Redesigning of Lamp Production Assembly Line

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Abstract

Manufacturing productivity is one of the most significant element that determines the position of a manufacturing company. The efficiency of an assembly line directly affects the productivity. A case study of lamp production assembly line was conducted in order to develop an improved version of assembly line with greater efficiency. This study was carried out by theoretically analyzing the various studies conducted previously on assembly line optimization. Process and time study of the current assembly line were conducted. Sequel to the data collected, root cause analysis was conducted to identify the cause of the problem in the assembly lines. FlexSim was used to simulate current assembly line and the performance result was generated. The result was analyzed using lean production review. A Karakuri system was implemented to eliminate the non-value added operations. Subsequently, assembly line balancing was applied by using 4 different heuristics methods. As a result, 4 versions of improved assembly line were developed. Furthermore, 4 versions of improved simulations on assembly line were conducted and the result of performance were generated. Lastly, comparison between the current assembly line and 4 versions of improved assembly line was conducted and the most productive assembly line was proposed.

Keywords
Assembly line, assembly line balancing, assembly line balancing heuristics, assembly line improvement, assembly line redesign

1. Introduction
Assembly line is component of a manufacturing plant where succession of identical products is progressively assembled. It was first introduced by Henry Ford in 1913 for mass production of automobiles. With high manufacturing efficiency and productivity, it completely replaced the traditional manufacturing methods and brought an industrial revolution in 19th century. A basic assembly line consists of workstations connected by material handling devices. Workstation is a point on an assembly line where a certain amount of the total assembly work is performed. Each workstation in an assembly line is assigned with different task(s) or operation(s) and is set up with all necessary materials, machines, operators or even robotic arms. The basic process of an assembly line begins with a part being fed into the first workstation. After the parts have been received, the first workstation will perform the assigned operation(s). Once the operation is completed, the part will be sent to the next station by material handling device and the next station will perform assigned operation(s) (Grzechca and Foulds 2015). These processes are repeated until the end product is achieved. The time needed to complete an operation at a workstation is called as operation time while the time required to complete all operations at the workstation is known as cycle time.

2. Literature review
2.1 Assembly Line Balancing Problem
The idea of line balancing was first introduced by Brython (1954). However, the first published work on assembly line balancing problem (ALBP) was presented by Salveson (1955). The intention of assembly line balancing was to ensure that an assembly line has a satisfied precedence relations and optimized measurements of effectiveness (for example, balance delay minimization, line efficiency enhancement, productivity increment and reduction of idle time). In the case study of Jamil and Razali (2016), two assembly line improvement layouts have been successfully proposed in order to improve the production rate and efficiency.

2.2 Classification of Assembly Line Balancing Problem

Baybars (1986) defined type-I and type-II simple assembly line balancing problem (SALBP) which are the most popular variants that research deal with. Based on the study by Scholl and Becker (2006) and Boysen *et al.* (2007), the SALBP can be classified in accordance with its objective. Following lists show the classification:

i. SALBP-1: Minimize the number of workstations, *K,* to achieve a desired cycle time, *CT.*
ii. SALBP-2: Minimize the cycle time, *CT,* to achieve a desired number of workstations, *K.*
iii. SALBP-E: To minimize the number of workstations, *K* and cycle time, *CT* and maximize the line efficiency simultaneously.
iv. SALBP-F: To determine feasibility of assembly line balance for a given number of combination of workstations*, K* and cycle time, *CT.*

2.3 Lean Production

Lean Production is a method to eliminate production waste and any expenditure with no value added with the basis of lean fundamentals (Elbert 2013; Nguyen and Do 2016; Indrawati & Ridwansyah 2015). Baudin (2002) and Womack and Jones (2003) described the seven wastes that exist in a manufacturing system as known as "Muda" which in Japanese means uselessness and wastefulness. The seven wastes are as follows:

i. Motion: unnecessary effort which is not related to the work and non-value added such as walking, stretching, lifting and reaching.
ii. Inappropriate processing: using facilities, equipment, systems or processes which are costly or time consuming while a simpler method would suffice.
iii. Rework: these are action of correcting faulty such as quality defects which consumes extra time and cost.
iv. Waiting: wasteful time which is non-value added and should be eliminated.
v. Inventory: excess inventory causes adverse effects such as space occupying, additional storage, extra handling cost and inhibits communication.
vi. Transportation: excessive material handling of product or movement of employees which is non-value added.
vii. Overproduction: overproduction incurred when an item is manufactured before it is needed. It creates other wastes like motion, transportation and inventory.

2.4 Karakuri

In this era, material handling is a major section in all the manufacturing industries especially for delicate and huge components. The typical material handing devices usually consume fuel or electricity. This adds extra cost to the manufacturing of the products as the demand and cost of energy resources are increasing day by day. For the purpose of solving this problem in one step of solution, Kakakuri is often used to replace energy consuming material handling devices. The term "karakuri" is a Japanese word which means "mechanisms" or "trick" (Law, 1997). Karakuri is an automation mechanism that was first invented by the Japanese around 18th century with the intention to create movement in puppets.

2.5 Selected Heuristic Procedure

Assembly line balancing problem is depending on a set of complex assumptions and considerations. The solution is flexible as there is no absolute solution. Heuristic method is a technique with no optimal or perfect assurance. However, it has been used by researchers for various case studies.

(a) Ranked Position Weight (RPW) technique

The RPW technique was introduced by Helgeson and Birnie (1961). RPW is a heuristic procedure to select tasks to assign on workstations on the basis of their positional weight (PW). PW is the total of the task processing time and the processing times of all its successors (longest path time for the corresponding task in the precedence diagram).

(b) Largest Candidate Rule (LCR)

The fundamental of LCR is to assign tasks to workstations on the basis of their processing times. Preparation of a tasks list has to be done before tasks assigning begins. The list should be arranged in a such manner that the task with largest processing time at the top of the list while the task with smallest processing time at the bottom of the list (descending order). Tasks assigning is then begin in accordance to the sequence of tasks on the list.

(c) Kilbridge and Wester Heuristic (KWM)

The KWM is a heuristic method that was proposed by Kilbridge and Wester (1961). The objective was to select tasks and assign them on workstations on the basis of their position in the precedence diagram. The prepared precedence diagram is needed to be rearranged in a manner that tasks with identical precedence are arranged in columns as shown in Figure 1.
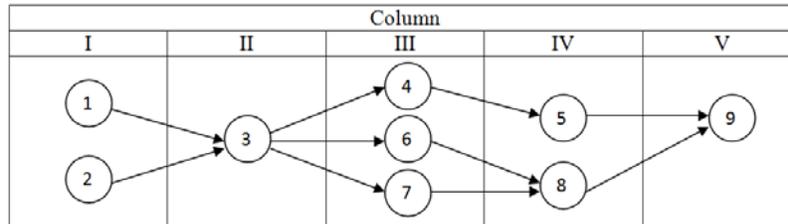

Figure 1: Precedence diagram with identical precedence tasks arranged in columns.

(d) Number of Predecessor (NOP) method

The NOP method has been widely used in assembly line balancing. In this method, the number of predecessor of all tasks are identified and listed in ascending order in a Table. The tasks are assigned to workstations in accordance to the number of predecessor staring from the top of the Table.

3. Data Collection

In this section, data collection method that is useful in the case study is presented. The data collection consists of two stages which are process and time study.

3.1 Process Study

Process study is the first stage of data collection. In this stage, a comprehensive study on the current assembly line including the full process, line construction, number of workstations, number of operators and task of operators was conducted. Long processes were divided into several segments (tasks) which were feasible and convenient for conducting time study. Process flow chart which clearly illustrates the process flow was developed. This was followed with the development of Table of the tasks and its description (as shown in Table 1A). Lastly, a Table including the workstations and its operators and operator's tasks (as shown in Table 1B) was obtained.

Table 1A: Tasks and description

Task	Description
Task A	Description A
Task B	Description B
Task C	Description C
Task D	Description D
Task E	Description E
Task F	Description F

Table 1B: Table of workstations, operators and tasks of operators

Workstation	Operator	Task
1	I	A, B
2	II	C, D
3	IV	E, F

3.2 Time Study

Time study was conducted in order to determine the time needed by qualified and well trained operators to complete a specific tasks in an assembly line. In order to achieve optimum result, time study was not be taken in the first 30 minutes of the working time of the day as the performance in this period is inconsistent and considered as the warm-up section.

First of all, a time study Table with all the tasks defined in process study was generated. A well calibrated professional stopwatch was used to measure the task time of each task. In order to ensure the accuracy, ten sets of data were collected. The cycle time of each set of data was calculated by using Equation 1. Table 2 shows an example of time study Table with data collected.

$$CT = \sum_{i=0}^{K} TT_i \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,
CT = Cycle time
K = Total number of tasks
TT_i = Task time of Task i

Table 2: Time study table

Task	Task time, TT (s)									
	1	2	3	4	5	6	7	8	9	10
A	1	2	1	1	2	2	1	1	1	2
B	4	3	3	4	4	4	3	4	3	4
C	1	1	1	2	1	2	2	1	1	1
D	6	6	7	6	6	6	7	7	6	6
E	8	8	8	9	7	8	8	8	7	8
F	1	1	2	1	3	2	1	1	2	2
CT	21	21	22	23	23	24	22	22	20	23

Based on the time study, a standard task time Table was created. The minimum task time, TT_{min} of each task among the ten sets of data and the summation of all minimum task times was identified. Then, the range of each task was computed using Equation 2. The summation of the ranges was then calculated.

$$Range = TT_{max} - TT_{min}\ldots\ldots\ldots\ldots\ldots..(2)$$

Where,
TT_{max} = *Maximum task time*
TT_{min} = *Minimum task time*

The allowance of each task was calculated by using Equation 3. Allowance is defined as any unavoidable extra time figures or delays which are to be added to the basic time of an operation. For instant, fatigue of operators, extra trivial steps, personnel or any special situation that occurred during the processing. Equation 4 was used to obtain standard task time of each tasks. Finally, the standard cycle time (cycle time in which allowances were taken into account) was computed by summing up the standard task time of each task. A standard task time Table as shown in Table 3 was created.

$$Allowance = \frac{CT_{min} - \sum TT_{min}}{\sum Range} \times Range_i\ldots\ldots\ldots\ldots..(3)$$

Where,
CT_{min} = Minimum cycle time
$Range_i$ = Range of Task i

Standard task time = TT_{min} + Allowance ……………………......(4)

Table 3: Standard task time table

Task	TT_{min} (s)	Range (s)	Allowance (s)	Standard task time (s)
A	1	1	0.125	1.125
B	3	1	0.125	3.125
C	1	1	0.125	1.125
D	6	1	0.125	6.125
E	7	2	0.25	7.25
F	1	2	0.25	1.25
$\sum$	19	8	1	Standard cycle time = 20 s

A standard workstation time table was generated. As shown in Table 4, the table consists of workstations, operators and tasks assigned to operators. Standard workstation time of each workstation was calculated using Equation 5.

Standard workstation time $= \sum_{i=0}^{K} TT_i$ ……………(5)
Where,
K   = Total number of tasks in the workstation
TT_i = Task time of Task i

Table 4: Standard workstation time table

Workstation	Operator	Task	Standard workstation time (s)
1	I	A, B	38.78
2	II	C, D	62.96
3	IV	E, F	74.25

4. Performance evaluation

Various measures of solution quality have appeared in order to evaluate and compare different solutions. Three of these are presented as following.

Rate of production is defined as the rate at which the product is produced.

Rate of production $= \dfrac{Total\ productivity\ per\ day}{Total\ running\ hour\ per\ day}$………………………(6)

Line efficiency is the degree to which the resources of the assembly line including human and capital resources are wisely and effectively used.

Line efficiency $= \dfrac{SCT}{SWT_{max}\ \text{x}\ K}$………………………..(7)
Where,
SCT = Standard cycle time
SWT_{max} = Maximum standard workstation time
K = Total number of workstation

Smoothness index is the relative smoothness of the assembly line. Perfect balance is indicated by smoothness index of 0 (Grzechca and Foulds 2015).

Smoothness index $= \sqrt{\sum_{i=1}^{K}(SWT_{max} - SWT_i)^2}$…………………(8)
Where,
K = Total number of workstations
SWT_{max} = Maximum standard workstation time
SWT_i = Standard workstation time of Workstation, i

5. The Case Study

The study consists of including process study, root cause analysis, lean production review and implementation, assembly line balancing and solution review.

5.1 Process Study

The headlamp manufacturing process consists of several major segments as following:
Lens assembly, Base assembly, Reflector assembly, Combine base, reflector and lens Packing
These major segments were then analyzed and further broken down into tasks as shown in Table 5 for the convenience of conducting time study. Alphabets were assigned to each of the tasks, for instance "A" was used to represent lens loading, "B" is for reflector loading and more. Furthermore, the process flow chat which clearly describes and depicts the current assembly line process is plotted and illustrated in Figure 2.

Table 5: Tasks and descriptions

	Task	Description
A	Lens loading	Take a lens from lens loading bay, unwrap the lens and visually check for any defects.
B	Reflector loading	Take a reflector from reflector loading, unwrap the reflector and visually check for any defects.
C	Base loading	Take a base from base loading bay, unwrap the base and visually check for any defects.
D	Shape big packing box	Shape up a big box.
E	Shape small packing box	Shape up a small box.
F	Lens assembly	Attach screws and clips.
G	Reflector assembly	Place spring bracket on reflector, attach nuts and a screw with spring.
H	Base assembly	Attach product label stickers, inset bolts and washers and hammer to the fix position.
I	Combine base and reflector (Part A)	Combine the base and lens to become Part A.
J	Photometric check	Use a light beam to check the reflection of the reflector.
K	Set on glue jig	Set Part A on glue jig.
L	Combine lens to Part A and set on air press	Combine Part A and lens, then set on air press machine.
M	Final assembly	Attach screws, brackets and clips.
N	Packing small box	Insert the lamp into a plastic bag and place in a small box. Then, inset bubble bag into the box and seal it.
O	Packing big box	Place the small box into a big box and insert bubble bag. Attach product information sticker and company sticker. Then, seal the box.

Based on the process study, the current assembly line consists of seven workstations and each workstation is operated by one skilled and well trained operator. As a result, this assembly line has a total number of seven operators. Six of the operators were assigned with two tasks respectively, while one operator is assigned with three tasks. Table 6 shows the tasks assigned by each operator in each workstation.
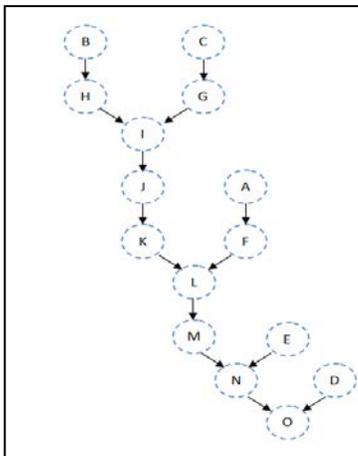

Figure 2: Process flow chart

Table 6: Tasks assigned to operator in each workstation

Workstation	Operator	Task
1	I	B, I
2	II	C, H
3	IV	A, F
4	III	G, J
5	V	K, L
6	VI	E, M
7	VII	D, N, O

A time study was conducted by using a well calibrated professional stopwatch. The time measurement of each task was conducted precisely without any delay and ten sets of sample were taken. Then, the cycle time of each set of sample has been calculated by using Equation 1. Table 7 shows the result obtained.

Table 7: Time study result

Task	1	2	3	4	5	6	7	8	9	10
					Task time, TT (s)					
A	7.30	7.98	6.08	7.21	6.95	8.82	7.75	7.34	8.41	7.55
B	7.68	6.98	8.30	7.29	6.86	7.37	8.30	7.57	7.93	8.32
C	8.11	7.86	7.42	7.72	8.39	7.55	7.78	8.17	7.96	7.45
D	12.91	12.91	10.85	10.85	11.46	11.46	10.22	10.22	10.51	10.51
E	13.59	9.68	15.45	10.33	12.33	13.54	8.76	11.63	13.55	12.97
F	83.68	74.01	76.27	60.16	58.34	82.68	83.32	58.59	64.20	75.44
G	43.77	40.53	41.48	38.09	37.99	40.71	42.29	39.01	43.56	41.62
H	48.93	57.31	58.02	55.98	49.02	51.30	66.84	55.08	54.43	58.80
I	29.14	33.87	32.69	32.07	31.06	31.83	35.64	32.87	31.78	33.43
J	30.03	25.58	31.71	30.33	41.37	33.45	26.70	29.11	32.08	29.30
K	7.46	8.16	12.44	8.78	10.18	8.14	6.49	8.62	9.20	8.11
L	44.13	48.11	50.15	50.37	50.06	49.64	41.33	51.77	42.50	41.38
M	86.91	93.88	97.59	109.55	100.93	109.87	96.77	109.52	109.71	98.19
N	38.80	44.05	47.85	44.68	52.40	49.03	42.88	44.13	42.77	43.01
O	31.65	31.65	33.92	33.92	32.53	32.53	34.54	34.54	32.38	32.38
CT	494.09	502.56	530.22	507.33	509.87	537.92	519.61	508.17	510.97	508.46

The minimum task time of each task was identified and the range was calculated by using Equation 2. Allowance and standard time were then calculated by using Equation 3 and 4 respectively. Based on the result, the standard cycle time of the current assembly line was 454.09s which means it will take 454.09s to produce a single unit of headlamp. Table 8 shows the result obtained from each calculation.

Table 8 Current assembly line standard time

Task	TT_{min} (s)	Range (s)	Allowance (s)	Standard task time (s)
A	6.08	2.74	0.96	7.04
B	6.86	1.46	0.51	7.37
C	7.42	0.97	0.34	7.76
D	10.22	2.69	0.94	11.16
E	8.76	6.69	2.35	11.10
F	58.34	25.34	8.87	67.21
G	37.99	5.78	2.02	40.01
H	48.93	17.91	6.27	55.20
I	29.14	6.50	2.27	31.41
J	25.58	15.79	5.53	31.11
K	6.49	5.95	2.08	8.57
L	41.33	10.44	3.66	44.98
M	86.91	22.96	8.04	94.95
N	38.80	13.60	4.76	43.56
O	31.65	2.89	1.01	32.66
Σ	444.50	141.71	49.62	Standard cycle time = 494.09s

By using the data obtained, a simulation model of current assembly line was developed by using Flexsim. Figure 3 illustrates the simulation model with designated area of each workstation. Each task in this model was assigned with the standard task time obtained from time study accordingly. The model was then simulated for a period of 28800s (8 hours) which is the one day running time of the assembly line. In this simulation, white colored material was used to represent the reflector, blue for the lens, black for the base, red for combined reflector and base, yellow for the combined headlamp while brown for the sealed big or small box. The simulation result shows that the line is capable of producing 258 units of headlamp in 28800s as shown in Figure 3. Furthermore, the simulation report for tasks and operators were generated. Table 9 shows the percentage of idle, processing and blockage of the tasks, while Table 10 shows the percentage of idle and utilization of the operators. Lastly, the overall of percentage of idle, processing, blockage and utilization were calculated by computing the average value.
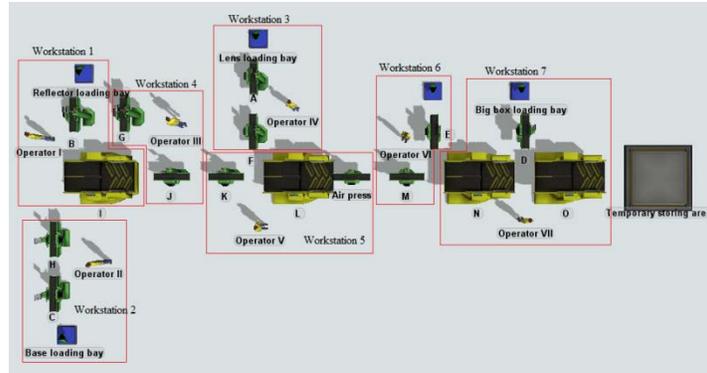
Figure 3: Current assembly line model with workstation area designated

Figure 4: Current assembly line simulation

Table 9 Current assembly line simulation report (tasks)

Task	Idle (%)	Processing (%)	Blockage (%)
A	0.01%	6.51%	28.71%
B	0.03%	6.89%	57.39%
C	0.00%	7.25%	38.43%
D	0.00%	10.20%	88.29%
E	0.00%	10.09%	2.05%
F	0.06%	61.89%	36.59%
G	0.03%	37.25%	26.20%
H	0.16%	51.43%	46.96%
I	0.94%	29.18%	66.11%
J	0.55%	28.79%	65.99%
K	0.59%	40.82%	48.92%
L	0.26%	41.28%	47.01%
M	1.12%	86.28%	0.00%
N	65.66%	21.39%	0.00%
O	0.04%	11.49%	0.00%
Overall =	4.63%	30.05%	36.84%

Table 10 Current assembly line simulation report (operators)

Operator	Idle (%)	Utilisation (%)
Operator I	56.93%	36.06%
Operator II	38.43%	65.99%
Operator III	26.23%	68.37%
Operator IV	28.71%	49.17%
Operator V	47.99%	96.36%
Operator VI	1.04%	43.05%
Operator VII	51.94%	59.67%
Overall =	35.90%	59.67%

5.2 Performance Evaluation

In this section, performance evaluation was conducted. First of all, a standard workstation time table (as shown in Table 11) was created by totaling up the standard workstation time of all tasks in each workstation.

Table 11: Standard workstation time

Workstation	Operator	Task	Standard workstation time (s)
1	I	B, I	38.78
2	II	C, H	62.96
3	IV	A, F	74.25
4	III	G, J	71.12
5	V	K, L	53.55
6	VI	E, M	106.05
7	VII	D, N, O	87.38

Next, the rate of production, line efficiency and smoothness index were calculated by using Equation 6, 7 and 8 respectively. Based on the calculation, the production rate of current assembly line is 32.25 units per hour, the current assembly line efficiency is 66.56% and the smoothness index is 108.25.

5.3 Root Cause Analysis

Table 12 was created for the convenience of examining and analyzing methodically the statistics of current assembly line in order to reveal the root cause. Based on Table 12, the overall percentage of blockage is 36.44%, overall percentage of task idle is 4.40%, overall percentage of processing is 32.45%, overall percentage of operators idle is 35.90% and overall percentage of operators utilization is 58.67%. The line efficiency is 66.56% while the smoothness index is 108.25.

Table 12: Current assembly line statistic

Current assembly line	
Number of operator	7
Number of workstation	7
Line efficiency	66.56%
Smoothness index	108.25
Overall blockage percentage	36.44%
Overall tasks idle percentage	4.40%
Overall tasks processing percentage	32.45%
Overall operators idle percentage	35.90%
Overall operators utilisation percentage	58.67%
Total productivity (1 day)	258
Production rate (units per hr)	32.25

For the intention of developing an improved version of assembly line which has a better performance and greater productivity, the line efficiency must first be improved by lowering the smoothness index. This can be done by improving the overall performance of the current assembly line. In addition, overall percentage of blockage must be minimized, tasks' and operators' idle time and maximize the overall percentage of tasks processing and operators' utilization. Based on Table 11, it is observed that the number of tasks had been assigned to operators in a fair and even manner. Six of the operators are assigned with two tasks respectively, whereas one operator is assigned with three tasks. On the other hand, it is observed that the work load distributed to the operators is imbalance. The greatest standard workstation time occurs at Workstation 6 which is operated by Operator VI, while standard workstation time of Workstation 1 is only 37% of it.

Furthermore, the standard workstation time of workstation 2 and workstation 5 are lower than 60% of workstation 6. In conclusion, the assembly line is identified to be having imbalance workstation time and the operators are having uneven work load which eventually led to low line efficiency and poor smoothness index. Hence, it is necessary to conduct assembly line balancing in order to optimize the operators' work load and workstation's time. As a chain reaction, the overall performance of every aspect can be improved which will improve the line efficiency and smoothness index.

5.4 Lean production review and implementation

In this section, a comprehensive lean production review has been conducted on the current assembly line through the perspectives of the Seven Muda. Based on rigorous analysis, Karakuri Flow Rack (as shown in Figure 5) is recommended to be adopted in the assembly line for the elimination of motion, transportation and waiting.

Three similar Karukuri Flow Racks which connected the base, lens and reflector loading bay to its respective immediate successor will be used to transfer the materials continuously. The operation is easy, fast and highly efficient whereby the material can be transferred automatically just by pressing down the pedal. With these devices installed, the manual material handling works and movement of employees which is non-value adding were eliminated.
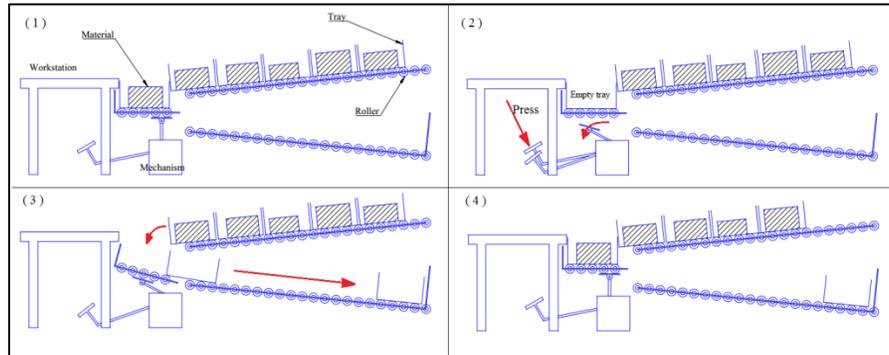

Figure 5 Karukuri Flow Racks diagram

Based on previous time study, it took 2 seconds to transfer a base, lens or reflector from the loading bay to its respective immediate successor. As a result, with the aid of Karakuri Flow Rack, the standard task time of each Task A, Task B and Task C was reduced by 2 seconds to become 5.04s, 5.37s and 5.76s respectively. The assembly line is 6 seconds shorter to complete one cycle as the standard cycle time decreased from 454.09s to 448.09s. Table 13 shows the standard task time and standard cycle time after the Karakuri Flow Rack were implemented.

Table 13. Statistics after karukuri implemented

Task	TT_{min} (s)	Range (s)	Allowance (s)	Standard task time (s)
A	4.08	2.74	0.96	5.04
B	4.86	1.46	0.51	5.37
C	5.42	0.97	0.34	5.76
D	10.22	2.69	0.94	11.16
E	8.76	6.69	2.35	11.10
F	58.34	25.34	8.87	67.21
G	37.99	5.78	2.02	40.01
H	48.93	17.91	6.27	55.20
I	29.14	6.50	2.27	31.41
J	25.58	15.79	5.53	31.11
K	6.49	5.95	2.08	8.57
L	41.33	10.44	3.66	44.98
M	86.91	22.96	8.04	94.95
N	38.80	13.60	4.76	43.56
O	31.65	2.89	1.01	32.66
Σ	438.50	141.71	49.62	488.09

5.5 ASSEMBLY LINE BALANCING
In this section, heuristics including Largest Candidate Rule (LCR), Number of Predecessor Rule, Kilbridge and Wester Method and Ranked Position Weight method were applied for assembly line balancing. Four different version of improvements were obtained and simulated by using FlexSim. The performance of workstations and operators were generated. The line efficiency and smoothness index were calculated.

5.5.1 LCR
LCR was implemented. Table 14 shows the result of task assigning by using LCR

Table 14. LCR task assigning

Workstation number	Operator	Task	Task time (s)	Workstation time (s)	Remaining time (s)
1	I	D	11.16	93.63	1.32
		E	11.10		
		C	5.76		
		H	55.20		
		B	5.37		
		A	5.04		
2	II	F	67.21	67.21	27.74
3	III	L	44.98	84.99	9.96
		G	40.01		
4	IV	I	31.41	71.09	23.86
		J	31.11		
		K	8.57		
5	V	M	94.95	94.95	0
6	VI	N	43.56	76.22	8.73
		O	32.66		

Next, the model of the LCR was improved assembly line constructed and simulated by using FlexSim as illustrated in Figure 6. The simulation shows that the assembly line is capable to produce 279 units of product in 28800s. Moreover, the performance statistic has been generated. Table 15 shows the percentage of idle, processing and blockage of the tasks, while Table 16 shows the percentage of idle and utilisation of the operators. Furthermore, by calculating the average value. the overall of percentage of idle, processing, blockage and utilisation were computed. Lastly, the line efficiency is 85.67% and the smoothness index is 38.94.
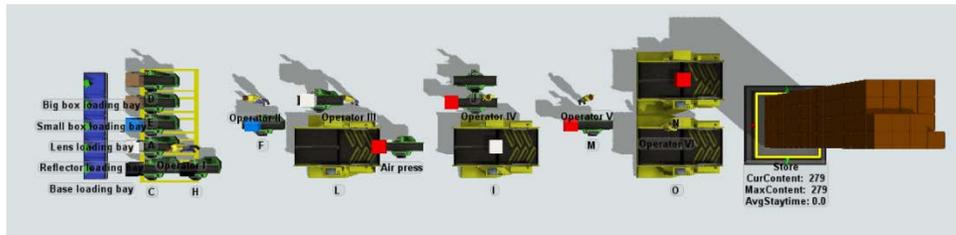

Figure 6. Simulation of LCR improved assembly line

TABLE 15. Tasks performance statistic (LCR method)

Task	Idle (%)	Processing (%)	Blockage (%)
A	0.02%	4.96%	1.75%
B	0.01%	5.32%	3.61%
C	0.00%	5.69%	0.00%
D	0.00%	10.83%	1.48%
E	0.00%	10.77%	2.31%
F	32.40%	65.88%	1.72%
G	10.06%	39.48%	34.39%
H	6.88%	54.30%	0.00%
I	0.20%	30.91%	0.00%
J	59.20%	30.58%	0.21%
K	46.79%	43.39%	1.39%
L	44.56%	44.06%	5.95%
M	1.32%	92.35%	6.33%
N	5.23%	22.83%	0.00%
O	45.16%	12.26%	0.00%
Overall =	16.79%	31.58%	3.94%

Table 16. Operators performance statistic (LCR method)

Operator	Idle (%)	Utilisation (%)
Operator I	0.00%	91.84%
Operator II	34.12%	65.88%
Operator III	16.45%	83.55%
Operator IV	30.13%	69.87%
Operator V	7.65%	92.35%
Operator VI	64.91%	35.09%
Overall =	25.54%	73.10%

5.5.2 NOP

In this section, Number of Predecessor rule was implemented. Table 17 presents the result of task assigning by using Number of Predecessor rule.

Table 17 NOP task assigning

Workstation number	Operator	Task	Task time (s)	Workstation time (s)	Remaining time (s)
1	I	D	11.16	94.51	0.44
		E	11.10		
		A	5.04		
		F	67.21		
2	II	B	5.37	51.14	43.81
		C	5.76		
		G	40.01		
3	III	H	55.20	86.61	8.34
		I	31.41		
4	IV	J	31.11	84.66	10.29
		K	8.57		
		L	44.98		
5	V	M	94.95	94.95	0
6	VI	N	43.56	76.22	8.73
		O	32.66		

Next, the model of the NOP improved assembly line was constructed and simulated by using FlexSim as illustrated in Figure 7. The simulation shows that the assembly line is capable to produce 291 units of product in 28800s. Moreover, the performance statistic has been generated. Table 18 shows the percentage of idle, processing and blockage of the tasks, while Table 19 shows the percentage of idle and utilisation of the operators. Furthermore, the overall of percentage of idle, processing, blockage and utilisation are computed by finding the average value. Lastly, the line efficiency is 85.67% and the smoothness index is 46.60.

Table 18. Tasks performance statistic (NOP method)

Task	Idle (%)	Processing (%)	Blockage (%)
A	0.02%	5.16%	0.51%
B	0.03%	5.56%	48.67%
C	0.00%	5.96%	44.38%
D	0.00%	11.28%	2.23%
E	0.00%	11.25%	6.02%
F	5.67%	68.62%	0.68%
G	0.10%	41.27%	56.26%
H	0.05%	56.94%	10.72%
I	10.26%	32.29%	64.05%
J	1.62%	31.88%	13.08%
K	1.26%	45.25%	43.81%
L	42.71%	45.77%	1.17%
M	13.81%	96.19%	0.00%
N	54.86%	23.85%	0.00%
O	47.02%	12.81%	0.00%
Overall =	11.83%	32.94%	19.44%

Table 19. Operators performance statistic (NOP method)

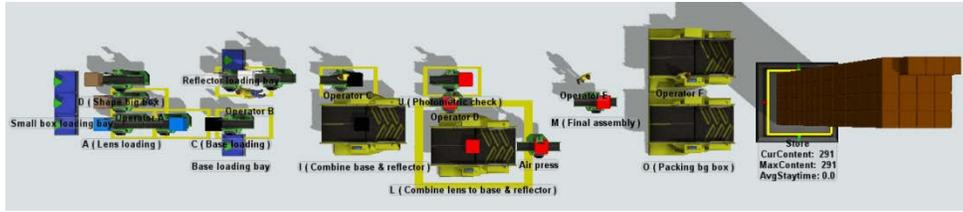| Operator	Idle (%)	Utilisation (%)
Operator I	0.37%	96.27%
Operator II	41.12%	52.79%
Operator III	10.77%	89.23%
Operator IV	13.60%	86.40%
Operator V	3.81%	96.19%
Operator VI	63.35%	36.65%
Overall =	22.17%	76.25%

Figure 7. Simulation of NOP improved assembly line

5.5.3 KWM

In this section, Kilbridge and Wester heuristic method was implemented. As illustrated in Figure 8, a precedence diagram which the tasks with identical precedence are arranged in columns has been generated. Then, the tasks are assigned to workstations in accordance to the procedure discussed in section 3. The result of task assigning by using Kilbridge and Wester heuristic method is shown in Table 20.
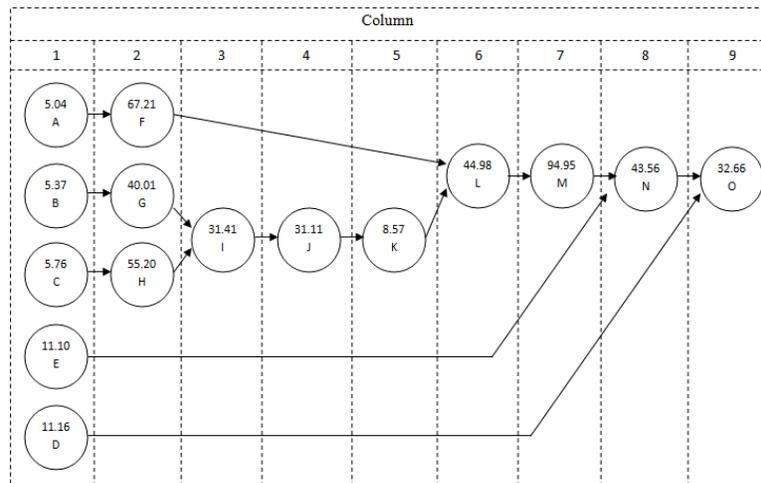

Figure 8. Precedence diagram

Table 20. KWM task assigning

Workstation number	Operator	Task	Task time (s)	Workstation time (s)	Remaining time (s)
1	I	D	11.16	93.63	1.32
		E	11.10		
		C	5.76		
		B	5.37		
		A	5.04		
		H	55.20		
2	II	F	67.21	67.21	27.74
3	III	G	40.01	71.42	23.53
		I	31.41		
4	IV	J	31.11	84.66	10.29
		K	8.57		
		L	44.98		
5	V	M	94.95	94.95	0
6	VI	N	43.56	76.22	8.73
		O	32.66		

Next, the model of the KWM improved assembly line was constructed and simulated by using FlexSim as shown in Figure 8. The simulation shows that the assembly line is capable to produce 279 units of product in 28800s. Following by that, the performance statistic has been generated. Table 21 shows the percentage of idle, processing

and blockage of the tasks, while Table 22 shows the percentage of idle and utilisation of the operators. Also, the overall of percentage of idle, processing, blockage and utilisation were computed by finding the average value. Lastly, the line efficiency is 85.67% and the smoothness index is 38.82.
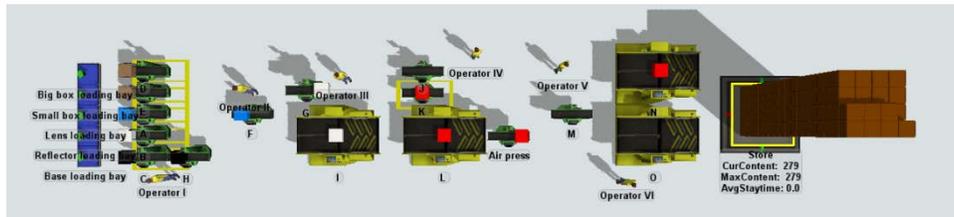

Figure 8 Simulation of KWM improved assembly line

Table 21. Tasks performance statistics (KWM method)

Task	Idle (%)	Processing (%)	Blockage (%)
A	0.02%	4.96%	2.24%
B	0.01%	5.32%	3.71%
C	0.00%	5.69%	0.00%
D	0.00%	10.83%	1.59%
E	0.00%	10.77%	2.71%
F	32.18%	65.88%	1.94%
G	10.06%	39.60%	60.34%
H	6.88%	54.30%	0.00%
I	10.18%	30.91%	0.13%
J	47.61%	30.58%	0.28%
K	5.27%	43.41%	0.11%
L	3.87%	43.91%	0.76%
M	7.68%	92.32%	0.00%
N	15.34%	22.83%	0.00%
O	44.86%	12.26%	0.00%
Overall =	12.26%	31.57%	4.92%

Table 22. Operators performance statistic (KWM method)

Operator	Idle (%)	Utilisation (%)
Operator I	0.00%	91.84%
Operator II	34.12%	65.88%
Operator III	29.53%	70.47%
Operator IV	17.11%	82.89%
Operator V	7.68%	92.32%
Operator VI	64.91%	35.09%
Overall =	25.56%	73.08%

5.5.4 RPW

In this section, the fourth heuristic which is the Ranked Position Weight method was implemented. Table 23 shows the result of task assigning by using Ranked Position Weight method
.

Table 23. RPW task assigning

Workstation number	Operator	Task	Task time (s)	Workstation time (s)	Remaining time (s)
1	I	D	11.16	93.63	1.32
		E	11.10		
		C	5.76		
		B	5.37		
		A	5.04		
		H	55.20		
2	II	G	40.01	71.42	23.53
		I	31.41		
3	III	F	67.21	67.21	27.74
4	IV	J	31.11	84.66	10.29
		K	8.57		
		L	44.98		
5	V	M	94.95	94.95	0
6	VI	N	43.56	76.22	8.73
		O	32.66		

Following by that, the model of the RPW improved assembly line was constructed and simulated by using FlexSim as shown in Figure 9. The simulation shows that the assembly line is capable to produce 279 units of product in 28800s. Furthermore, the performance statistic has been generated. Table 24 shows the percentage of idle, processing and blockage of the tasks, while Table 25 shows the percentage of idle and utilisation of the operators. Then, the overall of percentage of idle, processing, blockage and utilisation were calculated by calculating the average value. Lastly, the line efficiency is 85.67% and the smoothness index is 38.82.
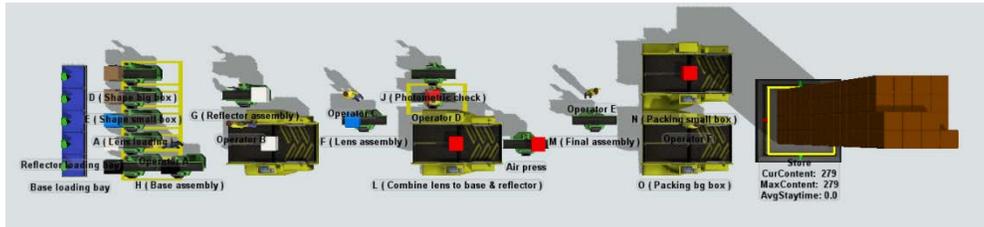

Figure 9 Simulation of RPW improved assembly line

Table 24. Tasks performance statistic (RPW method)

Task	Idle (%)	Processing (%)	Blockage (%)
A	0.02%	4.96%	2.34%
B	0.01%	5.32%	5.76%
C	0.00%	5.69%	0.00%
D	0.00%	10.83%	1.62%
E	0.00%	10.77%	2.79%
F	30.32%	65.88%	1.84%
G	0.05%	39.59%	58.38%
H	6.88%	54.30%	0.00%
I	10.19%	30.91%	0.07%
J	57.70%	30.58%	0.28%
K	5.28%	43.40%	0.11%
L	3.87%	43.90%	0.76%
M	7.69%	92.31%	0.00%
N	17.21%	22.82%	0.00%
O	44.81%	12.26%	0.00%
Overall =	13.14%	31.57%	4.93%

Table 25. Operators performance statistic (RPW method)

Operator	Idle (%)	Utilisation (%)
Operator I	0.00%	91.84%
Operator II	25.60%	74.40%
Operator III	32.16%	67.84%
Operator IV	17.12%	82.88%
Operator V	7.69%	92.31%
Operator VI	64.91%	35.09%
Overall =	24.58%	74.06%

6. SOLUTION REVIEW

In this section, the data of current assembly line, LCR, NOP, KWN and RPW improved assembly lines that were obtained from previous sections are listed in Table 26. Based on the observation, the data of the four improves versions of assembly line have successfully been improved.

Table 26 Data comparison table of current and improved versions of assembly line

	Current	LCR	NOP	KWM	RPW
Number of operator	7	6	6	6	6
Number of workstation	7	6	6	6	6
Line efficiency	66.56%	85.67%	85.67%	85.67%	85.67%
Smoothness index	108.25	38.94	46.60	38.82	38.82
Overall tasks idle percentage	4.40%	16.79%	11.83%	12.26%	12.27%
Overall tasks processing percentage	32.45%	31.58%	32.94%	31.57%	31.57%
Overall tasks blockage percentage	36.44%	3.94%	19.44%	4.92%	4.93%
Overall operators idle percentage	35.90%	25.54%	22.17%	25.56%	24.58%
Overall operator utilize percentage	58.67%	73.10%	76.25%	73.08%	74.06%
Total productivity (1 day)	258	279	291	279	279
Production rate (unit per hr)	32.25	34.88	36.38	34.88	34.88

First of all, the current assembly line consists of seven operators while the improved versions of assembly line consist only six operators. The number of workstation in the improved versions assembly line have been reduced from seven workstations to six workstations. Due to lesser operators and workstations, the production cost has successfully been reduced.

Furthermore, the line efficiency of LCR, NOP, KWM and RPW based assembly line increased from 66.56% to 85.67%. This number is indicating that the improved assembly lines are more effective than the current assembly line. Hence, the improved versions assembly line smoothness index have also been greatly improved. The best smoothness index is found at the KWM and RPW improved assembly line with the value of 38.82. It is followed by LCR and NOP improved assembly line with the value of 38.94 and 46.60 respectively.

By comparing the overall tasks idle percentage generated by FlexSim, it was observed that the overall idle time were increased. The biggest overall task idle percentage was found in LCR improved assembly line with the value of 16.79%, following by RPW (12.27%), RPW (12.26%) and NOP (11.83%) improved assembly line. Although the overall task idle percentage increased, it does not indicate that the improved version assembly lines have worse performance.

In fact, this phenomenon is due to the poor and uneven workload distribution in the current assembly line. By referring to Table 5, it is found that all the tasks are having low percentage of idle and an extremely high idle percentage (65.66%) found at Task N. The cause of high idle percentage at Task N was due to the high workload in the previous workstation which is Workstation 6 (workstation time = 106.05s as referred to Table 4.7). However, the workloads in the improved versions of assembly line are evenly distributed which lowered the highest task idle while increased the other tasks and eventually raised up the overall tasks idle. By comparing the overall processing percentage, it was found that NOP improved assembly line has the highest overall processing percentage with the value of 32.94%. On the other hand, the overall processing percentage of LCR, KWM and RPW improved assembly line were slightly lower than the current assembly line. Furthermore, the overall blockage percentages were compared. It was observed that the overall blockage percentage has been substantially reduced. LCR improved assembly line has the lowest overall blockage percentage of value of 3.94%, followed by KWM (4.92%), RPW (4.93%) and NOP (19.44%).

In addition, the overall operators idle and utilize percentages were compared. Based on the results, the overall operators idle and utilization percentages of improve versions of assembly line have successfully been improved by comparing with current assembly line. The lowest overall operators' idle percentage was found in NOP improved assembly line and the value is 22.17%. It is followed by RPW, LCR and KWM improved assembly line with the value of 24.58%, 25.54% and 25.56% respectively. On the other hand, the highest overall operators utilization percentage occurred in NOP improved assembly line and the value is 76.25%. However, the operators utilization percentage of LCR, KWM and RPW improved assembly line were 73.10%, 73.08% and 74.06% respectively.

Furthermore, the total productivity per day of NOP improved assembly line increased from 258 to 291 units while LCR, KWM and RPW improved assembly line increased from 258 to 279 units. As a result, the production rate of NOP improved assembly line is 36.88 unit per hour while LCR, KWM and RPW improved assembly line are 34.88 unit per hour.

Last but not least, a selection matrix table as shown on Table 27 has been created in order to select the best version of assembly line. The assembly line(s) with best score in each aspect will gain a tick. Based on the selection, NOP improved assembly line is chosen as the proposed version of assembly line as it gained the most ticks in the selection matrix.

Table 27. Assembly line selection matrix

	Current	LCR	NOP	KWM	RPW
Number of operator		√	√	√	√
Number of workstation		√	√	√	√
Line efficiency		√	√	√	√
Smoothness index				√	√
Overall tasks idle percentage	√				
Overall processing percentage			√		
Overall blockage percentage		√			
Overall operators idle percentage			√		
Overall operator utilize percentage			√		
Total productivity (1 day)			√		
Production rate (unit per hr)			√		

7. Conclusion and Recommendations

By implementing the methodology, three objectives of this study were met and achieved. First of all, a root cause analysis of the current lamp product assembly line was conducted. It was found that, the assembly line was having imbalance workstation time among the workstations. Furthermore, the operators were having uneven work load. These are the causes of bottlenecks, idles, blockages, non-processing and low utilization which eventually led to poor smoothness index of 108.25 and low line efficiency of 66.56%.

An improved version of assembly line was developed based on the assembly line balancing. Number of Predecessor (NOP) improved version assembly line which gained the highest score in Table 4.25 had been selected as the proposed assembly line among all the versions. This assembly line consists of three Kakaruri Flow Racks which eliminate non value added motion, transportation and waiting.

Lastly, a simulation model of Number of Predecessor (NOP) improved version assembly line was developed and simulation had been conducted using FlexSim. The proposed assembly line consists only 6 operators and workstations while current assembly line consists of 7 operators and workstations. Furthermore, the assembly line performance has been improved. The overall tasks processing and operators' utilization have been improved by 0.49% and 14.41% respectively. On the other hand, the tasks blockage and operators idle percentage have been reduced by 17% and 13.73% respectively. Besides that, the tasks had been evenly distributed to every operator in every workstation after assembly line balancing and results in the overall tasks idle percentage is increased by 7.43%. Moreover, the line efficiency is improved by 19.11% (from 66.56% to 85.67%) and the smoothness index has been reduced from 108.25 to 46.60. Lastly, the production rate is increased from 32.25 unit per hour to 36.38 unit per hour. Therefore, the proposed assembly line is capable of producing 291 units of headlamp in one day of operation.

Throughout the research, it was found that there are several studies can be done in the future to further improve the assembly line. Firstly, research on cost analysis can be conducted in order to provide an even better and more concrete validation of assembly line improvement. This can be done through comparison of expenditures including materials, labor and overhead costs between the current and improved version of assembly line.

Furthermore, manufacturing process is one of the most significant element in providing high manufacturing efficiency. A well designed manufacturing process is beneficial in several aspects including time, costs and resources reduction and ensure high quality of assembly and fabrication. Hence, research on process optimization is highly recommended to be conducted. Lastly, with the advancement of technology, research on technology implementation can be conducted. Technologies such as robotic assembly arm, automated conveying systems, automated packing systems, computer-integrated manufacturing or even Artificial Intelligence are capable of being adopted in the assembly line as a means of improving the performance of assembly line.

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