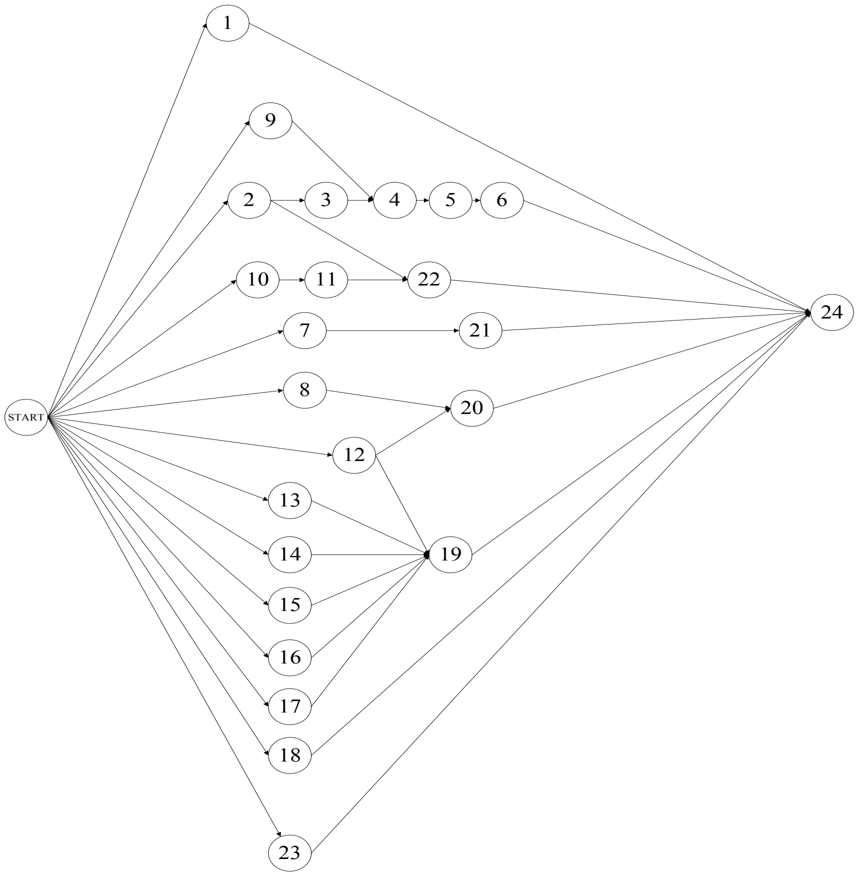

Figure 2. Precedence Diagram

Precedence diagram is supposed to be read from left to right. Each node represents work element according to the job number shown in the table 1. While the line or branch shows relationship between one or more work elements to another. Nodes that comes from more than one branch can only be done after the related work elements have been completed.

3.2. Generator Cycle Time
The cycle obtained from the sum of the work elements average time. The cycle time is 520,95 minutes or 8,7 hour.

Table 1. Generator Cycle Time

Work Element Number	Workstation	Process	Output Product	Operation Time (min)
1	1	Winding Wire	Arm Coil Winding	23.20
2		Winding Wire	Field Coil Winding	49.13
7	2	Wire Harness	Wire Harness Rocker	5.23
8		Wire Harness	Wire Harness Box	4.08
9	3	Stamping	Armature Core FA 5	7.50
10		Stamping	Pole Core FA 5	9.49
11	4	Welding	Pole Block FA - 5	72.00
12	5	Plate Bending	Control Box FA - 5	15.60
13		Plate Bending	Control Box Cover	5.60
14		Plate Bending	Protection Cover (S)	7.50
15		Plate Bending	Protection Cover (F)	6.90
16		Plate Bending	Bearing Cover S	4.00
17		Plate Bending	Bearing Cover F	3.00
18		Plate Bending	Clamper Wire	0.50
3	6	Armature Varnish	Varnished Field Coil	8.00
4	7	Rotor Varnish	Varnished Rotor Assy	9.88
5	8	Rotor Process	Rotor Assy	116.86
6	9	Lathe Process	Balanced Rotor Assy	13.57
20	10	Assembly Process	Control Box Assy	8.10
21		Assembly Process	Rocker Assy	10.53
22		Assembly Process	Pole Assy	14.77
23		Assembly Process	Output Term Bord Assy	2.57
19	11	Painting	Painting	65.80
24	12	Setting	Generator	57.13
			Cycle Time	520.95

3.3. Current Generator Manufacturing Process Efficiency
To know and to compare manufacturing process efficiency before and after line balancing applicated, measurement of current generator manufacturing process efficiency is done using three indicators; line efficiency, smoothness index and balance delay.

3.3.1. Line Efficiency. Current generator manufacturing process line efficiency (LE) is calculated using the equation:

$$LE = \frac{\sum T}{(K \ x \ C)} x \ 100\% \quad (1)$$

Explanation:
LE : Line Efficiency
$\sum$T : Cycle Time
K : Largest Work Station Time
C : Number of Workstations

Cycle time of current generator manufacturing process as shown in table 1 is 520,95 minutes. And for the largest workstation time is at the 5th workstation (rotor process) which needs 116.86 minutes to finish the activity. Therefore, the equation becomes:

$$\mathrm{LE} = \frac{520{,}95\ (\mathrm{min})}{(116{,}86\ (\mathrm{min})\mathrm{x}\ 12)}\mathrm{x}100\% = 37{,}15\%$$

3.3.2. Smoothness Index. This is the formulation to get the smoothness index:

$$SI = \sqrt{(\sum STi\ max - \sum STi)^2} \tag{2}$$

Explanation:
SI : Smoothness Index
STi max : Maximum Workstation Time
STi : i-Workstation Time

Smoothness index (SI) is an index that shows a relative smoothness of any assembly or manufacturing lines. The closer the index to zero, the smoother a production line gets [2]. A process line will get the perfect balance state when the smoothness index is equal to zero. In this equation, Maximum workstation time (STi-max) has the same meaning as 'K' in line efficiency's equation. Therefore, the equation for smoothness index for current generator manufacturing process becomes:

$$\mathrm{SI} = \sqrt{\begin{matrix}(72{,}33(\mathrm{min}) - 116{,}86(\mathrm{min}))^2 + (9{,}31(\mathrm{min}) - 116{,}86(\mathrm{min}))^2 + \cdots + \\ (57{,}13(\mathrm{min}) - 116{,}86(\mathrm{min}))^2\end{matrix}} = 278{,}672$$

3.3.3. Balance Delay. The formulation of balance delay is:

$$BD = \frac{(K\ x\ C) - \sum ti}{(K\ x\ C)}\ x\ 100\% \tag{3}$$

Explanation:
BD : Balance Delay
K : Number of Workstations
C : Largest Workstation Time
∑ti : Sum of Operation Time

Balance delay (BD) is the ratio between waiting time and time available in the process line. So, the smaller the balance delay value is, the less waiting time occur in the process line. Based on table 1, the balance delay equation of current generator manufacturing process is:

$$BD = \frac{(12x116{,}86(min)) - 520{,}96(min)}{(12\ x\ 116{,}86(min))} x100 = 62{,}85\%$$

3.4. Line Balancing

Line balancing is a task division of interrelated workstations in a production line [3]. The ultimate goal of line balancing is to maximize the speed of each workstation so that a high work efficiency can be achieved in every station [4]. There are some line balancing methods, three of them that are used in this research is ranked positional weight, J-Wagon, and largest candidate rule.

3.4.1. Ranked Positional Weight Method. This method prioritizes work element with the largest weight, followed by work elements with smaller weight [5]. The way to determine the weight of each work element is based on a precedence diagram that starts from the end of the process to the beginning of the process

Table 2 shows the last iteration data of line balancing using RPW method. Based on the result, the number of modifed workstation is five and the longest operation time is 116,86 minutes. By those data, LE, SI and BD of generator manufacturing process using RPW method can be calculated. The results are 89,16%, 48,14 and 10,24%.

3.4.2. J-Wagon Method. J-Wagon method prioritizes work process based on the number of operations it contains. In this method, the number of work element called number of wagon [6].

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Table 2. Modified Workstation Using RPW Method

Work Element Number	Process	Operation Time (min)	Modified Operation Time (min)	Modified Workstation
24	Setting	57.13	116.13	I
3	Armature Varnish	8.00		
9	Stamping	7.50		
10	Stamping	9.49		
12	Plate Bending	15.60		
14	Plate Bending	7.50		
15	Plate Bending	6.90		
16	Plate Bending	4.00		
2	Winding Wire	49.13	115.78	II
8	Wire Harness	4.08		
21	Assembly Process	10.53		
18	Plate Bending	0.50		
1	Winding Wire	23.20		
22	Assembly Process	14.77		
6	Lathe Process	13.57		
4	Rotor Varnish	116.86	116.86	III
20	Assembly Process	8.10	100.18	IV
23	Assembly Process	2.57		
19	Painting	65.80		
17	Plate Bending	3.00		
5	Rotor Process	9.88		
7	Wire Harness	5.23		
13	Plate Bending	5.60		
11	Welding	72.00	72.00	V

Table 3. Modified Workstation Using J-Wagon Method

Work Element Number	Process	Operation Time (min)	Number of Wagon	Modified Operation Time (min)	Modified Workstation
2	Winding Wire	49.13	6	106.54	I
9	Stamping	7.50	4		
3	Armature Varnish	8.00	4		
10	Stamping	9.49	3		
12	Plate Bending	15.60	3		
7	Wire Harness	5.23	2		
8	Wire Harness	4.08	2		
14	Plate Bending	7.50	2		
4	Rotor Varnish	116.86	3	116.86	II
11	Welding	72.00	2	115.45	III
13	Plate Bending	5.60	2		
15	Plate Bending	6.90	2		
16	Plate Bending	4.00	2		
17	Plate Bending	3.00	2		
18	Plate Bending	0.50	2		
5	Rotor Process	9.88	2		
6	Lathe Process	13.57	1		
1	Winding Wire	23.20	1	116.30	IV
20	Assembly Process	8.10	1		
21	Assembly Process	10.53	1		
22	Assembly Process	14.77	1		
23	Assembly Process	2.57	1		
24	Setting	57.13	0		
19	Painting	65.80	1	65.80	V

Table 3 shows that number of workstation modification for line balancing using J-Wagon method is five and the 2nd modified workstation has the longest operation time. Based on the line balancing result shown in table 3, the three efficiency indicators results are: LE = 89,16% , SI = 52,11 and BD = 10,84%.

3.4.3. Largest Candidate Rule Method. The last line balancing method used for this research is LCR, which sorts operation times from the longest to the shortest [5]. The last iteration result shown on table 4.

Table 4. Modified Workstation Using LCR Method

Work Element Number	Process	Operation Time (min)	Modified Operation Time (min)	Modified Workstation
4	Rotor Varnish	116.86	116.86	I
11	Welding	72.00	116.40	II
1	Winding Wire	23.20		
12	Plate Bending	15.60		
13	Plate Bending	5.60		
19	Painting	65.80	115.43	III
18	Plate Bending	0.50		
24	Setting	57.13	116.80	IV
2	Winding Wire	49.13		
21	Assembly Process	10.53		
22	Assembly Process	14.77	104.59	V
6	Lathe Process	13.57		
5	Rotor Process	9.88		
10	Stamping	9.49		
20	Assembly Process	8.10		
3	Armature Varnish	8.00		
9	Stamping	7.50		
14	Plate Bending	7.50		
15	Plate Bending	6.90		
7	Wire Harness	5.23		
8	Wire Harness	4.08		
16	Plate Bending	4.00		
17	Plate Bending	3.00		
23	Assembly Process	2.57		

Table 4 shows that number of workstation modification for line balancing using LCR method is five and the 1st modified workstation has the longest operation time (116,86 minutes). Based on the line balancing result shown in table 4, the three efficiency indicators results are: LE = 89,16%, SI = 12,36 and BD = 10,84%.

3.4.4. Best Line Balancing Method. According to the line balancing results using RPW, J-Wagon, and LCR method, the value of LE and BD using those methods are the same. They are 89,16% and 10,84%. Meanwhile the SI's are different. For RPW it is 47,51; for J-Wagon it is 52,11; and for LCR it is 12,36. Since the smallest SI is by the LCR method, then it can be concluded that the best line balancing method to be applicated in the generator manufacturing process between RPW, J-Wagon, and LCR is LCR.

3.5. Before and After Line Balancing Result Comparison

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3.5.1. Line Efficiency. Before: 37,15%; After: 89,16%
There is a line efficiency value difference of 52,01% after line balancing using LCR method applicated.

3.5.2. Smoothness Index. Before: 278,67; After: 12,36.
Smoothes index after line balancing applicated using LCR method reduce (it gets closer to perfect balance state) with value difference of 266,31.

3.5.3. Balance Delay. Before: 62,85%; After: 10,84%
The percentage of balance delay after line balancing using LCR method applicated decrease with 52% value difference.

4. Conclusion
Based on the result of line efficiency (LE), smoothness index (SI), and balance delay (BD) values of generator manufacturing process in DPG Inc., it can be concluded that the best line balancing to be applicated is LCR method. According to the result comparison of before and after line balancing applicated especially using LCR, the efficiency increased 52,01% , the smoothness index also increased to 12,36 point closer to perfect balance state and idle time decreased 52% from the current condition. Briefly, the proposed workstation setting modified using LCR method is more efficient than the current generator manufacturing process setting.

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