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A Comparative Study Of Different Methods For Line Balancing Problem

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Abstract

A production flow line plays a vital role in developing the line efficiency by reducing the production time. Line balancing problem of production flow has been occurred since long time ago. However, the problem still could not be solved since the researcher only focused on the problem of resource allocation. Thus, various types of production system and line balancing methods in the production flow line need to be analysed to choose the best methods which are suitable for the problem occurs. In this research, Largest Candidate Rule (LCR), COMSOAL and Hoffman method will be used and compared to choose the best line balancing method. These three methods will be used Delmia Quest software to get the simulation. In result, a case study has been used from by assuming a 22 workstations. A simulation was first done for the existing production line and show that the estimated production rate is 108 units/day. The results have been analysed based on utilization percentage. The first scenario is focusing on low utilization machines by adding machine on sub assembly workstation. The second scenario is also focusing on low utilization machines by reducing number of workstations from 22 to 9 workstations. Next, the third scenario is focusing on production rate per day by increasing number of final assembly workstation

Keywords: **Line Balancing, Delmia Quest, Simulation, Utilization, Production**

1. Introduction

Manufacturing systems are used for high production parts of product which require several operations. Each operation which needs to be processed will be conducted at workstation. The processes which usually will be conducted on the production lines are milling and drilling of machining. Furthermore, these processes may use transfer line which is also known as transfer machine in order to transfer the parts of product (Groover, 2002). Production lines may need a major capital investment. The application of this system is suitable for high demand of product which requires higher quantity of production. Besides, stable product design which means few changes on the design is difficult to be occurred as this system is production line. Also, long product life can be achieved and several operations can be conducted during manufacture the products. Production line has several workstations which are involving work handling system and parts will be transferred from one station to the other station (Groover, 2002). Assembly lines (ALs) are technique which always been used in mass production environment. This method allows the products to be assembled by labors with less experienced and also used of robots and machines. Assembly Line Design (ALD) is the design of products, processes and plant layout before proceed with production of line. The product analysis recommends product design review according to the standard `design for assembly' (DFA) rule and precedence limitations between tasks. Each task has three possible modes which are manual, automated and robotic for assembly method (Rekiek et al., 2006).

With globalization of manufacturing industries, challenges, competition and complexity have increased drastically in the manufacturing industries. These phenomena become more complicated for industrial managers as higher demand for a good quality product by the customers at competitive price. Therefore, shortening the time to market becomes a big challenge for the manufacturer to survive in this sever market. However, many factors are affecting the cycle time of production lines. Cycle time is the total time required to produce a product from start to finish. Improving the cycle time will lead to reduce cost and increase productivity. One of the most approaches in improving the cycle time is balancing assembly line methods (Kays et al., 2014). Balancing assembly lines is a very vital operation for manufacturing industries to decrease the cycle time or workstation number in order to improve productivity. The general purpose of assembly line balancing is to allocate tasks to workstations until the total time of assigned tasks to each workstation equal with cycle time (Hamza and Al-Manaa, 2013). There are several methods of assembly line balancing which have been studied. Each of methods has different of applications. The selection method to be used which according to minimum time of assembly (Pachghare and Dalu, 2012).

2. Case Study

The case study is shown in figure 1 which consists of 22 workstations. The figure show that there are 5 main parts will be assembly in workstation 22. Each need to pass through several workstations until the final product can be finalized.

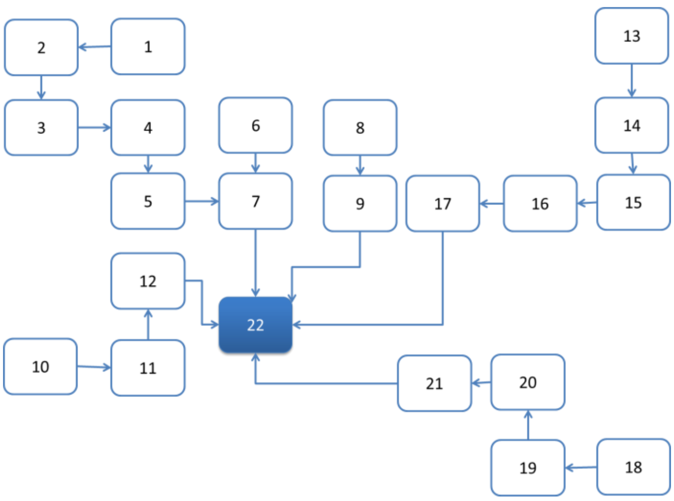

Figure 1: Production Flow Line.

Table 1 show the operation time assumed and type of operation for each workstation. Based on the table, two assembly workstations have been assumed 7 and 22. Therefore, their cycle time is much longer than other workstations.

Table 1: Operation Time and Type of Operation.

Operation number	Operation Time, X (sec/unit)	X (min/unit)
1	10.5	0.175
2	7	0.117
3	14	0.233
4	10.5	0.175
5	14	0.233
6	14	0.233
7	**514.5**	**8.575**
8	10.5	0.175
9	7	0.117
10	14	0.233
11	10.5	0.175
12	31.5	0.525
13	14	0.233
14	10.5	0.175
15	31.5	0.525
16	14	0.233
17	21	0.35
18	14	0.233
19	10.5	0.175
20	31.5	0.525
21	21	0.35
22	**532**	**8.867**
		∑=22.632

ASSEMBLY LINE BALANCING STUDIES

According to Mahto and Kumar (2012), cycle time is the general formula used by three chosen methods in line balancing. Meanwhile, Kayar and Akyalçin (2014) stated that loss of balance and line efficiency percentage is formula which has been used in order to choose method that has the highest line efficiency.

$$LB = [(nC - \sum Co) / nC] (100)$$

LB: loss of balance

n: total number of work stations

C: cycle time

Co: the average work station time

$$LE = (1 - LB) (100)$$

LE: line efficiency

Result and Calculation Based On Original Design

Total time = 22.63 minutes = 1358 seconds

$$LB = [(nC - \sum Co) / nC] (100)$$

n = 22

x = C = 532 s = 8.87 min

∑x = ∑Co = 1358 s = 22.63 min

LB = 88.4 %

LE = (1 - LB) (100)

= (1 – 0.8840) (100)

= 11.6 %

The result shows that the loss of balance percentage for original layout is too high with 88.4 % compared to line efficiency percentage with only 11.6 %. This shows that the efficiency of production line needs to be improved. The production line from this company is very suitable for assembly line balancing studies which performed by three chosen methods of line balancing which are LCR, COMSOAL and Hoffman method. Thus, an improvement can be made by these three methods in the next sections.

Largest Candidate Rule Method

To be able to apply this method, Table 2 must be formed. The table shows the order of operation number from the longest to the shortest operation time. When arranging the operations, the one that has similar operation time which of the first priority among them will be written first.

Table 2: Solution Stages of the Problem Using Of LCR Method.

OPERATION NO	TIME (s)	PREVIOUS OPERATION
22	532	7, 9, 12, 17, 21
7	514.5	6
12	31.5	11
15	31.5	14
20	31.5	19
17	21	16
21	21	20
3	14	2
5	14	4
6	**14**	-
10	**14**	-
13	**14**	-
16	14	15
18	**14**	-
1	**10.5**	-
4	10.5	3
8	**10.5**	-
11	10.5	10
14	10.5	13
19	10.5	18
2	7	1
9	7	8

Meanwhile, Table 3 shows the calculation on total time of production based on LCR method. Based on Table 2, the most appropriate operations to be assigned are 1, 6, 8, 10, 13 and 18 since they have no previous operation. The operation which has the longest time is operation 6, 10, 13 and 18. These operations are assigned to the first workstation and its remaining time is calculated as C – t1 = 532 – 56 = 476 s. Although operation times for operation 1 and 8 are shorter than first workstation, they cannot be assigned as first workstation because of difference in type of machine. The steps will be continued until all operations have been assigned to number of workstation.

Table 3: Line Balancing Results.

Workstation Number	Operation Number	Time (second)	Total Time (second)	Remaining Time
1	6	14	56	476
	10	14		
	13	14		
	18	14		
2	7	514.5	514.5	17.5
3	1	10.5	52.5	479.5
	8	10.5		
	11	10.5		
	14	10.5		
	19	10.5		
4	12	31.5	94.5	437.5
	15	31.5		
	20	31.5		
5	21	21	21	511
6	3	14	28	504
	16	14		
7	17	21	21	511
8	22	532	532	0
9	4	10.5	10.5	521.5
10	5	14	14	518
			Total = 1344 s	**Total = 3976 s**

Result and Calculation Based On LCR Method

LB = [(nC - ∑Co) / nC] (100)

n = 10

x = C = 532 s = 8.87 min

∑x = ∑Co = 1344 s = 22.4 min

LB = 74.75 %

LE = (1 - LB) (100)

= (1 – 0.7475) (100)

= 25.25 %

COMSOAL Method

To be able to apply this method, Table 4 must be formed. While assignments for the workstations are being made, any operation among those in the third column is chosen randomly. The operation selected is deleted from the first column and Table 4 is formed again. Operation number 1 is selected for the first workstation since it has zero amount of previous operation. The remaining time for the first workstation is calculated as C – t1 = 532 – 10.5 = 521.5 s. The steps will be continued until all operations have been assigned to number of workstation. The result for assigning workstation number is same with Hoffman as shown in Table 7 below.

Table 4: Solution Stages of the Problem Using Of COMSOAL Method.

Operation Number	Amount Previous Operation (APO)
1	0
2	1 (WS 1)
3	1 (WS 2)
4	1 (WS 3)
5	1 (WS 4)
6	0
7	2 (WS 5, 6)
8	0
9	1 (WS 8)
10	0
11	1 (WS 10)
12	1 (WS 11)
13	0
14	1 (WS 13)
15	1 (WS 14)
16	1 (WS 15)
17	1 (WS16)
18	0
19	1 (WS 18)
20	1 (WS 19)
21	1 (WS 20)
22	5 (WS 7, 9, 12, 17, 21)

Operation Without Previous Operation (OWPO)
1
6
8
10
13
18

Result and Calculation Based On COMSOAL Method

LB = [(nC - ∑Co) / nC] (100)

n = 15

x = C = 532 s = 8.87 min

∑x = ∑Co = 1358 s = 22.63 min

LB = 82.99 %

LE = (1 - LB) (100)

= (1 – 0.7475) (100)

= 17.01 %

Hoffman Method

Table 5 and 6 shows the solution matrix for designing an assembly line by using Hoffman Method for the first workstation and remaining workstations respectively. In the beginning, there are six operations (1, 6, 8, 10, 13 and 18) which have rate of 0 in code array since they have no previous workstation before them. The operation 1 which is first among them is assigned to first workstation. The cycle time is 532 s. The remaining time is calculated as C – t1 = 532 – 10.5 = 521.5 s. To make an assignment of second workstation, a new priority matrix is attained by crossing out the line and column number 1 in the priority matrix as shown in Table 7. The first rate 0 which is from left to right in the code number array can be seen in operation number 2. As this operation cannot be assigned to first workstation, it is assigned to second workstation. The remaining time is calculated as C – t2 = 532 – 7 = 525 s. The steps will be continued until all operations have been assigned to number of workstation.

Table 5: Solution Stages of the Problem Using Of Hoffman Method.

OP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
1		1																						
2			1																					
3				1																				
4					1																			
5							1																	
6							1																	
7																						1		
8									1															
9																						1		
10											1													
11												1												
12																						1		
13														1										
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15																1								
16																	1							
17																						1		
18																			1					
19																				1				
20																					1			
21																						1		
22																							OPERATION NO	WORKSTATION
CODE NO	0	1	1	1	1	0	2	0	1	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 1	WS 1
MACHINE	1	2	3	4	5	6	7	12	13	8	9	10	8	9	10	11	5	8	9	10	5	14		

Table 6: Solution Stages of the Problem Using Of Hoffman Method.

MACHINE	1	2	3	4	5	6	7	12	13	8	9	10	8	9	10	11	5	8	9	10	5	14	OPERATION NO	WORKSTATION
		0	1	1	1	0	2	0	1	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 2	WS 2
			0	1	1	0	1	0	1	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 3	WS 3
				0	1	0	1	0	1	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 4	WS 4
					0	0	1	0	1	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 5	WS 5

					0	1	0	1	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 6	WS 6
						1	0	1	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 8	WS 7
						1		0	0	1	1	0	1	1	1	1	0	1	1	1	5	OP 9	WS 8
						1			0	1	1	0	1	1	1	1	0	1	1	1	4	OP 10, 13, 18	WS 9
						1				0	1		0	1	1	1		0	1	1	4	OP 11, 14, 19	WS 10
						1					0			0	1	1			0	1	4	OP 12, 15, 20	WS 11
						1									0	1				0	3	OP 16	WS 12
						1										0				0	3	OP 17, 21	WS 13
																						OP 7	WS 14
																						OP 22	WS 15

Meanwhile, Table 7 shows the calculation on total time of production by using Hoffman and COMSOAL method. The result for assigning workstation number will be the same for both methods even though Hoffman used priority matrix for the assembly line while COMSOAL formed different table. But there will be different way for these two methods in finding percentage of efficiency.

Table 7: Line Balancing Results.

Workstation Number	Operation Number	Machine Type	Time (second)	Total Time (second)
1	1	1	10.5	10.5
2	2	2	7	7
3	3	3	14	14
4	4	4	10.5	10.5
5	5	5	14	14
6	6	6	14	14
7	8	12	10.5	10.5
8	9	13	7	7
9	10	8	14	42
	13		14	
	18		14	
10	11	9	10.5	31.5
	14		10.5	
	19		10.5	
11	12	10	31.5	94.5
	15		31.5	
	20		31.5	
12	16	11	14	14
13	17	5	21	42
	21		21	
14	22	14	532	532
15	5	7	514.5	514.5
				Total = 1358 s

<u>Result and Calculation Based On Hoffman Method</u>

LB = [(nC - ∑Co) / nC] (100)

n = 15

x = C = 532 s = 8.87 min

∑x = ∑Co = 1358 s = 22.63 min

LB = 82.99 %

LE = (1 - LB) (100)

= (1 – 0.7475) (100)

= 17.01 %

1. RESULTS

Based on Figure 2, the graph shows that Largest Candidate Rule gives better result compared to the original design, Hoffman and COMSOAL method since it has the largest percentage of line efficiency with 25.25 %. Furthermore, LCR method has the lowest percentage of loss of balance with 74.75 %. Meanwhile, the original design has the lowest percentage of line efficiency and it has the highest percentage of loss of balance. But according to previous research done by Kayar and Akyalçin (2014) [3], the result is supposed to be COMSOAL and Hoffman method which gives better result than LCR method.

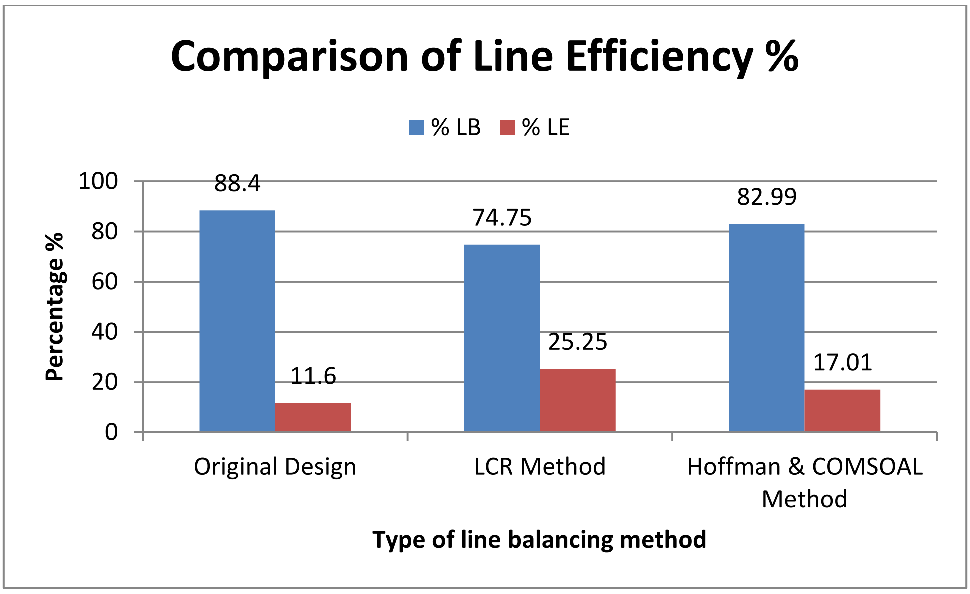

Figure 2: Graph of Comparison Results between Original Design, LCR, Hoffman and COMSOAL Method.

Based on analysis which has been done, there are few reasons why LCR is the best method among these three methods. First, the table is simple and easier to be formulated compared to other methods which are too complicated. Second, the efficiency is better according to many researchers that conducted the study of line balancing method. As can be concluded, the results conducted by using LCR method show that the number of workstation can be reduced since because some operations can be assigned to similar workstation.

Based on the results, the graph shows all the methods including the original design still give lower percentage of line efficiency. There are few reasons behind this. The first reason is because of less accurate data on duration of cycle time for each process. Second, the number of machines use for each workstation need to be considered because it affected the efficiency of line balancing. Besides, the speed and length of conveyor need to be considered as well even though it will gives slightly difference result. But the most important thing which affected the result is because of some problems happened during conducting line balancing process. For example, the labors had longer time in finishing their work. In addition, the transportation used to transport the material also affected the time to finish the whole process.

Therefore, several improvements need to be conducted to ensure the result gives higher percentage of line efficiency and lower percentage of loss of balance. First, the cycle time of each processes cannot has larger difference so that there will be no bottleneck during operation of producing the product. Second, if there is larger difference of cycle time among the operations, the workstation which has higher cycle time need to use several machines to reduce the bottleneck and balance the efficiency. Also, the speed and length of conveyor need to be controlled according to the duration of cycle time for each workstation in the production line. To conclude, the results of assembly line balancing studies conducted by Hoffman and COMSOAL method gives slightly the same result. LCR method gives the best results as it proved that it has higher percentage of line efficiency and has the lowest percentage of loss of balance compared to the original design.

2. METHODOLOGY

The Figure 3 shows the first improvement of simulation for original layout by increasing the number of workstation 7 by two workstations instead of one workstation to see the new percentage of utilization. Based on the simulation results, the number of parts produced still the same which is 108.

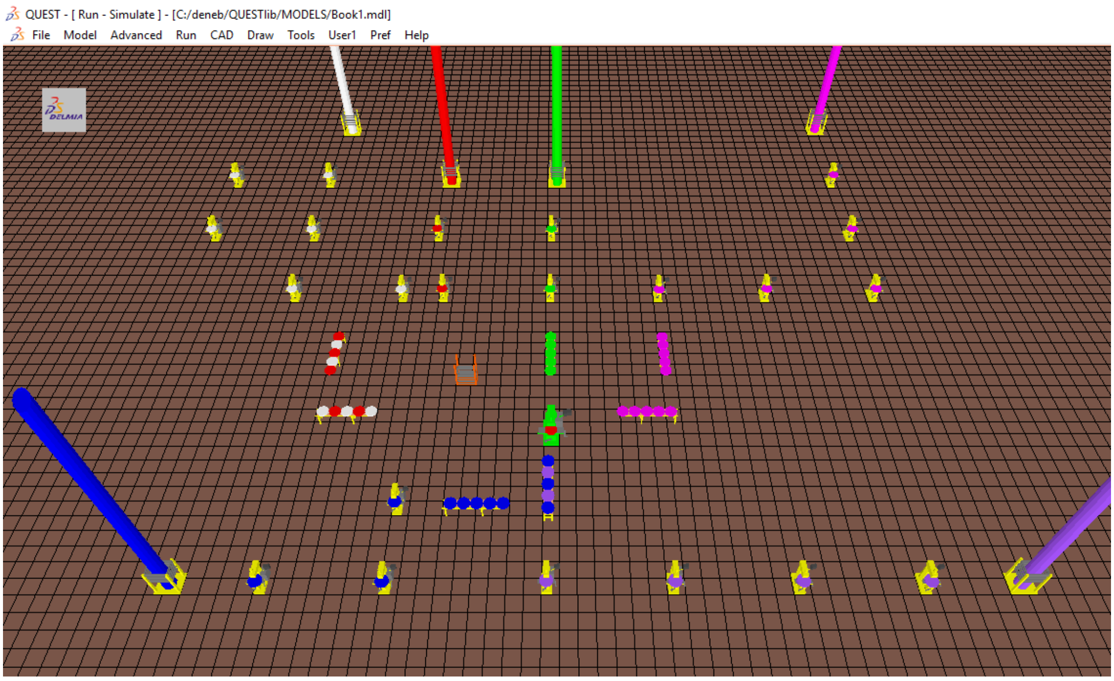

Figure 3: First Improvement Simulation Result of Original Layout.

5.1 PROPOSED DESIGN

5.1.1 SCENARIO 1

The Figure 4 shows the first improvement of simulation for original layout by increasing the number of workstation 7 by two workstations instead of one workstation to see the new percentage of utilization. Based on the simulation results, the number of parts produced still the same which is 108.

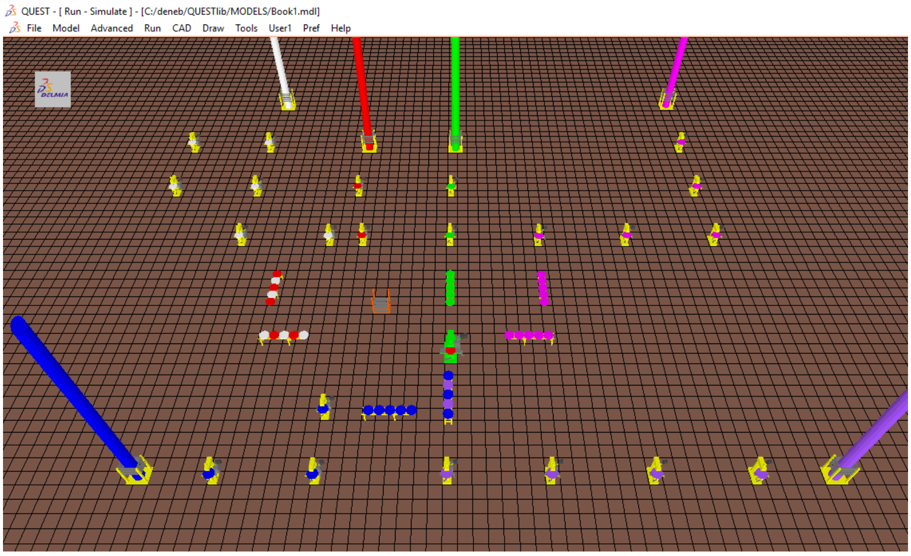

Figure 4: First Improvement Simulation Result of Original Layout.

5.1.2 SCENARIO 2

The Figure 5 and 6 shows the second improvement of simulation for original layout by reducing number of workstations from 22 to only 9 workstations. Based on the simulation results, the number of parts produced per day still the same which is 108.

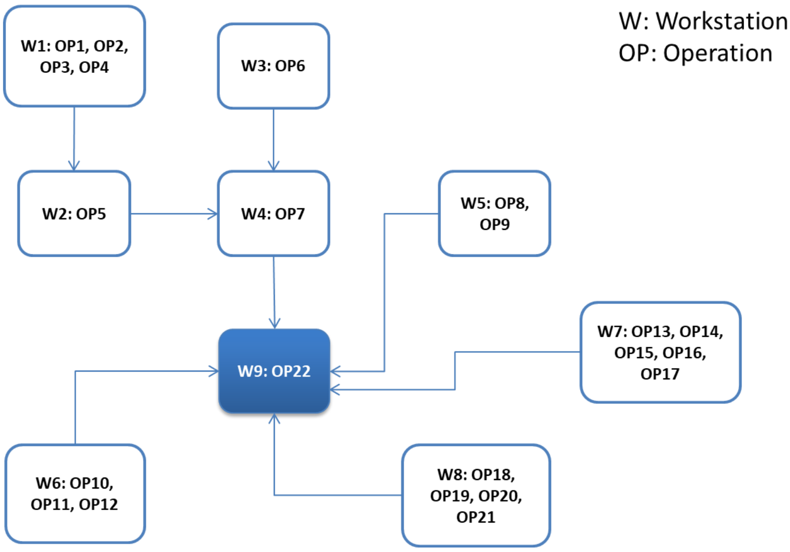

Figure 5: Second Improvement Production Line.

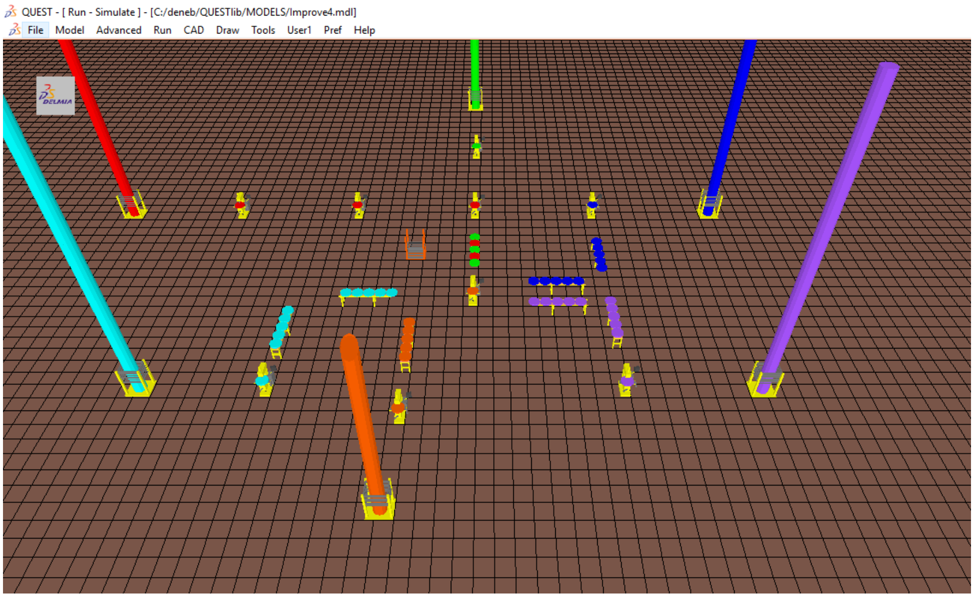

Figure 6: Second Improvement Simulation Result of Original Layout.

5.1.3 WHAT IF SIMULATION

There is another solution which has been suggested to improve the original layout design which is by using 'What If Simulation Method'. For this case study, the number of workstation 22 has been increased as shown in Table 8 to see what will happen to the number of parts produced per day.

Table 8: Number of Workstation 22.

Number of workstation 22
1
2
3
4
5
6

3. RESULT

Based on analysis which has been done, the sub assembly (7) and final assembly (22) workstation has given a problem to other workstations especially the previous operation before them. This is because, assembly operation may took longer time to finish assembled all the product parts. Thus, there will be longer idle or waiting time for the previous operations to wait until the assembly process finished. The simulation results for original design are concluded in Figure 7.

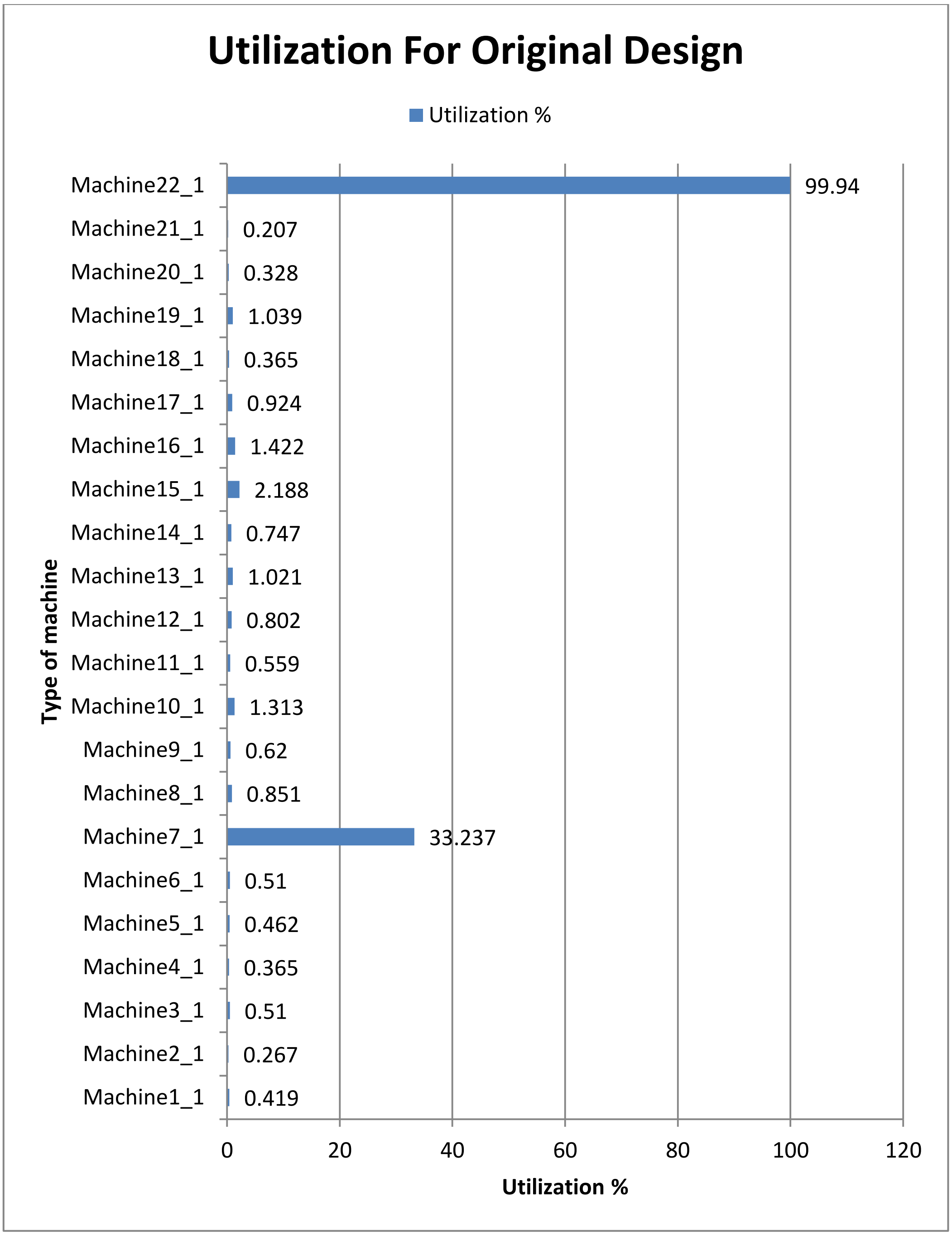

Figure 7: Utilization bar Chart for Original Design.

6.1 RESULT ON PROPOSED DESIGN

6.1.1 SCENARIO 1

Based on Figure 8, the result shows that the number of parts produced per day will be the same which is 108 parts per day. But the percentage of utilization for workstation 7 has reduced to 17.065 %. Based on analysis which has been done, this shows that there will be bottleneck on workstation 7 for original layout since it has longer cycle time to assemble the parts than the previous workstation 5 and 6. Therefore, an improvement needs to be made to improve the line efficiency of workstation 7 by adding one more machine at the workstation 7. To conclude, the percentage of utilization need to be reduced in order to balance the efficiency of production line since workstation has longer cycle time.

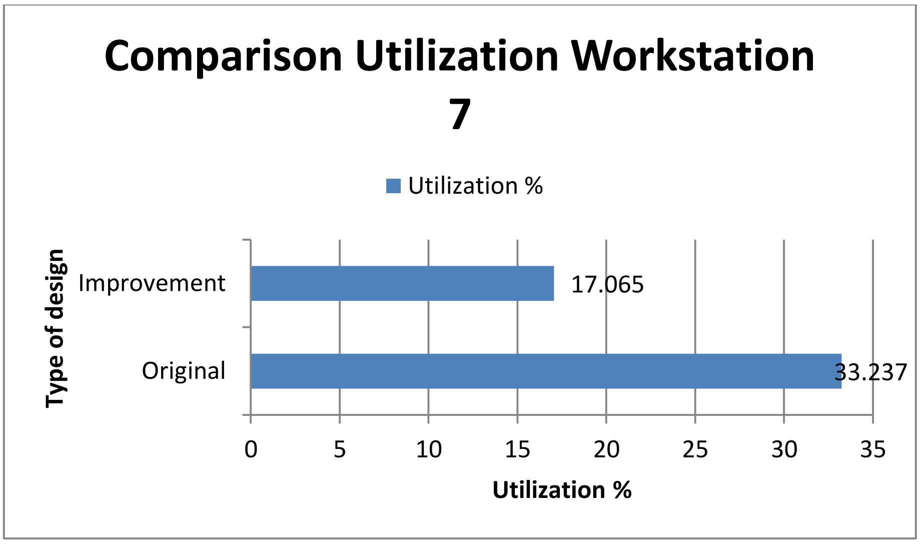

Figure 8: Bar Chart for Comparison Utilization of Workstation 7.

6.1.2 SCENARIO 2

Based on analysis which has been done, the result shows that the number of parts produced per day will be the same which is 108. But the percentage of utilization of workstation 7 has been reduced to 24.117 % as shown in Figure 9. The percentage need to be decreased in order to balance the efficiency of production line since workstation 7 has longer cycle time. Therefore, the company needs to reduce the number of workstations by assigning few operations to similar workstations to reduce the bottleneck among them and to improve the efficiency of production line even though the productivity will be the same.

<u>Utilization for Original Design</u>

Workstation 7 = Machine7_1 = 33.237 %

<u>Utilization for Improvement Design</u> (after reduced the workstation number)

Workstation 7 = Machine4_1 = 24.117 %

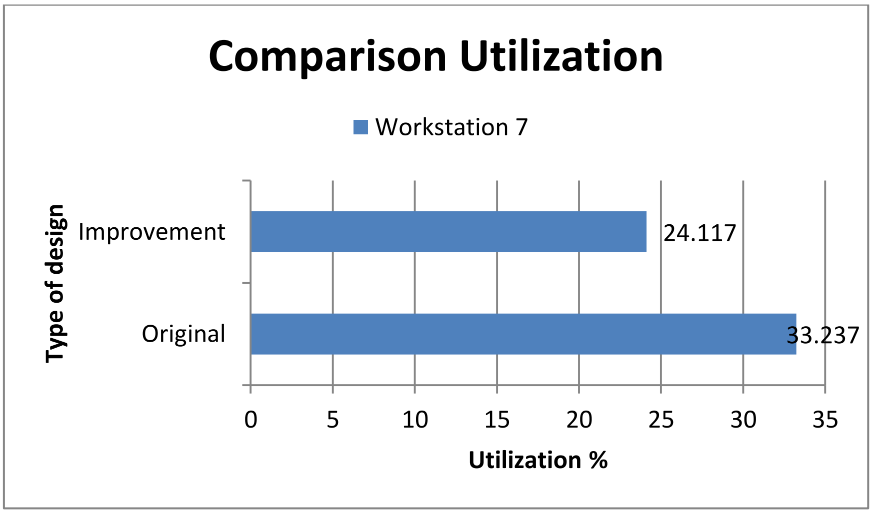

Figure 9: Bar Chart for Comparison Utilization of Workstation 7.

6.1.3 WHAT IF SIMULATION

Based on the result, the Table 9 shows that as the number of workstation 22 increased, the number of parts produced per day will be increased. Based on analysis which has been done, since the final assembly workstation which is workstation 22 has the highest cycle time, the result shows that it has the highest percentage of utilization. Therefore, few simulations have been made by adding more machines at workstation 22 to see the number of parts produced per day. As suggestion, the improvement can be made by adding more machines at final assembly workstation to increase their benefits even though it is costly to buy many machines.

Table 9: Number of Parts Produced Based On Different Number of Workstation 22.

Number of workstation 22	Number of parts produced
1	108
2	216
3	324
4	432
5	540
6	648

4. CONCLUSIONS

In conclusion, all the objectives for this study have been achieved. The first objective has been achieved by analysing the different types of production system and line balancing methods in the production flow line by selecting suitable method for case study. In the first case study, the result shows that Largest Candidate Rule (LCR) method gives the best result compared to COMSOAL and Hoffman methods with the highest percentage of line efficiency which is 25.25 % and the lowest percentage of loss of balance which is 74.75 %. Meanwhile, Hoffman and COMSOAL method gives nearly the same results.

The second objective has been achieved by evaluating different LB methods by making simulation using Delmia Quest software to improve the productivity and machine utilization. In the first case study, by increasing number of workstation 7 (sub assembly), the utilization percentage can be reduced from 33.237 % to 17.065 %, thus the efficiency becomes more stable even though with similar production rate of 108 parts per day. The second scenario also shows the utilization percentage for workstation 7 has reduced from 33.237 % to 24.117 % after decreasing number of workstations. Based on ‘What If Simulation’ method, the production rate can be increased from 108 to 648 parts per day if the number of workstation 22 (final assembly) used from 1 to 6 workstations respectively.

Last but not least, the third objective has been achieved by comparing proposed layout using three methods of line balancing to optimize the allocation of resources and improve the productivity. Based on studies of line balancing methods, the results approved that by assigning few operations in similar workstations in order to reduce the workstation number can improve the productivity. By implementing this method, the number of workstations can be reduced when making the simulation using Delmia Quest Software.

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