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Analysis and Improvement of Assembly Line: A Case Study at Automobile Rear-Axle Assembly Line-A PT. ZYX

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Abstract. *This paper explains the improvement of PT ZYX's productivity on the assembly line-A, using the production line balancing method. Four methods of line balancing were examined, namely, Ranking Positional Weight (RPW), Region Approach, J-Wagon, and Kaizen. The selection of the most suitable method is made based on the reduction of the number of workstations and cycle-time. Based on the result. Kaizen method shows better total cycle time, number of workstations, and number of operators required. This result is simulated using the 'Tecnomatix' software with the DES (Discrete Event Simulation) method.*

Keywords: *production line balancing, productivity, Kaizen, discrete event simulation*

I. INTRODUCTION

PT ZYX is located at West Java. The company manufactures and assembles rear-axle parts of automotive components (refer Figure 1, a rear axle of a vehicle is used as an illustration; the original picture could not be shown). By its operations, this company focuses on improving and increasing productivity at the Line-A assembly line. They are 17 workstations with 17 operators in a line. Based on their perception, balancing the line can be done either by reducing the amount of required production cycle time to produce finish product and/or by reducing the number of workstations by combining some operational sequences. By performing this, the product delivery lead time is expected to be significantly improved.

The problem of assembly line balancing consists of determining the set of tasks to be performed for every station in a way that the operation time does not exceed the cycle time (Salveson, 1955). The objective of assembly line balancing is to divide the workload of an assembly line among different individual workstations and determine which tasks should be performed at each workstation. According to Konully (2013), assembly line balancing steps is following: (1) list the sequential relationships among tasks and then draw a precedence diagram, (2) calculate the required workstation cycle time, (3) calculate the theoretical minimum number of workstations, (4) choose a primary rule that will determine how tasks are to be assigned to workstations, (5) assign each task one at a time, until the sum of task times is equal to the workstation cycle time, (6) repeat step (5) for the remaining workstation until all the tasks have been assigned to a workstation, and (7) evaluate the efficiency of the line balance.

These works may involve applying three heuristic methods. First, Ranked Position Weight (RPW) is chosen. This method has been widely implemented and proven to solve cases for line balancing (Hegelson & Bernie, 1955; Deshpande & Joshi, 2007; Hamzas et al., 2017; Alif & Aribowo, 2019). Secondly, the Region Approach (RA) heuristics was suggested by Bedworth &

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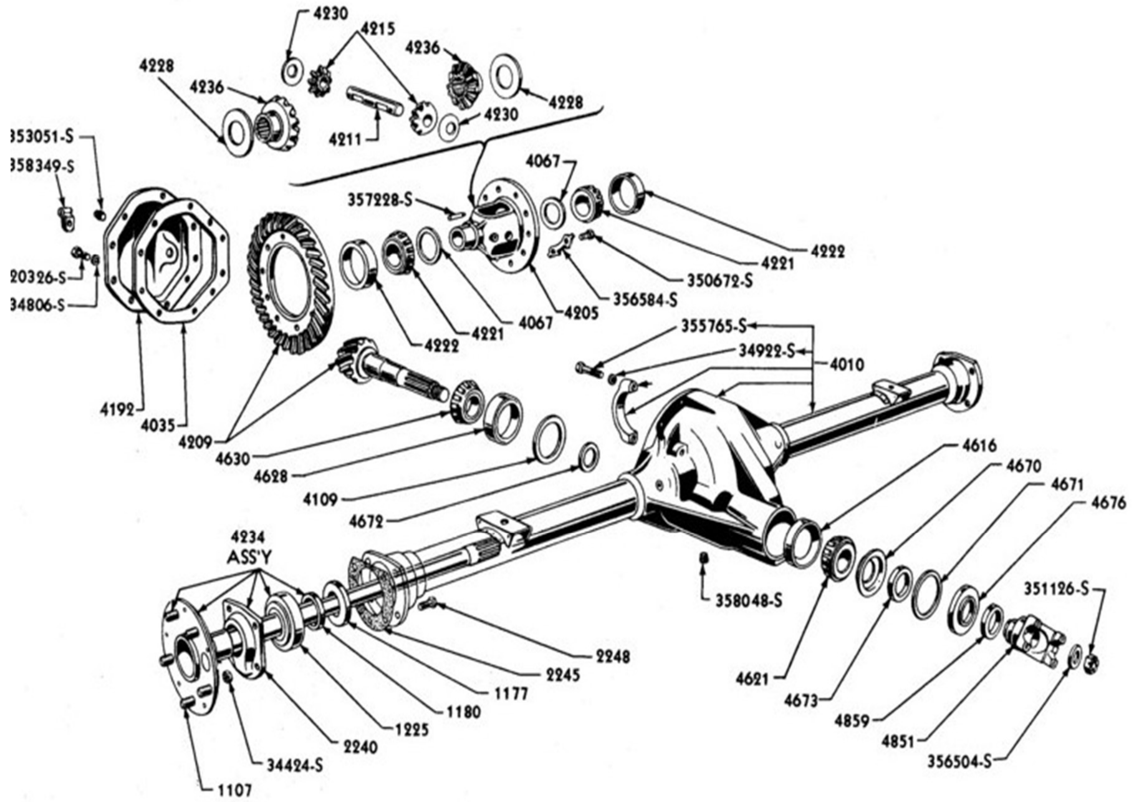


Figure 1. An illustration of A Rear Axle of A Truck (source: http://www.vanpeltsales.com/)

Bailey (1987) as an improvement based on the RPW method. The comparison of these two previous heuristic methods was presented, among others, by Baroto (2007). Last, the J-Wagon was also widely selected for particular work related to industries (Prasetyawati & Damayanti, 2016; Alif & Aribowo, 2019).

Those heuristic methods are based on the following assumption to perform the analysis: (a) all activities are movable without any constraint of equipment and resources, (b) all activities are transferable with constraint consideration either for equipment or resources.

Instead of the methods above, the Kaizen method is also proposed. This method has been adopted by PT ZYX to evaluate the productivity of Line-A. After implementing those 4 methods (including RPW, Region Approach, and J-Wagon), the success of the implementation will be simulated using the Discrete Event Simulation (DES) method.

Discrete Event Simulation is a useful decision support tool (Babulak & Wang, 2008). It is used to imitate a real process to see how the process can be affected by different conditions and test some ideas without risking the real process. Tecnomatix Plant Simulation software (Bangsow, 2016; Islam et al., 2019) enables the simulation, visualization, analysis, and optimization of production systems and logistics processes. The simulation techniques have been widely used for solving the line balancing problem (Güner & Ünal, 2008). This work uses the Tecnomatix Plant Simulation to visualize the result of the existing situation and to propose the results (Larasari, 2015).

Kaizen Method Overview

"Waste" always exists, and no matter how good the process is, it can always be better. Kaizen aims for improvement in productivity, effectiveness, safety, and "waste" reduction (Ortiz, 2006). PT. ZYX has a strategy for Kaizen (see

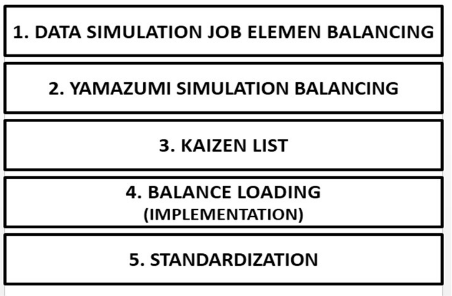


Figure 2. Kaizen Strategy by PT ZYX

Figure 2). It is required to analyst the current condition of an assembly line.

II. RESEARCH METHOD

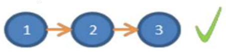
PT ZYX develops rules based on Kaizen in resolving the line balancing problem. There are 5 balancing rules discussed hereunder.

First, job balancing elements (parts) by assembly the sequence (Pn) must exist before (Pn+1). Table 1 shows an example of rule 1.

Table 1. Example of rule 1.

No.	Job Element	Rules
1	Installing Oil Deflector	P2
2	Installing Gasket	P3
3	Installing DC	P4

The balancing results that do not violate the order assy:



The balancing result that violates the order assy:

Second, job balancing elements based on elements that require special machines (poka-yoke). Examples of elements of the job that requires special elements: P2(x): The second element of the work order and require special machines (see Table 2).

Table 2. Example of rule 2.

No	Job Element	Rules	Special Machine Type
1	Torque (QL) Drain Plug	P2(x)	Torque poka-yoke machine
2	Nut DC Tightening	P3(x)	Tightening poka-yoke machine

Third, job balancing elements that are considerating a similar part in the component so that these elements can be split into several elements of the workload. Examples of job elements that have identical parts can be seen in Table 3.

Table 3. Example of rule 3.

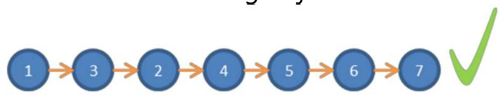
No.	Job Element	Rules
1	Installing Oil Seal	P2
2	Installing Brake	P3

Fourth, job balancing element that considers the work can be done in several posts (do not follow the order): (1) Fpn-pm: these elements can be done anywhere from sequence n to sequence m, and (2) Fp2-p6: these elements can be done anywhere on the order of 2 to the order of 7. Examples of work elements that can be done in several posts can be seen in Table 4.

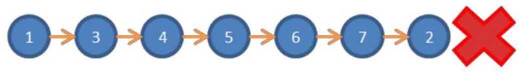
Table 4. Example of rule 4.

No.	Job Element	Rules
1	Installing Oil Deflector	P2
2	Installing Drain Plug	Fp2-p7
3	Installing Gasket	P3
4	Installing DC	P4
5	Installing Brake	P5
6	Installing Nut Brake	P6
7	Installing Drum Brake	P7

Result in the right job element balancing



Result in the wrong job element balancing



Fifth, HPn → handling part required so that when the balanced loading will follow the work elements in the order (Rule 1)

H → handling/work element parts that can be removed immediately eliminated when on-balance loading.

Examples of job elements HPn & H, can be seen in Table 5 and Table 6.

Table 5. HPn elements

No.	Job Element	Rules
1	Taking Oil Deflector	HP1
2	Taking DC	HP2

Table 6. H elements

No.	Job Element	Rules
1	Moving Drum Brake	HP1
2	Push Chutter Housing	HP2

III. Result and Discussion

Existing Layout of Rear Axle Assembly Line-A

The operations take place in the rear-axle assembly line-A. There are 17 workstations with 17 operators run the processes. Figure 3 shows the existing layout.

In Figure 3, operators are located at each workstation, following the assembly sequence shown by the 'blue' line from the section of 'washing machine', 'conveyor', and 'painting booth'.

Evaluating Cycle Time vs. Takt Time using Yamazumi Chart (Townsend, 2012)

Table 7 and Figure 4 show cycle time (CT) and takt time (TT) in second, of each operator.

Amount of WorkStation

The amount of workstations can be calculated using Eq.1 as follows,

$$N_w = \frac{\sum_{i=1}^{n} CT_i}{\sum_{i=1}^{n} TT_i} \quad \text{... (1)}$$

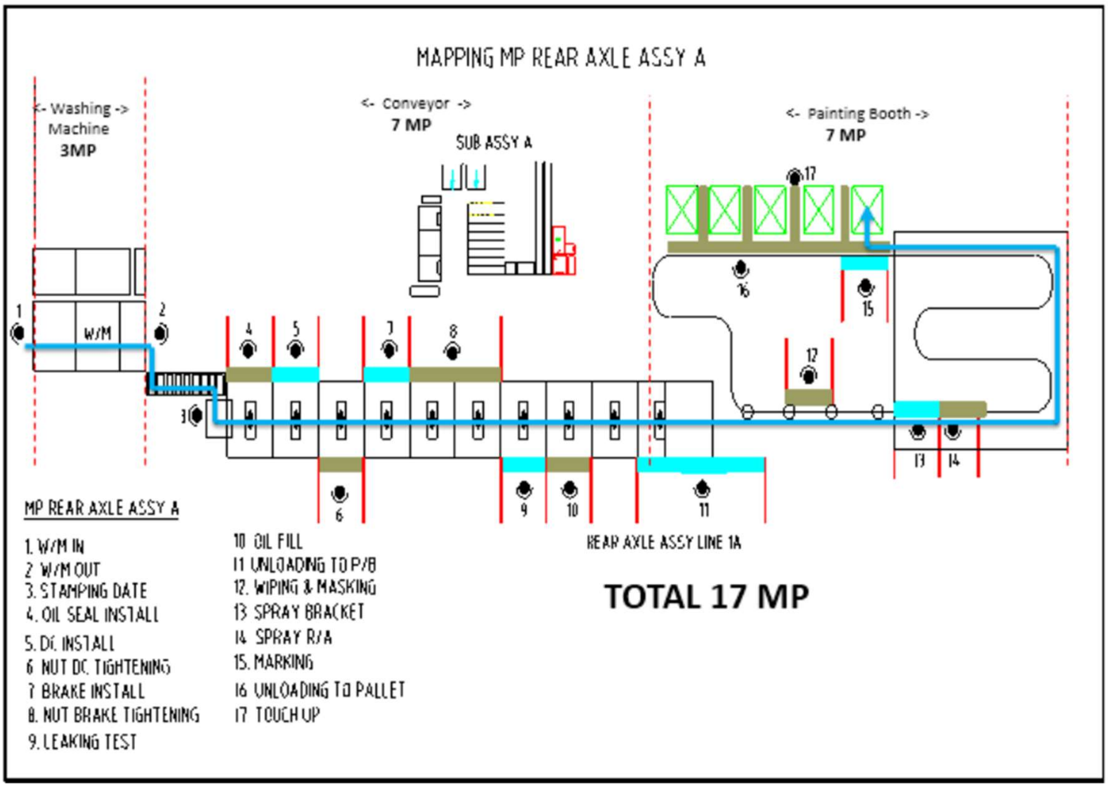


Figure 3. Existing Layout. The 'black dot' shows a human operator (MP = Man Power)

Table 7. Cycle Time and Takt Time

	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12	MP13	MP14	MP15	MP16	MP17
CT(sec)	46	57	52	57	48	59	58	59	60	53	55	58	53	58	55	43	57
TT(sec)	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60

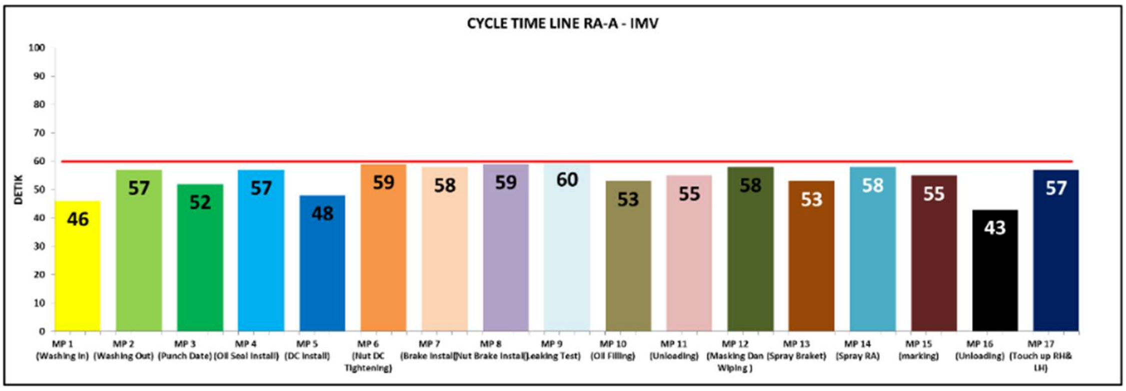


Figure 4. Yamazumi Chart

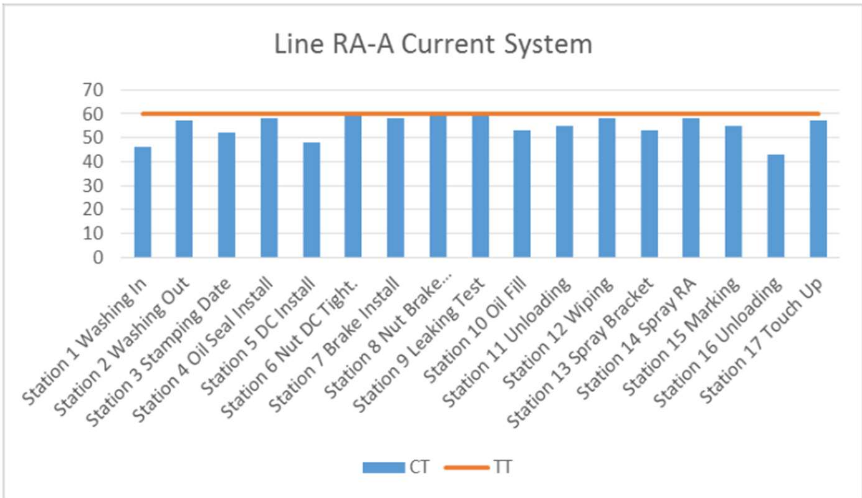


Figure 5. Line RA-A of the current system; CT = Cycle Time in sec, TT = Takt Time in sec. (Larasari 2015)

Table 8. Performance Evaluation

Method	Line Eff. (%)	Idle Time (s)	Balance Delay (s)	Smoothness Index (%)	Productivity (pcs/mh)
Current	91	91	8.9	29.61	1.06

where:

N_w = number of workstation,

CT_i = cycle time, in seconds,

TT_i = takt time, in seconds.

Based on Eq.1, the number of work stations in rear axle assembly line-A is 15.48, and it is round-down to 15 workstations.

Existing System Performance

Analysis of the current system is performed by observing the condition of the rear-axle assembly line-A at a specific period. The observed line is the process of assembling the IMV-models. When the company implemented the production system when the observations were made, it appears that the workload is less balanced between operations, resulting in less optimal line efficiency of each operation. The process of assembling in the rear-axle assembly line-A is divided into 17 work stations.

They are using heuristic methods above, with the assumption that all activities are moveable without any constraint of equipment. Table 8 shows the result of performance evaluated.

Table 9. Performance Comparison of Three Heuristics Method

Methods	Line Efficiency (%)	Idle Time (s)	Balance Delay (%)	Smoothness Index (%)	Productivity (pcs/mh)
RPW	97	31	3.2	25.33	1.21
Region Approach	97	31	3.2	25.33	1.21
J-Wagon	97	31	3.2	32.49	1.21

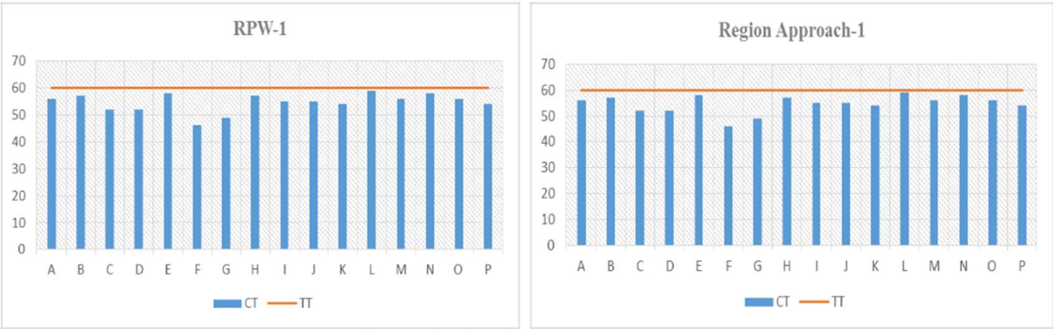


Figure 6. RPW Method and Regional Approach Method of the 1st Assumption (Larasari, 2015)

Performance Evaluation to the 1st Assumption

The performance comparison using three heuristics methods is shown by following Table 9.

From Table 9, it is shown that the proposed improvement to balance the line results in line efficiency, idle time, balance delay, and productivity having the same result. However, the smoothness index shows which method is better. The smoothness index shows the average of differences between one workstation to another. The smaller the smoothness index, the better the performance of balancing the line. From Table 9, it can be concluded that the proposed methods are Ranked Positional Weight (RPW) and Region Approach with a smoothness index value of 25.33. Another result of the best performance line is the reduced number of work stations from 17 to 16. Thus the number of operators reduced from 17 to 16, and the number of cycle time remains the same as 929 seconds.

However, referring to the assumption, those methods above are not possible to be implemented. The second assumption will be used to get the best line balancing method. Here is the calculation of the three heuristic methods with the second assumption, namely, all activities are moveable with any constraint or equipment.

Performance Evaluation based on the 2nd Assumption

The result of the 2nd assumption applied by three heuristics methods can be seen in Table 10.

From Table 9, it can be seen that all the proposed improvement line balancing methods, which result in line efficiency, idle time, balance delay, and productivity has the same result. With similar results in nearly all the above factors, the value of the smoothness index determines which method is better.

This value indicates the level of smoothness of a balanced line. The smaller the smoothness index value, the better the performance of the balance of the line. It can be concluded that the proposed method could be the method of Ranked Positional Weight

(RPW) and Region Approach with a smoothness index value of 26.68. Another result of the best performance line is the reduced number of workstations from 17 workstations to 16 workstations. The number of operators reduced from 17 to 16 workforce, and the number of cycle time decreased from 929 seconds to 874 seconds.

As a result of three heuristic line balancing methods, RPW and Region Approach is the best

Table 10. Performance of Three Heuristic Methods of the 2nd Assumption

Methods	Line Efficiency (%)	Idle Time (s)	Balance Delay (%)	Smoothness Index (%)	Productivity (pcs/mh)
RPW	91	86	8.9	26.68	1.13
Region Approach	91	86	8.9	26.68	1.13
J-Wagon	91	86	8.9	26.87	1.13

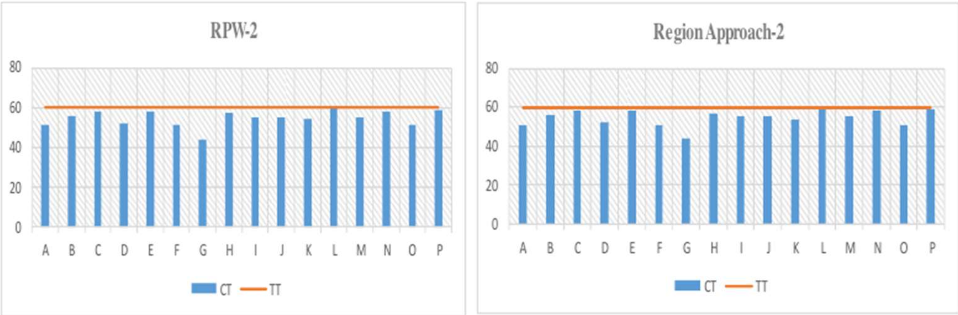


Figure 7. RPW Method and Regional Approach Method of the 2nd Assumption (Larasari, 2015)

methodology. There are 16 stations with 16 operators (workforce) in RPW and Region Approach Method. It can be concluded that the results of the proposed method are the reduction of one station and one operator (see Figure 7).

Those methods above are possible to be implemented based on the assumption. A new internal company approach, namely, line balancing based on the Group rules using Kaizen will be discussed.

Performance Line Balancing Method Based on ZYX Group Rules using Kaizen

Based on the rules made by OMDD (Operations Management Development Division) of ZYX, Table 11 shows the rules.

All the rules have been applied for each work element. Some work elements were eliminated after the balancing rule applied so that the total cycle time is reduced (see station 2, station 3, and station 11). There are also work elements being moved to another work station based on balancing rule that resulted in a reduction of two workstations, namely workstation 3 and workstation 11.

Figure 8 and Figure 9 show the cycle time with the takt time of each operator before and after simulation balancing. It can be seen that the distribution of work elements that have been applied by balancing rule resulted in a reduction of two workstations, namely, station 3 and station 11 (the 'x' sign in Figure 9). There is 2 balancing area. The purpose of making 2 balancing areas is to simplify the distribution of work element, which has a cycle time that exceeds the takt time, for example, station 3, 4, 7, and 11.

Kaizen List

Kaizen focuses on the constant elimination of "muda" (waste). Any non-value adding

Table 11. Example of Station 1: Washing In

ST	No.	Work Element (Station 1: Washing In)	Te	Rule	CT
1	1	Take one Kanban and put in a poly box	2	H	46
	2	Take the housing of the trolley with chute mechanic	4	HPn	
	3	Place housing in the stand housing	3	HPn	
	4	Setting up an empty box for a small part drum brake	5	H	
	5	Take a small box part	3	H	
	6	Take a drum brake on the trolley	4	HP1	
	7	Put a drum brake in the area stand W/M	5	HP1	
	8	Do wiping on the surface of the housing	14	P1	
	9	Push housing in booth W/M	3	HP1	
	10	Return to the starting position	3	H	

activities are considered waste. To eliminate waste, it is important to understand exactly what waste is and where it exists. Therefore, it is required to define the area balancing, item problem, Kaizen idea, Kaizen point, Kaizen criteria, and analyze the condition before and after Kaizen.

Table 12 shows the idea of reducing the NVW (Non-Valuable Work) by replacing the manual operator with a barcode scanner for the process of model input quantity to the database. As a result, the time required for scanning is reduced 2 seconds.

Kaizen Results

The final result after Kaizen is a reduction of two workstations, namely station 3 (stamping date) and the station 11 (unloading to painting) and the number of work stations now are 15 stations with 15 operators.

Figure 12 and Figure 13 show the comparison of the total cycle time and the total number of main power (operator) in the current system with the system after Kaizen. Figure 12 shows the cycle time reduces from 929 seconds to 818 seconds after the Kaizen, thus reducing the total cycle time to 111 seconds.

The number of workforces reduced from 17

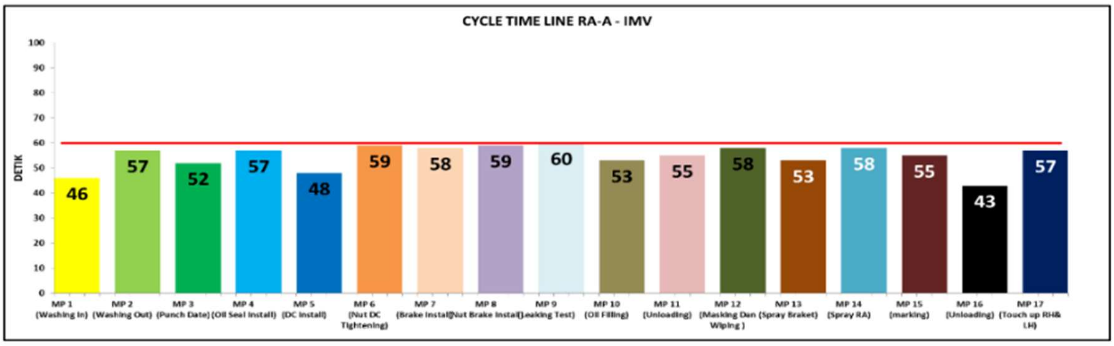


Figure 8. Yamazumi Chart before Line Balancing (existing) (Larasari, 2015)

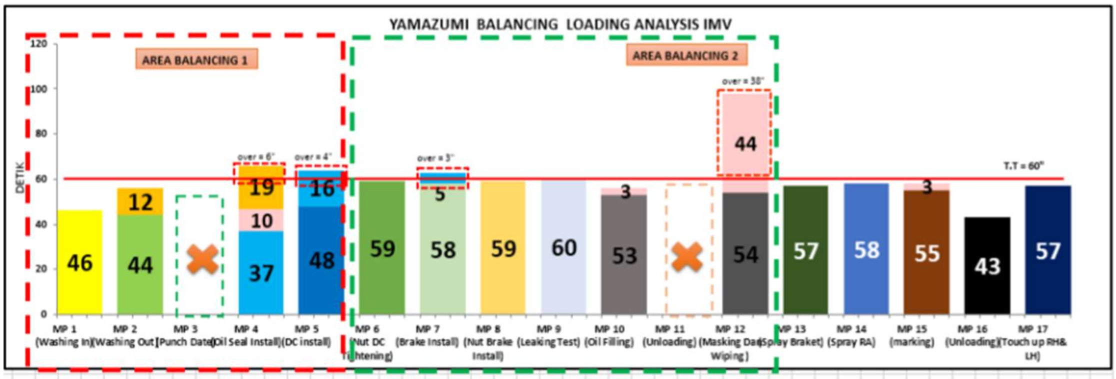


Figure 9. Yamazumi Chart after Simulation of Balancing (Larasari, 2015)

Table 12. Kaizen-1

Station & Area Balancing	No. Element	Item Problem	Kaizen idea	Kaizen point	Kaizen Criteria
11 & 2	93	The process of model input quantity to the database shop floor is done with manual input	The process of model input quantity to database replaced by using barcode scanning	Barcode stickers will be taped to the back of each Kanban. Position barcode scanning is located near to the operator when unloading	Reduce NVW OP unloading/IMV

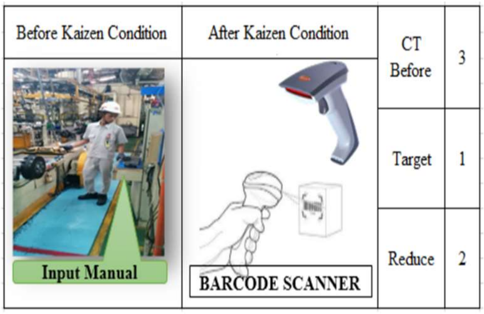


Figure 10. Kaizen

operators to 15 operators after Kaizen (see Figure 13). The three shift are applied at PT ZYX, thus the total number of workforce (operator) reduced is 6 workforces/line/day. The number of operators after Kaizen is following the ideal amount of operators that have been calculated (refer to Eq. 1).

Performance Evaluation of ZYX Group Rules using Kaizen

The result shows that the calculations with line balancing method based on ZYX group rule with cycle time 60 seconds has an efficiency line (LE) 91%, a total of 82 seconds of idle time, balance delay 9.1%, smoothness index of 28.28, and the productivity of 1.21 which can be seen at Table 13.

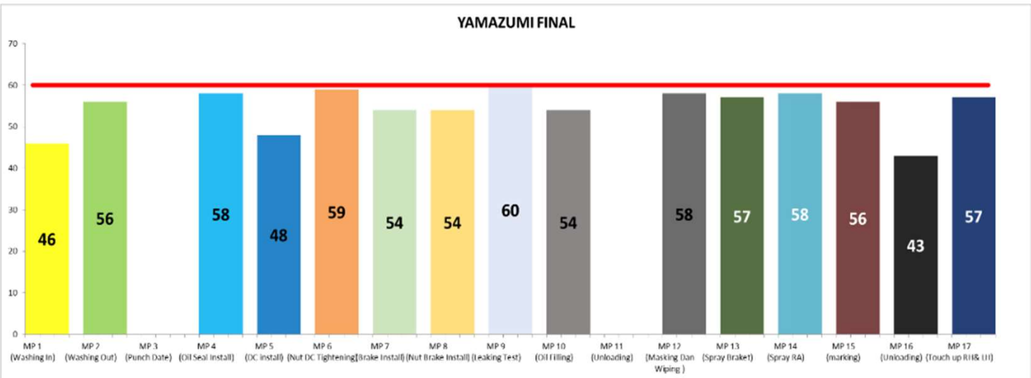


Figure 11. Yamazumi Chart (Final)

Figure 12. Total Cycle Time Comparison, Current vs. After Kaizen

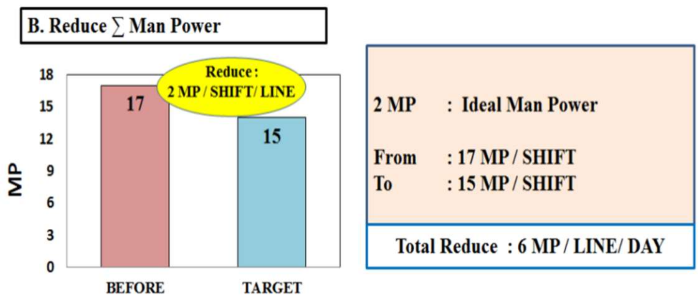


Figure 13. Total Man Power Comparison, Current vs. After Kaizen

Table 13. Performance of ZYX Group Method

Method	Line Efficiency (%)	Idle Time (s)	Balance Delay (%)	Smoothness Index (%)	Productivity (pcs/mh)
ZYX Kaizen	91	82	9.1	28.28	1.21

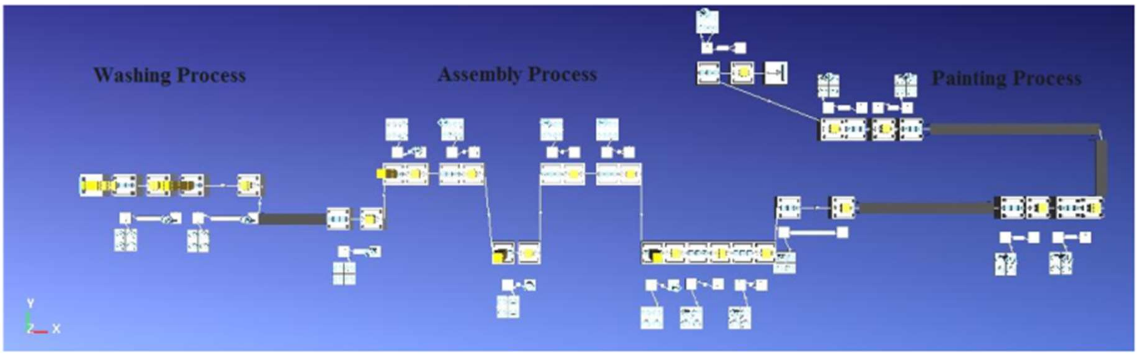


Figure 14. A general overview of the current system (using Tecnomatix Plant Simulation) (Larasari, 2015)

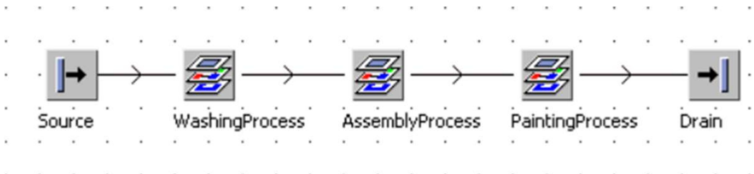


Figure 15. Three Main Frames (Washing, Assembly, and Painting Processes) of the Assembly Line (Larasari, 2015)

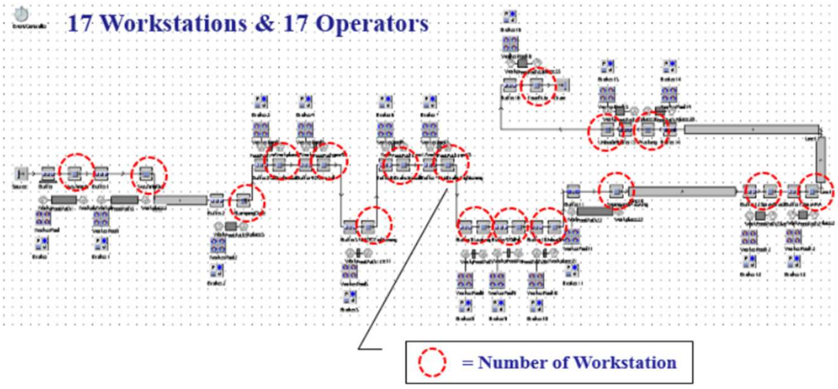


Figure 16. Conceptual Model of Existing Assembly Line (Larasari 2015)

Simulation

The next part of this work is to propose improvements to the assembly line using simulation (discrete event systems), which consists of a conceptual model, verification, and validation of the model. The simulation is prepared using Tecnomatix Plant Simulation software. The simulation study began by examining the whole assembly.

Figure 14 shows an overview of the layout of the assembly line for the current system. Rear-axle assembly line-A is divided into 17 stations with 17 operators, and it consists of three main processes; washing, assembly, and painting processes (see Figure 15).

Two types of simulation models were designed. First is the existing assembly line and second, is the ZYX group methodology. Figure 16

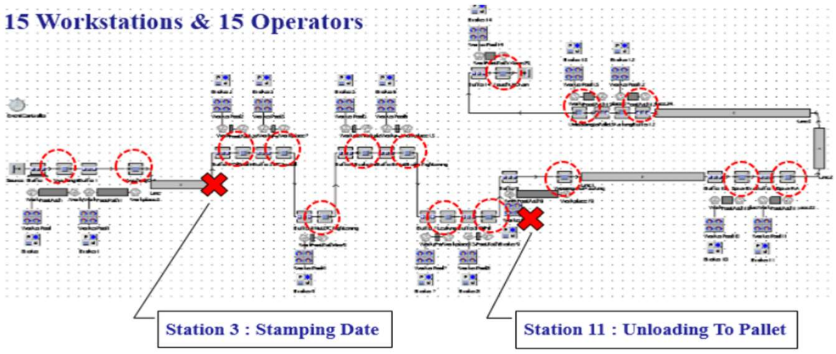


Figure 17. Conceptual Model of Proposed System (Larasari 2015)

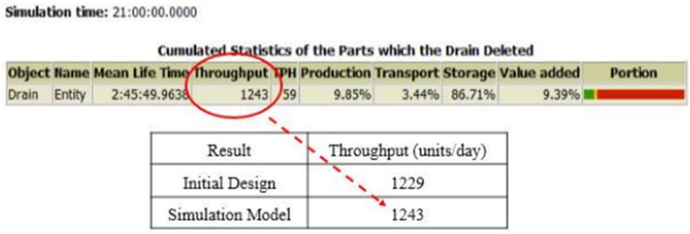


Figure 18. Throughput Result from Simulation

Table 14. Comparison of Methods based on Its Parameter (Larasari 2015)

No	Parameter	Current	Assumption 1			Assumption 2			
			RPW	Region Approach	J-Wagon	RPW	Region Approach	J-Wagon	Kaizen
1	Lean Efficiency (%)	91	97	97	97	91	91	91	91
2	Idle Time (s)	91	31	31	31	86	86	86	82
3	Balance Delay (%)	8.92	3.22	3.22	3.22	8.95	8.95	8.95	9.11
4	Smoothness Index (%)	29.61	25.33	25.33	32.49	26.68	26.68	26.87	28.28
5	Productivity (pcs/man-hour)	1.06	1.21	1.21	1.21	1.13	1.13	1.13	1.21
6	Cycle Time (s)	929	929	929	929	874	874	874	818
7	No. of workstation	17	16	16	16	16	16	16	15
8	No. of operator	17	16	16	16	16	16	16	15

shows the conceptual model of the current assembly line with 17 stations and 17 operators. Figure 17 shows the conceptual model of the ZYX group method with 15 stations and 15 operators.

$$Throughput = \frac{1243}{1229} x100\% = 101\%$$

From Figure 18, there is a slight difference between the simulation model and the initial design. In throughput percentage, the simulation model shows that the production line can meet 101% of forecast demand.

IV. Conclusion

Two assumptions have been used within the usage of the three heuristic methods. Based on the first assumption, the best method is the Ranked Positional Weight (RPW) and Region Approach. From Table 14, it is shown that the smoothness index is 25.33 %. The workload differences are lower between a station and another, while the other parameters showed similar but still better than the existing condition. However, RPW and Region Approach is not possible to be implemented. Thus, the second assumption will be used.

Based on the second assumption, the best method is still RPW and Region Approach since the smoothness index is 26.68%.

A new approach proposed using ZYX group rules based on Kaizen. The Kaizen performance result is not significantly different from the current system performance. However, this method managed to reduce the number of work stations from 17 to 15 workstations. Therefore, it reduces the number of operators from 17 to 15, and the number of cycle time is also reduced from 929 to 818 seconds.

Recommendation

It was focusing on the calculation of time for each workstation because it will affect the workstation layout changes. It is also required to consider cost, that might effect the selection of better method above.

A factor that might influence productivity is to consider the usage of operator energy. For this, ergonomic and human factor aspect need to be further analyzed.

It is advisable to reduce manual work with additional automation tools, which may reduce standard time and increase productivity. However, the business process would be significantly reconsidered.

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