ASSEMBLY LINE BALANCING IMPLEMENTATION IN MANUFACTURING INDUSTRY

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ABSTRACT

A wide range of the real world problems in industries are related to misbalances of the production line. In this paper, there is the demonstration of a practical approach to balance and synchronize a ceiling fan assembly line which is characterized by several manufacturing limitations. The Rank Positional Weight (RPW) which is a heuristic method was used to balance the ceiling fan motor assembly line of Nigerian Engineering Works Port Harcourt for performance improvement. Data collected for this research is based on primary information. This involved assigning the tasks or elements into work stations such that the cycle time was minimized from 0.729min to 0.583min. This in turn minimized the balance delay from 31% to 5% thereby maximizing the line efficiency from 69% to 95%. This increased the possible output of the assembly line from 608 units to 823 units of the assembled ceiling fan motor without additional resources. The study recommends that the company should adopt the new production line design.

KEYWORDS: Assembly Line Balancing, Heuristic Method; Rank Positional Weight; Cycle Time, Balance Delay and Efficiency

Received: Jun 06, 2020; **Accepted:** Jun 26, 2020; **Published:** Jul 30, 2020; **Paper Id.:** IJMPERDJUN2020541

INTRODUCTION

The purpose and philosophy of any manufacturing firm is to be in business by maximizing the control of those factors that determine its efficiency and productivity [1]. In addition, have quality product(s) and the capability to cope with customers' demands. The achievement of these goals are predicated on planning, controlling and measuring parameters related to the performance of the sector. Therefore, manufacturers should realize that performance depends on how well the production line is in term of output. Thus, Assembly Line Balancing (ALB) plays a vital function especially in the production line. This is because the installation of an assembly line requires large capital of investments. It is therefore important that such a system is designed and balanced so that it is able to work as efficiently as possible. As part of manufacturing system, an assembly system performs a set of sequential distinct minimum rational work (task) for the assembly of a product and it consists of a set of work stations linked together by transport mechanism and detailed specification of how the assembly of the product flows from one station to another. It comes crucially important for the manufacturing system and assembly line since the process need to be optimized with the correct sequence order [2].

The success of achieving the goal of production is influenced significantly by balancing assembly lines [3]. Line Balancing means balancing the production line, or any assembly line. The main objective of line balancing is to distribute the task evenly over the work station so that idle time of man, of machine can be minimized. Line balancing primary focus at grouping the facilities or workers in an efficient pattern in order to obtain an optimum or

most efficient balance of the capacities and flows of the production or assembly processes [4]. Therefore assembly line balancing problem can be said to be an optimization problem [5]. Assembly Line Balancing (ALB) is the term commonly used to refer to the decision process of assigning tasks to workstations in a serial production system. The task consists of elemental operations required to convert raw material in to finished goods. Toward the optimization subject, the most common variables are: The number of workstations necessary to execute all tasks; the maximum processing time that can be assigned to a single workstation (cycle time). The amount of time that one station execute no tasks (idle time) [6]. By managing an assembly line, few advantages occur; such as better labour and machine utilization, easy learning for workers, less work-in-progress inventory, less space requirement and reduction in production costs [7].

There are various techniques, which have been used for production line planning. It has been observed that the linear programming, fuzzy and stochastic programming, heuristic and simulation methods are the most common utilized methods in the real problems of production and assembly lines balancing [8]. Generally, the study on ALB has been classified into two classes either Simple Assembly Line Balancing (SALB) or General Assembly Line Balancing (GALB)[9, 10]. Basically, the assembly line in the SALB category consist of a straight line workstation that connects each other for completing each assigned task before the final product is released. 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 [11]. Next is SALB for type-E problem which generally focus to maximize the line efficiency. Here, it is believed to consider both objectives on SALB type-1 and type-2 to maximize the assembly line efficiency. 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 [12, 13, 14]. There is also the Mixed-model Assembly Line Balancing (MALB) problem which consider to assign the tasks into the workstation with different duration of time and different model to balance the assembly line[15]. 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. Therefore, UALB are practically suitable for a production system with a small space of assembly line.

This paper considered the single model assembly line balancing problem (SALB), which can implement heuristics methods. These are simple computing methods that have been used to obtain optimal solutions of assembly line balancing problems [16]. There are some recent studied which compared some heuristics methods such as; Largest Candidate Rule (LCR), Kilbridge and Wester (K-W), and Rank Positional Weight (RPW). [17] reported in their study on imitating of two stages gear box procedure that the Rank Position Weight has been found very handy even when less data is available. This was done using the three methods of LCR, K-W and RPW 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. In addition, the bottleneck problems in most assembly lines have proved to be reduced through this RPW approach [18, 2].

This research is considering an assembly line producing ceiling fan motor. The ceiling fan motor assembly line of Nigerian Engineering Works Port Harcourt was observed to be experiencing a technical problem of high idle time, high labour cost and low line efficiency. This problem was attributed to imperfect allocation of work along various workstations. This makes for an unbalanced and inefficient line, which tend to reduce the overall productivity of the

company. Therefore the objective of this work is to group the tasks into a given number of workstations such that the cycle time (the maximum of the sum of tasks times of the workstations) is minimized. This in turn maximizes the production rate and improved the efficiency of the line. This was achieved using the Rank Positional Weight (RPW) which is a heuristics method for this balancing problem because it offers a real practical tool which can be understood and applied. In addition, this study creates assembly line which have the highest line efficiency and to reveal the applicability of heuristic assembly line balancing methods for an optimal ceiling fan motor assembly line.

METHODOLOGY

In this study, the production of ceiling fan motor assembly in Nigeria Engineering Works Port Harcourt was investigated to solve the problem of assembly line balancing. The technological precedence diagram of the assembly line is shown in figure 1. The nodes correspond to the tasks that are involved in the assembly line; the arrows stands for the precedence relationship. Time is a very important factor and this can be shown on the diagram by numbers, representing units of time written adjacent to the task symbol. The unit of time in this work is in minutes. The objective of this research work is to minimize cycle time (maximizing the output rate) for a given number of workstations. The cycle time for a line (time between completion of successive items on the line) is determined by the maximum workstation time of the line. The required output of the line determines the cycle time of the line.

The cycle time is computed from the given production volume per shift using the following formula:

$$\text{Cycle time} = \frac{\text{Effective time available per shift (T)}}{\text{Production volume per shift (Q)}} \quad (1)$$

The total idle time (IT) for the line is given by

$$IT = nc - \sum_{i=1}^k t_i \quad (2)$$

A line is perfectly balanced if $IT = 0$ at the minimum cycle time.

Sometimes the degree to which a line approaches this perfect balance is expressed as a percentage or a decimal called the balance delay (B.D). As a percentage, the balance delay is given by:

$$B.D = \frac{\text{Idle time of all workstations}}{\text{Available working time for all stations}} = \frac{100(IT)}{nc} = \frac{(nc - \sum_{i=1}^k t_i) \times 100}{nc} \quad (3)$$

Therefore the balancing efficiency of the line is given by

Balancing efficient of line

$$E = 100 - B.D. \quad (4)$$

Equally balancing efficiency of the solution of the line balancing problem is given by the formula:

$$\text{Balancing efficiency} = \frac{\text{Sum of all task times}}{\text{Number of workstations \& cycle time}} = \frac{\sum_{i=1}^k t_i \times 100}{nc} \quad (5)$$

A well balanced line has a very low balance delay. Therefore the balance delay is a measure of the efficiency of the line.

The smoothness index (S.I) is a measure of how much station times deviates from the cycle time. It is called line standard deviation which is a measure of deviation from the mean. It is given as

$$S.I. = \sqrt{\sum_{i=1}^k (C - t_i)^2} \quad (6)$$

The line with high smoothness index has more inbuilt idle time. Therefore, the line with the smallest smoothness index has better efficiency.

The minimum number of workstations required in assembly line, n_{min} is the sum of all the element times divided by the cycle time, and taken to the next highest integer.

$$n_{min} = \frac{\sum_{i=1}^k t_i}{c} \text{ (to next highest integer)} \quad (7)$$

Rank Positional Weight (RPW)

The heuristic method was developed by Helgeson and Birnie of the General Electric Company in 1961 [19]. In this method, the ranked positional weight value of each operation is determined. The positional weight of a task or element is defined as the sum of that element time plus the times of all succeeding elements. Each element therefore has its positional weight and these are ranked so that the highest positional weight has rank 1, the next highest rank 2 and so on through the list of elements. Where two or more elements have the same positional weight they can be marked in the order they are found down the list.

The ALGORITHM for assignment of elements of work stations is carried out in the following manner:

- The element with the highest positional weight (or rank 1) is assigned to the first workstation.
- The time difference, Dt , between the assigned element time a_i and the cycle time, c , is

$$Dt = c - a_i \quad (8)$$

- The element with the next highest positional weight or lowest rank is then selected and also checks made on it.
 - Precedence: only elements which have all their proceeding elements assigned can be considered.
 - The element time must be equal to or less than the unassigned work station time Dt calculated in (ii) i.e.

$$a_{i+r} \leq Dt \quad (9)$$

If conditions (a) and (b) are met then the element is assigned to the first work station and (i) and (ii) are repeated for the element with the next lowest ranks. If one or both conditions (a) and (b) above are not met then that element is left and passed on to the next lowest rank and (a) and (b) for this element are checked.

- Items (ii) and (iii) are continued until there is no difference in time between the sum of the workstation assigned element times and cycle time (i.e. perfect balance), or it is not possible to assign any more element to the workstation because of precedence restrictions, or all the time of the remaining elements are greater than the unassigned station time.

- Assignment to second workstation is then started by selection. Firstly, the element with the lowest rank or highest positional weight of the remaining unassigned elements.
- Items (ii), (iii), (iv) and (v) are thus continued until all the elements have been assigned to workstations

The Newline ceiling fan motor assembly line comprises of nine workstations and 42 work elements or tasks as shown in Fig. 1. They include (1) dismantling of motor (2) decorative cap sub assembly (3) false cover subassembly (4) quality control run testing (5) regulation testing (6) cleaning and wrapping of motor (7) down rod sub assembly (8) canopy sub assembly (9) packing of motor with canopy, regulators and down rods. Each workstation has its elements or tasks as shown in Fig. 1 with the standard element time. The analysis of the assembly line before balancing was carried out to determine the efficiency performance index of the line. Then after balancing the assembly line by rank position method, which is a heuristic method, the efficiency performance index of the balanced line was also determined and the two results compared.

Figure 1: Precedence Diagram of Ceiling Fan Motor Assembling Line.

RESULTS AND DISCUSSIONS

Table 1: Summary Standard Time for N/C Ceiling Fan Motor Assembly Line

S/N	Operations/Workstations	Standard Time Per Piece (min)	Number Per Set (unit)	Total Time (min)	Expected Per set hr	Production Per Shift (x8)
1	Dismantling of motor	0.743	1	0.74	81	648
2	Decorative cap subassembly	0.38	1	0.38	158	1248
3	False cover subassembly	0.581	1	0.494	121	480
4	Quality control run testing	0.31	1	0.31	194	1552
5	Regulator testing	0.49	1	0.49	122	976
6	Cleaning and wrapping of motor	0.712	1	0.712	84	672
7	Down rod subassembly	0.792	1	0.792	76	608
8	Canopy subassembly	0.28	1	0.28	214	1712
9	Packing of motor and accessories	0.699	1	0.699	86	688

From Table 1, the ceiling fan motor assembly line efficiency performance index is calculated before balancing the line.

Total standard time to assemble motor and accessories = 4.987 min.

Cycle time = 0.792 min

$$\text{Standard hourly production} = \frac{60}{0.792} = 72 \text{ units}$$

Working hours per unit = 8

$$\text{Thus giving a line capacity of } \frac{60 \times 8}{0.792} = 608 \text{ units}$$

The manpower for the line = 9 men

The total idle time (IT) for the line = $(9 \times 0.792) - 4.987 = 2.23$ min

This is the in-built idle time in the system due to unbalanced workstation times.

$$\text{The Balance Delay (B.D) of the line} = \frac{(9 \times 0.792 - 4.987) 100}{(9 \times 0.792)} = 31\%$$

This is the percentage of inbuilt idle time in the line due to unbalanced workstation times.

$$\text{Therefore, efficiency of the line} = 100 - 31 = 69\%$$

Table 2: Workstations, Standard Element Time, Positional Weight and Ranks for N/C Ceiling Fan Motor Assembly Line

Element	Standard Element Time (min)	Positional Weight (min)	Rank
WST 1			
1	0.06	2.444	1
2	0.223	2.389	2
3	0.223	2.199	3
4	0.165	2.009	5
5	0.042	1.869	7
6	0.032	1.833	8
	0.743		
WST 2			
7	0.18	2.133	4
8	0.153	1.98	6
9	0.047	1.85	9
	0.38		
WST 3			
10	0.146	1.81	10
11	0.094	1.686	11
12	0.20	1.606	12
13	0.141	1.436	13
	0.581		
WST 4			
14	0.258	1.316	14
15	0.047	1.096	15
	0.305		
WST 5			
20	0.235	0.687	20

21	0.129	0.487	26
22	0.129	0.377	32
	0.493		
WST 6			
16	0.306	1.056	16
17	0.118	0.796	17
18	0.184	0.696	19
19	0.105	0.54	24
	0.713		
WST 7			
23	0.147	0.687	20
24	0.125	0.765	18
25	0.114	0.659	21
26	0.199	0.562	22
27	0.071	0.357	34
28	0.122	0.401	30
29	0.094	0.297	36
	0.792		
WST 8			
30	0.14	0.547	23
31	0.142	0.428	29
	0.282		
WST 9			
32	0.08	0.504	25
33	0.047	0.43	28
34	0.035	0.39	31
35	0.106	0.45	27
36	0.062	0.36	33
37	0.047	0.307	35
38	0.059	0.267	37
39	0.047	0.0217	38
40	0.082	0.177	39
41	0.044	0.107	40
42	0.082	0.07	41
	0.698		

Table 3: Balanced N/C Ceiling Fan Motor Assembly Line

Rank	Element Number	Standard Element Time (min)	Difference Between Cumulative Assigned Element Times and Cycle Time (min)	Comment
WST 1				
1	1	0.06	0.54	Assigned
2	2	0.223	0.317	“
3	3	0.223	0.94	“
		0.506		
WST 2				
4	7	0.18	0.42	“
5	4	0.165	0.255	“
6	8	0.153	0.102	“
7	5	0.042	0.06	“
8	6	0.032	0.028	“
		0.572		
WST 3				
9	9	0.047	0.553	“
10	10	0.146	0.407	“
11	11	0.094	0.313	“

12	12	0.20	0.113	“
28	33	0.047	0.066	“
		0.535		
WST 4				
13	13	0.141	0.459	“
14	14	0.258	0.201	“
15	15	0.047	0.154	“
18	24	0.125	0.029	“
		0.571		
WST 5				
16	16	0.306	0.294	“
17	17	0.118	0.176	“
20	23	0.147	0.029	“
		0.571		
WST 6				
19	18	0.184	0.416	“
20	20	0.235	0.181	“
26	21	0.129	0.052	“
31	34	0.035	0.017	“
		0.583		
WST 7				
21	25	0.114	0.486	“
22	26	0.119	0.367	“
34	27	0.071	0.296	“
30	28	0.122	0.174	“
23	30	0.14	0.034	“
		0.566		
WST 8				
24	19	0.105	0.495	“
27	35	0.106	0.385	“
29	31	0.142	0.247	“
32	22	0.129	0.118	“
33	36	0.062	0.126	“
		0.544		
WST 9				
35	37	0.047	0.553	“
37	38	0.05	0.503	“
38	39	0.047	0.456	“
39	40	0.087	0.369	“
40	41	0.044	0.325	“
41	41	0.082	0.243	“
25	32	0.087	0.156	“
36	29	0.094	0.062	“
		0.538		

In Balancing of the Assembly Line, the line is said to be balanced when the workstations have approximately the same operation times allocated to each, for the output of the line is determined by the slowest operation. From Tables 2 and 3, the ceiling fan motor assembly line is balanced. The output required from this line has been set at 800 complete assembled product of ceiling fan motor and accessories per day based on 480 useful minutes (i.e. 8 hours) per working period (shift).

$$\text{Thus, Target cycle time, } c = \frac{480}{800} = 0.6 \text{ min}$$

Since all standard times are less than the cycle time ($t_i < c$), then this cycle time is accepted. The sum of the standard element times equates to 4.987 min.

The minimum number of workstation $n_{\min}$ is $= \frac{4.987}{0.6} = 9$ (to the next highest integer).

From Table 3, the actual cycle time is = 0.583min.

Therefore, the idle time in the balanced line is $= 9 \times 0.583 - 4.987 = 0.26$ min.

Balance Delay (B.D) $= \frac{0.26 \times 100}{9 \times 0.58} = 5\%$.

Therefore, new line efficiency after balancing the line $= 100 - 5 = 95\%$. This gives a possible output of $\frac{480 \text{ min}}{0.583 \text{ min}} = 823$ units of ceiling fan motor assembled product per shift.

CONCLUSIONS

In this study, time studies of ceiling fan motor production was done, examined with respect to assembly line balancing and data which are necessary for balancing obtained. The assembly line is said to be balanced when the workstations have approximately the same operation times allocated to each; for the output of the line is determined by the slowest operation. The balanced line for the ceiling fan motor assembly line is given in Table 3 with the target cycle time of 0.6 minutes and the actual cycle time of 0.583min. On balancing the line by Rank Positional Weight (RPW) the actual cycle time was reduced from 0.729 min to 0.583 min. Equally, the balanced line reduced the idle time from 2.23 min to 0.26 min and the balance delay from 31% to 5%. The new line efficiency was increased from 69% to 95% thereby increasing the possible output from 608 units to 823 units per shift of 480 minutes. This shows an increase in productivity since more is produced within the same time without additional resources. Though RPW is a heuristic method, it offers practical tool especially in small scale manufacturing assembly line balancing problems where mathematically optimizing methods and other soft computing methods may be very expensive. It can readily be understood and applied from practical application viewpoint especially in societies like Nigeria where computer literacy is low.

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