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Development of an Effective Shopfloor Plan for the Heater Manufacturing Industry in Malaysia

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Keywords：Shopfloor plan, smoothness index, line efficiency, line balance loss

ABSTRACT

Manufacturers in Malaysia and overseas continuously seek for effective shopfloor plan and lean management tools to fulfil customers' requirements and overcome challenges such as fluctuations in market demands. One of the primary goals of a company regardless of industry is to gain a competitive edge in the local and/or global market. The objective of this research is to develop an effective shopfloor plan for the heater manufacturing industry, where Company XXX was selected for the pilot study. The line efficiency and percentage of line balance loss were determined in order to evaluate the proposed shopfloor plan.

INTRODUCTION

Lean manufacturing (LM) has been widely used by manufacturers worldwide over the last few decades. Nowadays, LM is not only implemented in the manufacturing industry but also in other industries ranging from service providers to healthcare and education. LM has become the paradigm for manufacturing processes because of its numerous benefits, which include minimizing wastes, simplifying process flow, and promoting continuous improvement (Womack & Jones, 2010). Various LM tools have been developed and implemented in companies such as Kaizen, Kanban, just-in-time, total quality management, total productive maintenance, 5S (sort, straighten, shine, standardize, sustain), supply chain management, and the seven wastes (muda) concept (Herron & Braiden, 2006). Most researchers and practitioners agreed that LM was developed from the Toyota Production System (TPS) based on its method and working principles (Powell et al., 2014).

LM is one of the well-established systems that is known to boost productivity. According to Dutta and Banerjee (2014), the implementation of LM offers significant benefits for a company such as reduction of process queues by 70%, reduction of lead time by 50–90%, reduction of operating costs, space savings, improved quality control, and continuous improvement. The LM concept emphasizes on making changes to the manufacturing process on an ongoing basis for continuous quality improvement and cost reduction (Lapinski et al., 2006). Despite the numerous benefits that can be gained from the implementation of LM, many companies do not exploit the advantages of LM tools and practices (Dutta & Banerjee, 2014).

The implementation of LM can boost the overall productivity of a company by significantly reducing the processing time and idle time, increasing efficiency by effective allocation of labour, and minimizing defective products (Ng & Ghobakhloo, 2018). With these improvements, the company can increase its profit margins.

At present, a large number of manufacturers in Malaysia (regardless whether they are small and medium enterprises or large enterprises) implement conventional shopfloor plans, which have been their standard practices for many years. These shopfloor plans lead to inefficiency owing to overlapping and repetitive tasks as well as the large number of operators in the production lines. To maximize productivity and overcome the problems associated

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with conventional shopfloor plans, companies are now geared towards the implementation of LM tools and factory automation.

In this research, Company XXX was selected for the pilot study. Company XXX was established in the 1990s and it is now one of the leading enterprises in Malaysia to supply and service heater-related products. Company XXX is now a major supplier of heater components in the local and global market. Similar to other companies in Malaysia, Company XXX implements conventional shopfloor plans for many years and therefore, faces problems such as redundant workers and manual processes. The quality of the final products is highly dependent on the skills of the operators. Thus, the company plans to adopt LM and factory automation in order to overcome the problems associated with the conventional production process.

The following problems were identified upon a site visit to Company XXX:

1. Some tasks are overlapping/repetitive.
2. Several substations consume more time to complete a particular task.
3. Sluggishness is present among the operators between the process lines.
4. There is lack of standardization in certain processes.

With this in mind, the objective of this research is to develop an efficient shopfloor plan to boost the productivity of the production line. By implementing the proposed shopfloor plan, the company can reduce both labour and overhead costs. In addition, the time required for subassemblies can be significantly reduced, which will speed up the overall process flow. The proposed shopfloor plan can also help promote safety awareness among the workers, which will reduce the likelihood of accidents in the production line. All of these will help boost the overall productivity of the company and improve the quality of products.

More importantly, the results obtained in this research provide a more realistic view of the scenario in the heater manufacturing industry since the pilot study was carried out in one of the leading enterprises of heater-related products in Malaysia. However, this research is subjected to the following limitations. Firstly, this research is limited to the implementation of LM in the production line of a manufacturing company in Malaysia. Hence, the shopfloor plan proposed and tested in this research may not be applicable for production lines in other countries. Secondly, this research is restricted to the heater manufacturing industry and therefore, the results may not be applicable for other manufacturing sectors such as automotive and electrical and electronics.

Numerous management tools have been used in various industries worldwide in response to the rise in competitive pressure and therefore, companies are focused on boosting productivity levels, maximizing cost savings, improving product quality, and increasing responsiveness towards the customers, suppliers, or internal departments within the company (Jayaram et al., 2004). These management tools are also known as LM tools. LM is known to eliminate wastes and nonvalue-added activities using the least amount of resources (Karim & Arif-Uz-Zaman, 2013). Even though LM originates from the manufacturing sectorm LM tools have been used in other sectors such as construction, software, and healthcare (Vamsi & Kodali, 2014; Landsbergis et al., 1999; Pekuri et al., 2012). The purpose of LM tools is to identify and eliminate numerous wastes in daily operations (Powell et al., 2014). The level of effectiveness is proportional to the level of LM implementation, which means that a company that has implemented a number of LM tools generally attains more lean outcomes compared with a company that has only implemented an LM tool (Kumar et al., 2013; Karim and Arif-Uz-Zaman, 2013; Hibadullah et al., 2014).

In general, lean systems enable a company to respond rapidly towards customers' requests. Because most business processes are linked to the supply chain, the implementation of lean systems with supply chain management can bring considerable benefits to a company (Melton, 2004). In addition, LM tools such as supply chain management is a key driver of a company's performance by reducing lead time and improving product quality (Jayaram et al., 2004).

One of the main objectives of assembly line balancing problem (ALBP) is to assign assembly operations to a set of workstations in order to optimize performance and satisfy technological, operational, and organizational constraints (Fathi et al., 2018). ALBP is one of the most well-studied problems. According to Koltai et al. (2014), ALBP can be categorized into two main groups (simple and generalized ALBPs) based on their underlying assumptions and limitations. In this research, the existing shopfloor plan was described as a simple ALBP and solved accordingly. According to Fathi et al. (2018), the line efficiency and idle time are reliable performance measures to solve assembly line balancing problems. Thus, the proposed shopfloor plan was assessed based on smoothness index, line efficiency, and percentage of line balance loss.

OBSERVATION

Figure 1 shows the actual process flow (existing shopfloor plan) for Model ABC produced by Company XXX observed in this research. Model ABC was selected for this research because it was one of the common heaters produced by the company. At the time of study, the production target was 1,000 pieces/day whereas the actual production was ~850 pieces/day including overtime. Hence, it was deemed necessary to upgrade the existing production line in order to achieve the production target and cope with the significant overhead and overtime costs.

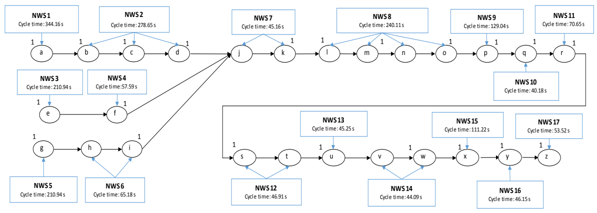

Fig. 1. Process flow for Model ABC produced by Company XXX (existing shopfloor plan).

The existing production line consisted of 17 workstations and 21 operators. The total number of tasks was 26, which were assigned to specific workstations and operators. The following six workstations were operated by operators and these stations were used for multiple tasks: NWS 2, NWS 6, NWS 7, NWS 8, NWS 12 and NWS 14. The tasks of these workstations were reviewed to improve the line efficiency and solve the ALBP. Time study was carried out to determine the cycle time and process time of each process in the existing shopfloor plan.

As shown in Figure 1, there are 17 workstations in the existing shopfloor plan. Table 1 shows the details of each workstation in the existing shopfloor plan, the task(s) involved at each workstation, and the average cycle time of each process recorded using a stopwatch. Fifty sets of readings were taken and the average cycle time was determined for each process. The cycle time refers to the time from when the product enters the workstation until the time when product is transferred to another workstation. The cycle time includes the process assembly time, waiting time, and idle time for the product at a particular workstation.

The details of the tasks listed in Table 1 are provided in Table 2. The number of operators required for each task, the process time, the number of preceding tasks, and the tasks that are the immediate predecessors are also presented in Table 2. The process time represents the actual time that an operator performs a specific task and it excludes the loading time, unloading time, and idle time. Time study was not carried out for other models in this research to prevent biases in the data.

Table 1: Average cycle time for each process in the existing shopfloor plan for Model ABC determined from the time.

Workstations no., NWS	Name of workstation	Task (s)	Average cycle time (s)
1	Press and solder stud to cap	a	344.16
2	Solder heater to top cap	g, h, i	278.65
3	Solder brass bushings to outlet pipe	b	210.94
4	Brazing outlet pipe to bottom cap	c	57.59
5	Solder brass bushings to inlet pipe	d	60. 08
6	Brazing inlet pipe and PS connector to tank	e, f	60.18
7	Press top cap and bottom cap to tank	j, k	45.16
8	Induction welding top cap and bottom cap to tank	l, m, n, o	240.11
9	Cleaning	p	129. 04
10	Cooling	q	834.00
11	Puncture / Insulation / Ohm test	r	70.65
12	Silicone sealant and ceramic bread insert	s, t	46.91
13	Hydraulic press	u	45.25
14	Spot welding and Hipot test	v, w	44. 09
15	Air leak test	x	111.22
16	Puncture / insulation test	y	46.15
17	Final checking and packing	z	53.52
Total cycle time			2677.70

Table 2: Details of tasks, number of operators required for each process, process time, number of preceding tasks, and immediate predecessors of the existing shopfloor plan for Model ABC identified from the time study (Chong et al., 2019).

Task no	Task name	No. of operators	Process time (s)	No. of preceding tasks	Immediate predecessors
a	Press and solder stud to cap	1	6.93	0	-
b	Solder heater to top cap – loading	1	27.85	1	a
c	Solder heater to top cap - appy flux	1	38.26	1	b
d	Solder heater to top cap – soldering	1	103. 07	1	c
e	Solder brass bushes to outlet pipe	1	45.36	0	-
f	Brazing outlet pipe to bottom cap	1	31.14	1	e
g	Solder brass bushes to inlet pipe	1	22.15	0	-
h	Brazing inlet pipe to tank	1	32.58	1	g
i	Brazing PS connector to tank		27.42	1	h

j	Press top cap to tank	1	22.96	3	d, f, i
k	Press bottom cap to tank		17.68	1	j
l	Weld top cap to tank	1	48.15	1	k
m	Apply flux	`		1	l
n	Insert C-shape filler to welding point	1	22.87	1	m
o	Induction welding bottom cap to tank	1	34.57	1	n
p	Cleaning	1	53.17	1	o
q	Cooling	1	834. 00	1	p
r	Puncture / insulation / ohm test	1	35. 03	1	q
s	Silicone sealant		10.37	1	r
t	Ceramic bead insert	1	11.46	1	s
u	Hydraulic press	1	45.25	1	t
v	Terminal spot welding	1	19.77	1	u
w	Hipot test		11. 08	1	v
x	Air leak test	1	40.44	1	w
y	Puncture / insulation test	1	46.15	1	x
z	Final check	1	53.52	1	y
	Total process time		1641.23		

RESULTS AND DISCUSSION

Figure 2 shows the proposed process flow for Model ABC produced by Company XXX in order to improve the overall productivity. In the proposed shopfloor plan, the tasks at NWS 1 and NWS 2 should be combined, robot welding should be used in place of the conventional welding process at NWS 8, and compressed air cooling should be used at NWS 9. The modifications made to the existing shopfloor plan are elaborated in the following subsections.

Robot Welding Workstation (NWS 8)

At the robot welding workstation (NWS 8), a welding robot is used to weld the top cap to the tank and then proceeds to weld the bottom cap to the tank. Thus, a jig was designed in this research to hold the tank firmly at the centre so that the welding robot can weld both areas simultaneously. Figure 3 shows the holding jig design. Figures 4 and 5 show the top view and close-up view of the holding jig design, respectively. The mechanism of the holding jig is as follows:

1. The operator at the NWS 7 workstation places the product onto the holding jig and then presses the START button. Alternatively, the process can be initiated by using a sensor integrated with a programmable logic controller.
2. The pneumatic system activates and fully operates in automatic mode.
3. Pneumatic cylinder no. 1 pushes the clamp to secure the product in the appropriate position.
4. Once the product is secured in place, pneumatic cylinder no. 2 retracts until it reaches the desired position and the welding process is initiated.
5. After the welding process is completed, pneumatic cylinder no. 2 pushes the cylinder forwards and pneumatic cylinder no. 1 retracts to open the clamp so that the operator can collect the finished product.

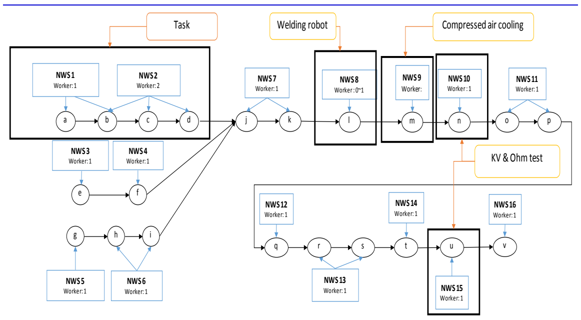

Fig. 2. Proposed process flow for Model ABC produced by Company XXX (proposed shopfloor plan).

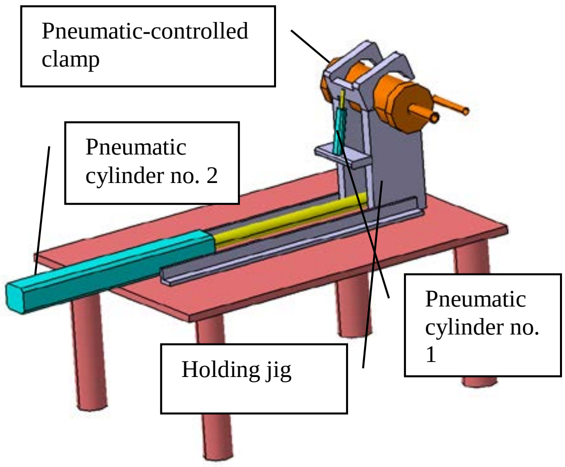

Fig. 3. Jig designed to hold the tank firmly at the centre of the robot welding workstation.

The cycle time of the robot welding process was estimated to be 40 s/unit whereas the total cycle time of the existing induction welding workstation was 240.11 s. The average cycle time for each process was 60.03 s.

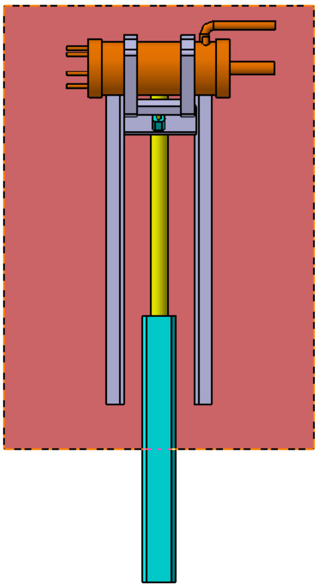

Fig. 4. Top view of the holding jig.

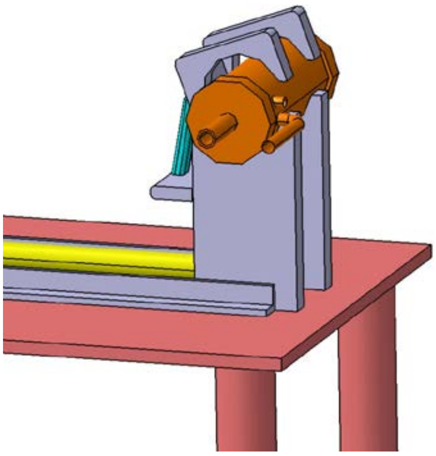

Fig. 5. Close-up view of the holding jig.

Assuming that the daily production target was 1,000 pieces, the weekly production target and weekly working hours would be 5,000 pieces and 44.8 hours, respectively. The weekly data were used to compare the productivity in order to obtain more accurate results owing to the fact that the working hours on Fridays were different from other days. In a week, the company could only produce 2,906 pieces using the existing production line ((44.8×60×60)/60.03 = 2,686.66 pieces ≈ 2,687 pieces). This corresponds to a welding production percentage of 53.74% ((2,687/5,000)×100 = 53.74%).

If a welding robot is used for the welding process within the same time frame, the company can produce a higher number of products because of the reduction in the welding process time. The company will be able to produce 4,032 pieces ((44.8×60×60)/40 = 4,032 pieces). This corresponds to a welding production percentage of 80.64% ((4,032/5,000)×100 = 80.64%).

Thus, by implementing the robot welding process, the productivity increases by 26.90% and the number of operators can be reduced by three people.

The robot welding process not only increases the productivity and reduces the number of operators, but also standardizes the welding process, ensuring consistency in the product quality. In the existing shopfloor plan, there were three operators (including a skilled operator) who performed the welding process at the NWS 8 workstation. These operators can be eliminated by implementing robot welding at the NWS 8 workstation. As to implement six sigma in the production plan, robot welding is suggested as the performance of welding is highly depend on the operators. Thus, performance of welding can be standardized by using robot welding. Furthermore, robot welding may eliminate the cleaning workstations because this process requires minimal cleaning of the excessive flux after the robot welding process. More importantly, the occurrence of leakages, which will improve the rate of defects at the air leak test workstation can be reduced through a standardized and consistent welding performance.

KV and Ohm Test Workstation

A jig was designed to transfer the product for testing, as shown in Figure 6. In this design, the operator needs to load the product onto the jig after inspecting its appearance. The mechanism of the KV and Ohm test is as follows:

1. The operator loads the product onto the holding jig.
2. By pressing the button once, the pneumatic cylinder pushes the jig forwards until the heater coils touch the contact plate. The details of the contact plate are shown in Figure 7.
3. The operator analyzes the KV test results based on the readings displayed on the screen of the oscilloscope.
4. The pneumatic cylinder retracts and the holding jig returns to its original position and the operator can unload the product.

If the KV and Ohm test workstation is upgraded with pneumatic cylinders, the process can be semi-automated, which will reduce the process time for the task. The most significant benefit that can be obtained from the upgraded configuration is that the test data can be extracted directly from the oscilloscope. If the existing oscilloscope is not equipped with a communication terminal with a programmable logic controller, it is suggested that the company should opt for an oscilloscope with better technical specifications since it is necessary to record the data for every rejected part prior to any rework.

Without these data, it is not possible to determine the rate of defects, which will affect the sequence of actions. In this research, observations were made at the KV and Ohm test workstation and air leak test workstation during the site visit. Based on the observations, in the current practice, the rejected product was still considered even if the product failed the tests for the first time. The operator would test the product again if the product failed the test. This practice may lead to misleading and erroneous data on product defects, which will disrupt the whole production process because precise data are needed to identify the root cause of a problem.

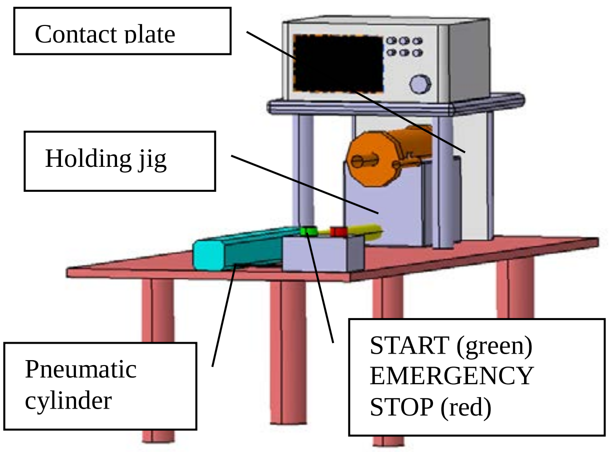

Fig. 6. Jig design for the KV test.

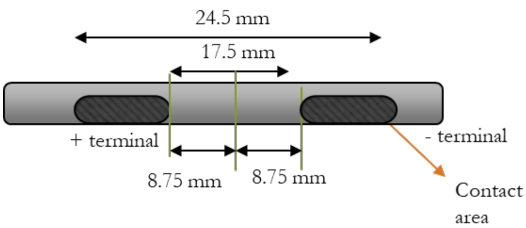

Fig. 7. Details of the contact plate.

Smoothness Index

The smoothness index (SI) is a useful tool in line balancing, which allows one to evenly distribute the workload between the workstations (Chong et al., 2019). The smoothness index is given by:

$$SI = \sqrt{\frac{\sum_{j=i}^{M}(T_{max} - T_j)^2}{M}} \quad (1)$$

where T_{max} is the maximum time of the workstation, T_j is the time of the j^{th} workstation, and M is the number of operators.

The SI values were calculated for the original and proposed overall shopfloor plans and the results are tabulated in Table 3. It can be seen that the original and new SI values for the overall shopfloor plan are 28.95 and 34.25, respectively. According to Fathi et al. (2018), the minimization of SI alone may not be the best solution to solve ALBPs although one of the objective functions in line balancing is to minimize the SI. For this reason, the number of workstations or the number of processes was also considered in the objective functions in addition to the minimization of SI.

Table 3. Smoothness index (Chong et al., 2019).

Smoothness index, SI	Original SI	New SI
Overall shopfloor plan	28.95	34.25
NWS 8	31.85	40.00
NWS 1 and NWS 2	24.93	28.79

Line Efficiency and Percentage of Line Balance Loss

Reducing manpower is the main priority compared with achieving the productivity target. In the proposed shopfloor plan, there are 16 workstations, 15 operators, and 22 tasks. Moreover, there are only 20 manual tasks in the proposed shopfloor plan since two of the tasks are replaced by automated solutions. With the reduced manpower, the productivity and line efficiency of the proposed shopfloor plan can be improved. The line efficiency (LE) is given by:

$$LE = \frac{\sum_{i=1}^{N} t_i}{M \times C} \quad (2)$$

where C is the average cycle time, M is the number of workers, and t_i is the total process time.

The line efficiency of the existing shopfloor plan is calculated as follows:

$$LE_{exist} = \frac{1641.23}{21 \times (\frac{2677.70}{17})} \times 100\% = 49.62\%$$

In the same manner, the line efficiency is determined for the proposed shopfloor plan as follows:

$$LE_{new} = \frac{1501.86}{15 \times (\frac{2233.83}{16})} \times 100\% = 71.71\%$$

Based on the results, it can be seen that there is a significant increase in the line efficiency from 36.41% to 68.83% with the proposed shopfloor plan.

The percentage of line balance loss (%BL) is given by:

$$\%BL = \frac{MT_{max} - \sum t_i}{MT_{max}} \quad (3)$$

The percentage of line balance loss of the existing shopfloor plan is calculated as follows:

$$\%BL_{exist} = \frac{21(344.16)-1641.23}{21(344.16)} \times 100 = 77.29\%$$

In the same fashion, the percentage of line balance loss of the proposed shopfloor plan is calculated as follows:

$$\%BL_{new} = \frac{15(278.65)-1501.86}{15(278.65)} \times 100 = 64.07\%$$

It can be seen that the percentage of line balance loss is reduced from 77.29% to 64.07% with the proposed shopfloor plan. Even though the SI of the proposed shopfloor plan is moderately higher than that of the existing shopfloor plan, the value is still acceptable and moreover, there is a significant improvement in the line efficiency and reduction in the percentage of line balance loss.

CONCLUSIONS AND DIRECTIONS FOR FUTURE RESEARCH

An improved shopfloor plan for the heater manufacturing industry in Malaysia has been proposed in this research based on a pilot study at Company XXX. Based on the results, the smoothness index is slightly higher for the proposed shopfloor plan compared with that of the existing shopfloor plan. However, the proposed shopfloor plan reduces the number of operators from 21 to 15 and eliminates the need for a cleaning station by substituting manual welding with robot welding (Chong et al., 2019). With the proposed shopfloor plan, the number of workstations can be slightly reduced from 17 to 16 (Chong et al., 2019). In addition, the process time at the NWS 8 workstation (where the task involves welding the top and bottom caps) can be reduced from 240.11 s to 40.00 s. With the implementation of the robot welding process, the productivity can be increased from 49.62% to 71.71%.

In general, the smoothness index should be considered before implementing a shopfloor plan. However, it is important not to merely rely on the smoothness index as an indicator of the effectiveness of the shopfloor plan in real-world applications. Based on the results obtained in this research, manufacturers should also consider other criteria such as boosting productivity, reducing lead time and the number of workstations in the production line, and improving allocation of labour in the production line (Chong et al., 2019). Even though the smoothness index in this research is slightly higher for the proposed shopfloor plan compared with the existing shopfloor plan, the value is still acceptable, considering that the proposed shopfloor plan significantly reduces the lead time and manpower of the production line for Model ABC. In addition, the percentage of line balance loss is reduced from 77.29% to 64.07%.

In summary, a different approach has been proposed in this research to solve the ALBP. Jigs were designed for the robot welding workstation and KV and Ohm test workstation in order to improve the process flow. Company XXX needs to first prioritize their objective and examine other criteria besides the smoothness index in order to design suitable shopfloor plan. Similar studies can be carried out in the near future to solve other types of ALBPs. The mentioned studies will be useful to investigate and develop shopfloor plans in a similar industry.

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