Assembly Line Balancing using Heuristic Approaches in Manufacturing Industry

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ABSTRACT

Assembly Line Balancing (ALB) plays a vital function especially in the production line. The installation of an assembly line is a long-term decision and requires large capital of investments. It is important that such a system is designed and balanced so that it able to work efficiently as possible. Many previous researches have proposed different heuristic approach in optimizing the assembly line. However little attention is given toward simulation analysis as proved of the proposed method. In this paper, a real industrial data of simple ALB problem is optimized and simulated for minimizing the number of workstation. Three proposed heuristics in order to improve the efficiency of the production are reviewed before a discrete simulation approach is used to compare the optimized performance. The anticipated performance of computational result is obtained from the problem comprising the workstation and labour performance output.

Keywords: *Assembly line balancing, Largest candidate rule, Kilbridge and Wester method, Ranked positional weight, Simulation method*

Introduction

An assembly system is usually designed for plants that comprise with a set of sequential elements (assembly task) to be performed on each assigned workstation. It comes crucially important for the manufacturing system and assembly line since the process need to be optimized with the correct sequence order. Literally, the development of assembly line was introduced

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in 1913 by Henry Ford throughout his successful automotive plants for mass production used. Initiated by his idea a balanced approach towards the assembly line has been presented named Assembly Line Balancing (ALB). Since that numerous evolution and improvement has been reported towards the ALB problem and the optimization method. Besides that, in 1955 the first mathematically formulation for ALB problem has been presented by Salveson focusing on equalified and fast solution approach for solving the line balancing problem. Nowadays the research still continued with more beneficial and improvisation of each previous method. The widely applied in many production systems again has brought to a new birth of the application and method on the ALB.

Generally, the study on ALB has been classified into two classes either Simple Assembly Line Balancing (SALB) [1, 2] or General Assembly Line Balancing (GALB). Fig. 1 describes the classification of ALB with some problem type examples. Basically, the assembly line in the SALB category consist of a straight line workstation that connected each other for completing each assigned task before the final product is released. Considering the numerous number of tasks, the correct and appropriate distribution of tasks into the workstation are needed. As shown in Fig. 1, several types of problem are classed under the SALB with different consideration of objective function. First, SALB type-1 (SALB-1) problem consists of assigning tasks to minimize the number of workstation with fixed cycle time. While for SALB type-2 (SALB-2), the objective is to minimize the cycle time with fixed workstation number. Next is SALB for type-E problem which generally focus to maximize the line efficiency. The SALB-E type is believed to consider both objectives on SALB type-1 and type-2 as proposed to maximised the assembly line efficiency [3]–[5].

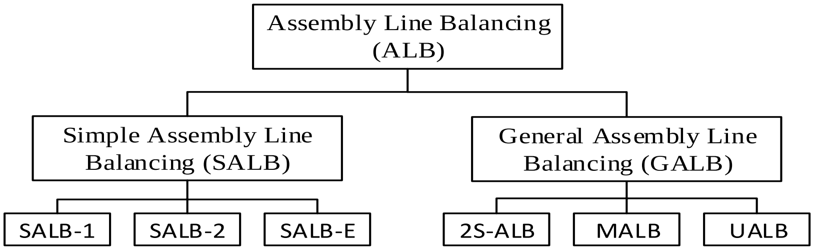


Fig.1 ALB classification

In solving the ALB problem another class of GALB also has been introduced. Because of different condition towards ALB this problem has placed separately against SALB. This classified problem usually involves with more massive scale series of production implementing different specification of assembly line and processing method. The GALB includes the problem such as the Two Sided Assembly Line Balancing (2S-ALB) that needs to operate the assembly in two serial connected assembly line with parallel formation [6]–[8]. This particular layout of 2S-ALB realistically improves the SALB layout for more systematic. However, the task distribution will be more confusing for to be completed. On the other hand, the Mixed-model Assembly Line Balancing (MALB) problem which introduced by Thomopoulos in 1967 consider to assign the tasks into the workstation with different duration of time and different model to balance the assembly line [9]. Besides that, the U-shaped Assembly Line Balancing (UALB) arranged the tasks in a narrow U workstation outline as the assembly layout. For the U-shaped ALB, each worker is allowed to complete his job on either side of the U-line. The U-shaped layout is able to shorten the line length and improve the space utilization. [10]–[12] Therefore, UALB are practically suitable for a production system with a small space of assembly line.

Since this paper considered towards SALB, the classical decision and method are studied to provide some reviewed on this topic. Either implementing mathematical models or heuristics method the previous scholar has attain a great success in developing each of their presented method. By minimizing the number of workstation with fixed cycle time value, Thangavelu and Shetty have accomplished to develop an integer programming model to solve the SALB-1 problem. Then another mathematical model also studied by Deckro and Rangachari implementing goal programming model considering various operational requirement on SALB-1 problem types. In 2013 a remarkable finding again on SALB-1 problem presented by Sivasankaran and Shahabudeen [13] which proposed a hybridize method of mathematical model in two stage. In the first stage the number of workstation is determined with a given cycle time, and using the workstation number the objective of minimizing the cycle time is achieved as in the second stage.

Besides that, a method known as heuristic has been presented by Ponnambalam et al. for a comparative evaluation with six popular ALB method: Rank Positional Weight (RPW), Kilbridge and Wester (K-W), Moodie and Young (M-Y), Hoffman Precedence matrix, immediate update first fit, and rank and assign heuristic. This research has considered four parameters which is the number of workstation, line efficiency, smoothness index, and CPU time as the best comparable heuristic considering SALB-1 problem. There also some recent studied which compared among the three methods: Largest Candidate Rule (LCR), Kilbridge and Wester (K-W), and Rank Positional Weight (RPW). [14] reportedly the rank position weight has found very handy even when less data is obtainable. In addition, the bottleneck problem that issued in most assembly lines has proved can be reduced through this kind of approach [15]. Mohammed et al. [14] also have done to study on imitating of two stages gear box procedure. Then the three methods of LCR, K-W and RPW have narrow down as to select the best method on minimum assembly time with better performance of essential retailing cost. This research also has found that RPW is the best method compared to other two. Another heuristic on SALB-1 has develop by Jiao et.al. in 2006 for Web-based interactive advisor method with objective to minimize the number of excess workstation. In his study, he also has simulated the line balancing to evaluate the lines performance.

Literally this paper is focused on presenting three different heuristic methods: Largest Candidate Rule (LCR), Kilbridge and Wester (K-W) method and Rank Position Weight (RPW) method which traditionally popular in solving the SALB problem. A real industrial SALB data set then will be tested for minimizing the excess number of workstation with the best sequence of assigned task. Besides, a simulation of current and after the optimization will further discussed. Therefore, the particular feature of the three heuristic method and simulation activity will further expose.

Assembly Line Balancing Methods

The existing heuristic method in solving SALB problem has promising a better finding. Besides the favourable advantage in implementing ALB method have revealed the capability in maintaining the good efficiency on each generated solution. Many researchers also have been devoted to consider this SALB type problem even it classically exposed in the past few decades. In this section, the detail explanation with a real industrial data is presented. The comparable result of three different methods then will proved the strength and stability of ALB method in solving the real industrial data set. In completing this studied only a single data set are considered that taken from manufacturing industry.

In adopting three ALB methods into this real industrial problem each working element from Table 1 that related towards the assembly process is relevant to be transformed into a precedence relation diagram. This is necessarily important to provide a flow of every processing element in making the desired product. Fig. 2 illustrates the precedence relation diagram with 12 number of tasks in the studied industry. The circle indicated the assembly task, while the arrows linked represent the precedence relation with other task. The related data of the processing duration also specified on top of each circle (assembly task).

Table 1: Assembly data

Working element	Time	Predecessor
1	4.7	-
2	2.5	1
3	5.7	1
4	4.3	2,3
5	6.3	4
6	6.8	5
7	6.8	6
8	10.4	7
9	12.8	8
10	4.7	9
11	2.7	10
12	7.2	11

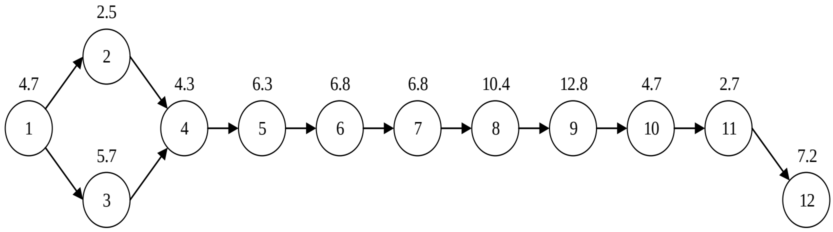


Figure 2: Precedence relation diagram

For the selected manufacturing process, only 12 working element are involved to be distributed among the workers and also workstation in the assembly line. The analysis adopting three ALB method with aim to obtain the optimal number of workstation in the manufacturing assembly line are conducted based on every constructed figure and data. The heuristic method that to be present are :-

1. Largest candidate rule
2. Kilbridge and Wester’s method
3. Ranked positional weights method

Largest candidate rule (LCR)

In this method the working element from Table 1 will be arranged in descending order by refering to the processing time on every working element. The worker then will be assigned to the first element that satisfy the precedence relation (Fig. 2). Table 2 have shown the descending order of each processing time for every working element. Then, based from Table 2 the arrangement of each working element are arranged to satisfy the precedence order. From the element in Table 3 the workstation are asigned considering with the maximum cycle time which is 30. The element also are grouped together without exceeding the maximum cycle time value.

Table 2. Descending time working element

Element	Time	Predecessor
9	12.8	8
8	10.4	7
12	7.2	11
6	6.8	5
7	6.8	6
5	6.3	4
3	5.7	1
1	4.7	-
10	4.7	9
4	4.3	2,3
11	2.7	10
2	2.5	1

Table 3. Grouped element

Element	Time	Total time	Work station
1	4.7		
3	5.7		
2	2.5	23.4	1
4	4.3		
5	6.3		
6	6.8		
7	6.8	24.0	2
8	10.4		
9	12.8		
10	4.7	27.4	3
11	2.7		
12	7.2		

By implementing this LCR method the assembly task have been assigned in only three number of workstation. The arrangemant of element then have obtain 27.4 as the maximum processing time.

Kilbridge and Wester's (K-W)

This heuristic method has received a lot of attention since it first introduce in 1961. Where the elements in this method are set into the workstation according to the position from the precedence relation diagram. For this K-W method each nodes (working element) from the precedence diagram are grouped together into a vertical columns. The listing element then is tabulated depend on the column position. Meanwhile the node selection will then provide a base sequence of arrangement with each processing time needed. Table 4 below shows the element with each assigned column that extract from Fig. 3. The obtained arrangement then used to construct a few of workstation as shown in Table 5.

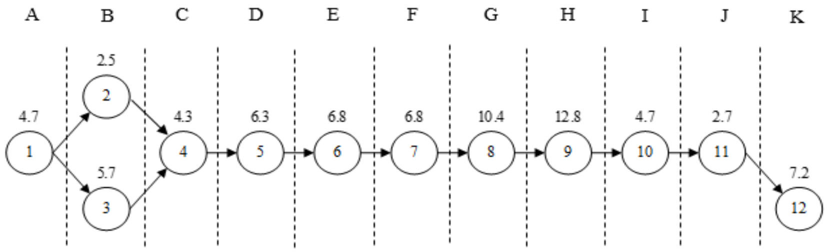


Figure 3: Column arrangement for K-W method

The grouped element are selected and arranged from left to right as each nodes and arrows are depicted from the precedence relation diagram (Fig. 2) which significantly moving towards the right side. By this K-W method the assign column has successfully separates the working element into several sections as to provide a selection choice for each node before the maximum cycle time are reached. Therefore, for this problem as 30 minute is the maximum cycle time, the grouped element shall not exceed this duration. As shown in Table 5 the total processing time for workstation 1 is only 23.5 minute, while workstation 2 need 24 minute and 27.4 minutes which is the maximum processing time needed by workstation 3 to complete it assigned working element or tasks.

Table 4: Element arrangement with column

Element	Column	Time	Total time
1	A	4.7	4.7
2	B	2.5	8.2
3	B	5.7	
4	C	4.3	4.3
5	D	6.3	6.3
6	E	6.8	6.8
7	F	6.8	6.8
8	G	10.4	10.4
9	H	12.8	12.8
10	I	4.7	4.7
11	J	2.7	2.7
12	K	7.2	7.2

Table 5: Grouped element

Element	Time	Total time	Work station
1	4.7	23.5	1
2	2.5		
3	5.7		
4	4.3		
5	6.3		
6	6.8	24.0	2
7	6.8		
8	10.4		
9	12.8	27.4	3
10	4.7		
11	2.7		
12	7.2		

Rank Position Weight (RPW)

This RPW method generally was introduce by Helgeson and Birnie in 1961. It significantly represent for more efficient as to assign the working element into each workstation. In the RPW method a cumulative processing time are need to be calculated before it sorted in descending order. However, the precedence relation diagram from Fig. 2 is important to be considered as to express the flow and it predecessor. Besides, only the related element that connected towards the cumulative nodes will be considered. For example on working element 2 which the arrow chain only take 4 until 12 as it successor. Means the RPW value for element 2, are the cumulative of all processing time except for working element 1 and 3. The RPW value then are arranged in descending order as shown in Table 6 together with it predecessor.

Generally this approach has adopted both the processing time of the element and the position from the precedence relation diagram. The cumulative value which in descending order is worthy and applicable to be used as the assigned assembly sequence. Beside that, the RPW method also assign the best cycle time and workstation required for the production line. As the given cycle time which is 30 minute the summation of time required of each workstation should only be equal or less than the 30 minute. Table 7 shows the grouped element after implementing the RPW method with only three number of workstations. Besides the maximum time (cycle time) required for the assembly is reduced into 27.4 without considering any available manpower.

Table 6: Element arrangement with RPW descending order data

Element	Time	RPW	Predecessor
1	4.7	74.9	-
3	5.7	67.7	1
2	2.5	64.5	1
4	4.3	62	2,3
5	6.3	57.7	4
6	6.8	51.4	5
7	6.8	44.6	6
8	10.4	37.8	7
9	12.8	27.4	8
10	4.7	14.6	9
11	2.7	9.9	10
12	7.2	7.2	11

Table 7: Grouped element

Element	Time	Total time	Work station
1	4.7	23.5	1
3	5.7		
2	2.5		
4	4.3		
5	6.3		
6	6.8	24	2
7	6.8		
8	10.4		
9	12.8	27.4	3
10	4.7		
11	2.7		
12	7.2		

The recognition on RPW method for numerous real aplication has been reported in many studied. This method also can reduce the assemblies bottleneck problem with synchronies workstation. Initially the assembly line of real industrial layout for this problem is occupied 5 number of workstation. The reduction from five into three number of workstation with grouped element is impressive. However, from this studied the other two method also have shown no difference in the result of grouped element in the assembly line with 27.4 minutes as the highest processing time.

Assembly Simulation and Improvement

In this section the analysis of SALB-1 problem is further discussed with the aid of Witness simulation software comparing before and after improvement. For this purpose every information towards the assembly process and layout are considered. This actually intended to provide a real situation on the assembly line with comparable performance of the production system. Initially the assembly line has been equipped with five number of workstation. But from the earlier proposed method of LCR, K-W, and RPW approach the workstation is able to be reduced into three. Hence for this section a comparable performance on ALB simulation before and after improvement are sudied.

Initial assembly line

For the initial assembly line five number of workstation are prepared as depicted in Fig. 4. The small circle (red) on the left present as a former or product that moving from one to another workstation until it fully complete all the assigned work. While the green block respectively is the workstation that connected to complete each working element before shipping process that considered finished.

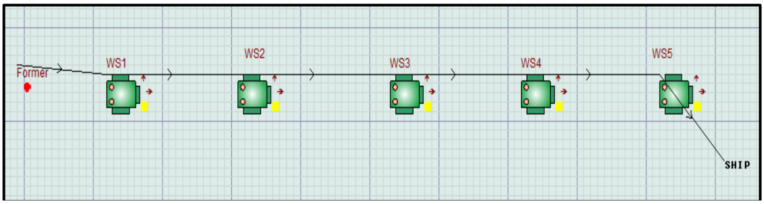
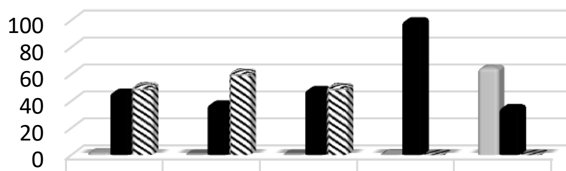


Figure 4: Simulation of initial assembly line

From the simulation three different parameter are analysed comparing idle, busy and blocked percentage. Idle actually is the time associated with waiting, or a machinery which not being used. While busy means the working activity in completing the assigned working element. The highest idle percentage is shown in Fig. 5 at workstation 5 with 64.59%. Meanwhile the highest busy percentage is at workstation 4 with 99.87%. The percentage become synchronized where once workstation 4 is busy the workstation 5 become idle. Besides in this initial simulation the blockage percentage only shown in the first three workstation with 51.55%, 61.92% and 51.18% respectively. The blockage plays an important role in where high block percentage will disturb the flow of working order in the assembly line to complete the mission due to high workload.



	WS1	WS2	WS3	WS4	WS5
IDLE (%)	1.78	0.06	0.08	0.13	64.59
BUSY (%)	46.67	38.02	48.73	99.87	35.41
BLOCKED (%)	51.55	61.92	51.18	0	0

Figure 5: Results of initial workstation simulation

Improvised assembly line

The ALB method have suggested three workstation as the optimal number of workstation with only 27.4 minute as the best cycle time. Each workstation are studied to provide a comparison before and after the optimization considering the same parameter idle, busy and blockage percentage. Fig. 6 illustrated the three number of workstation (green block) after the reduction from five workstations. The comparable result using Witness simulation is used to identify whether the results obtain from the ALB method is applicable.

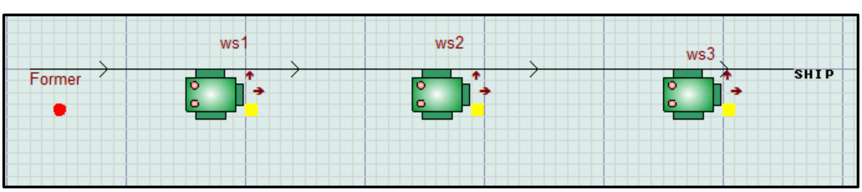
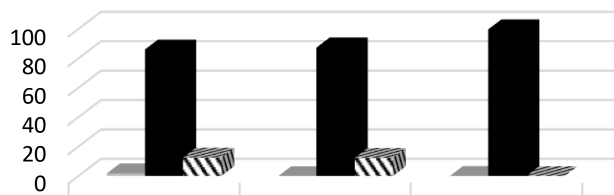


Figure 6: Improvised simulation of assembly line

Fig.7 it depicted the improvised simulation result in only three number of workstation. The favourable result have proved with successfully increase the busy percentages in all of workstation, which previously only certain workstation shows the high percentage result as workstation 4 is the highest. The idle percentage also presented with minimum result as 1.78% is the highest among those three workstations. Besides reducing the workstation number, the simulation also showed the encouraging result towards blockage percentage. Only two workstations presented with a small percentage of blockage which respectively in workstation 1 and 2. The decreasing blockage and increasing busy percentage have shown the improvement achieved in the suggested layout.



	WS1	WS2	WS3
IDLE (%)	1.78	0.09	0.17
BUSY (%)	86.15	87.53	99.83
BLOCKED (%)	12.6	12.39	0

Figure 7: Results of improvised workstation simulation

Line balancing analysis

In this subsection the analysis is further discuss involve with the number of labor and the output product. The relationship between labors number and output are determined and analyze still using Witness simulation software. The three assigned workstation is fixed considering different situation with increasing number of labors. Generally this analysis is modified to obtain the optimum output for the assembly line. Below presents different situation for balancing approach with increasing number of labors.

Situation 1: 3 workstation and each workstation have 1 labors (3 labors)
Situation 2: Additional 1 labor with 3 workstation (4 labors)
Situation 3: Additional 1 labor to be shared on workstation 1 and 2 (5 labors)
Situation 4: Each 3 workstation is assigned with 2 worker (6 labors)

The particular situation are studied with comparable result that stated on Fig 8. This figure depicted the division of labor activity on idle and busy percentage for every situation with increasing number of labor. The gray section from Fig. 8 indicated as the idle percentage while black section presents as the busy percentage. Situation 2 presents 4 labors that shows the higher idle percentage in two workstation with 43.02% and 43.01% respectively. Since the idle is higher means the busy percentage will significantly drop. Meanwhile the other situation have greatly shows the minimum idle percentage which below than 20%.

Next the workstation progress also classified into four different situation. Fig. 9 below have illustrated the percentage graph on each workstation considering idle, busy and blockage percentage. In Fig. 9 situation 2 also shows the higher idle percentage which 43.02% followed by situation 3. In situation 3 the busy working percentage has been interrupted by the blockaged that present with black section. The higher blockaged percentage means the greater disturbance of working flow in the assembly line. However the output result have significantly propotional to the number of labor. The next figure have graphically present the output of the four proposed situations.

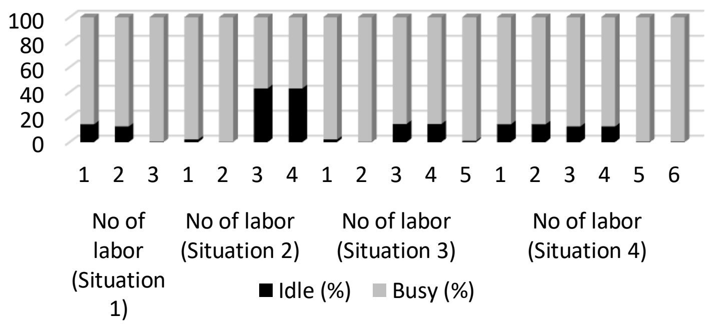


Figure 8: Percentage of labor activity based on situation

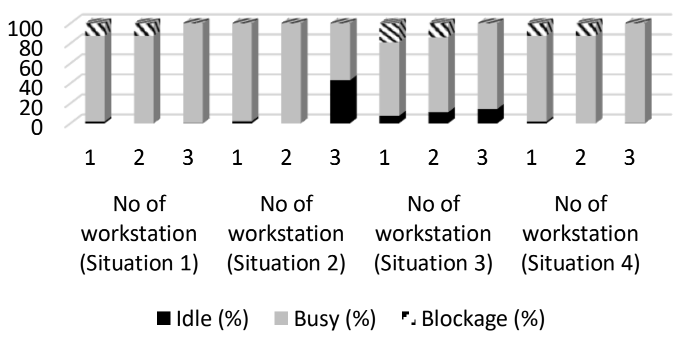


Figure 9: Percentage of workstation progress based on situation

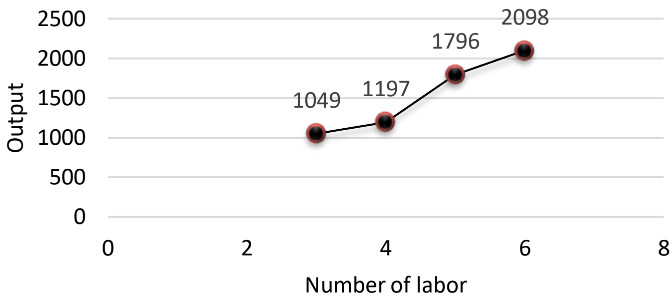


Figure 10: The line balancing output graph

From the simulation of line balancing result the generated output shows with better improvement as the increased number of labor. Situation 1 which only used 3 labors that respectively assigned to each workstation produced 1049 output. Meanwhile, with one additional assigned labor the output have increased to 1197 in situation 2. Then a greater improvement has shown after the assigned labor is added to five with 1796 output. The incremental progress are continuously increase until the number of labor is six that successfully shows the higher output with 499 product difference. Therefore as the improvement made from the erlier workstation layout the ALB optimization with simulation method has successfully proved applicable and is appropriate to be implemented on the assembly line.

Discussion

Since all the three ALB approach in this study are successfully minimize the workstation number it significantly indicated this real industrial data could become another simple ALB banchmark problem. Only 12 working element are studied in assigning each element towards the minimum workstation. The previous optimization result have considered LCR, K-W and RPW method but it have shows the same computed result with only three number of workstation. Generally in an assembly line each working element are need to be investigated for every difference aspect before being placed in the appropriate workstation.

The simulated analysis of the SALB-1 problem also has been previously discussed for initial and improvised layout from five into three number of workstations. From the simulation three parameter are examined which idle, busy and the blockage percentages. Then as expected the three number of workstation is able to have a better result which all the workstation shows better busy percentage depicted in Fig.7. Another line balancing analysis also have been examined considering the performance of workstation and labor which resulting the number of output. In determining the best number of labor and bigger output this research is able to become as a guideline or an example of implementing the real simulation for the assembly line as the improvement method. Besides by implementing this simulation approach the assembly production output also can be measured in certain duration of processing time. Which the production output is able to be determine before conducting the real assembly process. It is important that such a system is to be designed and measured so that it able to work efficiently as planned apart to avoid losses

Conclusion

In this paper three ALB heuristic methods are discussed for the SALB-1 problem to minimize the number of workstation. This study was undertaken to implement heuristic methods with simulation to compare the assembly line. The minimization number of workstation has become as the main objective for the ALB method while the simulation approach is aimed to provide a real measure of each performance and the production output. Further simulation evaluation of labor number also presented. The comparison performance of improvised assembly line and labor have influence to be investigated to provide some clear explanation through it achievement.

Although the real industrial data used in this study is good as to provide the real assembly condition, the assembly problem is still considered simple. Hence as the future work the more complex problem with more intricate assembly process will be considered using the discussed ALB and simulation method. This study also fit to investigate the other heuristic or combinatorial ALB simulation whether the proposed method is reliable for to be implemented.

Acknowledgments
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