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Analysis of Line Balancing using Ranked Positional Weight (RPW), Largest Candidate Rule (LCR), and J-Wagon Methods in Crane Girder Production at PT MHE Demag Surabaya, Indonesia

Farida Pulansari[1*] and *Isna* Nugraha[2]

[1,2] Industrial Engineering, Faculty of Engineering, Universitas Pembangunan Nasional "Veteran" Jawa Timur, Surabaya 60294, Indonesia
Email: farida.ti@upnjatim.ac.id[1*], isna.nugraha.ti@upnjatim.ac.id[2]

Abstract. Every company is required to enhance its quality by implementing improvement actions within the company's production system. PT MHE Demag Surabaya is a company engaged in crane girder manufacturing. This research aims to determine the optimal line balancing using the Helgesson-Birnie/Ranked Positional Weight (RPW) method, the Largest Candidate Rule method, and the J-Wagon method. Line balancing is necessary due to excess operating time in the crane girder manufacturing workstations, which increases the risk of accidents for the workers. The results of data processing which employed these three heuristic methods demonstrate that the RPW method is the most efficient. The Helgesson-Birnie/Ranked Positional Weight (RPW) method yields the most optimal output, with a line efficiency of 96.67%, balanced delay of 3.33%, and total idle time of 4936.8 seconds using 15 workstations. By utilizing the heuristic methods for line balancing, the efficiency decreases to 144.76%, the balanced delay increases to 14.76%, and the total idle time increases to 86,400 seconds.

1 Introduction

The increasing number of emerging competitor industries in various fields accelerates the development of the industrial world. This situation demands companies to consistently provide satisfaction to their consumers [1]. One of the ways that companies can compete is by enhancing the quality of their products through improvements in the company's production system [2]. Inappropriate production planning can result in imbalanced operating times at workstations [3].

PT. MHE Demag Surabaya is a company engaged in the manufacturing of heavy transport equipment, particularly in crane production. In work systems, humans play a crucial role in designing, planning, controlling, and evaluating the work systems. At PT. MHE Demag, workload accumulation occurs at a particular workstation during the crane production process. Imbalance in the operating times of workstations results in production line imbalances. Line balancing is necessary to create equilibrium in the production flow, ensuring smooth production processes [4]. In particular tasks, there is significant idle time. To address this idle time, line balancing needs to be implemented to equalize time and workload across each production line [5].

Production productivity is influenced by the production system employed, and thus, a good production system is essential to achieve desirable output [6]. However, PT. MHE Demag Surabaya, particularly in the assembly line, does not exhibit efficient productivity. This issue disrupts the production line balance and results in low line efficiency within the assembly line. Consequently, line balancing is necessary to enhance productivity. Line balancing is a method of distributing work assignments among interconnected workstations in a production line, aiming to minimize idle time and maximize workstation efficiency [7]. These workstations must maintain their operation times within the cycle and workstation times. The function of line balancing is to create a well-balanced flow path [8]. In this study, to address line balancing issues, heuristic methods including Ranked Positional Weight (RPW), Largest Candidate Rule, and J-Wagon methods are employed to find the optimal line balancing solution.

The Largest Candidate Rule (LCR) method balances the production line by prioritizing the placement of the longest operating time element at workstations [9]. Using the LCR method, work elements are arranged in descending order (from the largest to the smallest value) based on their operating time. The underlying principle is to combine processes based on the sorting of operations from the longest processing time [10]. The Ranked Positional Weight (RPW) method, on the other hand, is a heuristic method that prioritizes the largest work element's time. The largest work elements are given priority in placement at other workstations, representing shorter work element times. This process involves assigning weights (ranks) and is depicted in a precedence matrix.

The weighting is done according to the order of work elements in the precedence diagram. On the other hand, the J-Wagon method is based on prioritizing work elements at workstations with the highest quantity [11]. These work elements are given priority in the workstation planning, followed by work elements with fewer quantities [12]. The grouping is done similarly to the Helgeson-Birne method (Ranked Position Weight/RPW), but with a difference in determining the weight, which is calculated based on the number of operations rather than the time of operations [13]. Consequently, to address the issue of low production line productivity, this study was conducted to identify the causes of low line efficiency and perform line balancing using three methods: Ranked Positional Weight (RPW) method, Largest Candidate Rule, and J-Wagon to determine the most suitable improvement method for the Assembly Line.

The novelty of this research lies in its primary objective to identify the optimal line balancing time by comparing three heuristic methods. Most studies only utilize a single heuristic method. By comparing these three methods, it is expected that the researchers can identify the strengths and weaknesses of each heuristic method.

2 Literature Review

2.1 Optimization

Optimization refers to the state in which the best course of action is taken in decision-making for a given problem [14][15]. The optimization of production capacity can be achieved through various means, including creating an optimal work schedule, adding overtime hours, increasing the workforce, or adding machinery. To accelerate the production rate, the involvement of various technologies is essential. Fundamentally, time measurement in the workplace is closely related to efforts aimed at determining the duration required by an individual to complete a task. Stopwatch Time Study, an application of time measurement, is used for tasks that are performed quickly, have short work cycles, and involve repetitive cycles of work [2].

2.2 Line Balancing Method

Line balancing method is used to plan the sequence related to time aspects [16]. The issue of assembly line balancing is concerned with minimizing the number of workstations, reducing cycle time, and maximizing workload distribution to enhance line efficiency [17]. The balancing of process lines is a crucial factor for industries to improve work productivity by optimizing the number of workstations or minimizing cycle time [18]. Assembly line balancing is one of the criteria to determine industrial effectiveness, where a set of assembly work elements is grouped into several workstations. Imbalance in the production process can be observed when some workstations remain idle while others operate at full capacity [19].

2.3 Ranked Position Weight (RPW), Largest Candidate Rule, and J-Wagon method

Ranked Position Weight (RPW) or positional weight method is one of the heuristic methods [20]. This method prioritizes the longest work element times [21]. To select and determine the appropriate method for line balancing, it is necessary to develop an analytical method to assess the performance of each existing method concerning the production task characteristics. This allows the identification of the most efficient workstation arrangement method [22]. The implementation steps are as follows [23]:

1. Determining the precedence operation matrix
2. Calculating the positional weights for each operation
3. Obtaining the results of the positional weight calculations
4. Assigning the operations in the workstation design
5. Precedence diagram resulting from the design.

The Largest Candidate Rule (LCR) method or the longest operation time method, which was introduced by Moodie and Young [24], is a part of the heuristic methods used to determine the optimal line balancing. The research results indicate an improvement in line performance, manifested by increased efficiency [25]. The implementation steps of this method are as follows [26]:

1. Creating a summary of predecessor and successor operations
2. Designing the determination of workstations
3. Precedence diagram resulting from the design.

The Line Balancing method used to optimize the production process is the J-Wagon method. This heuristic method prioritizes the highest number of work elements, where these work elements are given priority in placement at workstations, followed by work elements with fewer elements [12]. The steps of this method are as follows [13][11]:

1. Determination of operation weights and dependencies
2. Determination of weights and priority assignments
3. Designing the determination of workstations
4. Creating a precedence diagram resulting from the design.

3 Methodology

The research began with the identification of the issues at PT MHE Demag Surabaya. Upon gathering and analyzing the identified problems, a literature review was conducted to obtain appropriate methods and compared them with recent journal articles. Data collection involved gathering production time data for cranes from the company to determine the daily production target. This was followed by measurement of time required for each activity in the production department. Other data collected includes layout time and production capacity per work element. Next, the data was processed using three heuristic methods for line balancing: Helgesson-Birnie/Ranked Positional Weight (RPW) method, Largest Candidate Rule method, and J-Wagon method. From these three methods, the best line balancing method was selected based on several criteria, such as line efficiency, balance delay, longest cycle time, idle time, and the number of newly formed workstations. After comparing the results of the three methods with the criteria and considering the existing layout, the conclusion was drawn by determining the best line balancing method to address the imbalance in the production area of the company.

4 Discussion

4.1 Standard Time Data

Before conducting the initial line balancing calculations, it is necessary to gather standard time data for each workstation process to be used as a reference time. The following table presents the standard time data for the Crane Girder manufacturing process, obtained from observations conducted at PT MHE Demag.

Table 1. Standard Time Data for Crane Girder Manufacturing

Operation	**Station**	**Process**	**Standard Time Data (second)**
1	1	Loading Material	1395.6
2		Marking Material	1114.2
3		Setting Machine & Material	940.2
4		Cutting Material	19372.2
5		Cleaning Material	1671
6		Check & Move to Next Station	1957.8
7	2	Prepare But Welding Material Process	2504.4
8		Grinding & Welding Top Layer	2145
9		Grinding & Welding Join Web	1674.6
10		Grinding & Welding Bottom Layer	2415
11		Prepare Siku Process	748.2
12		Marking & Welding Siku Top Layer	1780.8
13		Marking & Welding Siku Bottom Layer	2044.8
14		Check & Move to Next Station	1596
15	3	Marking & Welding Diaphragm	1677.6
16		Prepare Welding Web Process	1028.4
17		Press & Welding Web	13174.8
18		Grinding After Welding Web	848.4
19		Prepare Boxing Process	1212.6
20		Boxing Material	4938
21		Check & Move to Next Station	1399.8
22	4	Prepare Filled Material	4659.6
23		Filled Top Layer	4926.6
24		Filled Bottom Layer	5379.6
25		Grinding After Filled Layer	4546.2
26		Check. & Move to Next Station	1678.8
27	5	Marking End Carriage	1031.4
28		Levelling Bottom	2981.4
29		Prepare & Fitting End Carriage To	3076.2
30		Girder	1501.2
31		End Carriage Alignment Check	4375.2
32		Marking. Welding. & Filled End	1127.4
33		Carriage Cover	2521.8
34		Grinding After Filled End Carriage	3623.4
35		Cover	1414.8
36		Marking & Fitting Wheels End	1043.4
37		Carriage	1500
38		Wheels Base End Carriage &	4829.4
39		Alignment Check	1683
40		Marking & Filled Lifting Eye	1033.8
41	6	Welding & Grinding Bracket Panel	1032.6
42		Disassembly End Carriage	10126.2
43		Fitting & Filled Cover Girder to Top	1683
44	7	Layer	750.6
45		Fitting Cable & Cable Bracket	3907.8
46		Move To Next Station	1861.8
47		Prepare Sand Blasting Process	1128.6

PT. HME Demag Surabaya has 8 working hours per day for the production of 3 units of crane girder. Hence, the total time required for the entire crane girder manufacturing process is 139,063.2 seconds. Consequently, the cycle time is calculated as follows :

Cycle Time Required (CT)

$$CT = \frac{8 \times 3600}{3} = 9600 \text{ seconds}$$

The total overall time and cycle time will be used for calculating line efficiency, balance delay, total idle time, workstation efficiency, and idle time for each workstation [27].

4.2 Initial Assembly Line Balancing Calculation

PT. HME Demag Surabaya requires 8 working hours to produce 3 units of crane girder daily. The results of the initial assembly line balancing calculation for the production of 3 units of crane girder each day are as follows:

1. Total Overall Operation Time
   = 139063.2
2. Cycle Time Required (CT)
   $CT = \frac{8 \times 3600}{3} = 9600$
3. Line Efficiency (LE)
   $LE = \frac{139063.2}{47 \times 9600}$ x 100%= 30.82%
4. Balance Delay (BD)
   $BD = \frac{(47 \times 9600) - 139063.2}{47 \times 9600}$ x 100% = 69.18 %
5. Total Idle Time
   = 47 x 9600 – 139063.2= 312136.8 seconds
6. Workstation Efficiency
   Operation 1 = $\frac{1395.6}{9600}$ x 100 = 14.54 %
7. Idle Time
   Operation 1 = 9600-1395.6= 8204.4 seconds

Table 2. Initial Assembly Line Balancing Calculation

Operation	**Operation Time (second)**	**Workstation Efficiency (%)**	**Idle Time (second)**
1	1395.6	14.5375	8204.4
2	1114.2	11.60625	8485.8
3	940.2	9.79375	8659.8
4	19372.2	201.7938	-9772.2
5	1671	17.40625	7929
6	1957.8	20.39375	7642.2
7	2504.4	26.0875	7095.6
8	2145	22.34375	7455
9	1674.6	17.44375	7925.4
10	2415	25.15625	7185
11	748.2	7.79375	8851.8
12	1780.8	18.55	7819.2
13	2044.8	21.3	7555.2
14	1596	16.625	8004
15	1677.6	17.475	7922.4
16	1028.4	10.7125	8571.6

17	13174.8	137.2375	-3574.8
18	848.4	8.8375	8751.6
19	1212.6	12.63125	8387.4
20	4938	51.4375	4662
21	1399.8	14.58125	8200.2
22	4659.6	48.5375	4940.4
23	4926.6	51.31875	4673.4
24	5379.6	56.0375	4220.4
25	4546.2	47.35625	5053.8
26	1678.8	17.4875	7921.2
27	1031.4	10.74375	8568.6
28	2981.4	31.05625	6618.6
29	3076.2	32.04375	6523.8
30	1501.2	15.6375	8098.8
31	4375.2	45.575	5224.8
32	1127.4	11.74375	8472.6
33	2521.8	26.26875	7078.2
34	3623.4	37.74375	5976.6
35	1414.8	14.7375	8185.2
36	1043.4	10.86875	8556.6
37	1500	15.625	8100
38	4829.4	50.30625	4770.6
39	1683	17.53125	7917
40	1033.8	10.76875	8566.2
41	1032.6	10.75625	8567.4
42	10126.2	105.4813	-526.2
43	1683	17.53125	7917
44	750.6	7.81875	8849.4
45	3907.8	40.70625	5692.2
46	1861.8	19.39375	7738.2
47	1128.6	11.75625	8471.4
Total	139063.2		312136.8

4.3 Line Balancing Diagram

Line balancing is a crucial aspect of production management aimed at optimizing efficiency and productivity in the production process flow [28]. Three methods utilized to achieve line balancing are Ranked Positional Weight Method, Largest Candidate Rule Method, and J-Wagon Method.

The Ranked Positional Weight Method involves assessing the level of difficulty and complexity of each task or operation within the production line [20]. The Largest Candidate Rule Method focuses on identifying production stages with the longest process times, known as "bottlenecks" [29]. On the other hand, the J-Wagon Method employs a dynamic approach to achieve production line balancing [12]. In this method, continuous monitoring of production variability and customer demand is conducted.

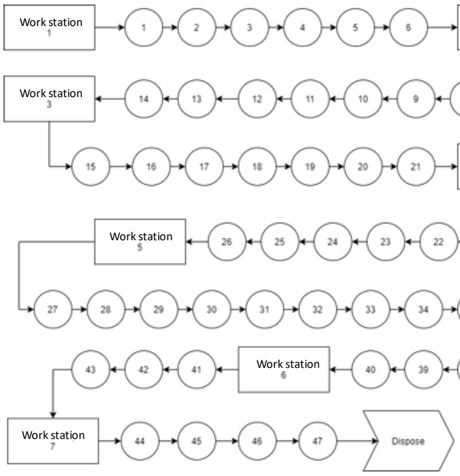

Figure 1. Precedence Diagram

Figure 1 is the precedence diagram, which illustrates the relationships between work elements, displaying the overall and interdependencies of each operation. This precedence diagram is arranged based on the sequence of operations being performed.

The data used in the calculation of line balancing using these three methods is obtained as follows:

a. Determining the Cycle Time / *Cycle Time* (CT)
- Working hours per day = 8 hours
- Production per day = 3 units

Thus, the cycle time (CT) is calculated as follows:

$$CT = \frac{8\ x\ 3600}{3} = 9600$$

b. Determining the Minimum Number of Workstations (N):

$$N = \frac{139063.2}{9600} = 14.49 \approx 15$$

4.4 Ranked Positional Weight (RPW) Method

From the obtained precedence diagram (Figure 1), the positional weight value for each work element can be calculated as follows:

a. Weight of operation 47 or RPW(47) = 2990.4
b. Weight of operation 46 or RPW(46) = 1861.8 + RPW(47) = 1861.8 + 2990.4 = 4852.2
c. Weight of operation 45 or RPW(45) = 3907.8 + RPW(46) = 3907.8 + 4852.2 = 8760

The next step is grouping the work operations by allocating each operation based on the highest positional weight priority of workstations, followed by calculating the total operation time starting from the highest positional weight priority until the station operation time meets the specified cycle time of 9600 seconds.

Table 3. Results of Workstation Grouping based on Ranked Positional Weight (RPW) Method

Work Station	Workstation Time (seconds)	Operation	Operation Time
1	9282,24	1	1395,6
		2	1114,2
		3	940,2
		4.1	3874,44
		6	1957,8
2	9419,88	4.3	3874,44
		4.4	3874,44
		5	1671
3	9423,48	4.4	3874,44
		4.5	3874,44
		9	1674,6
4	9593,4	7	2504,4
		8	2145
		10	2415
		11	748,2
		12	1780,8
5	9175,5	13	2044,8
		14	1596
		16	1028,4
		17.1	3293,7
		19	1212,6
6	9113,4	15	1677,6
		17.2	3293,7
		17.3	3293,7
		18	848,4
7	9263,1	17.4	3293,7
		20	4938
		27	1031,4

Work Station	**Workstation Time (seconds)**	**Operation**	**Operation Time**
8	9586,2	22	4659,6
		23	4926,6
9	9136,2	21	1399,8
		26	1678,8
		28	2981,4
		29	3076,2
10	9375,6	25	4546,2
		38	4829,4
11	9402,6	24	5379,6
		30	1501,2
		33	2521,8
12	9126	31	4375,2
		32	1127,4
		34	3623,4
13	9206,55	35	1414,8
		36	1043,4
		37	1500
		39	1683
		40	1033,8
		42.1	2531,55
14	9377,85	41	1032,6
		42.2	2531,55
		42.3	2531,55
		42.4	2531,55
		44	750,6
15	8581,2	43	1683
		45	3907,8
		46	1861,8
		47	1128,6

After placing and grouping each operation, the calculated potential output of the balanced line using the Ranked Positional Weight (RPW) method is as follows:

1. Line Efficiency (LE)

   $$LE = \frac{139063.2}{15 \; x \; 9600} \text{ x } 100\% = 96.57\%$$

2. Balance Delay (BD)

   $$BD = \frac{(15 \; x \; 9600) - 139063.2}{15 \; x \; 9600} \text{ x } 100\% = 3.33\%$$

3. Total Idle Time

   = (15 x 9600) – 139063.2= 4936.8 detik

4. Workstation Efficiency

   $$\text{Station 1} = \frac{9282.24}{9600} \text{ x } 100 = 96.69\ \%$$

5. Idle Time

   Station 1 = 9600-9282.24 = 317.76

Table 4. Results of Workstation Performance using the Ranked Positional Weight (RPW) Method

Station	**Workstation Time (seconds)**	**Work Station Efficiency (%)**	**Idle Time (second)**
1	9282,24	96,69%	317,76
2	9419,88	98,12%	180,12
3	9423,48	98,16%	176,52
4	9593,4	99,93%	6,6
5	9175,5	95,57%	424,5
6	9113,4	94,93%	486,6
7	9263,1	96,49%	336,9
8	9586,2	99,85%	13,8
9	9136,2	95,16%	463,8
10	9375,6	97,66%	224,4
11	9402,6	97,94%	197,4
12	9126	95,06%	474
13	9206,55	95,90%	393,45
14	9377,85	97,68%	222,15
15	8581,2	89,38%	1018,8
Total	139063,2	-	4936,8

4.5 Largest Candidate Rule (LCR) Method

From the Largest Candidate Rule method procedure, the results of work element grouping are obtained, as shown in Table 5 below.

Table 5. Workstation Grouping Using the Largest Candidate Rule Method

Operation	**Operation Time (second)**	**Work Station**	**Work Station Time**
24	5379.6	1	5379.6
20	4938	2	4938
23	4926.6	3	4926.6
38	4829.4	4	9489
22	4659.6		
25	4546.2	5	8921.4
31	4375.2		
45	3907.8	6	7782.24
4.1	3874.44		
4.2	3874.44	7	7748.88
4.3	3874.44		
4.4	3874.44	8	7497.84
4.5	3874.44		
34	3623.4	9	6587.4
17.1	3293.7		
17.2	3293.7	10	9351.3
17.3	3293.7		
17.4	3293.7		
29	3076.2	11	7594.65
28	2981.4		
42.1	2531.55		
42.2	2531.55	12	9586.2
42.3	2531.55		
42.4	2531.55		
33	2521.8		
7	2504.4	13	9328.2
8	2415		
10	2145		
13	2044.8		
6	1957.8		
46	1861.8	14	8385
12	1780.8		
39	1683		
43	1683		
26	1678.8		
15	1677.6	15	8807.4
9	1674.6		
5	1671		
14	1596		
30	1501.2		
37	1500		
35	1414.8	16	8724
21	1399.8		
1	1395.6		
19	1212.6		
47	1128.6		
32	1127.4		
2	1114.2		
36	1043.4		
40	1033.8	17	4315.8
41	1032.6		
27	1031.4		
16	1028.4		
3	940.2		
18	848.4		
44	750.6		
11	748.2		

After balancing the assembly line, the potential output of the balanced line using the Largest Candidate Rule method is as follows:

1. Line Efficiency (LE)

   $$LE = \frac{139063{,}2}{17 \; x \; 9600} \text{ x } 100\% = 85.21\%$$

2. Balance Delay (BD)

   BD = $\frac{(17 \, x \, 9600) - 139063.2}{17 \, x \, 9600}$ x 100% = 14.79%
3. Total Idle Time

   = 17 x 9600 – 139063.2= 24136.8 second
4. Workstation Efficiency

   Station 1 = $\frac{5379{,}6}{9600}$ x 100 = 56.03 %
5. Idle Time

   Station 1 = 9600-5379 = 4220.4

The workstation efficiency and idle time for other stations can be seen in the following Table 6.

Table 6. Results of Workstation Performance using the Largest Candidate Rule (LCR) Method

Station	Work Station Time (second)	Work Station Efficiency	Idle Time
1	5379,6	56,03%	4220,4
2	4938	51,43%	4662
3	4926,6	51,31%	4673,4
4	9489	98,84%	111
5	8921,4	92,93%	678,6
6	7782,24	81,06%	1817,76
7	7748,88	80,71%	1851,12
8	7497,84	78,10%	2102,16
9	6587,4	68,61%	3012,6
10	9351,3	97,40%	248,7
11	7594,65	79,11%	2005,35
12	9586,2	99,85%	13,8
13	9328,2	97,16%	271,8
14	8385	87,34%	1215
15	8807,4	91,74%	792,6
16	8724	90,87%	876
17	4315,8	44,95%	5284,2
Total	139063,2		24136,8

4.6 J-Wagon Method

The first step in the J-Wagon method is calculating the positional weight of each work operation. The results of the positional weight calculation using the J-Wagon method are as follows [13].

1. Weight of operation 47 = 0
2. Weight of operation 46 = 1 (i.e., process 47)
3. Weight of operation 45 = 2 (i.e., processes 46 and 47)
4. CT = 9600 seconds

The next step is placing and grouping the work elements into workstations, considering the order of positional weight values and the cycle time previously calculated using the Ranked Positional Weight (RPW) method.

Table 7. Workstation Grouping in J-Wagon Method.

Work Station	Work Station Time (second)	Operation	Operation Time (second)
1	5379.6	24	5379.6
2	4938	20	4938
3	4926.6	23	4926.6
4	9489	38	4829.4
		22	4659.6
5	8921.4	25	4546.2
		31	4375.2
6	7782.24	45	3907.8
		4.1	3874.44
7	7748.88	4.2	3874.44
		4.3	3874.44
8	7497.84	4.4	3874.44
		4.5	3874.44
9	6587.4	34	3623.4
		17.1	3293.7
10	9351.3	17.2	3293.7
		17.3	3293.7
		17.4	3293.7
11	7594.65	29	3076.2
		28	2981.4
		42.1	2531.55
12	9586.2	42.2	2531.55
		42.3	2531.55
		42.4	2531.55
		33	2521.8
13	9328.2	7	2504.4
		8	2415
		10	2145
		13	2044.8
		6	1957.8
14	8385	46	1861.8
		12	1780.8
		39	1683
		43	1683
		26	1678.8
15	8807.4	15	1677.6
		9	1674.6
		5	1671
		14	1596
		30	1501.2
		37	1500
16	8724	35	1414.8
		21	1399.8
		1	1395.6
		19	1212.6
		47	1128.6
		32	1127.4
		2	1114.2
		36	1043.4
17	4315.8	40	1033.8
		41	1032.6
		27	1031.4
		16	1028.4
		3	940.2
		18	848.4
		44	750.6
		11	748.2

After placing and grouping each operation, the potential output of the balanced line using the J-Wagon method is as follows:

1. Line Efficiency (LE)

   LE = $\frac{139063.2}{17 \, x \, 9600}$ x 100%= 85.21%
2. Balance Delay (BD)

   BD = $\frac{(17 \, x \, 9600) - 139063.2}{17 \, x \, 9600}$ x 100% = 14.79%
3. Total Idle Time

   = 17 x 9600 – 139063.2= 24136.8 seconds
4. Workstation Efficiency

   Station 1 = $\frac{53796}{9600}$ x 100 = 56.03 %
5. Idle Time

   Station 1 = 9600-5379 = 4220.4

Table 8. The Results of Workstation Performance using the J-Wagon Method

Station	Workstation Time (second)	Workstation Efficiency (%)	Idle time (second)
1	5379,6	56,03%	4220,4
2	4938	51,43%	4662
3	4926,6	51,31%	4673,4
4	9489	98,84%	111
5	8921,4	92,93%	678,6
6	7782,24	81,06%	1817,76
7	7748,88	80,71%	1851,12
8	7497,84	78,10%	2102,16

9	6587,4	68,61%	3012,6
10	9351,3	97,40%	248,7
11	7594,65	79,11%	2005,35
12	9586,2	99,85%	13,8
13	9328,2	97,16%	271,8
14	8385	87,34%	1215
15	8807,4	91,74%	792,6
16	8724	90,87%	876
17	4315,8	44,95%	5284,2
Total	139063,2		24136,8

4.7 Analysis of Line Balancing Results After Improvement

Table 9. Line Balancing Performance: Comparison of Results from the 3 Methods

Potential Output	Initial Assembly Line	Ranked Positional Weight (RPW) method	Largest Candidate Rule (LCR) method	J-Wagon method
Number of Workstations	7	15	17	17
Line Efficiency	30,82%	96,67%	85,21%	85,21%
Balance Delay	69,18 %	3,33%	14,79%	14,79%
Total Idle Time (seconds)	312136,8	4936,8	24136,8	24136,8
Smoothness Index	51019,56	1570,51	10818,37	10818,47

The good line balancing is achieved when the line efficiency approaches 100%, the balance delay approaches 0, and the total idle time is minimal. Based on the table above, the comparison of line balancing through the three used methods, namely Ranked Positional Weight (RPW) method, Largest Candidate Rule (LCR) method, and J-Wagon method, can be determined. The optimal line balancing is achieved when the line efficiency approaches 100%, the balance delay approaches 0, the total idle time is minimal, and the smoothness index is small. From the calculations of the three methods performed, it is found that the Ranked Positional Weight (RPW) method has the highest line efficiency of 96.67%, the smallest balance delay of 3.33%, the smallest total idle time of 4936.8, and the smallest Smoothness Index with a value of 1570.51. Therefore, it can be concluded that the Ranked Positional Weight method is the most optimal method compared to the Largest Candidate Rule (LCR) method and J-Wagon method. With the highest line efficiency, the Ranked Positional Weight method can balance the operation process time in the initial assembly line calculation at PT. HME Demag Surabaya.

5 CONCLUSION

The conclusion obtained after processing the data to address the line balancing problem using the Ranked Positional Weight (RPW) method, Largest Candidate Rule method, and J-Wagon method to determine the efficiency in the Crane Grider production system is as follows. The Ranked Positional Weight (RPW) method has the most optimal line efficiency, balance delay, total idle time, and Smootness Index compared to the Largest Candidate Rule method and J-Wagon method. The RPW method produces the most optimal potential output with a line efficiency of 96.67%, a balanced delay of 3.33%, a total idle time of 4936.8 seconds, and the smallest Smootness Index of 1570.51 with 15 workstations. By using the heuristic line balancing method, there was an increase in line efficiency by 65.85%, a decrease in balance delay by 65.85%, and a decrease in total idle time by 307,200 seconds. The research and case study have successfully presented the field conditions and are expected to assist researchers in applying the objectives and concepts of the heuristic method in line balancing issues in daily life and industrial development. The heuristic method can be used in broader research and applied to solve line balancing problems with efficiency in the Crane Grider production system at PT MHE Demag Surabaya. For future research and improvement, it is suggested to not only focus on stations with cycle times exceeding the standard takt time but also consider which stations can be improved to accelerate the cycle time of those workstations.

The limitation of this research is that it only seeks the optimal line balancing value using heuristic methods. In the future, a comparison can be made between heuristic methods and mathematical and probabilistic methods. Additionally, for further research, if heuristic methods are still used, the Helgesson-Birnie method and Region Approach method can be added to obtain more detailed and improved results.

References

[1] F. Pulansari, S. Dewi, I. Nugraha, and S. S. Maulana, “The Effects of Elasticity Of Demand For Product Quality And Discount Rate In Dual-Channel Supply Chains,” *E3S Web Conf.*, vol. 5004, no. 328, 2021.

[2] A. S. Gusmon and A. Hutomo, “Time Study Analysis to Find Normal Time Workforce Scheduling ILO Standard Time : Case Study of Parking Pay Station Bandung Electronic,” vol. 11, no. 1, pp. 1–619, 2019.

[3] P. H. Ara, “Time and motion study applied to a production line of organic lenses in Manaus Industrial Hub,” pp. 901–915, 2018.

[4] L. P. S. Hartanti, “WORK MEASUREMENT APPROACH TO DETERMINE STANDARD TIME IN ASSEMBLY LINE,” *Int. J. Manag. Appl. Sci.*, vol. 2, no. 10, pp. 192–195, 2016.

[5] N. Nurhasanah, L. Saraswati, S. Hidayat, and N. Hasanati, “Increase of efficiency of workstation design through production scheduling for moslem clothes in sme ‘ xyz ,’” *Proceeding 7th Int. Semin. Ind. Eng. Manag.*, no. ISSN: 1978-774X, 2014.

[6] F. Shrouf, J. Ordieres-meré, A. García-sánchez, and M. Ortega-mier, “Optimizing the production

scheduling of a single machine to minimize total energy consumption costs," *J. Clean. Prod.*, vol. 67, pp. 197–207, 2014, doi: 10.1016/j.jclepro.2013.12.024.

[7] N. Kumar and D. Mahto, "Assembly Line Balancing : A Review of," *Glob. J. Res. Eng.*, vol. 13, no. 2, pp. 29–50, 2013.

[8] A. Adeppa, "A Study on Basics of Assembly Line Balancing," *Int. J. Emerg. Technol.*, vol. 6, no. 2, pp. 294–297, 2015.

[9] U. Tarigan and M. B. Ambarita, "Line Balancing Application Analysis of Generator Manufacturing Process in DPG Inc . Line Balancing Application Analysis of Generator Manufacturing Process in DPG Inc .," pp. 0–8, 2019, doi: 10.1088/1757-899X/528/1/012057.

[10] S. P. Yudha and I. P. Tama, "JOURNAL OF ENGINEERING AND MANAGEMENT ALTERNATIVE PLASTIC BOX 260 ASSEMBLY LINE USING HEURISTIC METHOD AND SIMULATION METHOD APPROACH TO INCREASE ASSEMBLY LINE EFFICIENCY," vol. 5, no. 2, pp. 58–66, 2018.

[11] J. N. Sagitta, L. Gozali, and F. J. Daywin, "Comparison Study of the Application of Line Balancing and the Theory of Constraint," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 852, no. 012111, 2020, doi: 10.1088/1757-899X/852/1/012111.

[12] L. Gozali, F. J. Daywin, and A. Jestinus, "Calculation of Labor Amount with Theory of Constraints and Line Balancing Method in PT . XYZ Fish Crackers Factory Calculation of Labor Amount with Theory of Constraints and Line Balancing Method in PT . XYZ Fish Crackers Factory," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 852, no. 012092, 2020, doi: 10.1088/1757-899X/852/1/012092.

[13] P. A. Larasari, P. I. Tanaya, and Y. Indrayadi, "Analysis and Improvement of Assembly Line: A Case Study at Automobile Rear-Axle Assembly Line-A PT. ZYX," *J. Ilm. Tek. Ind.*, vol. 19, no. 1, pp. 95–107, 2020, doi: 10.23917/jiti.v19i1.8866.

[14] I. KUCUKKOC and D. Z. ZHANG, "Type-E Parallel Two-Sided Assembly Line Balancing Problem: Mathematical Model and Ant Colony Optimisation based Approach with Optimised Parameters," *Comput. Ind. Eng.*, 2015.

[15] I. Nugraha, M. Hisjam, and W. Sutopo, "Aggregate Planning Method as Production Quantity Planning and Control to Minimizing Cost," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 943, no. 012045, pp. 0–12, 2020, doi: 10.1088/1757-899X/943/1/012045.

[16] N. Putu, C. Sasmita, D. Diah, and M. D. Astuti, "Improving Assembly Line Balancing Using Moodie Young Methods on Dump Truck Production Improving Assembly Line Balancing Using Moodie Young Methods on Dump Truck Production," 2018, doi: 10.1088/1757-899X/288/1/012090.

[17] A. T. Y. Y. M. Kayar, "Heuristic production line balancing problem solution with MATLAB software programming," *Int. J. Cloth. Sci. Technol.*, vol. 28, no. 6, 2016.

[18] S. Nallusamy and V. Saravanan, "Enhancement of Overall Output in a Small Scale Industry Through VSM , Line Balancing and Work Standardization," *Int. J. Eng. Res. Africa*, vol. 26, pp. 176–183, 2016, doi: 10.4028/www.scientific.net/JERA.26.176.

[19] Z. Zhang, W. Cheng, and Á. Á. Position, "Improved Heuristic Procedure for Mixed-Model U-line Balancing Problem with Fuzzy Times," *Proc. China Mod. Logist. Eng.*, no. 286, pp. 395–406, 2015, doi: 10.1007/978-3-662-44674-4.

[20] R. O. Edokpia and F. U. Owu, "Assembly Line Re-Balancing Using Ranked Positional Weight Technique and Longest Operating Time Technique : A Comparative Analysis," *Adv. Mater. Res.*, vol. 824, pp. 568–578, 2013, doi: 10.4028/www.scientific.net/AMR.824.568.

[21] T. Immawan and R. Kurniawan, "Analysis of Line Balance Sound Board Glue Production on Assembly Grand Piano Process : Case Study PT Yamaha Indonesia Idle time," *Adv. Ergon. Manuf. Manag. Enterp. Futur. Adv. Intell. Syst. Comput.*, no. 490, pp. 349–359, 2016, doi: 10.1007/978-3-319-41697-7.

[22] S. Alif and B. Aribowo, "Line Balancing Application Analysis of Generator Manufacturing Process in DPG Inc.," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 528, no. 012057, pp. 0–8, 2019, doi: 10.1088/1757-899X/528/1/012057.

[23] S. T, Ghutukade, S. M, and Sawant, "Use of Ranked Position Weighted Method for Assembly Line Balancing," *Int. J. Adv. Eng. Res. Stud.*, vol. 2, no. 4, 2013.

[24] P. Phiphatsompom and P. Pongchairerks, "Double assembly line balancing methods for a manufacturer of digital rice cookers," *Proc. 2015 Int. Conf. Sci. Technol. TICST*, vol. 7369396, no. 10.1109/TICST.2015.7369396, pp. 424–429, 2015.

[25] I. S. Fahin and N. Banuwati, "Reducing Work Overtime in Production Line by Comparing Two Heuristic Line Balancing Method: Case Study of Beam Comp Stering Hanger at PT. Metindo Era Sakti," *Int. Conf. Des. Eng. Comput. Sci.*, vol. 453, no. 012049, 2018, doi: 10.1088/1757-899X/453/1/012049.

[26] R. N. Kumar, R. Mohan, and N. Gobinath, "Materials Today : Proceedings Improvement in production line efficiency of hemming unit using line balancing techniques," *Mater. Today Proc.*, no. xxxx, pp. 3–7, 2021, doi: 10.1016/j.matpr.2021.03.020.

[27] S. Talapatra, Sharif-Al-Mahmud, and I. Kabir, "Overall Efficiency Improvement of a Production Line by Using Yamazumi Chart : A Case Study," *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, 2018.

[28] M. Kayar and Ö. C. Akyalçin, “Applying Different Heuristic Assembly Line Balancing Methods in the Apparel Industry and their Comparison,” *FIBRES Text. East. Eur.*, vol. 6, no. 108, pp. 8–19, 2014.

[29] M. R. A. Make, M. F. F. Rashid, M. M. Razali, and M. Perumal, “Assembly Line Balancing using Heuristic Approaches in Manufacturing Industry,” *J. Mech. Eng.*, vol. 4, no. 2, pp. 171–185, 2017.