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Improve Efficiency of Production Line Painting Areas in Transportation Equipment Products Mining Through Standard Specifications and Ranked Weighted Position (RPW) Line Balancing Methods

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ABSTRACT

The growth of coal is currently experiencing a very significant increase. This has resulted in higher demand for mining equipment, companies in the field of mining equipment manufacturing processes are competing to make mining transportation equipment products with good quality, timely delivery of products and competitive prices. The speed of the production process will increase the productivity of a production line. This competition must be supported by the smooth production process, where there should be no waste in each production line. One of the mining equipment manufacturing companies found ineffectiveness, namely bottlenecks in the painting line production painting area. The ineffectiveness after lines identified is based on over specification which results in over production so that there is an ineffective production line. With reference to the use of painting material specifications through the ISO12944-5 reference and with the Line Balancing Ranked Position Weight (RPW) method. The painting production line has improved, this can be seen based on lead time (LT) data has increased by 52.86%, Total delay has decreased by 85.78%, reducing the number of workstations from 6 workstations to 4 work stations, cycle time reduced by 25%, balance delay reduced to 58.94%, line efficiency increased to 26.52%, Smoothness Index decreased to 82.82% to be better.

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INTRODUCTION

The potential of coal energy resources in Indonesia has a high production rate. The coal production process has several stages of the mining process, the process can start from lancing clearing & topsoil removal, overburden removal, coal extraction, coal transport, coal crushing, overland transport, port stockpiles and finally shipping which is the last process where the coal will be sent to the customers. The stages of the process will be highly dependent on the product of mine transportation equipment as a transport facility.

The products used for mine transportation equipment are Excavators, Dump Truck/off Highway Truck, Water Truck, Fuel Truck/Lube Truck, Bulldozer, Trailer and others. There are many variants in mining transportation equipment products, these variants can be seen from the function, shape, and dimensions. These variants will affect the production lead timeline of the running manufacturing process.

The manufacturing process of mine transportation equipment starts from raw materials to finished good. This process includes the machining process (cutting, bending, rolling), the fabrication process, which is fixing and welding, system installation process, hydraulic, pneumatic, electric and the last process is the painting process. In the manufacturing process trajectory, there is a bottleneck in the painting process. This can be seen from the current Value Stream Mapping (VSM) in Figure 1.

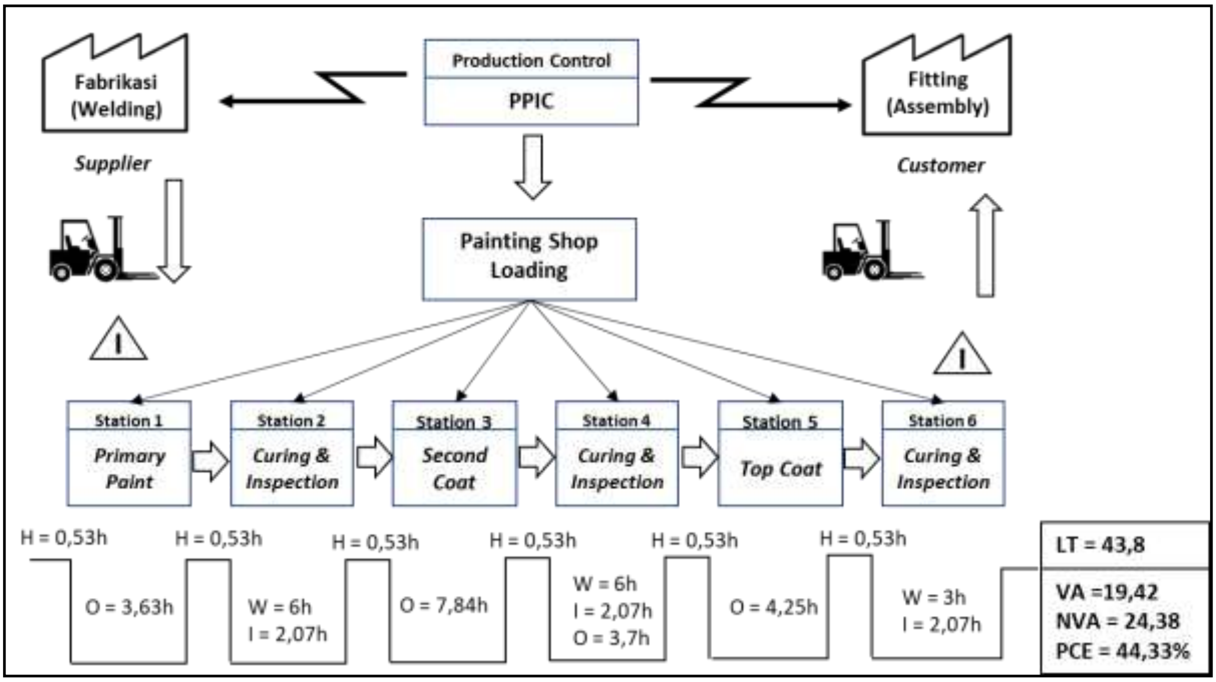

Figure 1. Present Value Stream Mapping

Bottleneck on the painting production line must be solved immediately, because this will affect the productivity of the output of the finished product. If this is not identified immediately what is the problem, it will be detrimental to the company in facing the competition that exists at this time. An interconnected graphical representation of one job, which shows the overall relationship and dependence of each process. (Rachman & Aviantarisantoso, 2019). The following Precedence diagram for the painting process.

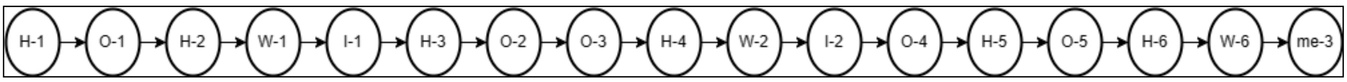

Diagram 1. Precedence Diagram

Table 1. Description of Precedence Chart

Work Elements	Description Work Elements
H-1	Entry Handling
O-1	Paint Primer
H-2	Exit Handling
W-1	Waiting for Paint to Dry
I-1	inspection
H-3	Entry Handling
O-2	sand
O-3	2nd layer application
H-4	Handling
W-2	Waiting for the 2nd paint to dry
I-2	2nd inspection
O-4	Putty & Sanding
H-5	Entry Handling
O-5	3rd Layer Application
H-6	Exit Handling
W-3	Waiting for Dry Time
me-3	3rd inspection

It is known that the current specification application uses three layers of painting, this makes a lot of waste in the painting area of the production line. The amount of waiting and transportation time that makes the painting production line ineffective. By using the Rank Positional Weight (RPW) method to maximize speed in the painting area so that high work efficiency can be achieved.

LITERATURE REVIEW

1.1 Line Balancing

Line balancing according to Gaspersz (2004) is the balancing of work process assignments from an assembly line to workstations to minimize the number of workstations and minimize the total price of idle time at all stations for a certain output level. A workstation that does not exceed the cycle time of the workstation is called a balanced line. (Rachman & Aviantarisantoso, 2019). In the production line balancing process each time per unit and in each workstation is specified and calculated, add the time with an allowance. Allowance is the normal time to get a standard time that matches the actual event. Trajectory imbalance can be seen in the workstation problem. The time required in a workstation is greater than the speed of the track at the workstation. The speed is determined by capacity, customer demand and the time required for the operation.

1.2 Idle Time

Waste is any activity in a process that consumes resources without adding value to the final product. Value, quantity, time, and motion are some of the metrics by which waste can be described. Idle time is seven well-known wastes. Idle Time is the difference between cycle time (CT) and station time (ST). Idle time can be reduced with the objective of line balancing which is able to reduce the idle time on the track which is determined by the operation with the slowest time (Baroto, Elvi, 2013).

$$Idle\ Time = n.Ws - \sum_{i=1}^{n} Wi \quad (1)$$

Description:

n = Number of workstations
Ws = The largest number of workstations
Wi = Actual time at the workstation
I = 1,2,3,…,n

1.3 Ranked Positional Weight (RPW) Calculation

Stages of Average Cycle Time Calculation. Calculation of the average cycle time of each running process

$$Ws = \frac{\sum X_1}{N} \quad (2)$$

$\sum X_1$ = Average price of the i-th subgroup
N = Number of observations made

1.4 Normal Time Calculation

At this stage, the normal calculation is obtained from multiplying the average cycle time combined with the performance rating of each operator obtained from the Westing House system rating table which is adjusted to the actual conditions in the field.

$$Wn = Ws\ x\ p \qquad (3)$$

1.5 Raw Time Calculation

At this stage, the calculation of standard time (standard) is obtained from multiplying the standard time (standard) obtained from multiplying the normal time combined with the allowance time value of each operator which is adjusted to the work method carried out with the actual conditions in the field.

$$Wb = Wn + (1 + l \qquad (4)$$

Where is the allowance given to workers to complete their work in addition to the normal time. The allowance is given in 3 conditions, namely,

- Personal needs
- Relieving fatigue
- An unavoidable distraction.

1.6 Trajectory Balance Analysis Stage

At this stage, trajectory balance planning is carried out using 2 heuristic methods, namely the rank position weight method and the region approach method.

1.7 Stage of Production Trajectory Selection

At this stage, the best production trajectory is selected, judging from the comparison of initial conditions and planning results based on balance delay, idle time, production output and number of work stations.

1.8 Balance Delay

Balance Delay is a measure of trajectory inefficiency from idle time. The trajectory is the presence of imperfect allocation between workstations.

$$D = \left(n.c - \frac{\sum_{i=1}^{k} t_i}{n.c}\right) \times 100\% \qquad (5)$$

Where:

n = Number of workstations

c = Cycle time of the path or cycle time of the largest workstation CT_{max}

t_i = Standard time of work element i

k = Number of work elements

1.9 Line Efficiency

Line efficiency is the ratio between time used and time available. The distribution of work elements forms a workstation based on cycle time. The higher the efficiency percentage, the better the production track performance (Djunaidi & Angga, 2018).

$$\eta = 100\% - D \qquad (6)$$

1.9.1 Smoothness Index (SI)

Smoothing index is an index that indicates the relative smoothness of a particular assembly line balancing. The smaller the smoothing index value, the better the production line balance. To calculate the smoothing index, it is necessary to know the time of the largest workstation and the time of the i-th workstation.

$$SI = \sqrt{\sum_{i=1}^{N} (CT_{max} - CT_i)^2} \qquad (7)$$

$$n = \frac{\sum_{i=1}^{k} t_i}{c} \qquad (8)$$

$$PCE(\%) = \frac{\sum VA}{Lead\ Time} \qquad (9)$$

Which is:

CT_i = Cycle time of the i-th workstation.

CT_{max} = The largest number of workstations

D_i = Track cycle time minus station cycle time (CT_{max} - CT_i)

LT = *Lead Time*, i.e. the total amount of track work time ($\sum_{i=1}^{n} CT_i$)

RESEARCH METHODS

Time data standard for each operation painting process work for requirement for a while this shown in Table 2

Table 2. Standard Time Data for Painting Processes in Current Conditions

element Work	Description element Work	Cycle Time (Minutes)	Cycle Time (Hours)	*Performance evaluation*	*Allowance*	Regular Hours (Hours)	Standard Time (Hours)
H-1	Entry Handling	20	0.33	1.14	28%	0.38	0.53
O-1	Paint Primer	105	1.75	1.14	45%	2.00	3.63
H-2	Exit Handling	20	0.33	1.14	28%	0.38	0.53
W-1	**Waiting for Paint to Dry**	**360**	**6.00**	**1.00**	**0%**	**6.00**	**6.00**
me-1	inspection	60	1.00	1.14	45%	1.14	2.07
H-3	Entry Handling	20	0.33	1.14	28%	0.38	0.53
O-2	sand	70	1.17	1.22	45%	1.42	2.59
O-3	Application 2nd layer	152	2.53	1.14	45%	2.89	5.25
H-4	handle _	20	0.33	1.14	28%	0.38	0.53
W-2	**Waiting for the 2nd Paint to dry**	**360**	**6.00**	**1.00**	**0%**	**6.00**	**6.00**
me-2	2nd inspection _	60	1.00	1.14	45%	1.14	2.07
O-4	Putty & Sanding	100	1.67	1.22	45%	2.03	3.70
H-5	Entry Handling	20	0.33	1.14	28%	0.38	0.53
O-5	Application 3rd layer	123	2.05	1.14	45%	2.34	4.25
H-6	Exit Handling	20	0.33	1.14	28%	0.38	0.53
W-3	**Waiting for Dry Time**	**180**	**3.00**	**1.00**	**0%**	**3.00**	**3.00**
me-3	3rd inspection _	60	1.00	1.14	45%	1.14	2.07

Standard time, which is the time required by a worker who has a normal level of ability to produce one product in a certain work area. It is known that the determination of the performance rating used by the company is the Westinghouse method. Meanwhile, the determination of the allowance factor refers to the International Labor Organization (ILO) standard.

The layout of the drawing area can see in 6 stations work

- Station 1: Primary Painting
- Station 2: Curing & Inspection 1
- Station 3: Second Coating
- Station 4: Curing & Inspection 2
- Station 5: Final Coat
- Station 6: Curing & Inspection 3

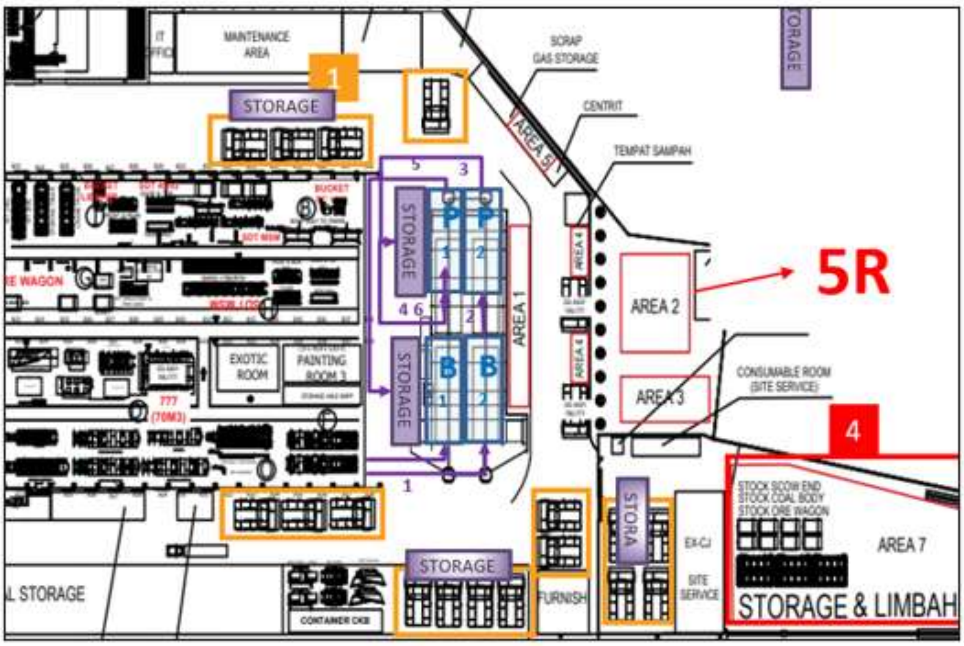

Figure 2. Painting Area Layout

The work element arrangements for each workstation, for the current conditions, are shown in Table 3.

Table 3. Settings Station Current Painting Work

Station Work	Station Name Work	element Work	Description element Work	Standard Time (Hours)
1	*Main Drawing*	H-1	Entry Handling	0.53
		O-1	Paint Primer	3.63
		H-2	Exit Handling	0.53
2	*Preservation & Inspection 1*	W-1	Waiting to Dry	6.00
		me-1	inspection	2.07
3	*Second Coating*	H-3	Entry Handling	0.53
		O-2	sand	2.59
		O-3	Application 2nd layer	5.25
		H-4	handle _	0.53
4	*Preservation & Inspection 2*	W-2	Wait dry	6.00
		me-2	2nd inspection _	2.07
		O-4	Putty & Sanding	3.70
5	*Final Coat*	H-5	Entry Handling	0.53
		O-5	Application 3rd layer	4.25
		H-6	Exit Handling	0.53
6	*Preservation & Inspection 3*	W-3	Wait dry	3.00
		me-3	3rd inspection _	2.07

In relation to this research, namely the painting process on mining transportation equipment, the handling process, waiting for curing time, and inspection process can be categorized as Non-Value Added (NVA) processes.

It is then possible to identify which work elements fall into the Value-Added Time (VA) and Non-Value-Added Time (NVA) categories, as shown in Table 4.

Table 4. Identification of Value Added and Non Value-Added Time

Station Work	Station Name Work	element Work	Description element Work	Standard Time (Hours)	category
1	*Main Drawing*	H-1	Entry Handling	0.53	NVA
		O-1	Paint Primer	3.63	VA
		H-2	Exit Handling	0.53	NVA
2	*Preservation & Inspection*	W-1	Waiting to Dry	6.00	NVA
		me-1	inspection	2.07	NVA
3	*Second Coating*	H-3	Entry Handling	0.53	NVA
		O-2	sand	2.59	VA
		O-3	Application 2nd layer	5.25	VA
		H-4	handle _	0.53	NVA
4	*Preservation & Inspection*	W-2	Wait dry	6.00	NVA
		me-2	2nd inspection _	2.07	NVA
		O-4	Putty & Sanding	3.70	VA
5	*Final Coat*	H-5	Entry Handling	0.53	NVA
		O-5	Application 3rd layer	4.25	VA
		H-6	Exit Handling	0.53	NVA
6	*Preservation and Inspection*	W-3	Wait dry	3.00	NVA
		me-3	3rd inspection _	2.07	NVA
	Total VA			**19,42**	
	Total NVA			**24,38**	
	Prime Time			**43.80**	

By using the data in Table 4, the *Process Cycle Efficiency* (PCE) can be calculated as the follows :

$$PCE(\%) = \frac{\sum VA}{Lead\ Time} \times 100\% = \frac{19{,}42}{43{,}80} \times 100\% = 44{,}33\%$$

2.1 Line Balancing Efficiency

Using the data in Table 5, calculations are then carried out on the performance parameters of the painting process trajectory for the current conditions, including: Balance Delay (D), Line Efficiency (η), and Smoothness Index (SI). The results are shown in Table 5.

Table 5. Balance Analysis Current Track

Station Work	Station Name Work	element Work	Description element Work	Standard Time (Hours)	Station Time (Hours)	Idle Time (Hours)	% Idle time	Efficiency Station Work
1	*Main Drawing*	H-1	Entry Handling	0.53	4.68	7.09	60.21%	39.79%
		O-1	Paint Primer	3.63				
		H-2	Exit Handling	0.53				
2	*Preservation & Inspection*	W-1	Waiting to Dry	6.00	8.07	3.70	31.41%	68.59%
		I-1	inspection	2.07				
3	*Second Coating*	H-3	Entry Handling	0.53	8.89	2.88	24.43%	75.57%
		O-2	sand	2.59				
		O-3	Application 2nd layer	5.25				
		H-4	handle _	0.53				
4	*Preservation & Inspection*	W-2	Wait dry	6.00	11.77	0.00	0.00%	100.00%
		I-2	2nd inspection _	2.07				
		O-4	Putty & Sanding	3.70				
5	*Final Coat*	H-5	Entry Handling	0.53	5.30	6.47	54.93%	45.07%
		O-5	Application 3rd layer	4.25				
		H-6	Exit Handling	0.53				
6	*Preservation and Inspection*	W-3	Wait dry	3.00	5.07	6.70	56.90%	43.10%
		I-3	3rd inspection _	2.07				
Amount				**43.80**	**43.80**	**26,82**	**37.98%**	**62.02%**

2.2 Balance Delay

$$D = \left(n.c - \frac{\sum_{i=1}^{k} t_i}{n.c}\right) \times 100\% = \left(6 \times 11{,}77 - \frac{43{,}80}{6 \times 11{,}77}\right) \times 100\% = 37{,}98\%$$

where:

n = Number of workstations
c = Cycle time of the path or cycle time of the largest workstation CT_{max}
t_i = Standard time of work element i
k = Number of work elements

2.3 Line Efficiency

η= 100% - D = 100% - 37.98% = 62.02%

2.4 Smoothness Index (SI)

$$SI = \sqrt{\sum_{i=1}^{N} (CT_{max} - CT_i)^2}$$

$$SI = \sqrt{(7{,}09^2 + 3{,}7^2 + 2{,}88^2 + 0^2 + 6{,}47^2 + 6{,}7^2)} = 12{,}93$$

CT_i = Cycle time of the i-th workstation.
CT_{max} = The largest number of workstations
D_i = Track cycle time minus station cycle time (CT_{max} - CT_i)
LT = *Lead Time*, i.e. the total amount of track work time $(\sum_{i=1}^{n} CT_i)$

RESULT & DISCUSSION

After we make improvements, we can see the results as in the table below.

Table 6. RPW after Repair (Two Layers painting)

element Work	Description element Work	H-1	O-1	H-2	W-1	H-3	O-2	O-5	H-6	W-3	me-3	Total RPW	rank
H-1	Entry Handling	0.53	3.63	0.53	3.00	0.53	2.59	4.25	0.53	3.00	2.07	**20.65**	1
O-1	Paint Primer	0.00	3.63	0.53	3.00	0.53	2.59	4.25	0.53	3.00	2.07	**20,12**	2
H-2	Exit Handling	0.00	0.00	0.53	3.00	0.53	2.59	4.25	0.53	3.00	2.07	**16,49**	3
W-1	Waiting for Paint to Dry	0.00	0.00	0.00	3.00	0.53	2.59	4.25	0.53	3.00	2.07	**15.97**	4
H-3	Entry Handling	0.00	0.00	0.00	0.00	0.53	2.59	4.25	0.53	3.00	2.07	**12.97**	5
O-2	Sanding and Putty	0.00	0.00	0.00	0.00	0.00	2.59	4.25	0.53	3.00	2.07	**12.44**	6
O-5	Application 2nd layer	0.00	0.00	0.00	0.00	0.00	0.00	4.25	0.53	3.00	2.07	**9.85**	7
H-6	Exit Handling	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.53	3.00	2.07	**5.60**	8
W-3	Wait dry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	2.07	**5.07**	9
me-3	inspection	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.07	**2.07**	10

For the post-improvement condition, i.e the application of two layers of painting, the company targeted a decrease in the track cycle time from 8 hours (for the three-layer system) to 6 hours (for the two layer-system). The consideration is the movement of workpieces can be maximized in the effective working hours of each shift. Thus, the optimal number of workstations can be recalculated as follows:

$$n = \frac{\sum_{i=1}^{k} t_i}{c} = \frac{20{,}65}{6} = 3{,}44 \cong 4\ stasiun\ kerja$$

The number of workstations remains at 4, but there will be a rearrangement of the work elements at each workstation. The results are shown in Table 7.

Table 7. Analysis of Track Balancing After Improvement (Two Layers of Painting)

Station Work	Station Name Work	element Work	Description element Work	Standard Time (Hours)	Station Time (Hours)	Idle Time (Hours)	% Idle time	Efficiency Station Work
1	*Main Drawing*	H-1	Entry Handling	0.53	4.68	1.43	23.43%	76.57%
		O-1	Paint Primer	3.63				
		H-2	Exit Handling	0.53				
2	*preservation 1*	W-1	Waiting for Paint to Dry	3.00	6,12	0.00	0.00%	100.00%
		H-3	Entry Handling	0.53				
		O-2	Sanding and Putty	2.59				
3	*Top Coat*	O-5	Application 2nd layer	4.25	4.78	1.34	21.89%	78.11%
		H-6	Exit Handling	0.53				
4	*Preservation & Insp*	W-3	Waiting for the paint to dry	3.00	5.07	1.04	17.05%	82.95%
		me-3	inspection	2.07				
Amount				**20.65**	**20.65**	**3.81**	**15.59 %**	**84.41%**

Using the track performance calculation, the following result were obtained:

3.1 Station cycle time

CT = CT_{max} = 6.12 hours

3.2 *Balance Delay*

$$D = \left(4 \times 6{,}12 - \frac{20{,}65}{4 \times 6{,}12}\right) \times 100\% = 15{,}59\%$$

3.3 Line Efficiency

η = 100% −D = 100% - 15.59% = 84.41%

3.4 Smoothness Index

$$SI = \sqrt{(1{,}43^2 + 0^2 + 1{,}34^2 + 1{,}04^2)} = 2{,}22$$

The resulting total improvement, when compared to the condition before improvement (Three-layer painting system), the results can be summarized again in Table 8.

Table 8. Summary of Trajectory Improvement Analysis Before and After Improvement

Track Performance Parameters	Variables	3 Layer System (Beginning)	2 Layer System (RPW)	Total Increase (%)
Prime Time (Hours)	LT	43.80	20.65	52.86%
Total Delay (Hours)	DT	26,82	3.81	85.78%
Amount Station Work	n	6.00	4.00	33.33%
Target Cycle (Hours)	$_{Target}$ CT	8.00	6.00	25.00%
Station Time Max (Hour)	CT_{max}	11.77	6,12	48.04%
Balance Delay (%)	*D*	37.98%	15.59%	58.94%
Line Efficiency (%)	η	62.02%	84.41%	26.52%
Fluency Index	S.I	12.93	2.22	82.82%

The process lead time was reduced from 43.8 hours to 20.65 hours, or about 52.86% improvement. Total delay is reduced from 26.82 hours to 3.81 hours, or about 85.78% improvement. The number of workstations was reduced from 6 to 4 stations or about 33.33% improvement. The cycle time of the tracks was reduced from 11.77 hours to 6.12 hours, or about 48.04% improvement. Balance delay reduced from 37.98% to 15.59%, or about 58.94% improvement. Line efficiency increased from 62.02% to 84.41%, or about 26.52% improvement. The smoothness index dropped from 12.93 to 2.22, or about 82.82% improvement.

CONCLUSION

Based on the data that has been processed, it can be concluded that before the repair and after the repair have better values, this can be seen from Table 9.

Table 9. Analysis of Painting Process Performance Before and After Repair

Performance Parameters	Before this fix it	After fix it
Process Cycle Efficiency (PCE)		
Process lead time (hours)	43.80	20.65
Value Added Time (hours)	19,42	10.46
Value Added Time (hours)	24,38	10,18
PCE (%)	44,33	50,68
Line Balance Analysis		
Amount station Work	6	4
Cycle time trajectory (CTmax) _	11.77	6,12
Total Delay (hours)	26,82	3.81
Balance Delay (%)	37.98	15.59
Line Efficiency (%)	62.02	84,41
Fluency Index	12.93	2.22

Process Cycle Efficiency (PCE)

PCE has increased from 44.33% before improvement to 50.68% after improvement. This means that in addition to a 52.86% reduction in process lead time, from 43.8 hours to 20.65 hours, the percentage of Non-Value Added (NVA) time to process lead time also decreased.

Line Balancing Analysis

The number of workstations is reduced from 6 workstations to 4 workstations. The reduction in the number of workstations means that the activity of moving workpieces from one workstation to another is also reduced. As shown in the operation process map after improvement, transportation (handling) operations are reduced from 6 operations to 4 operations.

Total delay is reduced from the previous 26.82 hours to 3.81 hours or reduced by about 85.78%. This means that the total waiting time in the queue experienced by the workpiece has decreased very significantly. This shows a good indication in the context of waste elimination, because waiting time is included in the category of waste that must be eliminated.

Balance delay is reduced from 37.98% to 15.59% which leads to an increase in track efficiency from 62.02% to 84.41%. This means that the process flow on the production trajectory (in this case the painting process) is more efficient and smoother and disturbance free, as shown in the smoothness index value which drops from 12.93 to 2.22.

Furthermore, the track cycle time after improvement exceeds the company's target of 8.0 hours before the improvement process (3 layers of paint) and is close to the target of 6.0 hours after improvement (2 layers of paint). This means that the movement of workpieces from one workstation to another can be optimized during the effective working hours at the end of each shift, thereby improving the rhythm of the production process flow.

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