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A CASE STUDY OF PRODUCTION LINE BALANCING WITH SIMULATION

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ABSTRACT

The purpose of this paper is to simulate production line improvement using computerized simulation software. The model is developed based on current state operation system which had been identified to have imbalanced performance between 18 workstations. The paper presents the analysis of simulation model to overcome the stated problems. The findings found that by having balance production system in assembly line will be able to optimize overtime and job performance while eliminating a number of buffer stock (work in progress). The results also encourage the multi-tasking and job rotation which can promote job optimization.

Keywords*:* simulation, line balancing, assembly line

INTRODUCTION

Assembly lines are flow oriented production layout used for well-organized and mass production of products (Boysen et al., 2007). An assembly line consists of a certain number of workstations located beside material handling system (e.g., on conveyer belt etc.) which are composed of particular tasks. Assembly workpieces are moved down the assembly line from one station to another for different assembly operations. Assembly of parts is divided into a set of a small number of operations. These operations are called tasks related to certain assembly product and there exists precedence relation among different tasks. These precedence relations among tasks are used to define the appropriate priority of performing certain tasks relative to other tasks in the assembly operation of the product. Assembly line balancing problems are mostly focused on identifying feasible line balance which can satisfy all the precedence constraints and some other restrictions which may include some of the objectives of the problem (Saif et al., 2014).

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The problem of assembly line balancing consists of determining the set of task to be performed for every station in a way that the operation time does not exceed the cycle time and that the technological precedence relation between single task are not violated that a task preceding on another task has to be performed at an earlier station or at the station to which the other task is assigned to at the latest. Besides, the line balancing method attempts to allocate an equal amount of time for each worker so that the production flows smoothly without long waiting times (Bhattacharjee and Sahu, 1988). The concept was to design or group tasks at workstations so that the workforce (the number of stations) is minimized or the output rate is maximized, which is equal to minimizing the cycle time, or as a combination of optimizing problem for finish first time.

Line balancing can be defined as the process to minimize the imbalance between machine and personnel while meeting a required output from the assembly line. Balancing of the assembly line is being one of the importance strategies as steps for cost reduction and standardization. Many companies started to re-think about the importance of balancing the production line to reduce the cost and time hence increase the number of output. Research has been conducted by Falkenauer (2004) and found that the waste caused by the line balancing issue can attain millions of dollars per year. There are a few things that need to be taken into consideration and these include the number of product, model, the line layout, the automation used in the line, the flow of workpiece throughout every station, the complexity of production environment. Hence, balancing the line is just one of the method to ensure that the manufacturing procedure can create the item within the approximately estimation period time (Lang, 2011).

Typically, the goal of this balancing problem is the minimization of idle time of line through the minimization of a wide range of necessary workstations, the minimization of cycle time, or a mixture of both. The good line balancing shows that the cycle time for each workstation is close to balancing's line. The further of the cycle time of a workstation to line balancing will trigger the waiting time in each job between stations. This will be among the issues experienced in balancing line. The well-balanced line can be described briefly as utilizing the maximum resource in work, gear to lessen the wide range of waiting time between stations, thus reducing the production cost. In a labour-intensive production process, the task time is uncertain since it depends on the skill of each employee, the work environment, fatigue, etc. In labour-intensive manufacturing processes, the task time is varied, then, implementing the Line balancing approach will balance the time taken at each station in the production line by allocating the right number of employees to each station.

The line balancing issue is defined as the grouping regarding the jobs needed to assemble the last product towards the stations that are organized in a serial style and connected collectively by a transportation system. When the permanent production condition has been achieved, the

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manufacturing products flow along the line at a continual piece, and every workstation features an equivalent allocated time for completing particular jobs.

PROBLEM STATEMENT

In the case study, there is a production line facing a problem where the specific product cannot achieve standard target output in normal working hour. On the other hand, the number of buffer (or Work in Progress- WIP) in particular workstations is also imbalance and the issue has been considered as one of the main problems to the assembly line as per new company policy to achieve zero WIP when normal working hours end. The modeling and simulation system play an important role in managing the system such as using simulation to imitate the current production line before implementing to the actual system.

There are about six models that are developed. The authors can identify the disadvantages based on the models; there is a certain model that used to be different in many ways such as the component, the position of the station of the machine or jig, etc. The following are factors that enhanced the line balancing model:

- Operator flexibility: Since walking distance is shorter, it is easier for an operator to oversee several workstations.
- Number of workstations: The number of workstations required is never more than that required on a normal line. There are more possibilities for grouping tasks into workstations.
- Material handling: A production line eliminates the need for special material-handling equipment such as conveyors and other special material handling operators. Instead, production operators move products from machine to machine.
- Visibility and teamwork: In a straight line layout, operators are spread out along a long line and may be separated by walls of inventory. The compact size of a U-line improves visibility and communication. This enhances teamwork, gives a sense of belonging, and increases responsibility and ownership compared to a straight line.
- Rework: The distance to return the defective product is short. It is easier to correct a quality problem quickly by returning a defective product to the station where the product was produced.
- Takt time: Takt time can be defined as the rate of customer need, calculated by dividing the readily available production time by the quantity the customer requires in that time. The reciprocal of the production rate, industrial manufacturing lines must have production cycle time at least as short as the takt time so that the production can match the customer demand.

$$\text{Takt Time} = \frac{\text{Available Working Minutes per Day}}{\text{Daily Quantity Required}} \quad \text{OR} \quad \frac{\text{Time}}{\text{Volume}} \qquad \text{(eq. 1)}$$

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- Work in Process: Work in Process (WIP) refers to all products and partially done items that are at different phases regarding the manufacturing process. WIP excludes inventory of raw materials at the start of the production cycle and finished products inventory at the end of the production cycle. WIP indicates that too many productions can lead to a situation where some stations will not have enough time to complete one set of product and this may lead to waiting time on the worker.

DEVELOPMENT OF SIMULATION MODEL

Flow system is the first of many steps to make a simulation system. The importance of the process flows chart to the system is to give the guidance to the system where it will be a medium to propose a good production layout. Figure 1 shows the flow of the processes where it contains 18 steps which are divided into three main sections: assembly preparation; main assembly line; and inspection line. Each workstation (WS) required at least one operator to do the assembly job. All the operators work daily from 8:00 a.m. to 5:30 p.m. with an hour break between 9:30 a.m. and 10:00 a.m., one-hour lunch break from 1:00 p.m. to 2:00 p.m., and 30 minutes tea break after 3:30 p.m. The overtime is allowed but not more than two hours.

The process goes as follows: the assembly kit will be served by the operator in assembly prep section which is composed of three workstations (WS1 to WS3) where the number of the workstation is determined based on machine and special product jig and a fixture on the particular process. Section two is main assembly line which can be distributed into two groups. Group A consists of WS4 to WS9 while group B consists WS10 to WS14. In this section, the conveyor is used for material handling where each of the group will have a different flow of product movement. The last section is inspection line. Four operators are required and consist of workstations WS16 to WS18, involving almost similar testing instrument.

The daily quantity required is 200. Table 1 shows the cycle time distribution that has been generated by input analyser (one of the ARENA simulation tool) to determine the best data with a less square error in the model development while Figure 2 shows the ARENA simulation model.

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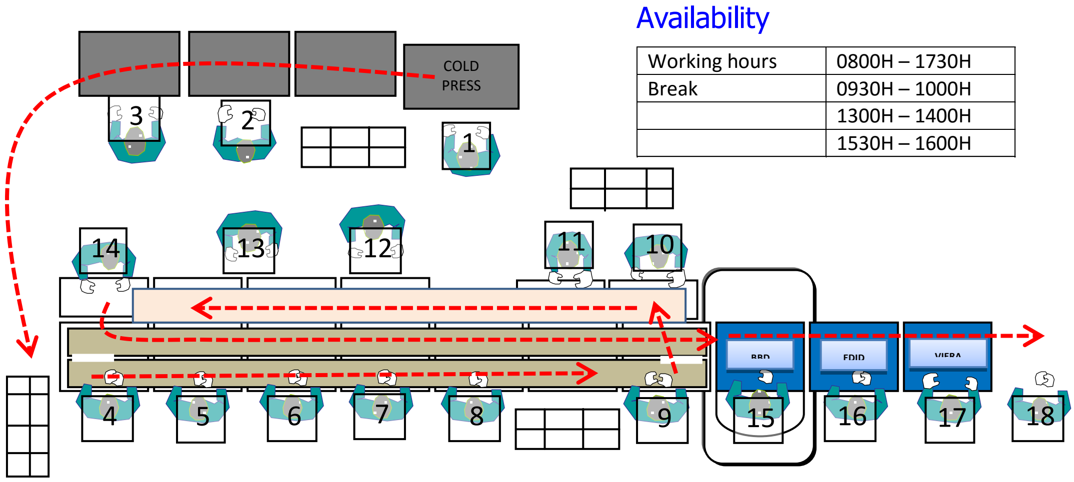

Figure 1: The flow of the current production line

Table 1: Cycle Time Distribution Analysis

WS	Mean (in second)	CT Distribution	Square Errors
WS1	75.8	75.1 + 1.45 * BETA(1.43, 1.63)	0.018456
WS2	85.7	84 + 2.96 * BETA(1.17, 0.951)	0.018570
WS3	176.0	TRIA(173, 176, 177)	0.100998
WS4	146.0	143 + 5.72 * BETA(1.07, 0.9)	0.056070
WS5	88.5	85 + 6 * BETA(0.991, 0.708)	0.008087
WS6	83.8	82.1 + LOGN(1.75, 1.44)	0.011701
WS7	112.0	110 + LOGN(1.93, 1.3)	0.019281
WS8	113.0	109 + 7 * BETA(0.893, 0.848)	0.057365
WS9	86.3	TRIA(83.1, 87.1, 88.8)	0.013379
WS10	69.1	66 + 5 * BETA(0.835, 0.525)	0.044335
WS11	71.8	TRIA(70.3, 70.6, 74.5)	0.004522
WS12	88.6	85 + 6 * BETA(1.1, 0.777)	0.022879
WS13	75.5	UNIF(73, 78)	0.020000
WS14	85.1	NORM(85.1, 1.39)	0.027741
WS15	73.1	71 + GAMM(0.989, 2.11)	0.047108
WS16	82.2	UNIF(80, 84)	0.080000
WS17	86.7	TRIA(83.2, 88, 89)	0.050658
WS18	58.6	56.3 + LOGN(2.45, 1.83)	0.061772

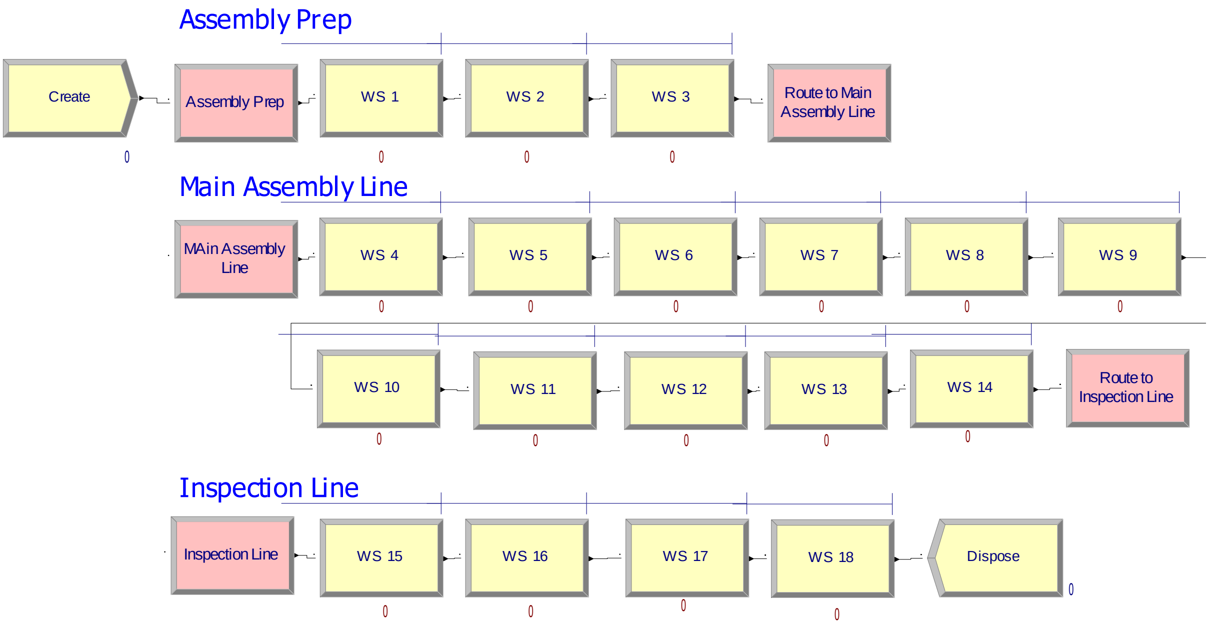

Figure 2: Arena simulation model

RESULT AND DISCUSSION

Verification of Simulation Model

Verification is a medium to identify the simulation, either the simulation is good enough to implement or not. Verification of simulation model could be done by calculating the number of output and comparing the similarities of the output of the actual production line with the simulation model. The reason a verification method is made is to identify the confident level of the simulation model. Table 2 shows the verification of the simulation model by using the data from the study.

Table 2: The Verification process of the simulation system and takt time calculation

Content	Actual Production line	Simulation model
Input	200	200
Output	168	166
Different	2	
Level verification	100 – (2/168 * 100)	98.81%

The input of the line was 200 same as the simulation but the different is the number of the output produced. The total output of the actual production line was 168 sets compare to the output produced by the simulation model which was 166 sets. Both, the actual and the simulation model are based on the same data of time study. The verification calculation is based on the differences of the number of output produced. The result shows that the difference of the output is 2 sets, the simple calculation, and the total calculation shows that

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the confident level of the simulation model is about 98.81%. In other words, the simulation model and actual production line have 98.81% similarities. There is standard verification that the simulation should follow in order to achieve a good simulation with higher similarities between the actual line and the simulation model. The simulation has a total verification of 95% and above, the simulation have complete similarities with the actual production line but if it is below the 95%, the simulation confident level is low.

The similarities of both actual production line and the simulation model are important because as both of the line have high similarities, the problem caused by the actual production line now can be easily monitored by the simulation model.

Analysis of Takt time

There are four alternatives of working hours that have been considered: normal working hour (10.5 hours); normal working hour with 1 hour overtime job (11.5 hours); 1.5 hours (12 hours) and 2 hours (12.5 hours). The considerations of all the four alternatives are due to the takt time limitation. Each process must not exceed the takt time (153 seconds). If any process is equal to or more than takt time value, the overtime is not applicable. This constraint is the first consideration in the production line balancing.

Figure 2 shows the analysis of takt time. From Figure 2, cycle time at WS3 is the highest and exceeds the limitation. So, overtime for this workstation is not applicable. On the other hand, WS4 also will be not allowed for overtime job due to similar reason as WS3. Otherwise, the workstations need to improve cycle time less than takt time value, 153 seconds. The analysis also showed that some processes have potential to be merged but it is limited to process or job design in the particular workstation including special machinery or equipment or jig and fixture. WS1, WS2, WS5, WS6, WS10 TO WS18 are the most potential workstation to be combined if the company required reducing the number of the workstation. Besides, they also can optimize the manpower utilization through job rotation or job enlargement as suggested by previous researchers (Boenzi et al., 2015; Bortolotti et al., 2015).

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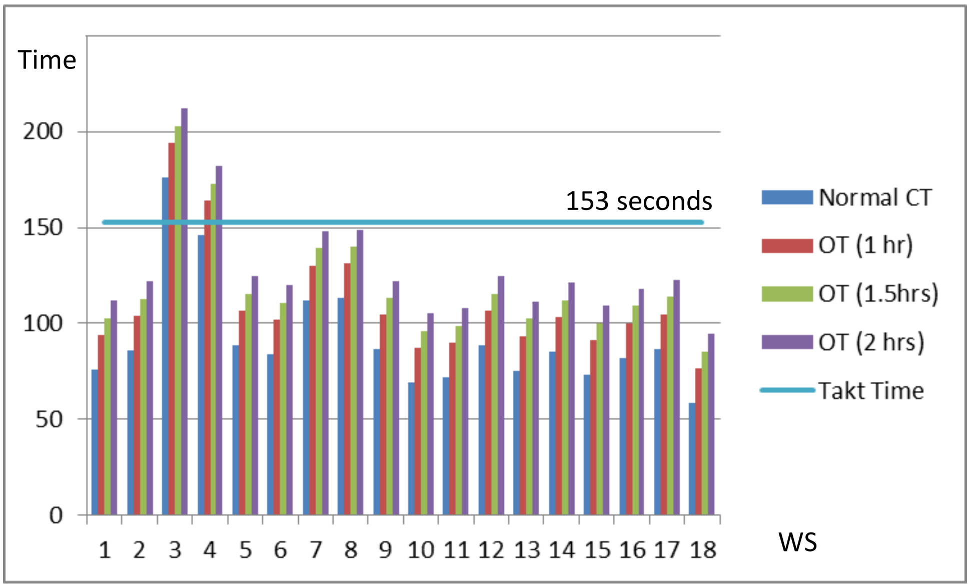

Figure 2: Analysis of Takt time

The calculation of takt time is as follows:
Given information:
Normal working hours: 10.5 hrs
Normal break time: 2 hrs
Available Working Hours per Day = 10.5 – 2 = 8.5 hrs ~ 30600 seconds
Daily Quantity Required = 200 units

$\therefore$ Takt Time = 30600 ÷ 200 = 153 seconds

If overtime job is allowed (for example WS1) the new cycle time will be considered as follows:

WS1 normal cycle time = 75.8
With 1 hr overtime job will give additional 18 seconds to the operator to meet daily quantity demand, 200 units of finish goods. In other words, the new specific takt time will increase while the operator has a chance to complete at least 47 unit additional product in WS1.

Given information:
Additional working hours: 1 hr ~ 3600 seconds
Daily Quantity Required = 200 units
New takt time for WS1: 75.8 + (3600/200) = 93.8 seconds
Additional WIP product completion = 3600 ÷ 75.8 = 47.49 ~ 47 units

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Table 3 shows the detailed analysis on specific takt time in 18 workstations. Based on Table 3, the highlight in the table shows that overtime job status allocations are not be allowed. WS3 and WS4 are clearly identified as critical workstations and lead-time reduction must be performed to meet customer takt time.

Table 3: Specific takt time calculations

WS	Normal CT	Specific takt time in WS		
		OT (1 hr)	OT (1.5hrs)	OT (2 hrs)
WS1	75.8	93.8	102.8	111.8
WS2	85.7	103.7	112.7	121.7
WS3	176	194	203	212
WS4	146	164	173	182
WS5	88.5	106.5	115.5	124.5
WS6	83.8	101.8	110.8	119.8
WS7	112	130	139	148
WS8	113	131	140	149
WS9	86.3	104.3	113.3	122.3
WS10	69.1	87.1	96.1	105.1
WS11	71.8	89.8	98.8	107.8
WS12	88.6	106.6	115.6	124.6
WS13	75.5	93.5	102.5	111.5
WS14	85.1	103.1	112.1	121.1
WS15	73.1	91.1	100.1	109.1
WS16	82.2	100.2	109.2	118.2
WS17	86.7	104.7	113.7	122.7
WS18	58.6	76.6	85.6	94.6

Analysis of WIP and Manpower Utilization

Grounded on the four types of working hours, six ARENA model configurations have been performed. Table 4 shows the results of the analysis which is represented by A (current performance with normal working hours), B (extended 1 hour working hour), C (with 1.5 hour overtime job), D (with 2 hour overtime job), E (with 1.5 hour overtime job into two types of working hour: WS1 – WS8: 800H – 1730H; WS9 – WS18: 830H – 1800H), and F (Standard working hour (with additional 1 manpower at WS3), flexibility job in WS16, WS17, and WS18 and two type of working hours: WS1 – WS15: 800H – 1730H; WS16 – WS18: 830H – 1800H).

The configurations were based on potential generated output, WIP and manpower utilization (MU). The settings also consider low-cost impact and work balance. From Table 3, it can be seen that the configuration on A, B and C does not achieve the daily quantity required – 200.

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The A has 34 WIP where B and C are 14 and 4 respectively. WS3 is the most critical workstation if A and B are nominated. For D, E and F, the results show that no WIP is generated but the costs involve varies.

Table 4: WIP and Manpower utilization

WS	A	B	C	D	E	F
	WIP	WIP	WIP	MU	MU	MU
WS1	-	-	-	33.67	33.68	38.27
WS2	-	-	-	38.04	38.05	43.24
WS3	27	6	-	77.93	77.93	44.38
WS4	1	1	-	64.93	64.93	73.80
WS5	-	1	-	39.32	39.33	44.69
WS6	1	-	-	37.25	37.23	42.35
WS7	-	1	-	49.73	49.74	56.54
WS8	1	-	-	50.03	50.01	56.90
WS9	1	1	-	38.36	38.38	43.57
WS10	-	-	-	30.69	30.71	34.89
WS11	-	1	-	31.89	31.90	36.27
WS12	1	-	1	39.32	39.31	44.68
WS13	-	1	-	33.54	33.54	38.12
WS14	1	-	1	37.83	37.86	43.01
WS15	-	1	-	32.46	32.45	36.92
WS16	1	-	1	36.44	36.43	38.51
WS17	-	1	-	38.55	38.55	38.51
WS18	-	-	1	26.11	26.12	38.51
	34	14	4	-	-	-

Figure 4 shows the manpower utilization graph. From Figure 3, the F is better than D or E because it can improve the utilization of several workstations and can be considered more balanced. For F, the range of manpower utilization is 38.91 percent while D and E are 51.8 percent respectively.

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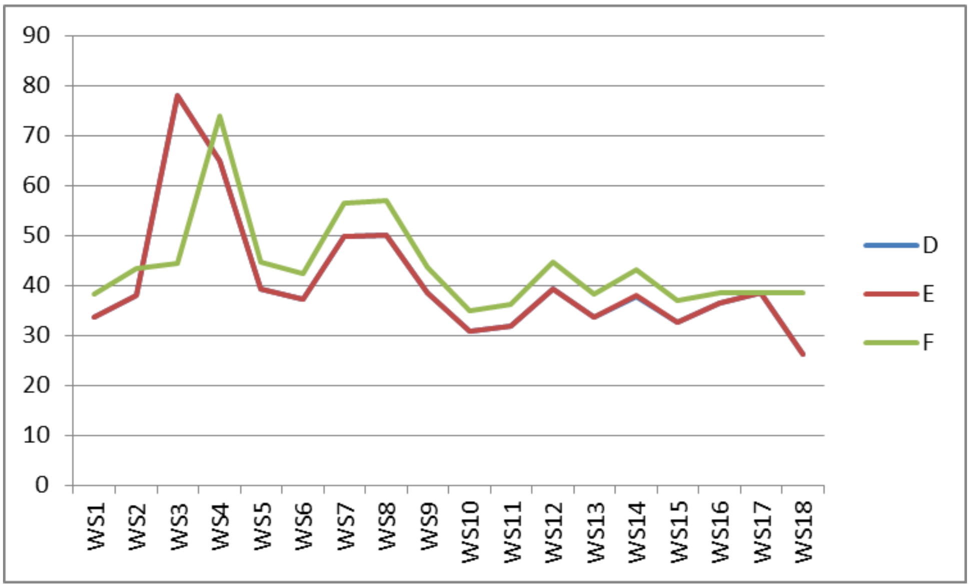

Figure 3: Analysis Of Manpower Utilization

CONCLUSION

In conclusion, this paper proved that with simulation, the manager can be able to define several numbers of alternatives in business improvement strategy. In this case study, at least 6 configurations have been determined. Each of the settings provided different results where every analysis was able to enhance decision-making in the industry. Flexibility is also been identified as an important component to boost up the productivity while reducing the operational cost especially job multi-tasking and job rotation. For future study, the authors will identify the specific improvement by the workstations if any other evolution can be proposed to enhance the production line performance.

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