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The Application of U-shaped Line Balancing at Furniture Manufacturing

Frittandi[1], Rainisa Maini Heryanto[1], David Try Liputra[1], Angling Sugiatna[2]

[1] Bachelor Program in Industrial Engineering, Universitas Kristen Maranatha, Indonesia

[2]Furniture Manufacturing Company in Bandung, Indonesia

Abstract

Setting the number of operators in a production line is very important because it affects the production line's ability to achieve production targets. In the manufacturing industry with make-to-stock (MTS) production with several production lines, operators are often moved from certain production lines to production lines that require more operators. One of the reasons for the need for increasing operators in the production line is the approaching orders due date. This problem was faced by a furniture manufacturing in Indonesia which had imprecise number of operators arrangements and task assignments so that implicated to unachieved production target. This research applied U-shaped line balancing to increase the line efficiency to meet the production target. The research data were collected from direct observation on the actual production line and also from company documents. The methods used in the U-shaped line balancing were maximum ranked positional weight, maximum total number of follower tasks, minimum total number of follower tasks, maximum task time, and minimum task time. The highest line efficiency was obtained by the maximum ranked positional weight method which was 84.08%, increased by 24.37% from the actual one. Besides, the required operators were reduced from 15 to 10 persons with a production capacity of 76,688 units in 12 weeks.

Keywords: *heuristic, line efficiency, production target, number of operators, U-shaped line balancing*

INTRODUCTION

In the manufacturing industry which has several production lines, operators' transfer from one line to another line is a common occurrence. One of the causes of transfer is the other production lines that require additional operators as the order due to date approaches. A production line is the placement of work areas where operations are arranged sequentially and material moves continuously through a balanced sequence operation (Santoso & Heryanto, 2017). A good production line is a balanced production line.

Production line balancing or line balancing is the assignment of jobs to certain workstations that are interrelated in a production line or line (Baroto, 2002). Some of the advantages of balancing the production line are minimum material movement distance due to the arrangement of the workplace, flow is measured by production speed, not by specific quantity, the division of tasks is divided evenly so that it has more efficient use of labor, operations could be carried out simultaneously or at the same time on a single production line, the movement of the workpiece corresponds to the set-up of the line and is fixed, and the production process in a line requires a minimum of time.

This research was applied research in a furniture manufacturing in Indonesia, a make-to-order industry that focused on steel frames folding chairs, and performing operator transfer activity on the production line. The company faced a problem that the production target was not achieved

Corresponding author
frittandi@gmail.com

because of an imprecise number of operators arrangements and task assignments. Imprecise arrangement of operators was affected by operator transfer from one line to another line with the influence of operator absence that caused the company's inability to meet production targets. The imprecise tasks arrangement could be seen from the existence of idle workstations for example assembly workstation of cushion seat that causes the production line to have low line efficiency. The condition of the company's production floor supports the balancing of the U-shaped production line because the layout of the production line was already u-shaped even though the division of tasks and flow took place in a straight line. Therefore, this research used U-shaped line balancing to increase line efficiency to ensure the production targets were achieved.

LITERATURE REVIEW

Rearrange work elements is one way to balance the production line and increase both efficiency line and productivity. The assembly line balancing problem can be divided into two fields (Baybars, 1986). The first one is simple assembly line balancing which determines the tasks assigned to a workstation with the same cycle time, each task has a deterministic processing time and must be performed in only one of the workstations. The second one is general assembly line balancing.
Many previous types of line balancing research have been done to rearrange work elements and implemented at manufacturing, including in Indonesia. Prabowo (2016) in his research about the application of the line balancing concept to achieve optimal work efficiency at each workstation in cigarette manufacturing used the rank positional weight method. Another research was Azwir and Pratomo (2017) about the line balancing implementation to improve efficiency in welding line using 3 methods, i.e. Helgeson-Birnie, Kilbridge-Wester heuristics, and Moodie-Young. Make et al. (2017) use line balancing in the manufacturing industry.

U-shaped line balancing is one of the generalizations of simple assembly line balancing problems (Baykasoğlu & Dereli, 2009). Miltenburg and Winjngaard (1994) were the first to formally publish U-shaped line balancing with a modified positional weight method (Miltenburg & Wijngaard, 1994). According to Cheng et al. (2000) in Martinez & Duff (2004), a U-shaped production line is a special type of cellular manufacturing that is utilized in just-in-time (JIT) and lean manufacturing. The U-shaped production line puts machines in a U-shaped line in the order of production operations are completed.

A traditional production line arranges the tasks sequentially along a straight line. In a U-shaped production line, tasks are arranged and organized into workstations that could cross from one side of the line to the other. The assignment of the tasks to the workstations on a U-shaped line exploits the geometry of the line to keep the return and crossover distances as small as possible. Consequently, total travel distance and, hence, travel time is less on a U-shaped line (Baykasoğlu & Dereli, 2009).

One of the distinguishing features of U-shaped assembly lines over straight assembly lines is that their entrance and exit points are in the same location. Some of the advantages that make U-shaped production line balancing acceptable are volume flexibility, operator flexibility, the number of workstations, eliminating the need for material handling, visibility and cooperation, and shorter distance to return defective products (Cheng, et al., 2000). The layout for the U-shaped production line could be seen in Figure 1.

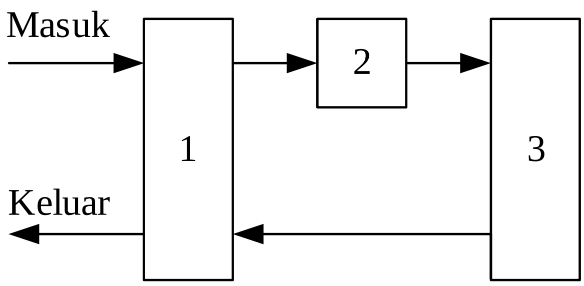

Figure 1. Layout for U-shaped production line (Avikal, et al., 2013)

Solving the large problem of line balancing by using exact and classical optimization procedures is very difficult hence effective heuristic methods are developed. Many researchers used U-shaped line balancing with heuristic methods such as Chen and Plebani (2008) for balancing U-shaped assembly lines with parallel stations, Fathi et al. (2011) for solving U-shaped assembly line balancing problems type-1, and Avikal et al. (2013) for improving labor productivity.
Many previous researches related to line balancing had been carried out, including U-shaped line balancing with various considerations, such as in Kazemi et al. (2011) considering duplicated tasks, Widyadana (2009) and Nakade et al. (2015) considering temporary workers, Varnasilpin and Masuchun (2016) considering uncertainty processing time, and Kucukkoc and Zhang (2017) considering model sequences. Research about the application of U-shaped line balancing in Indonesia was done by Pratikto and Octavia (2009) with applied U-shaped in the water pump assembly.

METHODOLOGY

This research was applied U-shaped line balancing research in a furniture manufacturing in Indonesia. This research used 5 heuristic methods i.e. maximum ranked positional weight, maximum total number of follower tasks, minimum total number of follower tasks, maximum task time, and minimum task time (Martinez & Duff, 2004).

Research methodology could be seen in Figure 2:

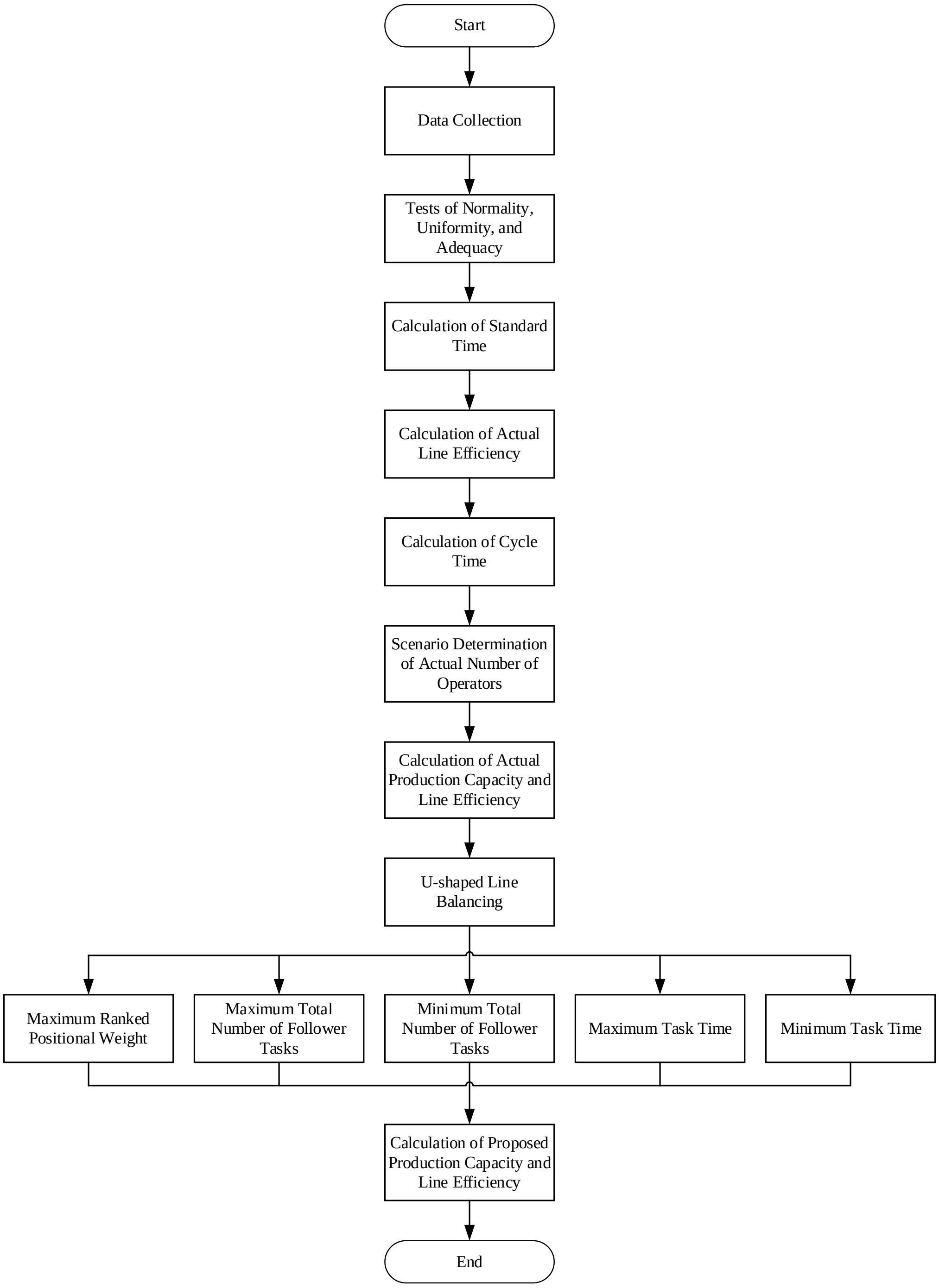

Figure 2. Research methodology

This research began with data collection, which were obtained from direct observation on the actual manufacturing production line and also from company documents. The first step was the testing for normality, uniformity, and adequacy. Normality and uniformity test were performed using IBM SPSS Statistic 21 application with a data confidence level of 95%. All these tests were used so that the data used were normally distributed, not of extreme values, and had sufficient amounts to be processed in the further data processing. The second step was the calculation of cycle time, normal time, and standard time calculation. The third step was the calculation of efficiency percentage to measure the work productivity of the assembly line and utilization percentage to measure the proportion of operator work and operator efficiency at each workstation.

The fourth step was the calculation of actual line efficiency to see the actual effectiveness of a line and to compare the effectiveness of the proposed line and continue with cycle time calculation as a limit in the task assignment of production line balancing and as a reference for the ability of the production line to achieve production targets. The fifth step was to determine scenarios of an actual number of operators. Operators' transfer and absence affect production capacity. Therefore, the scenario was conducted based on operator transfer and absence data to get the possibilities that can happen in the production line. The sixth step was calculating the production capacity and line efficiency of the scenario to prove the inability of the production line to meet the production target. The seventh step was U-shaped line balancing and calculated line efficiency. Balancing with the U-shaped type provides a larger possibility of a task assignment than the straight-line balancing, so the U-shaped production line balancing could provide the possibility of providing higher line efficiency. The eighth step was to generate the scenario number of the proposed workforce. Calculation of the right number of workers needs to be done so that the production line was not disturbed by operator transfers to other production lines and operator absences so that they could meet production targets. The last step was to calculate the proposed production capacity and line efficiency. The effect of the number of operators would be seen for its effect on production capacity and line efficiency.

FINDINGS AND DISCUSSION

The division of operator tasks in the actual production line could be seen in Figure 3. Operations are represented as circles and inspections are represented as squares. It is symbolized as a black box for machines or tools that are not used. The precedence diagram for the product assembly process could be seen in Figure 4.

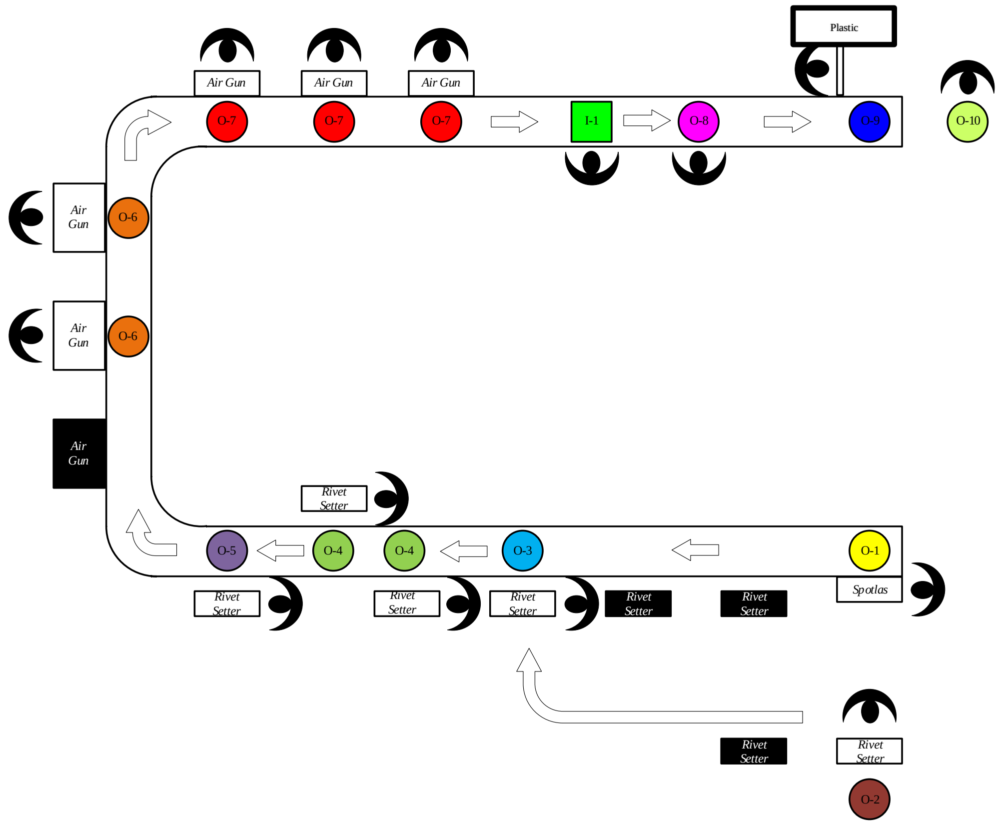

Figure 3. Division of operator tasks

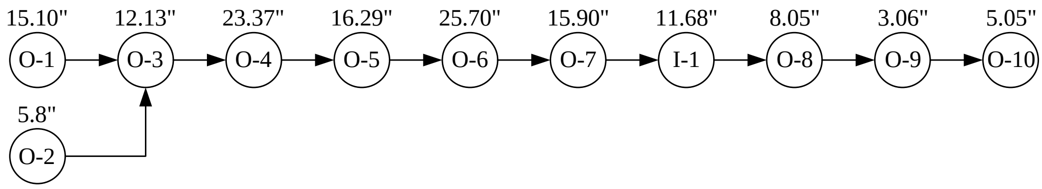

Figure 4. Precedence diagram

Furniture manufacturing had a total production target of 65,455 units for 12 weeks. Based on theoretical calculation, the production line had an efficiency of 59.71% with 15 operators and a production target of 82,297 units for 12 weeks without operator transfer or absence. The production line could meet the target demand because the maximum cycle time that occur after paralleling in the production area was 16.29 seconds, below the required cycle time of 20.48 seconds. However, non-fulfillment of production targets often occurs, this is influenced by the number of operators being transferred to other production lines or not being present.

In the process, operators often move to other production lines or operators were not present, this was known from the work plans and daily work. This certainly affects production capacity and line efficiency. Scenarios were made to prove the effect of operator reduction on actual production capacity. From the data, it was known that 1 to 3 operators were absent per day. Based on this data, 10 scenarios were made, the number of operators/scenarios and the number of transfers are shown in Table 1.

Table 1. Scenario

Operation	Scenario									
	1	2	3	4	5	6	7	8	9	10
O-1	1	1	1	1	1	1	1	1	1	1
O-2	1	1	1	1	1	1	1	1	1	1
O-3	1	1	1	1	1	1	1	1	1	1
O-4	1	2	2	1	1	2	2	1	1	2
O-5	1	1	1	1	1	1	1	1	1	1
O-6	2	1	2	1	2	1	2	1	2	1
O-7	3	3	2	3	2	2	1	2	1	1
I-1	1	1	1	1	1	1	1	1	1	1
O-8	1	1	1	1	1	1	1	1	1	1
O-9	1	1	1	1	1	1	1	1	1	1
O-10	1	1	1	1	1	1	1	1	1	1
Total	14	14	14	13	13	13	13	12	12	12

Scenarios could occur supported by the operator's ability to operate all machines and all operations due to the training received beforehand. The assumption used in this section was that the initial total operator required was 15 operators according to the observations. The reduction of workers is influential throughout the period (12 weeks), and the reduction of workers was only carried out at workstations that have more than 1 operator, of which there are O-4, O-6, and O-7. Table 2 shows the effect of operators transfer and absence to production target.

Table 2.
Effects of operators transfer and absence

Scenario	Number of transfers and absences of operators	Operating	Number of transfers and absences of operators	Operating	Number of transfers and absences of operators	Operating	Production Target
1	1	O-4		O-6		O-7	Unachieved
2			1				Unachieved
3					1		Achieved
4	1		1				Unachieved
5	1				1		Unachieved
6			1		1		Unachieved
7					2		Achieved
8	1		1		1		Unachieved
9	1				2		Unachieved
10			1		2		Unachieved

From the 10 scenarios that have been made, it could be seen that 8 out of 10 scenarios of operator shifting to another production line and the absence of the operator could make a production line that should be able to achieve its production target unable to achieve its production target. The effect of the number of operators was very significant and must be designed properly. In addition to influencing the achievement of demand, the number of operators also affects the line efficiency. One way to improve line efficiency and control the number of operators is to balance the production line.

The U-shaped line balancing was carried out to obtain the possibility of higher line efficiency due to the combination of more loading and more flexibility than traditional production line balancing. The higher number of combinations due to loading could be done by looking at it from two directions, operations that are free from previous operations and operations that do not have successor operations (available operations). Coupled with the arrangement of the production line layout on the production floor that has formed a U but the balancing and division of the U-shaped type of production line have not been carried out.

In this research, 5 heuristic methods were used to balance the U-shaped production line, including the maximum rank positional weight, maximum total number of follower tasks, minimum total number of follower tasks, maximum task time, and minimum task time. The calculation result for heuristic methods in U-shaped line balancing could be seen in Table 3 and the result for maximum rank positional weight could be seen in Table 4.

Table 3. Result for U-shaped line balancing

Method	Number of Operators	Line Efficiency	Smoothness Index	Production Capacity in 12 weeks
Maximum Rank Positional Weight	10	84.08%	9.75	76,688
Maximum Total Number of Followers Tasks	10	72.95%	17.45	66,536
Minimum Total Number of Followers Tasks	10	72.95%	17.45	66,536
Maximum Task Time	10	72.95%	19.15	66,536
Minimum Task Time	10	74.50%	15.86	67,953

Table 4. Result for maximum rank positional weight

Workstation	Operation	Operation Time (second)	Cumulative Time (second)	Number of Operator	Time per Operator (second)	Line Efficiency
1	O-10	5.05	16.16	1	16.16	84.08%
	O-9	3.06				
	O-8	8.05				
2	O-1	15.10	15.10	1	15.10	
3	O-2	5.80	17.48	1	17.48	
	I-1	11.68				
4	O-3	12.13	12.13	1	12.13	
5	O-7	15.90	15.90	1	15.90	
6	O-4	23.37	23.37	2	11.68	
7	O-6	25.70	25.70	2	12.85	
8	O-5	16.29	16.29	1	16.29	

From Table 3, it could be seen that each method could reduce the number of operators by 5 operators, increase line efficiency, and increase production capacity in 12 weeks, but the best results are found in the maximum ranked positional weight method with line efficiency reaching 84.08% and capacity production/period reached 76,688 units in 12 weeks. In this method, operation 8, operation 9, and operation 10 are combined using a workbench (at workstation 1) and combining operation 2 with a rivet setter machine with inspection using a workbench (at workstation 3).

From Table 4, the effect of the operating load on workstation 3 is a shift in the position of the operator when carrying out operation 2 and inspection, of course also affects and reduces the percentage of use of the rivet setter machine in operation 2 because the operating time of the workstation 3 is 17.48 seconds consisting of 5.8 seconds operation 2 and 11.68 seconds of inspection. Since workstation 3 is the bottleneck in the production line, it can be concluded that the use of the rivet setter machine in operation 2 is only 5.8/17.48 ~ 33.2%. In addition, there was a reduction in production capacity in 12 weeks from 82,297 units in 12 weeks to 76,688 units in 12 weeks or a decrease of 6.82%.

However, the reduction in the percentage of machine usage to 33.2% and a reduction in production capacity of 6.82% could be covered by a reduction of 5 operators and a 24.37% increase in line

efficiency from the actual system (see Figure 5). In addition, reducing production capacity is not a problem because production capacity was still above the production target.
Similar research on the application of u-shaped line balancing in Indonesia was on the water pump assembly line. In that study, the line efficiency increased by 15.91% i.e. from 79.53% to 95.44%. U-shaped line balancing required the fewer number of workstations, reduced the number of workstations, and also required a smaller number of workers, but as a consequence, a more skilled workforce was needed. A comparison of the increase in line efficiency from the two studies can be seen in the Figure 5.

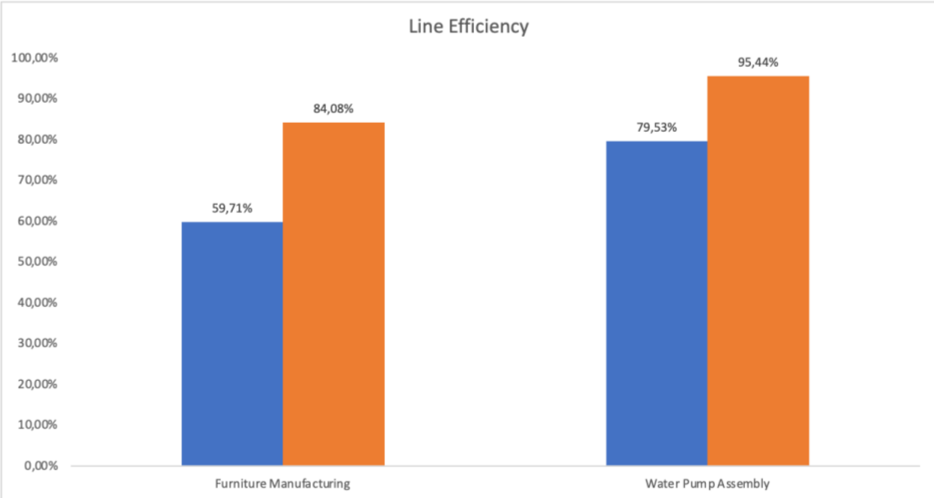

Figure 5. Comparison of production line efficiency

CONCLUSION AND FURTHER RESEARCH

The U-shaped production line balancing could meet the demand target, improve line efficiency, reduce the longest processing time, and at the same time could reduce the number of operators. In this application research, the actual production line could theoretically meet the demand target. The operator transferred to other production lines and absence affected the production line's ability to meet demand targets. In reducing the possibility of operator absence, balancing the U-shaped type of production line was carried out and it was known that the number of operators needed to meet the production target is 10 operators with a production capacity of 76,688 units in 12 weeks. The balancing of the U-shaped production line was carried out to increase the line efficiency from 59.71% to 84.08%.

Further research should be considered about the scenario of using the proposed number of operators based on the needs of operators in other production lines and the possibility of unavoidable operator absence so that the company could employ more than 10 operators. Five operators are deducted from the actual system if the operator is transferred, gets a job in another production line, and not be unemployed. Therefore, from operator transfer data to other production lines and operator absence, one to three operators may be transferred to another production line while still leaving more than 10 operators to avoid the possibility of operator absence resulting in the production target not being achieved. From this possibility, the reduction in the number of operators could only be done from one to three operators assuming the operators work in other production lines.

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