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Line Balancing Analysis to Optimize Production line of Bushing Rubber Using Theory of Constraints and Heuristics Method with Promodel Simulation at PT. Madya Putera Tehnik

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Abstract. The development of manufacturing industry is currently experiencing very rapid development, although the Covid-19 pandemic is still ongoing, this development cannot be inhibited. PT. Madya Putera Tehnik is an industry-engaged automotive part manufacturer that produces bushings. The problem experienced is that the high demand for bushing rubber products makes companies have to optimize the performance of employees and their machines so that targets can be met on time. This study aims to analyze the effectiveness of the production line in the process of making rubber bushings as well as to provide suggestions regarding the balance of the track to increase productivity by using the Theory of Constraints and Heuristic methods. The results obtained from data processing, namely the ranked positional weight and largest candidate rules method have the same results with the number of work stations as many as 14 work stations, track the efficiency of 70%, balance delay of 30%, smoothing index of 66.57, and total exits as many as 1145 units of rubber bushings. It can be interpreted that the two methods have proposed the most optimal trajectory conditions. The company should review the balance of the track and the current production capacity of the company.

Keyword: Line Balancing, Theory of Constraints, Heuristic

Abstrak. *Perkembangan industri manufaktur saat ini terus mengalami perkembangan yang sangat pesat, walaupun pandemi Covid-19 masih berlangsung perkembangan tersebut tidak dapat dihambat. PT. Madya Putera Tehnik merupakan industri yang bergerak di bidang automotive part manufacturer yang memproduksi bushing. Permasalahan yang dialami adalah tingginya permintaan terhadap produk bushing rubber membuat perusahaan harus mengoptimalkan kinerja karyawan dan mesinnya agar target dapat terpenuhi tepat pada waktunya. Penelitian ini bertujuan untuk menganalisis efektifitas lintasan produksi pada proses pembuatan bushing rubber serta memberikan usulan mengenai keseimbangan lintasan guna meningkatkan produktivitas dengan menggunakan metode Theory of Constraints dan Heuristic. Hasil yang didapatkan dari pengolahan data, yaitu metode ranked positional weight dan largest candidate rules memiliki hasil yang sama dengan jumlah stasiun kerja sebanyak 14 stasiun kerja, efisiensi lintasan sebesar 70%, balance delay sebesar 30%, smoothing index sebesar 66,57, dan total exits sebanyak 1145 unit bushing rubber. Dapat diartikan bahwa kedua metode tersebut telah memberikan usulan kondisi lintasan paling optimal. Perusahaan sebaiknya meninjau kembali mengenai keseimbangan lintasan dan kapasitas produksi yang dimiliki perusahaan saat ini.*

Kata Kunci: Keseimbangan Lintasan, Theory of Constraints, Heuristic

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1. Introduction

The development of manufacturing industry currently continues to experience very rapid development, although the Covid-19 pandemic is still ongoing, this development cannot be inhibited. This development has forced the manufacturing industry to run production systems effectively and efficiently, through optimal production planning, to produce maximum products.

This rapid development forces manufacturing companies to continue to develop and innovate. Companies that can develop and innovate will increase their advantages in competition in the industrial world. Competitive advantage can be achieved if the company has effective operational management. Operational effectiveness is determined by the balance of the production line based on employee performance factors and production time efficiency factors.

PT. Madya Putera Tehnik is an industry engaged in the field of automotive part manufacturing which produces several types of bushings including Rubber Bushings, Metal Bushings, and Bimetal Bushings. PT. Madya Putera Tehnik uses a make-to-order production system, where in this production system the company carries out its production process when a request order is received and the production results are immediately sent before the agreed due date.

Every company always tries to meet demand from consumers, but sometimes high demand causes companies to have difficulty fulfilling these requests. The same thing also happened to PT. Madya Putera Tehnik, the high demand for bushing rubber products makes companies have to optimize the performance of their employees and machines so that targets can be met on time. Various efforts have been made by the company to increase its productivity but did not produce significant changes. Meanwhile, unknowingly there were obstacles in one of the production processes in the manufacture of rubber bushings which slowed down the overall processing time.

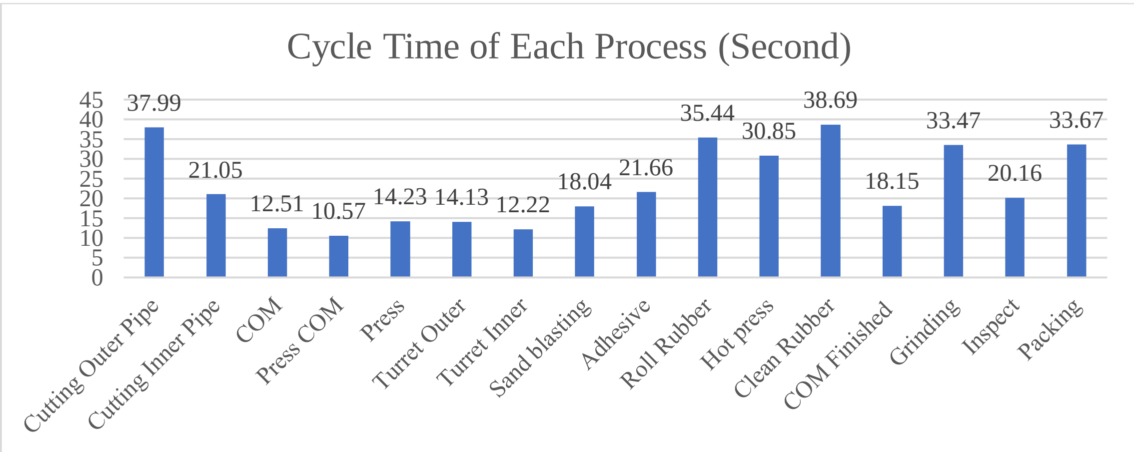

Figure 1 Cycle Time of Each Process (Second)

From the picture above it can be seen that there is a large difference in cycle time in the process of cutting outer pipe, roll rubber, hot press, clean rubber, grinding, and packing. This reason is the background for carrying out an analysis of the effectiveness of the production line in the rubber bushing manufacturing process and providing suggestions regarding track balance to increase productivity using the Theory of Constraints and Heuristic methods.

Problems with the balance of the production line generally occur because of the large difference in cycle times between one operating process and another. If one of several operating processes has a cycle time that is not ideal, then the next operating process will experience an idle state. Idle time results in the accumulation of raw materials to be processed or is called a bottleneck. The method used to identify the bottleneck is the Theory of Constraints method. Theory of Constraints is the knowledge that deals with anything that limits the ability of a company to achieve its goals. The approach of this theory is to accept inconsistencies in the production process, where there are resources with less capacity than other resources [1]. Another method used to calculate the balance of the production line is the Heuristic method. The Heuristic method is a planning method that has the most realistic possibility of being realized and applied to real problems, planning the trial and error method, by observing the cumulative demand and the average cumulative demand [2]. After obtaining the results of the trajectory balance, a simulation was carried out using ProModel. ProModel is software for conducting simulations in modeling a manufacturing system, services, and business processes [3]. ProModel functions to test an alternative scenario from a proposal before implementing it on a real system.

From the previous description, it can be concluded that by applying the theory of constraints and heuristic methods a company can determine its production capacity so that it can take appropriate corrective steps. In addition, the company can also improve the balance of its tracks so that production can run optimally. The purpose of this study is to determine the factors that cause imbalances in the production line, and to determine the efficiency of the initial line state at PT. Madya Putera Tehnik, and find out the results of track efficiency after optimal improvements have been made.

2. Related Work

Based on previous research [4] uses the theory of constraints method to overcome workstations that experience bottlenecks. The optimal master production schedule is set by applying the theory of constraint by using a drum, buffer, and rope scheduling system with the addition of a time buffer, it is found that work station IV has become a non-bottleneck work station.

Based on previous research [5] used the ranked positional weight (RPW) method to balance the workstation trajectory. The results obtained are four workstations with cycle times of 5131s, 5000s, 5219s, and 2474s respectively. Then calculate the balance delay, track efficiency, and smoothing index to measure the performance of the designed production line of 15.85%, 84.15%, and 2842.14, respectively.

3. Methodology

The research was conducted at PT. Madya Putera Tehnik located on Jl. Pangkalan 1A RT. 002/RW. 010, Bantar Gebang, Bekasi City, West Java, Indonesia. This research started on April 18, 2022 until June 6, 2022.

The data was obtained by observing directly the bushing rubber production section, to determine the working time of each production process. In addition, the data was obtained from the results of interviews with the QC Head and Production Head of PT. Madya Putera Tehnik, to find out the flow of the production process, production targets, working days, hours and work shifts, and the number of operators. The stages of the research are described in the research framework as follows Figure 2.

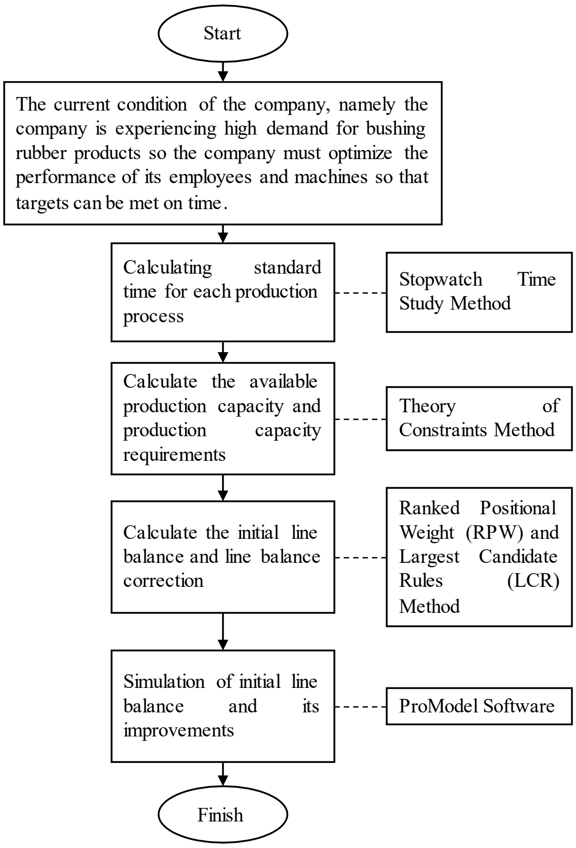

Figure 2 Research Framework

3.1. Calculating Normal Time and Standard Time

The formula used to calculate normal time and standard time is as follows [6]:

1. Normal time

$$Wn=Ws\times P \quad (1)$$

Wn is defined as normal time, Ws is defined as cycle time, and P is defined as performance rating

2. Standard time

$$Wb=Wn\times(1+a) \quad (2)$$

Wb is defined as standard time, Wn is defined as normal time, and a is defined as allowance

3.2. Theory of Constraint

The theory of Constraints is the science that deals with anything that limits a company's ability to achieve its goals. The basic premise of TOC is that every company has constraints that prevent it from achieving high performance. Constraints must be identified and managed to improve performance. Constraints or constraints in question can be physical (such as a bottleneck that occurs when the resources owned by a company have a capacity below demand which results in idle time) or non-physical (such as procedures, morale, and training).

A. Available production capacity

To determine the available capacity, it can be searched by using the multiplication result between the available working time, the number of shifts determined by the company, and the number of operators for each production process. The formula used is as follows [7]:

$$\text{Available capacity} = \text{working time/day} \times \text{number of shifts/day} \times \text{number of operators in each process} \quad (3)$$

B. Production capacity requirements

To find out the production capacity needs of each production process, namely by:

$$\text{Production capacity requirements} = \text{production targets} \times \text{processing time} \times \text{number of operators in each process} \quad (4)$$

3.3. Heuristic Method

It is a planning method that has the most realistic possibility to be realized and applied to real problems. Some commonly known heuristic methods include:

1. Ranked Positional Weight method

This method is to determine the minimum number of workstations and divide the work elements into workstations by assigning a position weight to each workstation so that each work element is placed on the workstation based on the order of its weights [8].

2. Largest Candidate Rules method

The basic principle of this method is to combine processes based on ordering operations from the largest processing time to the element with the smallest operating time [9].

Several terms are commonly used in line balancing [10]. Here are the terms:

1. Cycle Time (CT)

Cycle Time is the average time required to produce a unit at each station.

$$CT = \frac{\text{Effective working hours}}{\text{production targets}} \quad (5)$$

2. Work Station

Is a location on an assembly line or manufacture of a product where work is done either manually or automatically.

$$n\ min=\frac{\sum Te}{CT} \tag{6}$$

Te is defined as the total time of all work elements and CT is defined as cycle time

3. Balance Delay

Is a measure of the path inefficiency resulting from actual idle time caused by imperfect allocation between workstations.

$$D=\frac{(n.CT)\text{-}Twc}{(n.CT)}\times 100\% \tag{7}$$

D is defined as balance delay (%), Twc is defined as total cycle time, n is defined as number of workstations, and CT is defined as cycle time

4. Line Efficiency

Is the ratio of the total time per work station to the relationship between cycle time and the number of work stations, which is expressed as a percentage.

$$LE=\frac{Twc}{n.CT}\times 100\% \tag{8}$$

LE is defined as line efficiency, Twc is defined as total cycle time, n is defined as number of workstations, and CT is defined as cycle time

5. Smoothing index (SI)

Is an index that shows the relative smoothness or a way to measure the relative lead time level of a particular assembly line balancing [11].

$$SI=\sqrt{\sum_{i=1}^{k}(ST_{max}\text{-}ST_i)^2} \tag{9}$$

SI is defined as smoothing index, STmax is defined as maximum time at the station, and Sti is defined as station time at work station-i.

3.4. Simulation Using ProModel

ProModel is a software to perform simulation in modeling a manufacturing system, service, and business process. ProModel serves to test an alternative or scenario from a proposal before implementing it on a real system [12].

4. Result and Discussion

4.1. Normal Time and Standard Time

The following results from the calculation of normal time and standard time can be seen in Table 1.

Table 1 Normal Time and Standard Time

Process	CT	NT	ST
Operation 1 (Cutting Outer Pipe)	39.23	45.77	54.01
Operation 2 (Cutting Inner Pipe)	22.41	26.15	30.85
Operation 3 (COM)	13.89	17.37	20.49
Operation 4 (Press COM)	11.41	14.26	16.83
Operation 5 (Press)	15.21	20.28	23.93
Operation 6 (Turret Outer)	15.47	18.05	21.30
Operation 7 (Turret Inner)	13.02	15.19	17.93
Operation 8 (Sand blasting)	19.24	24.05	28.38
Operation 9 (Adhesive)	23.00	26.84	31.67
Operation 10 (Roll Rubber)	36.64	45.80	54.05
Operation 11 (Hot Press)	31.67	36.95	43.60
Operation 12 (Clean Rubber)	39.84	46.48	54.85
Operation 13 (COM Finished)	19.52	24.40	28.79
Operation 14 (Grinding)	34.66	40.43	47.71
Operation 15 (Inspect)	21.95	27.43	32.37
Operation 16 (Packing)	34.45	45.93	54.20

Based on Table 1 calculations, the normal time and standard time for the bushing rubber production process are obtained.

4.2. Comparing Available Production Capacity with Production Capacity Requirement

The following is a comparison of the available production capacity with the production capacity requirement to find out which production processes are experiencing bottlenecks it shows on Table 2.

Table 2 Comparing Available Production Capacity with Production Capacity Requirement

Process	Number of Operators	Available Capacity (Second)	Production Capacity Requirement (Second)	Difference	Explanation
Operation 1 (Cutting Outer Pipe)	1	57600	59408.05	-1808.05	Bottleneck
Operation 2 (Cutting Inner Pipe)	1	57600	33936.21	23663.79	Fulfilled
Operation 3 (COM)	1	57600	22543.83	35056.17	Fulfilled
Operation 4 (Press COM)	1	57600	18511.91	39088.09	Fulfilled
Operation 5 (Press)	1	57600	26325.17	31274.83	Fulfilled
Operation 6 (Turret Outer)	2	115200	46861.05	68338.96	Fulfilled
Operation 7 (Turret Inner)	2	115200	39442.33	75757.67	Fulfilled
Operation 8 (Sand blasting)	1	57600	31214.47	26385.53	Fulfilled
Operation 9 (Adhesive)	1	57600	34831.94	22768.06	Fulfilled
Operation 10 (Roll Rubber)	2	115200	118906.54	-3706.53	Bottleneck
Operation 11 (Hot Press)	3	172800	143867.72	28932.28	Fulfilled
Operation 12 (Clean Rubber)	1	57600	60335.58	-2735.58	Bottleneck
Operation 13 (COM Finished)	1	57600	31671.20	25928.80	Fulfilled
Operation 14 (Grinding)	1	57600	52483.76	5116.24	Fulfilled
Operation 15 (Inspect)	2	115200	71211.53	43988.48	Fulfilled
Operation 16 (Packing)	2	115200	119246.39	-4046.39	Bottleneck

Table 2 shows that there are 4 production processes that experience bottlenecks, namely the process of cutting outer pipe with a difference of -1808.05, roll rubber with a difference of -

3706.53, clean rubber with a difference of -2735.58, and packing with a difference of -4046.39. To reduce or eliminate bottlenecks in the production process, cutting outer pipe, roll the rubber, clean the rubber, and packing each of these production processes requires an additional 1 operator. As for the production process of the turret outer and turret inner, each operator has the advantage of 1 operator.

4.3. Production Process Grouping Based on Required and Available Capacity

Capacity Constraint Resources (CCR) are resources that, if not properly scheduled and managed, will cause product flow on the production floor to deviate from what was planned. There are several categories in this grouping, namely CCR and bottlenecks which can hinder the actual flow in terms of quantity and time and must be considered in production flow planning, CCR and non-bottlenecks can inhibit actual flow time but not quantity and must be considered in production flow planning. non-CCR and bottlenecks may impede actual flow, in quantity and time but do not require consideration in production flow planning, non-CCR and non-bottleneck do not affect the flow, neither quantity nor time, and do not require consideration in production flow planning.

The following table shows the production processes that experienced bottlenecks which have been grouped based on the required and available capacity it shows on Table 3.

Table 3 Grouping of Bottleneck and CCR Production Processes

	Bottleneck	**Non-Bottleneck**
CCR	Cutting Outer Pipe Roll Rubber Clean Rubber Packing	Turret outer Turret inner
Non-CCR		Cutting Inner Pipe COM Press COM Press Sand blasting Adhesive Hot press COM Finished Grinding Inspect

In Table 3 it can be seen that the process of cutting outer pipe, roll rubber, clean rubber, and packing is placed on the CCR section that is experiencing a bottleneck, which means that the process will hinder the actual flow in terms of quantity and time, so it needs to be considered in planning the production flow.

4.4. Repair Analysis

In this step, improvements are made in the form of allocating 1 operator on the turret outer process to the cutting outer pipe process and 1 operator on the turret inner process to the roll rubber process. As well as the addition of new operators, namely the clean rubber process added 1 operator and the packing process added 1 operator. The following is the processing time required for each production process after the allocation and addition of operators it shows on Table 4.

Table 4 Production Process Time and Number of Operators After Repair

Process	Number of Operators	Time (Second)
Operation 1 (Cutting Outer Pipe)	2	27.00
Operation 2 (Cutting Inner Pipe)	1	30.85
Operation 3 (COM)	1	20.49
Operation 4 (Press COM)	1	16.83
Operation 5 (Press)	1	23.93
Operation 6 (Turret Outer)	1	42.60
Operation 7 (Turret Inner)	1	35.86
Operation 8 (Sand blasting)	1	28.38
Operation 9 (Adhesive)	1	31.67
Operation 10 (Roll Rubber)	3	36.03
Operation 11 (Hot Press)	3	43.60
Operation 12 (Clean Rubber)	2	27.43
Operation 13 (COM Finished)	1	28.79
Operation 14 (Grinding)	1	47.71
Operation 15 (Inspect)	2	32.37
Operation 16 (Packing)	3	36.14

In Table 4 it can be seen that there was an increase in the number of operators, from 23 to 25 operators. In addition, there was also a reduction in cycle time in the process of cutting outer pipe from 54.01 to 27.00 seconds, roll rubber from 54.05 to 36.03 seconds, clean rubber from 54.85 to 27.43 seconds, and packing from 54.20 to 36.14 seconds.

4.5. Line Balancing Initial Line Conditions

At this stage, first the calculation of line balancing on the initial path conditions, including the calculation of line efficiency, balance delay, and smoothing index. In this calculation, the cycle time used comes from the largest processing time, which is 54.85 seconds. The following is the calculation of line balancing at the initial line conditions.

1. Balance Delay, obtained using equation (7), is found to be 36%.

2. Line Efficiency, obtained using equation (8), is found to be 64%. The total cycle time is obtained from the sum of all cycle times in each production process.

3. Smoothing index obtained using equation (9), is found to be 96,17.

4.6. Line Balancing with the Ranked Position Weight Method

The calculation on the ranked position weight method is a calculation that places work elements on the workstation based on position weights. The following is a precedence diagram based on the production process.

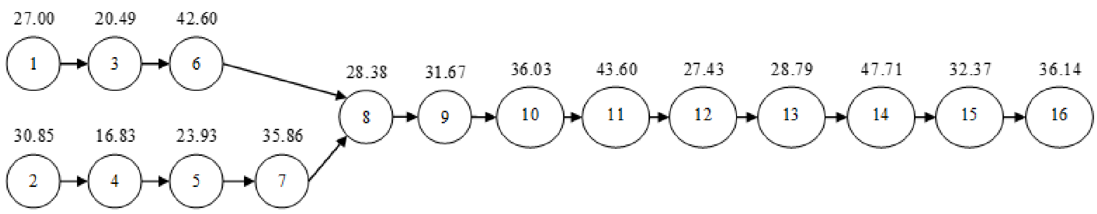

Figure 3 Precedence Diagram of Rubber Bushing

After the precedence diagram has been made, the next step is to determine the position weights for each work element related to the operating time for the longest working time from the start of the operation to the rest of the operations afterward. The following is the result of the weighting of each work element it shows on Table 5.

Table 5 Precedence Matrix

Preceding Operation	**Following Operation**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	-	0	1	0	0	1	0	1	1	1	1	1	1	1	1	1
2	0	-	0	1	1	0	1	1	1	1	1	1	1	1	1	1
3	0	0	-	0	0	1	0	1	1	1	1	1	1	1	1	1
4	0	0	0	-	1	0	1	1	1	1	1	1	1	1	1	1
5	0	0	0	0	-	0	1	1	1	1	1	1	1	1	1	1
6	0	0	0	0	0	-	0	1	1	1	1	1	1	1	1	1
7	0	0	0	0	0	0	-	1	1	1	1	1	1	1	1	1
8	0	0	0	0	0	0	0	-	1	1	1	1	1	1	1	1
9	0	0	0	0	0	0	0	0	-	1	1	1	1	1	1	1
10	0	0	0	0	0	0	0	0	0	-	1	1	1	1	1	1
11	0	0	0	0	0	0	0	0	0	0	-	1	1	1	1	1
12	0	0	0	0	0	0	0	0	0	0	0	-	1	1	1	1
13	0	0	0	0	0	0	0	0	0	0	0	0	-	1	1	1
14	0	0	0	0	0	0	0	0	0	0	0	0	0	-	1	1
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	1
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-

After knowing the results of the precedence matrix in table 5, then the position weight calculation can be carried out by entering the standard time according to each process to get the position weight of each work element it shows on Table 6.

Table 6 Matrix of Position Weight Calculation

Process	Standard Time	The Operation that Follow																Position Weight
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1	27.00	-	0	20.49	0	0	42.60	0	28.38	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	402.20
2	30.85	0	-	0	16.83	23.93	0	35.86	28.38	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	419.57
3	20.49	0	0	-	0	0	42.60	0	28.38	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	375.20
4	16.83	0	0	0	-	23.93	0	35.86	28.38	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	388.72
5	23.93	0	0	0	0	-	0	35.86	28.38	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	371.89
6	42.60	0	0	0	0	0	-	0	28.38	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	354.71
7	35.86	0	0	0	0	0	0	-	28.38	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	347.96
8	28.38	0	0	0	0	0	0	0	-	31.67	36.03	43.60	27.43	28.79	47.71	32.37	36.14	312.10
9	31.67	0	0	0	0	0	0	0	0	-	36.03	43.60	27.43	28.79	47.71	32.37	36.14	283.73
10	36.03	0	0	0	0	0	0	0	0	0	-	43.60	27.43	28.79	47.71	32.37	36.14	252.06
11	43.60	0	0	0	0	0	0	0	0	0	0	-	27.43	28.79	47.71	32.37	36.14	216.03
12	27.43	0	0	0	0	0	0	0	0	0	0	0	-	28.79	47.71	32.37	36.14	172.43
13	28.79	0	0	0	0	0	0	0	0	0	0	0	0	-	47.71	32.37	36.14	145.01
14	47.71	0	0	0	0	0	0	0	0	0	0	0	0	0	-	32.37	36.14	116.22
15	32.37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	36.14	68.50
16	36.14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	36.14

The results obtained from the calculation of the position weights in Table 6 are then processed to rank each work element based on the position weight. Sorting starts from the largest weight to the smallest weight it shows on Table 7.

Table 7 Order of Work Elements Based on Position Weight

Priority	Operation	Position Weight
1	2	419.57
2	1	402.20
3	4	388.72
4	3	375.20
5	5	371.89
6	6	354.71
7	7	347.96
8	8	312.10
9	9	283.73
10	10	252.06
11	11	216.03
12	12	172.43
13	13	145.01
14	14	116.22
15	15	68.50
16	16	36.14

After obtaining the ranking for each work element based on the position weights in Table 7. The next step is to determine the cycle time and the number of workstations. The following is a calculation to determine the cycle time and the number of workstations.

1. Calculating cycle time. Cycle time, obtained using equation (5), is found to be 52.36 second. To find out the available production time per day, you can find it by multiplying the available working time, which is 8 hours/day, then multiplying it by the number of shifts, which is 2 shifts, and the number of operators.

2. Determine the minimum number of work stations. The number of work stations, obtained using equation (6), is found to be 10. Based on the results of the calculation of cycle time and the minimum number of work stations, it can then be done the placement of work elements on the work station based on the weight of the position and not exceed the predetermined cycle time of 52.36 seconds. Placement of work elements at each work station it shows on Table 8.

Table 8 Placement of Work Elements at Each RPW Work Station

Station	Operation	Standard Time	Total Standard Time
1	Operation 2 (Cutting Inner Pipe)	30.85	47.68
	Operation 4 (Press COM)	16.83	
2	Operation 1 (Cutting Outer Pipe)	27.00	47.50
	Operation 3 (COM)	20.49	
3	Operation 5 (Press)	23.93	23.93
4	Operation 6 (Turret Outer)	42.60	42.60
5	Operation 7 (Turret Inner)	35.86	35.86
6	Operation 8 (Sand blasting)	28.38	28.38
7	Operation 9 (Adhesive)	31.67	31.67
8	Operation 10 (Roll Rubber)	36.03	36.03
9	Operation 11 (Hot Press)	43.60	43.60
10	Operation 12 (Clean Rubber)	27.43	27.43
11	Operation 13 (COM Finished)	28.79	28.79
12	Operation 14 (Grinding)	47.71	47.71
13	Operation 15 (Inspect)	32.37	32.37
14	Operation 16 (Packing)	36.14	36.14
Total		509.67	509.67

After placing the elements at each work station, the next step is to perform calculations including line efficiency, balance delay, and smoothing index as follows.

1. Balance Delay, obtained using equation (7), is found to be 30%.
2. Line Efficiency, obtained using equation (8), is found to be 70%. The total cycle time is obtained from the sum of all cycle times in each production process.
3. Smoothing index obtained using equation (9), is found to be 66,57.

4.7. Line Balancing with the Largest Candidate Rules Metode Method

The principle of this method is to combine processes based on ordering operations from the largest to the smallest processing time, the work elements are sorted according to the provisions of the precedence diagram. Here are the results of the sorting it shows on Table 9.

Table 9 Order of Work Elements Based on Preceding Stages

element to-	Work Element	Preceding Element	Total
1	Cutting Outer Pipe	-	0
2	Cutting Inner Pipe	-	0
3	COM	1	1
4	Press COM	2	1
5	Press	2,4	2
6	Turret Outer	1,3	2
7	Turret Inner	2,4,5	3
8	Sand blasting	1,2,3,4,5,6,7	7
9	Adhesive	1,2,3,4,5,6,7,8	8
10	Roll Rubber	1,2,3,4,5,6,7,8,9	9
11	Hot Press	1,2,3,4,5,6,7,8,9,10	10
12	Clean Rubber	1,2,3,4,5,6,7,8,9,10,11	11
13	COM Finished	1,2,3,4,5,6,7,8,9,10,11,12	12
14	Grinding	1,2,3,4,5,6,7,8,9,10,11,12,13	13
15	Inspect	1,2,3,4,5,6,7,8,9,10,11,12,13,14	14
16	Packing	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15	15

In Table 9 it can be seen that the work element with the most elements that precede it is packing with a total of 15 elements that precede it. Furthermore, it can be done the placement of work elements at each work station it shows on Table 10.

Table 10 Placement of Work Elements at Each LCR Work Station

Station	Operation	Standard Time	Total Standard Time
1	Cutting Outer Pipe	27.00	47.50
	COM	20.49	
2	Cutting Inner Pipe	30.85	47.68
	Press COM	16.83	
3	Press	23.93	23.93
4	Turret Outer	42.60	42.60
5	Turret Inner	35.86	35.86
6	Sand blasting	28.38	28.38
7	Adhesive	31.67	31.67
8	Roll Rubber	36.03	36.03
9	Hot Press	43.60	43.60
10	Clean Rubber	27.43	27.43
11	COM Finished	28.79	28.79
12	Grinding	47.71	47.71
13	Inspect	32.37	32.37
14	Packing	36.14	36.14
Total		**509.67**	**509.67**

After placing the elements at each work station, the next step is to perform calculations including line efficiency, balance delay, and smoothing index as follows.

1. Balance Delay, obtained using equation (7), is found to be 30%.
2. Line Efficiency, obtained using equation (8), is found to be 70%. The total cycle time is obtained from the sum of all cycle times in each production process.
3. Smoothing index obtained using equation (9), is found to be 66,57.

4.8. Simulation Using ProModel

The following is a comparison of the initial condition simulation layout and proposals based on the ranked position weight and largest candidate rules method, which can be seen in Figures 4, 5, and 6.

Based on the comparison of layouts in Figures 4, 5, and 6, it can be seen that the layout in the initial line conditions has 16 workstations. In the proposed method of ranked positional weight and largest candidate rules, the number of workstations is reduced to 14.

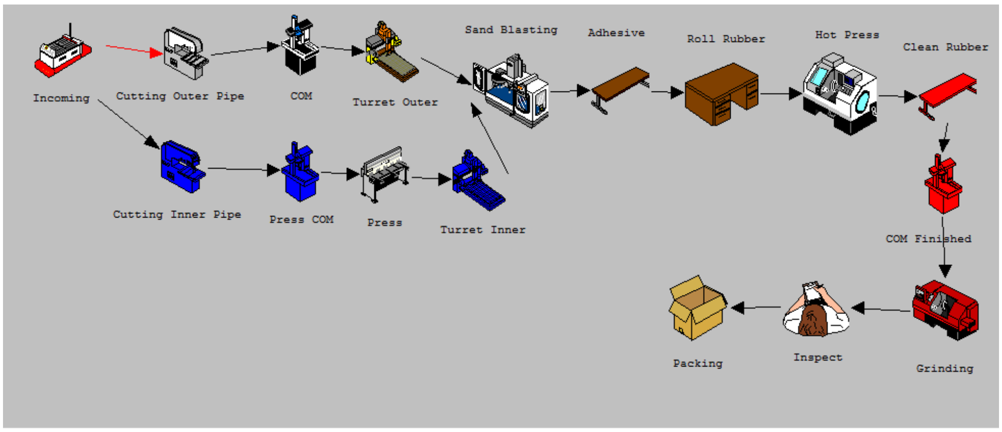

Figure 4 Layout of Initial Line Conditions

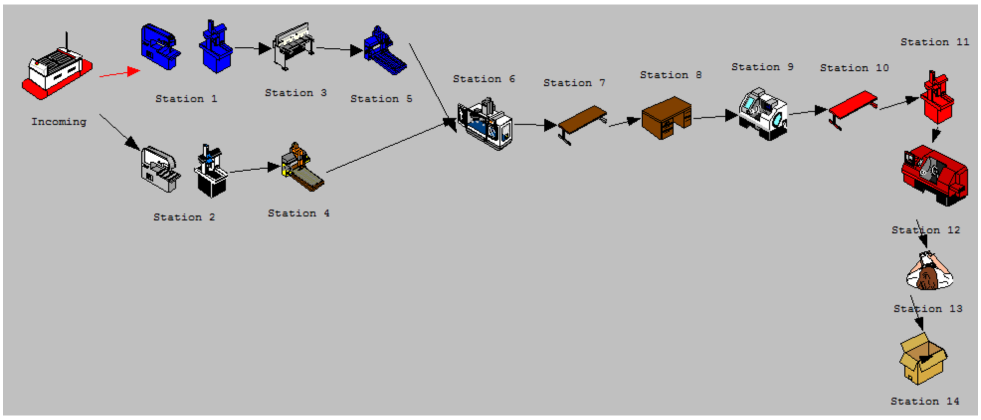

Figure 5 Proposed Layout with Ranked Positional Weight Method

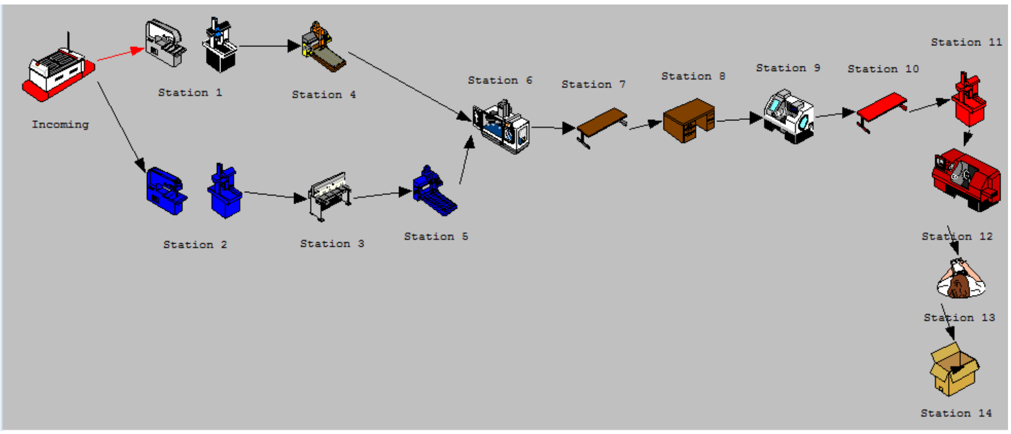

Figure 6 Proposed Layout with the Largest Candidate Rules Method

The following is a comparison of the results of total bushing rubber exits based on the initial condition simulation and the proposed method of ranked position weight and largest candidate rules. Can be seen in Table 11.

Table 11 Comparison of Total Exits Bushing Rubber Results

Production Line	Total Exits (Unit)
Initial Condition	1042
Ranked Positional Weight	1145
Largest Candidate Rules	1145

Based on the comparison of the simulation results in table 11, the total exits in the initial conditions were 1042 units of bushing rubber, where the results were still less than the number of products that had been targeted. After doing a simulation based on calculations using the ranked position weight method and the largest candidate rules, the results were obtained from a total of 1145 units of bushing rubber exits, where these results met the predetermined target.

5. Conclusion

Based on the results of research that has been done at PT. Madya Putera Tehnik following the objectives that have been set, can be concluded as follows. Based on the results of the research that has been done, the factors that cause an imbalance in the production line are processes that have a deficiency in their production capacity. From the results of data processing using the theory of constraints method, the results obtained are that 4 production processes experience a shortage of production capacity, namely the process of cutting the outer pipe with a difference in production requirements of -1808.05 seconds, rolling rubber with a difference in production requirements of -3706.53 seconds, net rubber with a difference in production requirements of -2735.58 seconds, and packing with a difference in production requirements of -4046.39 seconds.

Based on the results of research on the initial trajectory conditions at PT. Madya Putera Tehnik obtained a total of 16 workstations with a tracking efficiency of 64%, a balance delay of 36%, a smoothing index of 96.17, and a total of 1042 bushing rubber exits. It can be interpreted that the distribution of work weight on the initial track conditions is still uneven, there is a large amount of idle time between workstations, and the track balance is still not balanced. After processing the data, it was found that the optimal track balance was improved by using the ranked position weight and largest candidate rules methods. The results obtained were improvements in track efficiency of 70%, balance delay of 30%, smoothing index of 66.57, and a total of 1145 units of bushing rubber exits.

Suggestions for further research, it is expected to use other path balancing methods so that they can be used as a comparison to the ranked positional weight and largest candidate rules methods so that this research develops further and companies can find out the most effective method to apply to their company.

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