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Framework Study on Single Assembly Line to Improve Productivity with Six Sigma and Line Balancing Approach

Inaki Maulida Hakim, T. Yuri M. Zagloel, Astari Wulandari

Abstract**—**Six sigma is a framework that is used to identify inefficiency so that the cause of inefficiency will be known and right improvement to overcome cause of inefficiency can be conducted. This paper presents result of implementing six sigma to improve piston assembly line in Manufacturing Laboratory, Universitas Indonesia. Six sigma framework will be used to analyze the significant factor of inefficiency that needs to be improved which causes bottleneck in assembly line. After analysis based on six sigma framework conducted, line balancing method was chosen for improvement to overcome causative factor of inefficiency which is differences time between workstation that causes bottleneck in assembly line. Then after line balancing conducted in piston assembly line, the result is increase in efficiency. Efficiency is shown in the decreasing of Defects per Million Opportunities (DPMO) from 900,000 to 700,000, the increasing of level of labor productivity from 0.0041 to 0.00742, the decreasing of idle time from 121.3 seconds to 12.1 seconds, and the increasing of output, which is from 1 piston in 5 minutes become 3 pistons in 5 minutes.

Keywords**—**Assembly line, efficiency, improvement, line balancing, productivity, six sigma, workstation.

I. Introduction

ASSEMBLY line introduced by Henry Ford is a set of works which is divided into several stations that arranged in line to produce finished products. Assembly line has been applied extensively in manufacturing industries, such as electronic, automotive, and furniture [1]-[3]. Improvement in assembly line also continues to develop. Improvement in assembly line has goal to optimize production process which led to increasing of productivity.

Many previous studies have discussed improvement in assembly line with various methods. Reference [1] used line balancing to eliminate bottleneck and wastes. Reference [2] used job rotation scheme and Rapid Entire Body Assessment (REBA) to eliminate workload variability between workers. Reference [3] used modeling and iterative procedure to evaluate line production rate at furniture manufacturing plant and then lot size adjustment and bottleneck analysis was carried out to improve the system throughput. Reference [4] improved the assembly line by using lean manufacturing techniques for eliminating wastes in manufacturing operation. While [5]-[7] improved piston assembly line by using anthropometric approach.

One method that is frequently used to improve performance of assembly line is Line Balancing (LB). LB is the problem of assigning operations to workstation along an assembly line, in such a way that the assignment is optimal in some sense [8]. LB can eliminate many forms of wastes such as inventory, waiting time, and transport so that it can enhance the operation effectiveness of the line [1].

Before conducting improvement in the assembly line, first learning and analysis the cause of problem must be done so that the right solution to improve known. Six sigma is a common framework that is widely used in industry to identify problems until meet the right solution, such as in aerospace, automotive, and fan manufacturing industry [9]-[11]. Six sigma focuses on eliminating mistakes, waste and rework with five-phase of improvement cycle; 'Define, Measure, Analyze, Improve, and Control cycle' (DMAIC) [9], [11]. So, six sigma can be applied as tool for solution maker.

Application of six sigma in manufacturing industry has been discussed in many researches. In this paper, six sigma framework will be applied for laboratory scale of assembly line, which is piston assembly line miniature in Manufacturing System Laboratory, Industrial Engineering, Universitas Indonesia, with 1 capacity of buffer, and 4 workstations. Six sigma is used to analyze strategy of improvement for this assembly line so that the productivity can be increasing. Previously, research for this object has been conducted to improve piston assembly line. Previous research used anthropometric approach to determine the recommended measurement in operator's work area, then it generated new design for the work area that fit for Indonesian people by considering ergonomic aspect [5], [6]. Then, Rapid Upper Ruler Assessment (RULA) also has been conducted for this piston assembly line to evaluate and assess ergonomic aspect to improve its productivity [7].

The current condition of the object of the research is the assembly line can produce 1 piston in 5 minutes' continuous flow. But, the ideal condition claimed that the assembly line can produce 10 outputs in 5 minutes, which means the productivity is less than expectation. So, study on this piston assembly line was conducted to improve the assembly line that impact in increasing of productivity by using six sigma

Inaki Maulida Hakim is with Industrial Engineering Department, Universitas Indonesia, Depok, Indonesia (Phone: +62-818-205-290; e-mail: inakimhakim@ie.ui.ac.id).
T. Yuri M. Zagloel is with Industrial Engineering Department, Universitas Indonesia, Depok, Indonesia (Phone: +62-8118-692-003; e-mail: yuri@ie.ui.ac.id).
Astari Wulandari is with Industrial Engineering Department, Universitas Indonesia, Depok, Indonesia (Phone: +62-852-8403-1645; e-mail: astari.wulandari@yahoo.com).

approach, because six sigma can deal with improvement of overall cost of quality, both tangible and intangible parts [10].

II. Methodology

Assembly line in Manufacturing System Laboratory, Industrial Engineering, Universitas Indonesia consists of a series of process that divided into 4 workstations to produce finished piston. Visualization of assembly line in Manufacturing System Laboratory, Industrial Engineering, Universitas Indonesia is shown in Fig. 1 and task for each station is shown in Table I.

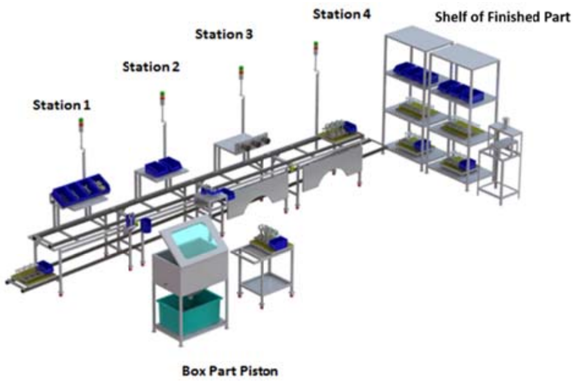

Fig. 1 Piston assembly line in manufacturing system laboratory

TABLE I
Task of Piston Assembly Line Workstation

Station	Task	Tool
1	Attach connecting rod bolts Preparing piston crown, piston pin and connecting rod bolts installed onto pallets which are then given to Station 2	Mounting bolts drill
2	Install piston pin and snap ring to connect piston crown and its connecting rod	Piston pin installer and snap ring pliers
3	Install oil ring, N1, and N2 on the piston	Mounting ring oil, N1, and N2
4	Inspect the installation of the piston	Not require special tools

The objective of this study is to increase the assembly line's productivity; therefore, improvement on assembly line should be conducted. In this research, six sigma framework is established to find right improvement for increasing productivity of piston assembly line. So, the step of research is not far from DMAIC cycle. The methodology of research shown in Fig. 2 is divided into 4 main steps that will be explained further in this section.

A. Step 1: Problem Identification

The causative factors that interrupt production were identified. Two causative factors are selected to be analyzed further, which are breakdown time and differences time of workstation that can reduce the output.

To analyze the causative factors, time study was conducted to get theoretical result. Fig. 3 shows the result of cycle time in each station.

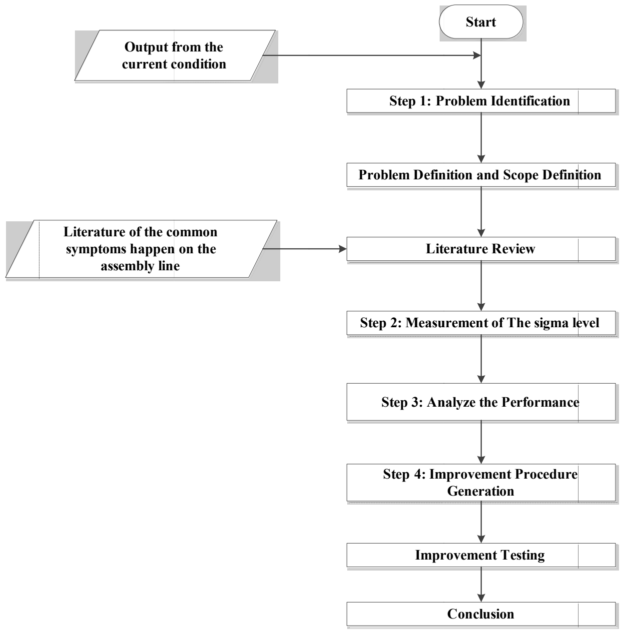

Fig. 2 Methodology of research

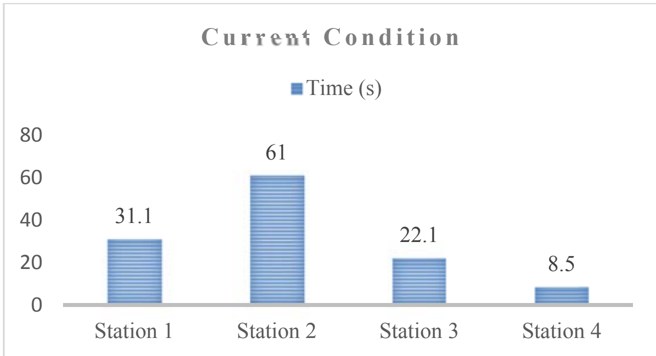

Fig. 3 Cycle time in each station before improvement

With cycle time 61 seconds, the piston that can be produced based on experiment is 1 piston in 5 minutes. And this research is targeted to increase finished product within this assembly line with 10 pistons produced in 5 minutes as the target, so cycle time 30 seconds is needed to increase the productivity. And the object of this research is piston assembly line in Manufacturing System Laboratory, Universitas Indonesia that has 4 workstations.

B. Step 2: Measurement of Sigma Level and Labor Productivity

Sigma level and labor productivity are measured so that the performance before and after improvement can be seen.

Sigma level is procedure to know the existing condition of a production shop. The calculation of sigma level is based on the number of DPMO [11]. Equation to calculate DPMO is shown in (1):

$$DPMO = \frac{(No.\ of\ defects * 1000000)}{((No.\ of\ defects\ opportunities\ per\ unit) * No.\ of\ units)} \quad (1)$$

By using (1), DPMO of current condition is calculated. The number of units is 10 based on the ideal condition of production and the number of piston that could not be produced compared to ideal condition is converted into number of defects. So, the value of DPMO at current condition is 900,000. Then, level of labor productivity was also calculated. As in [12], labor productivity for the problem can be calculated by:

$$P = 1/(CT * M) \quad (2)$$

where P is the labor productivity level; M is the number of workstation; CT is the cycle time of the workstation. In this case, the number of workstation is fix so the level of labor productivity is inversely proportional to the cycle time.

From the current situation, the cycle time obtained based on experiment is 61 seconds. So, the labor productivity level for current condition is 0.0041.

C. Step 3: Analyze the performance

Factors that cause inefficiency in assembly line were analyzed. As stated before in step 1, the causative factors that have been identified are breakdown time and differences time of the workstation. And based on analysis, differences time of workstation was the most significant factor on this research because there is a wide different in cycle time of workstation, especially in workstation 2. As can be seen in Fig. 3, workstation 2 has biggest cycle time among the other workstation, so it resulted on low DPMO and labor productivity level.

While the second factor, breakdown time, has low significant effect on assembly line because based on experiment, breakdown that happened during experiment was almost zero.

D. Step 4: Improvement

The main factor that makes inefficiency is differences time of workstation. So, improvement will be conducted to overcome that causative factor. One method that can overcome differences time of workstation is LB, because LB can minimize imbalance between/among workers and workloads in order to achieve required run rate [1]. LB is also a method to balance worker's workload to minimize number of worker or idle time. And to measure the performance of assembly line, calculating the idle time before and after improvement can be conducted. Below is the equation to calculate idle time of assembly line [13]:

$$Idle\ Time = n.Ws - \sum_{i=1}^{n} Wi \quad (3)$$

where n is the number of workstation; Ws is the largest of workstation's time; Wi is workstation i. In this piston assembly line case, the idle time before improvement can be calculated using this formula, resulting 121.3 seconds as the idle time.

There are many previous studies that used LB to gain effectiveness and efficiency on production system. Reference [8] used simulation techniques to design hard disk drive manufacturing process by applying LB to improve both productivity and quality of hard disk drive process then resulted in increasing of output by 80%, decreasing of average time in the system by 86% and decreasing of waiting time by 90%. Reference [12] used heuristic approach to balance U-shaped assembly line. Reference [14] proposed bidirectional heuristic method to solve single-model stochastic assembly LB Type II (number of workstation is fix), then smoothing the workload by swapping tasks among workstation until the smallest cycle time reached. Then, [13] used ranked position weight method to minimize bottleneck and number of worker to produce same amount of product in shoes manufacturer.

In piston assembly line case, to minimize the differences time between worker, authors used ranked position weight to balance cycle time among workstation. Ranked position weight considers greatest number of followers' rule and break ties with longest processing time rule [13].

First of all, precedence table and diagram of piston assembly line were established as the first step of improvement, which are shown in Table II and Fig. 4.

TABLE II
PRECEDENCE TABLE OF PISTON ASSEMBLY LINE

Task	Predecessors	Task	Predecessors
a	-	**o**	c, n
b	A	**p**	o
c	A	**q**	o
d	A	**r**	p, q
e	D	**s**	r
f	d, e	**t**	s
g	F	**u**	t
h	F	**v**	t
i	g, h	**w**	t
j	I	**x**	u, v, w
k	J	**y**	x
l	B	**z**	y
m	J	**aa**	y
n	l, k, m	**ab**	z, aa

After precedence table and diagram were established, cycle time for each task is needed to make new allocation of task within the workstation. Fig. 5 represents the cycle time for each task to produce piston. And based on the precedence diagram and cycle time for each task, the new task allocation for 4 workstations was assigned using ranked position weight. Then, new cycle time for each workstation after improvement was obtained as shown in Fig. 6.

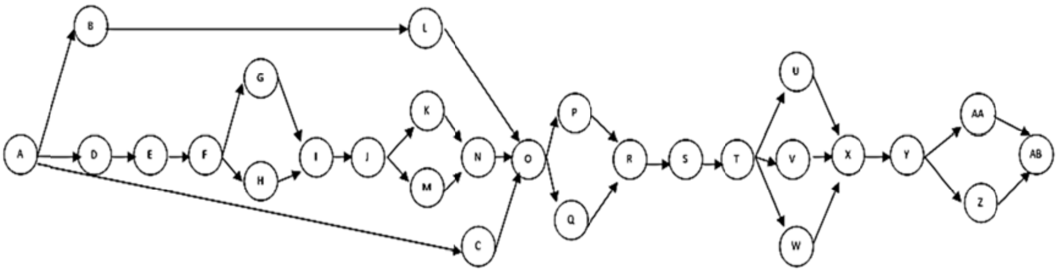

Fig. 4 Precedence diagram of piston assembly line

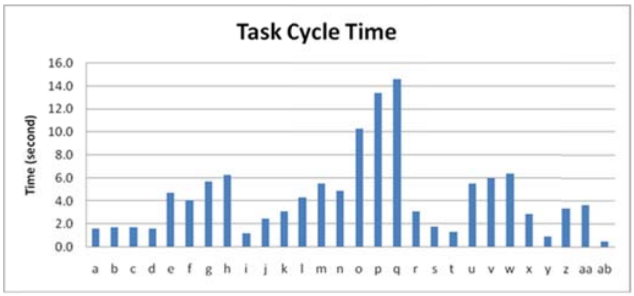

Fig. 5 Cycle time for each task

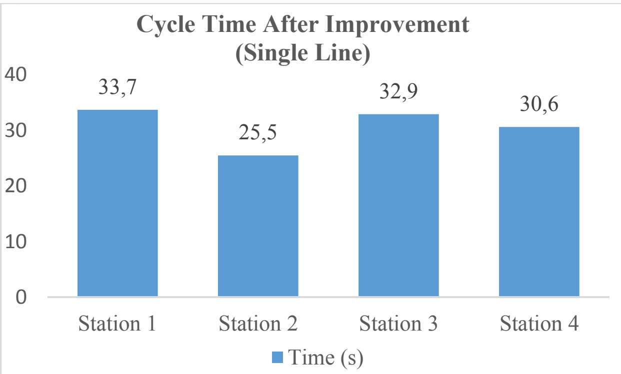

Fig. 6 Cycle time for each workstation after improvement

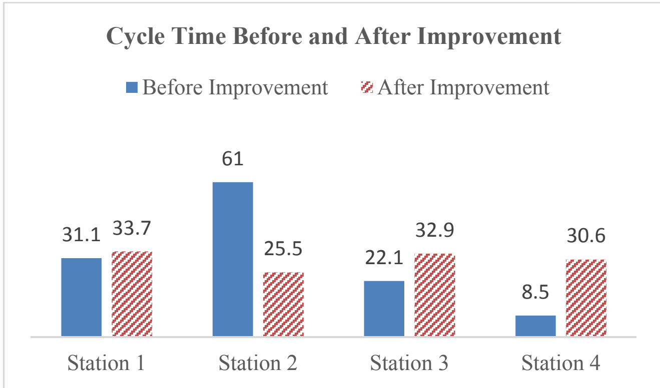

Fig. 7 Cycle time for each workstation before and after improvement

TABLE III
COMPARISON OF PERFORMANCE BEFORE AND AFTER IMPROVEMENT

	Before Improvement	After Improvement
Number of piston produced	1 piston in 5 minutes	3 pistons in 5 minutes
DPMO	900,000	700,000
Labor Productivity	0.0041	0.00742
Idle Time (s)	121.3	12.1

III. RESULT

The LB improvement resulted in more balance workload and decreasing of workstation's cycle time from 61 seconds to 33.7 seconds. Fig. 7 represents the comparison of cycle time each workstation before and after the improvement conducted. The improvement of assembly line also resulted on increasing of the number of piston produced from 1 piston to 3 pistons in 5 minutes. After that, the sigma level, level of labor productivity, and idle time before and after improvement was compared using (1)-(3). With the number of output increases to 3 pistons in 5 minutes, the DPMO value decreases to 700,000. Then with cycle time becomes 33.7 seconds, the level of labor productivity increases to 0.00742 and the idle time decreases to 12.1 seconds. Table III represents the comparison performance before and after improvement.

IV. DISCUSSION AND FUTURE RESEARCH

The piston assembly line in Manufacturing System Laboratory, Industrial Engineering, Universitas Indonesia has been improved by using anthropometric approach. And in this paper, LB was conducted for continuous improvement of this assembly line. LB was chosen for assembly line's improvement because current condition of each workstation's cycle time was unbalance, with workstation 2 as caused of blocking because it has biggest cycle time, which is 61 seconds. This cycle time of workstation 2 has difference of 29.9 seconds with workstation 1, 38.9 seconds with workstation 3, and 52.5 seconds with workstation 4, that was resulted on idle time of 121.3 seconds. 121.3 seconds of idle time means that this inefficient assembly line caused of 121.3 seconds waste of time in form of waiting time in workstation 1, 3, and 4 to wait until workstation 2 finishes its work for each piston produced.

LB improvement assigns task in efficient way to decrease idle time. Smaller idle time occurs in assembly line resulted on less waste of waiting time so that more pistons can be produced. It has been proven from this study that piston that can be produced after improvement increase from 1 piston in 5 minutes become 3 pistons in 5 minutes. Then, DPMO, labor productivity, and idle time also calculated as key performance indicator to compare performance before and after improvement. DPMO shows a decrease from 900,000 to 700,000. Decreasing of DPMO happened because after improvement, the number of piston produced is increasing that effects on decreasing in number of defects. So based on (1), DPMO will also decrease parallelly with decreasing of number of defects. Then, the labor productivity was also calculated. Variables that affect on level of labor productivity are number of workstation (*M*) and cycle time (*CT*). In this research, piston assembly line as object of research has fix number of workstation, so labor productivity just affected by cycle time. Cycle time itself is the greatest time between workstation to produce 1 output. So to increase labor productivity in piston assembly line, cycle time must be lowered because in (2), cycle time act as denominator. So, decreasing of cycle time from 61 seconds to 33.7 seconds resulted on increasing of labor productivity from 0.0041 to 0.00742. And the last calculation is line idle time. Idle time is affected by differences time between workstation. Before improvement, the differences time between workstation was high, especially in workstation 2 that has highest cycle time. So after balancing of assembly line was conducted, differences time between workstation becomes smaller that resulted on dereasing of idle time from 121.3 seconds to 12.1 seconds.

Overall, based on number of piston produced, DPMO, labor productivity, and idle time calculation, the piston assembly line has been improved. But the result from this research improvement still below the expected result which is can produce 10 pistons in 5 minutes, while the improvement only made the assembly line produce 3 pistons in 5 minutes. So, further research must be conducted in this piston assembly line by using another approach that will increase productivity until the ideal condition reached.

V. Conclusion

Six sigma is a common framework that used to identify problem in industry. Six sigma can eliminate mistake, waste and rework by following five-phase of improvement cycle; 'Define, Measure, Analyze, Improve, and Control cyle' (DMAIC). So, six sigma can be stated as tool for solution maker, including to improve assembly line.

Assembly line is a set of works which is divided into several stations that arranged in line, to produce finished products. In the middle of competition in manufacturing industry, the improvement of assembly line becomes important to increase productivity that results on reducing cost. One of method that can be used to improve assembly line is LB, that assign operations in assembly line until become balance or optimal.

This research used LB as the method of improvement and six sigma as framework to analyze the causative factor of inefficiency. This research conducted in piston assembly line in Manufacturing System Laboratory, Industrial Engineering, Universitas Indonesia. Four key performance indicators was applied in this research to compare the result before and after improvement, which are DPMO, labor productivity, idle time, and number of piston produced. The result of improvement showed the decreasing of DPMO from 900,000 to 700,000, the increasing of level of labor productivity from 0.0041 to 0.00742, and the decreasing of idle time from 121.3 seconds to 12.1 seconds. Then, the number of output also increased from 1 piston in 5 minutes become 3 pistons in 5 minutes, which is show the increasing of productivity.

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References

[1] Lam, Nguyen Thi, Le Minh Toi, Thi Thanh Tuyen, and Do Ngoc Hien, "Lean line balancing for an electronics assembly line", *Procedia CIRP*, vol. 40, 2016, pp. 437–442.

[2] Yoon, Sang-Young, Jeonghan Ko, and Myung-Chul Jung, "A model for developing job rotation schedules that eliminate sequential high workloads and minimize between-worker variability in cumulative daily workloads: Application to automotive assembly lines", *Applied Ergonomics*, vol. 55, July 2016, pp. 8–15.

[3] C. Zhao and J. Li, "Modeling, Analysis, and Improvement of a Multi-product Furniture Assembly Line", *IFAC Proceedings Volumes*, vol. 47, Issues 3, 2014, pp. 1672–1677.

[4] Nguyen, Minh-Nhat and Ngoc-Hien Do, "Re-engineering Assembly line with Lean Techniques", *Procedia CIRP,* vol. 40, 2016, pp 590–595.

[5] T. Yuri M. Zagloel, Inaki M. Hakim, and A. M. Syarafi, "Pre-Eliminary Design Adjustable Workstation for Piston Assembly Line Considering Anthropometric for Indonesian People", World Academy of Science, Engineering and Technology. *J. Industrial and Manufacturing Engineering,* vol. 9, No. 8, 2015.

[6] T. Yuri M. Zagloel, Inaki M. Hakim, and Rieke Adyartie, "Motion and Time Study: Measurement of Workstation for Piston Assembly Line Considering Anthropometrsic for Indonesian", *Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management Kuala Lumpur, Malaysia, March 8-10, 2016.*

[7] Inaki M. Hakim and T. Yuri M. Zagloel, "An Ergonomic Evaluation and Assessment to Improve Productivity for Piston Assembly Line", *Advanced Science Letters,* vol. 22, No. 7, July 2016, pp. 1791-1794.

[8] T. Saehaeaw, N. Charoenchai, and W. Chattinnawat, "Line Balancing in the Hard Disk Drive Process Using Simulation Techniques", World Academy of Science, Engineering and Technology. *J. Industrial and Manufacturing Engineering,* vol. 3, No. 12, 2009.

[9] Khaled, Masimuddin Mohd, "Analysis of Six Sigma in the Aerospace Industry", World Academy of Science, Engineering and Technology. *J. Mechanical and Mechatronics Engineering,* vol. 7, No. 12, 2013.

[10] M. Sokovic, D. Pavletic, and E. Krulcic, "Six Sigma process improvements in automotive parts production", *Journal of Achievements in Materials and Manufacturing Engineering,* vol. 19, Issue 1, November 2016, pp 96–102.

[11] H. Nath Roy, S. Saha, T. Bhowmick, and S. Chandra Goldar, "Productivity Improvement of a Fan Manufacturing Company by using DMAIC Approach: A Six-Sigma Practice", *Global Journal of Researches in Engineering,* vol. 13, Issue 4, 2013.

[12] S. Avikal, R. Jain, P.K. Mishra, and H.C. Yadav, "A heuristic approach for U-shaped assembly line balancing to improve labor productivity", *Computers and Industrial Engineering,* vol. 64, Issue 4, April 2013, pp 895–901.

[13] Purnamasari, Ita, and Atikha Sidhi Cahyana, "Line Balancing dengan Metode Ranked Position Weight (RPW)", *Spektrum Industri,* vol. 13, No. 2, 2015, pp 157–168.

[14] S.B. Liu, H.L. Ong, and H.C. Huang, "A bidirectional heuristic for stochastic assembly line balancing Type II problem", *The International Journal of Advanced Manufacturing Technology,* vol. 25, Issue 1, January 2005, pp 71–77.

Inaki Maulida Hakim (b. 1986) is a researcher in Manufacturing System Laboratory, Universitas Indonesia. She obtained her Bachelor Degree in Industrial Engineering, Universitas Sebelas Maret (UNS). She continued her study in Industrial Engineering and Management, Institut Teknologi Bandung (ITB). She often writes and publishes international journal and conference. Her research focuses on manufacturing system, logistic & supply chain management, and sustainability. She is also active as a lecturer at Industrial Engineering Department, Universitas Indonesia.

T. Yuri M. Zagloel (b. 1963) is a professor and head of Manufacturing System Laboratory, Universitas Indonesia. He obtained his Bachelor Degree in Machine Engineering, Universitas Indonesia. He continued his study in Industrial and Management, University of New South Wales. He got Phd in Faculty of Engineering, Universitas Indonesia. He often writes and publishes international journal and conference. His research focuses on manufacturing system, total quality management, and introduction to industrial engineering.

Astari Wulandari (b. 1995) is assistant researcher in Manufacturing System Laboratory, Universitas Indonesia. She is also a student of Industrial Engineering Department, Universitas Indonesia and has interest in manufacuring, production, and supply chain management.