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Application of Heuristic Assembly Line Balancing Methods to Lighting Automation Industry

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ABSTRACT

The assembly line balancing problem is an important issue for every manufacturing company. A balanced assembly line ensures that a product is produced in the optimum time, and as a result of this effect, less machinery, materials and labour are used during this production. In this article, theoretical information about assembly line balancing has been given, and then the data needed for assembly line balancing has been obtained by making a time study of the production of Downlight Luminaire. With these data obtained, assembly line balancing was done and compared by using Hoffman and Comsoal methods. The aim of this study is to investigate the applicability of Hoffman and Comsoal methods, which are one of the heuristic assembly line balancing methods, in the assembly lines of the companies producing in the lighting sector.

1. INTRODUCTION

Assembly lines, whose main feature is to transfer work pieces from one station to another, are places where product parts and components are put together and processed in different ways [1].

Assembly line balancing, which is also defined as the allocation of work pieces to operating systems, is also expressed as providing the processes needed during product formation to assembly stations in order to reduce lost time [2].

Assembly line balancing methods according to the way they are produced; it is divided into three groups as single model, multi model and mixed model assembly lines [3-5].

Assembly line balancing methods-based solution approaches are threefold: Heuristic methods, analytical methods and simulation techniques [6].

The heuristic methods in the literature are given in the Table I. [7-10].

In this study, time studies of Downlight Luminaire production which are examined in assembly line balancing are carried out and the data which are necessary for balancing are obtained.

With the parallel of these obtained data, assembly line balancing studies are performed by heuristic methods which are called Hoffman Method and Comsoal Method. The results which are obtained by applying heuristic method after studies of assembly line balancing is given.

When the studies on this subject are examined, very few studies have been found in the literature.

In his study, Ling examined the Cold Cathode Fluorescent Lamp assembly production line and achieved more stability, increased efficiency and satisfactory results in the production line [11].

In his study, Yao examined bottleneck workstations on the lamp assembly line and issues affecting line production capacity, such as redundant capacity. To overcome these shortcomings, he proposed a new line balancing scheme [12].

Saptari and colleagues conducted a case study on the assembly line of an electrical accessory manufacturer in Malaysia. The productivity of the existing assembly line has been examined. They proposed an assembly line setup based on the Line Balancing Method [13].

The aim of this study is to create assembly lines which have the highest line efficiency and to reveal the applicability of heuristic assembly line balancing method on lighting automation manufacturing assembly line.

2. EXPERIMENTAL STUDY

In this research Downlight Luminaire is analysed. All the necessary data and measurements within the scope of the study were obtained from the company X, which produces downlight Luminaire. The model of the analysed Downlight Luminaire is shown in Fig. 1.

Figure 1. Model of Downlight Luminaire

TABLE I
HEURISTIC METHODS

Ranked Positional Weight Method (Helgeson-Birnie)
Hoffman Method
Enumeration Method (Jackson)
Moddie-Young Method
Basic Heuristic Method
Related Activity Method (Agrawal)
Raouf-Tsui-Elsayed Method
Shortest Path Method (Klein-Gutjahr)
Grouping Method (Tonge)
Probabilistic Assembly Line Balancing Method (Elsayed-Boueher)
Candidate Matrix Method (Salveson)
Kilbridge-Wester Method
Comsoal Method
Dynamic Programming Method (Karp-Held-Shareshian)

The Downlight Luminaires production which is shown above consists of 3 main parts including body, frame and power supply. The Downlight Luminaire is produced when parts are treated in appropriate machines according to operation order. Fig. 2. shows production flow that is necessary for producing the Downlight Luminaire.

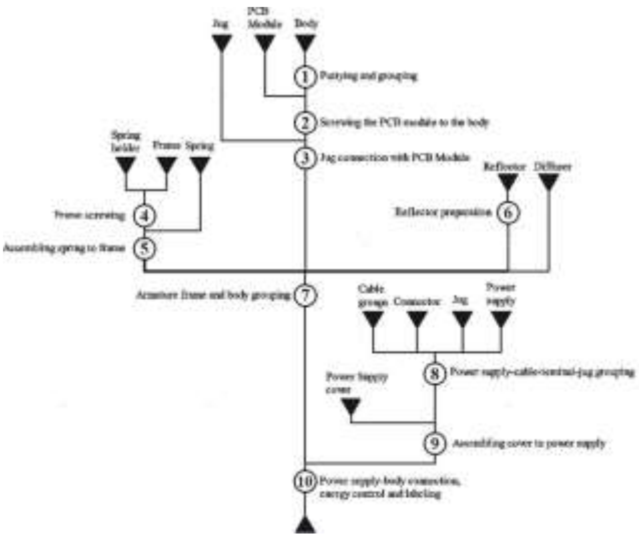

Figure 2. Flow chart of the operations in Downlight Luminaire production

2.1. Time Study and Assembly Line Balancing Studies

Time study provides needed information to design, to plan, to organize and to control the production process [14].

The most widely technique among time study techniques used in the companies is the time study, in other words it is called the stopwatch technique.

All operation durations are measured by using stopwatch to determine the standard time of production of Downlight Luminaire.

As these measurements are being done, the data on how many measurements are necessary to be done for each operation are provided by means of the formula given below. These measurements are repeated by considering the data which are generated. In this statistical method, several pre-observations (n^1) are conducted firstly. Afterwards the formula given Eq. 1 is solved for 95.45 security level and ± 5% error margin [15].

$$n = \left(\frac{40\sqrt{n^1 \sum x^2 - (\sum x)^2}}{\sum x} \right)^2 \quad (1)$$

Where;

n is Actual Sample Size, n^1 is number of pre-observations, x is measured time.

Afterwards the standard time is calculated for each operation by using formula shown Eq. 2.

$$ST = MT \cdot R + MT \cdot R \cdot t \quad (2)$$

Where;

ST is standard time (minute), MT is measured time (minute), R is performance (%), t is tolerance (%) [16].

The durations obtained as a result of the measurements which are done for each operation by considering tolerance share, performed performance assessments, the arithmetic mean of performance rates in terms of PM which are measured by using stopwatch are shown in Table II. As it is shown in Table II, Downlight Luminaire production in assembly line involve in 10 operations and total production duration of Downlight Luminaire is 4.802 minutes.

Assembly line balancing studies are carried out according to Downlight Luminaire production which consists of 10 operations which are shown in Fig. 3 with its diagram. The operation time which belongs to Downlight Luminaire production, machines which are used during this operation and previous operations are shown in Table II.

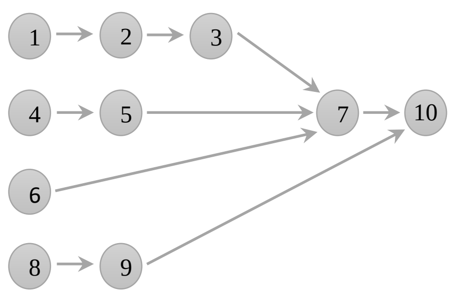

Figure 3. Priority diagram for Downlight Luminaire

Loss of balance of assembly lines, their efficiency and their daily total production amount is estimated by using formulas which are given Eq. 3,4 and Eq. 5.

$$LB = \left[\frac{(nC - \sum C_0)}{nC} \cdot 100 \right] \quad (3)$$

$$LE = (1 - LB) \cdot 100 \quad (4)$$

$$PA = \frac{T}{C} \quad (5)$$

Where;

LB is Loss of Balance (%), *LE* is Line Efficiency (%), *C* is Cycle Time (minute), *n* is Total Number of Work Stations (number-unit), C_o is Average of Work Station Time (minute), *PA* is Daily Total Production Amount (unit) and *T* is Daily Total Production Time (minute) **[10]**.

In all assembly line balancing studies which are carried out within the scope of this study, it is supposed that handwork operations are done by all operators on condition that operations are done by same type of machines.

TABLE II
OPERATION TIMES, USED MACHINE TYPES AND PREVIOUS OPERATIONS FOR DOWNLIGHT LUMINAIRE

Ope. No.	*Operations*	*Machine Type*	*Ope. Times (min.)*	*Prev. Ope.*
1	Putting and grouping	Hand-made	0.477	-
2	Screwing the PCB module to the body	Electric screwdriver	0.405	1
3	Jug connection with PCB module	Hand-made	0.444	2
4	Frame screwing	Electric screwdriver	0.711	-
5	Assembling spring to frame	Hand-made	0.683	4
6	Reflector preparation	Hand-made	0.416	-
7	Armature frame and body grouping	Electric screwdriver	0.594	3-5-6
8	Power supply – cable – terminal – jug grouping	Hand-made	0.489	-
9	Assembling cover to power supply	Hand-made	0.183	8
10	Power supply – body connection, testing and labelling	Hand-made	0.400	7-9
		Total Time	**4.802**	

2.2.1. Hoffman Method

Before the method can be applied; if i precedes j, 1 is written at the intersection of the columns (i and j) of the matrix, otherwise, the priority matrix is developed by giving the value 0 to all the rest. So that the priority item can be used to generate all possible work item permutations, each column of the matrix is summed together to form a row matrix called "code numbers". The originally obtained sequence of code numbers (row matrix) has as many elements as the number of work items, at least one of which is zero. The next steps are explained in detail on the example of line balancing work for downlight luminaire **[1]**.

Firstly, priority matrix is designed as assembly line is being constituted by using Hoffman Method (Table III-a). There are 4 operations (1, 4, 6 and 8) which have rate 0 in code number array. The operation numbered 1 which is the first one among them is assigned to 1st work station. The cycle time is 1.35 minute. As the time of the first operation is 0.477 minute, remaining work station time is calculated as $C\text{-}t_1 = 1.35 - 0.477 = 0.873$ minute. The time of second operation which have rate 0 (the operation numbered 4) is 0.711 minute. It is shorter than remaining time of 1st work station and the operation numbered 4 can be assigned to 1st work station.

To make an assignment to 2nd work station, a new priority matrix is obtained by crossing out line and column numbered 1 and 4 in priority matrix (Table III-b).

The first rate 0 which is left to right in code number array can be seen in operation numbered 2. As this operation cannot be assigned to 1st work station it is assigned to 2nd work station. Remaining time of 2nd work station is calculated as $C\text{-}t_2 = 1.35 - 0.405 = 0.945$ minute.

The time of the second operation which has rate 0 (operation numbered 5) is 0.683 minute. As it is shorter than remaining time of 2nd work station, the operation numbered 5 is assigned to 2nd work station. The remaining time of 2nd work station is calculated as $C\text{-}t_5 = 0.945 - 0.683 = 0.262$ minute.

To make an assignment to 3rd work station a new priority matrix is designed by crossing out lines and columns numbered 2 and 5 in the priority matrix (Table III-c).

The first rate 0 which is left to right in code number array can be seen in operation numbered 3. As this operation cannot be assigned to 1st and 2nd work station it is assigned to 3nd work station. Remaining time of 3nd work station is calculated as $C\text{-}t_3 = 1.35 - 0.444 = 0.906$ minute.

The time of the second operation which has rate 0 (operation numbered 6) is 0.416 minute. As it is shorter than remaining time of 3nd work station, the operation numbered 6 is assigned to 3nd work station. The remaining time of 3nd work station is calculated as $C\text{-}t_6 = 0.906 - 0.416 = 0.490$ minute.

The time of the third operation which has rate 0 (operation numbered 8) is 0.489 minute. As it is shorter than remaining time of 3nd work station, the operation numbered 8 is assigned to 3nd work station. The remaining time of 3nd work station is calculated as $C\text{-}t_8 = 0.490 - 0.489 = 0.001$ minute.

To make an assignment to 4rd work station a new priority matrix is designed by crossing out lines and columns numbered 3, 6 and 8 in the priority matrix (Table III-d).

The first rate 0 which is left to right in code number array can be seen in operation numbered 7 (0.594 minute). As this operation cannot be assigned to 1st, 2nd and 3rd work station it is assigned to 4th work station. Remaining time of 4nd work station is calculated as $C\text{-}t_7 = 1.35 - 0.594 = 0.756$ minute.

The second rate 0 which is left to right in code number array can be seen in operation numbered 9. As this operation cannot be assigned to 1st work station it is assigned to 3nd work station. Remaining time of 2nd work station is calculated as $C\text{-}t_9 = 0.262 - 0.183 = 0.079$ minute.

To make an assignment a new priority matrix is designed by crossing out lines and columns numbered 7 and 9 in the priority matrix (Table III-e).

The time of second operation which have rate 0 (the operation numbered 10) is 0.400 minute. It is shorter than remaining time of 1st work station. It is longer than remaining time of 1st, 2nd and 3rd work station and the operation numbered 10 can be assigned to 4st work station.

TABLE III
SOLUTION MATRIX

Op.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	**0**	1	0	**0**	0	**0**	0	**0**	0	0
2	**0**	0	1	**0**	0	**0**	0	**0**	0	0
3	**0**	0	0	**0**	0	**0**	1	**0**	0	0
4	**0**	0	0	**0**	1	**0**	0	**0**	0	0
5	**0**	0	0	**0**	0	**0**	1	**0**	0	0
6	**0**	0	0	**0**	0	**0**	1	**0**	0	0
7	**0**	0	0	**0**	0	**0**	0	**0**	0	1
8	**0**	0	0	**0**	0	**0**	0	**0**	1	0
9	**0**	0	0	**0**	0	**0**	0	**0**	0	1
10	**0**	0	0	**0**	0	**0**	0	**0**	0	0
Code No	**0**	1	1	**0**	1	**0**	3	**0**	1	2

(a)

Op.	**2**	**3**	**5**	**6**	**7**	**8**	**9**	**10**
2	**0**	1	**0**	**0**	0	**0**	0	0
3	**0**	0	**0**	**0**	1	**0**	0	0
5	**0**	0	**0**	**0**	1	**0**	0	0
6	**0**	0	**0**	**0**	1	**0**	0	0
7	**0**	0	**0**	**0**	0	**0**	0	1
8	**0**	0	**0**	**0**	0	**0**	1	0
9	**0**	0	**0**	**0**	0	**0**	0	1
10	**0**	0	**0**	**0**	0	**0**	0	0
Code No	**0**	1	**0**	**0**	3	**0**	1	2

(b)

Op.	**3**	**6**	**7**	**8**	**9**	**10**
3	**0**	**0**	1	**0**	0	0
6	**0**	**0**	1	**0**	0	0
7	**0**	**0**	0	**0**	0	1
8	**0**	**0**	0	**0**	1	0
9	**0**	**0**	0	**0**	0	1
10	**0**	**0**	0	**0**	0	0
Code No	**0**	**0**	2	**0**	1	2

(c)

Op.	**7**	**9**	**10**
7	**0**	**0**	1
9	**0**	**0**	1
10	**0**	**0**	0
Code No	**0**	**0**	2

(d)

Op.	**10**
10	**0**
Code No	**0**

(e)

As it can be seen in the assignment example which is done for 1st, 2nd, 3rd and 4th work station, one can achieve a solution. The solution results according to designing assembly line by using Hoffman Method are shown Table IV.

TABLE IV

LINE BALANCING RESULTS

Workstation No	Ope. No	Machine Type	Time (min.)	Total Time for Workstation (x)	Remaining Time (C-x)
1	1 4	Hand-made Electric screwdriver	0.477 0.711	1.188	0.162
2	2 5 9	Electric screwdriver Hand-made Hand-made	0.405 0.683 0.183	1.271	0.079
3	3 6 8	Hand-made Hand-made Hand-made	0.444 0.416 0.489	1.349	0.001
4	7 10	Electric screwdriver Hand-made	0.594 0.400	0.994	0.356
Total Time			***4.802***	***4.802***	***0.598***

As it can be deduced from Table IV, the assembly line is designed according to having 1.35 minute cycle time with 4 work stations. Loss of balance and assembly line efficiency of designed assembly line are shown Eq. 6 and 7.

$$LB = \left[\frac{(4 \cdot 1.35) - (4.802)}{(4 \cdot 1.35)}\right] \cdot 100 = 11.074\% \qquad (6)$$

$$LE = (1 - 0.11074) \cdot 100 = 88.925\% \qquad (7)$$

2.2.3. COMSOAL Method

To be able to apply this method, the table which is shown below must be designed (Table 5-a). In the first column of the table, operation numbers are shown. In the second column, the Amounts of the Previous Operation (APO) are shown. In the third column, Operation Without Previous Operation (OWPO) takes place.

While assignments for work stations are being made, first operation among the operations which is written in 3rd column is chosen respectively. The selected operation is deleted from 1st column and table is created again. Factors which immediate the chosen operation and haven't other factors that follow them are added to 3rd column. This procedure continues until cycle time at the station and work factors runs short and they are not able to assign new factors. After then it is started to make assignments to next stations.

In Table V, the all of steps of applying the method are given as in the example.

TABLE V

SOLUTION STAGES OF PROBLEM USING OF COMSOAL METHOD

Op. No	APO	OWPO	Op. No	APO	OWPO	Op. No	APO	OWPO
1	0	1	2	0	2	3	0	3
2	1	4	3	1	4	4	0	4
3	1	6	4	0	6	5	1	6
4	0	8	5	1	8	6	0	8
5	1		6	0		7	3	
6	0		7	3		8	0	
7	3		8	0		9	1	
8	0		9	1		10	2	
9	1		10	2				
10	2							

(a) (b) (c)

Op. No	APO	OWPO	Op. No	APO	OWPO	Op. No	APO	OWPO
4	0	4	5	0	5	7	0	7
5	1	6	6	0	6	8	0	8
6	0	8	7	2	8	9	1	
7	2		8	0		10	2	
8	0		9	1				
9	1		10	2				
10	2							

(d) (e) (f)

Op. No	APO	OWPO	Op. No	APO	OWPO
9	0	9	10	0	10
10	1				

(g) (h)

In the Table V which is schemed while applying the method, the operation numbered 1 which is written in 3rd column is selected for first work station assignment. Number 1 operation is assigned to the 1st work station. Remaining time of the 1st work station is calculated as $C\text{-}t_1 = 1.35 - 0.477 = 0.873$ minute.

In the Table V-b the operation numbered 2 (0.405 minute) in 3rd column is selected. The time of the operation is shorter than the residual time of 1st work station (0.873 minute) and can be assigned to 1st work station. Remaining time of the 1st work station is calculated as $C\text{-}t_2 = 0.873 - 0.405 = 0.468$ minute.

In the Table V-c the operation numbered 3 (0.444 minute) in 3rd column is selected. The time of the operation is shorter than the residual time of 1st work station (0.468 minute) and can be assigned to 1st work station. Remaining time of the 1st work station is calculated as $C\text{-}t_3 = 0.468 - 0.444 = 0.024$ minute.

In the Table V-c the operation numbered 4 (0.711 minute) in 3rd column is selected. The time of the operation is longer than the residual time of 1st work station (0.024 minute) and cannot be assigned to 1st work station and it is assigned to the 2nd station. Remaining time of the 2nd work station is calculated as $C\text{-}t_4 = 1.35 - 0.711 = 0.639$ minute.

In the Table V-d the operation numbered 5 (0.683 minute) in 3rd column is selected. Since the time of the operation is longer than the residual time of 1st and 2nd work station (0.024 minute - 0.639 minute) and cannot be assigned to 1st and 2nd work stations it is assigned to the 3rd station. Remaining time of the 3rd work station is calculated as $C\text{-}t_5 = 1.35 - 0.683 = 0.667$ minute.

This procedure continues until cycle time at the station and work factors runs short and they are not able to assign new factors. After then it is started to make assignments to next stations.

TABLE VI

LINE BALANCING RESULTS

Workstation Number	Ope. No	Machine Type	Time (min.)	Total Time for Workstation (x)	Remaining Time (C-x)
1	1 2 3	Hand-made Electric screwdriver Hand-made	0.477 0.405 0.444	1.326	0.024
2	4 6 9	Electric screwdriver Hand-made Hand-made	0.711 0.416 0.183	1.310	0.040
3	5 7	Hand-made Electric screwdriver	0.683 0.594	1.277	0.073
4	8 10	Hand-made Hand-made	0.489 0.400	0.889	0.461
	Total Time		***4.802***	***4.802***	***0.598***

As it can be deduced from Table VI, the assembly line is designed according to having 1.35-minute cycle time with 4 work stations. Loss of balance and assembly line efficiency of designed assembly line are shown Eq. 8 and 9.

$$LB = \left[\frac{(4 \cdot 1.35) - (4.802)}{(4 \cdot 1.35)}\right] \cdot 100 = 11.074\% \qquad (8)$$

$$LE = (1 - 0.11074) \cdot 100 = 88.925\% \qquad (9)$$

3. RESULTS

In this study, Downlight Luminaire production line balancing was done by using Hoffman and Comsoal methods, one of the heuristic assembly line balancing methods.
The results of the assembly line studies which are carried out by using Heuristic Methods are shown in the table below (Table VII). As can be seen from the table, line balancing was carried out with 4 workstations in the assembly line balancing work performed with both methods. When both methods are examined in terms of line efficiency, high line efficiency has been achieved with both methods.
When Table VII is examined, it is seen that the difference between the methods is due to the operation assignments made to the two workstations. In the Hoffman method, 2 operations were assigned to the 1st work station, while 3 operations were assigned in the Comsoal method. Likewise, 3 operations are assigned to the 3rd workstation in the Hoffman method, while 2 operations are assigned to the Comsoal method. This difference arises due to the uniqueness of the methods.

TABLE VII
RESULTS OF STUDIES FOR ASSEMBLY LINE BALANCING

Work-station	Assembly Line Balancing Methods			
	Hoffman		**Comsoal**	
	Op.	**Eff. (%)**	**Op.**	**Eff. (%)**
1	1 4	88.00	1 2 3	98.22
2	2 5 9	94.14	4 6 9	97.03
3	3 6 8	99.92	5 7	94.59
4	7 10	73.62	8 10	65.85
Line Eff. (%)	**88.925**		**88.925**	

4. CONCLUSION

The aim of this study is to examine the applicability of heuristic assembly line balancing methods to design the highest performing assembly lines in lighting automation companies.
Within the scope of the study, a line balancing study was carried out in a company that produces Downlight Luminaire with the methods of Hoffman and Comsoal, one of the heuristic methods. As a result of the line balancing work performed with both assembly line balancing methods, a high line efficiency of 89% was achieved. This has led to the conclusion that high efficiency production can be made with less labour, less time and therefore less cost. The results also showed that both methods can be used in lighting automation companies.
When the two methods are compared with each other, it is seen that the difference between them consists of the operations distributed to the workstations and there is no difference in terms of line efficiency.
This study also revealed that all companies operating in the electricity sector can achieve high line efficiency by using these methods in the production of different products.
With further studies on this subject, it will shed light on the applicability of the results that will emerge as a result of the application of the other Heuristic Methods, especially for researchers and manufacturers.

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BIOGRAPHIES

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