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Applying Different Heuristic Assembly Line Balancing Methods in the Apparel Industry and their Comparison

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Abstract
The problem of assembly line balancing is extremely important for apparel companies. It indicates the necessity of a well-balanced assembly line since the process of the production of clothes is complicated and it consists of many processes. A well-balanced assembly line enables to produce a product in an optimum time, as a result of which it allows to use fewer machines as well as less material and labour during this production. In this article, studies performed on assembly line balancing were theoretically analysed, and then a time study of T-shirt production with respect to assembly line balancing was performed and data needed for assembly line balancing acquired. In parallel to these data obtained, firstly assembly line balancing was applied using 5 different heuristic methods, and then the assembly line was balanced using the classical method. The results of the solutions for the assembly line are compared. The aim of this study was to establish the assembly lines which have the highest line efficiency and to research the applicability of the methods examined in ready-to-wear assembly lines.

Key words: *assembly line balancing, ready-made clothing, heuristic assembly line balancing methods, hoffman method, ranked positional weight method, COMSOAL method, moodie & young method, kilbridge & wester method, largest candidate rule method, classical method.*

Introduction

Assembly lines are places where the parts and components of the products are pieced together and treated in different ways. The basic specialty of an assembly line is to transfer work pieces from one station to another [1]. *Assembly line balancing* or *line balancing* is used to achieve operations required during product formation at assembly stations in a way that the duration of lost time can be reduced. In other words it is described as allocating work pieces to operation systems [2].

Assembly lines are classified according to the number of models and products that are treated. They are divided into groups according to the way they are produced. Assembly line balancing methods are separated into three groups according to the solution approach: single model, multi-model and mixed-model assembly lines [3 - 5].

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

Although there are quite a lot of heuristic methods, some basic ones taken from literature can be listed as follows: ranked positional weight method (Helgeson-Birnie), enumeration method (Jackson), Hoffman method, Moddie-Young method, COMSOAL method (Arcus), dynamic programming method (Karp-Held-Shareshian), Kilbridge-Wester method, candidate matrix method (Salveson), probabilistic assembly line balancing method (Elsayed-Boueher), grouping method (Tonge), shortest path method (Klein-Gutjahr), Raouf-Tsui-Elsayed method, related activity method (Agrawal), and basic heuristic method [7 - 9].

The assembly line balancing method, which is called the classical method is one which is frequently used by ready to wear companies. By this method, firstly the daily total production amount is calculated considering the number of machines and operators that are available to be used and the standard time of production. How many machines and operators needed, on the basis of the operation, to carry out each operation is also estimated. After that operations which are carried out by the same type of machine are proportionately assigned to machines. The aim of this placement is to enable each operator and machine to function in the most effective way and to evenly distribute the tasks among machines [10].

In this study, time studies of t-shirt production, examined with respect to assembly line balancing, were carried out and data which are necessary for balancing obtained. In conjunction with these obtained, assembly line balancing studies were performed by heuristic balancing methods, which are called the Hoffman, ranked positional weight, COMSOAL, Moodie & Young, Kilbridge & Wester and Largest Candidate Rule and Clas-

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sical Methods. The results obtained by applying heuristic methods after studies of assembly line balancing and those received by applying classical methods are comparatively given.

The aim of this study was to create assembly lines which have the highest line efficiency and to reveal the applicability of heuristic assembly line balancing methods for a ready-to-wear assembly line.

Literature review

Researchers have studied the subject of balancing assembly lines in many different industrial areas. The first line balancing researches were applied to the automotive sector. Up to now, assembly line balancing studies have been conducted in the textile industry as in other industries.

When the history of researches assembly line balancing is considered, it appears that the idea of assembly line balancing was originally suggested by Bryton in his article called "Balancing of Continuous Production Line" in 1954 [11]. The first research published was called "The assembly Line Balancing Problem", conducted by Salveson in 1995 [12]. After this study a great variety of researches were conducted by academics who gave their name to assembly line balancing methods. The names of the researchers that can be given as an example are Bowman in 1960, Kilbridge and Wester, Helgeson and Birnie, Tonge in 1961, Hoffman in 1963, Moodie and Young in 1965, Arcus in 1966, Talbotin 1975 and the following years, F.B. and Patterson, J.H, Gehrlein, W. V in 1984 and 1986, Agrawal ve El-Sayed ile Boucher in 1985, Baybars in 1986 and Hoffman in 1990 [13 - 26].

When the studies of assembly line balancing in the ready-to-wear industry are reviewed, it can be seen that in one conducted by Basmak, a new method was developed for the assembly line balancing problem [27].

In the studies conducted by Eryuruk and his colleagues, a ready-to-wear assembly line balancing study was carried out by applying the probabilistic line balancing technique developed by El-Sayed and Boucher and the Ranked Positional Weight Technique by Helgeson and Birnie [28, 29].

In a study conducted by Dündar and his collagues, a ready-to-wear assembly line balancing study was conducted by using the graph theory [30].

In a study conducted by Güner and his colleagues, the Longest Operation Time Method, Ranked Positional Weight Method, Shortest Operation Time Method, Most Following Tasks Method and Fewest Following Tasks Method were used [31].

In another study carried out by Eryuruk, a ready-to-wear assembly line study was undertaken by applying the Largest Set Rule Algorithm developed by Agrawal and the Probabilistic Line Balancing Technique by El-Sayed and Boucher [32].

In a study carried out by Kayar, assembly line balancing was conducted by applying the Hoffman Method and Classical Method to a ready-to-wear assembly line [10].

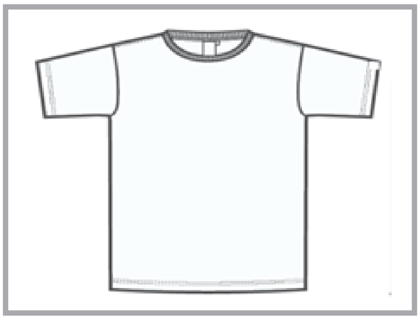

Figure 1. *Model of t-shirt.*

Experimental

In this research a t-shirt is analysed. A model of the t-shirt used is shown in ***Figure 1***.

The t-shirt which is shown in ***Figure 1*** consists of 5 parts including a front, back, sleeve (2) and collar (1). The t-shirt was produced on appropriate machines according to the operation order. ***Figure 2*** shows the production flow that is necessary for producing the t-shirt.

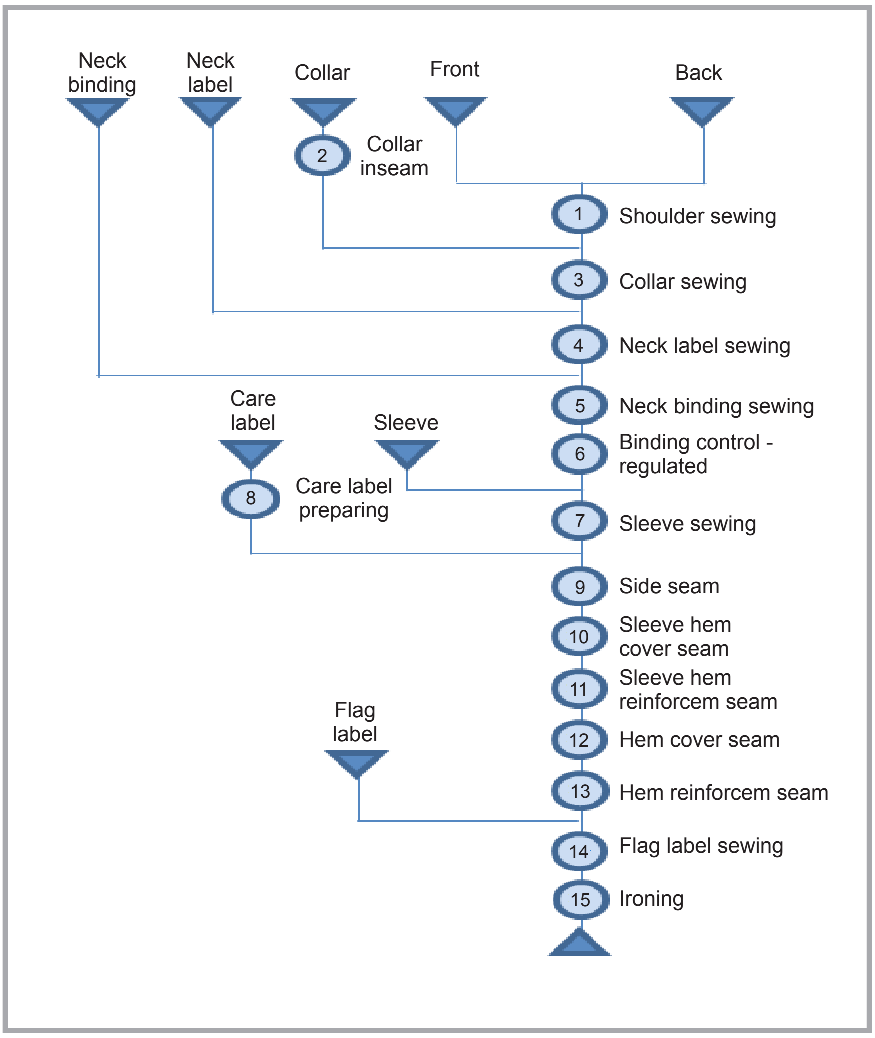

Figure 2. *Operations and flow chart of the operations in t-shirt production.*

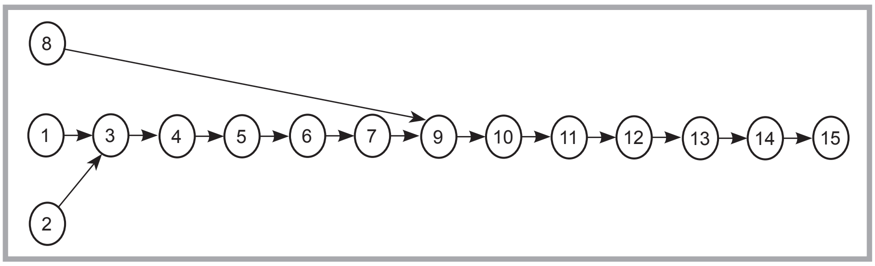

***Figure 3.** Priority diagram for t-shirt sewing.*

***Table 1.** Operation times, machine types used and previous operations for t-shirt sewing.*

Operation number	Operations	Machine type	Operation times, min	Previous operations
1	Shoulder sewing	4 thread overlock machine	0.29	-
2	Collar inseam	Lock – stitch sewing machine	0.08	-
3	Collar sewing	4 thread overlock machine	0.34	1 - 2
4	Neck label sewing	Lock – stitch sewing machine	0.25	3
5	Neck binding sewing	Chain stitch sewing machine	0.35	4
6	Binding control – regulated	Hand-made	0.08	5
7	Sleeve sewing	4 thread overlock machine	0.36	6
8	Care label preparing	Lock – stitch sewing machine	0.09	-
9	Side seam	4 thread overlock machine	0.43	7 - 8
10	Sleeve hem cover seem	Blade cover stitch machine	0.42	9
11	Sleeve hem reinforcement	Lock – stitch sewing machine	0.13	10
12	Hem cover seam	Blade cover stitch machine	0.33	11
13	Hem reinforcement	Lock – stitch sewing machine	0.06	12
14	Flag label sewing	Lock – stitch sewing machine	0.25	13
15	Ironing	Iron	0.45	14
		Total time	**3.91**	

Time study

Before constituting a production line for a t-shirt it is necessary to obtain information about the assembly line that will be used. In consequence of the time study, data about the name of the operation, the duration and order of operations, the machines used during the operation, and the operations undertaken by operators are clear.

The time study provides information needed to design, plan, organise and control the production process. It should be done by considering the structure of the company and its financial means [33, 34]. The time study method most widely used in companies is called the stopwatch technique [10].

All operation durations are measured using a stopwatch to determine the standard time of production of t-shirt sewing. Measurements are made in PM (percentage- minute) and are turned into minutes (percentage-minute/60) by calculating their arithmetic means.

As these measurements are being done, data on how many measurements are necessary to be made 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 below is solved for the 95, 45 security level and ± 5% error margin [35].

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

where: n is the actual sample size, n^1 the number of pre-observations, and x is the time measured.

Pre-observations are made for each operation (the number of pre-observations is 5). In conjunction with these pre-observations, the formula is solved to determine how many times operations are needed to be measured. The maximum rate regarding measurement numbers for all operations is found to be 15. As well as this result taken from pre-observations 10 measurements are made for every operation.

For instance the durations which are measured by stopwatch as a result of observations during shoulder sewing are established as: 16.20, 17.43, 16.72, 18.81 and 17.94 pm. In resolving the formula considering these rates, the measurement number is calculated as 4.38 = 5.

Time studies also necessitate unorthodox usage of techniques such as performance assessment to attain the operation speed and link it with the standard operation pace [33].

Performance estimation is a process that really requires being experienced and having vast knowledge [36]. While operation durations are being measured, performance assessment is done for each operation.

The normal duration, which is estimated by multiplying the time measured with the distilled performance, needs some additions. Some operations that cannot be repeated in every loop, with an unpredictable loss of time, where some reasons such as fatigue require an increased normal duration with deliberately appointed additions called tolerance (highly forgiving) [34].

During an interview conducted with executives of the company in which t-shirts are produced, it was stated that the tolerance share was calculated as 15%, as a result of previous measurements, which is used to estimate the standard time.

Afterwards the standard time is calculated for each operation using the formula shown below.

$$ST = MT \times R + MT \times R \times t \qquad (2)$$

where: ST is the standard time, MT the measured time, R the performance, and t is the tolerance [37].

The durations obtained as a result of the measurements made for each operation by considering the tolerance share, the performance assessments performed and the arithmetic mean of performance rates in terms of PM, which are measured using a stopwatch, are shown in ***Table 1***. As is shown in ***Table 1***, t-shirt sewing on an assembly line with manual machine operation involves 15 operations and the total sewing duration of jean trousers is 3.91 minutes.

Assembly line balancing studies

Assembly line balancing studies werer carried out for t-shirt production which consists of 15 operations, shown in ***Figure 3*** with its diagram. The operation time of t-shirt production, machines used

Table 2. *Solution matrix 1 – 3.*

a)

Op.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1			1												
2			1												
3				1											
4					1										
5						1									
6							1								
7									1						
8									1						
9										1					
10											1				
11												1			
12													1		
14														1	
14															1
15															
Code No	0	0	2	1	1	1	1	0	2	1	1	1	1	1	1

b)

Op	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2		1												
3			1											
4				1										
5					1									
6						1								
7								1						
8								1						
9									1					
10										1				
11											1			
12												1		
13													1	
14														1
15														
Code No	0	1	1	1	1	1	0	2	1	1	1	1	1	1

c)

Op	3	4	5	6	7	8	9	10	11	12	13	14	15
3		1											
4			1										
5				1									
6					1								
7						1							
8							1						
9								1					
10									1				
11										1			
12											1		
13												1	
14													1
15													
Code No	0	1	1	1	1	1	1	1	1	1	1	1	1

during this operation and previous operations are shown in ***Table 1***.

The cycle time in the assembly line balancing studies was accepted as 0.45 minute. The loss of balance of assembly lines, their efficiency and their daily total production amounts were estimated using the formulas given below.

$$LB = [(nC - \sum C_0)/nC)]\ 100 \qquad (3)$$

$$LE = (1 - LB)\ 100 \qquad (4)$$

$$PA = T/C \qquad (5)$$

where: LB is the loss of balance, LE the line efficiency, C the cycle time, n the total number of work stations, C_0 the average work station time, PA the daily total production amount and T is the daily total production time [10].

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

Hoffman method

Firstly a priority matrix is designed for the assembly line constituted using the Hoffman method (***Table 2.a***). There are 3 operations (1, 2 and 8), which have a rate of 0 in the code number array. The operation numbered 1, which is the first one among them, is assigned to the 1st work station. The cycle time is 0.45 minute. As the time of the first operation is 0.29 minutes, the remaining work station time is calculated as C - t_1 = 0.45 - 0.29 = 0.16 minutes. The time of the second operation, which has a rate of 0 (operation numbere 2), is 0.08 minutes, which is shorter than the remaining time of the 1st work station. But since it is carried out by different types of machine, the operation numbered 2 cannot be assigned to the 1st work station.

The time of the third operation, which has a rate of 0 (operation number 8), is 0.09 minutes, which is shorter than the remaining time of the 1st work station. But since it is conducted by different machines operation number 8 cannot be assigned to the 1st work station.

To make an assignment of the 2nd work station, a new priority matrix is obtained by crossing out thw line and column number 1 in the priority matrix (***Table 2.b***).

The first rate 0, which is left to right in the code number array, can be seen in operation number 2. As this operation cannot be assigned to the 1st work station it is assigned to the 2nd work station. The remaining time of the 2nd work station is calculated as C - t_2 = 0.45 - 0.08 = 0.37 minutes.

The time of the second operation, which has a rate of 0, (operation number 8) is 0.09 minutes. As it is shorter than the remaining time of the 2nd work station, in which the same types of machines are used, operation number 8 is assigned to the 2nd work station. The remaining time of the 2nd work station is calculated as C - t_8 = 0.37 - 0.09 = 0.28 minutes.

To make an assignment to the 3rd work station a new priority matrix is designed by crossing out lines and columns numbered 1 and 8 in the priority matrix (***Table 2.c***).

As can be seen in the assignment example for the 1st and 2nd work stations, one can achieve a solution. Solution results for designing an assembly line using the Hoffman method are shown ***Table 3***.

Table 3. *Line balancing results.*

Workstation number	Operation No	Machine type	Time, min	Total time for work station (x)	Remaining time (C - x)
1	1	4 thread overlock hand - made	0.29	0.37	0.08
	6		0.08		
2	2	Lock - stitch sawing machine	0.08	0.42	0.03
	4		0.09		
	8		0.25		
3	3	4 thread overlock	0.34	0.34	0.11
4	5	Chain stitch sawing machine	0.35	0.35	0.10
5	7	4 thread overlock	0.36	0.36	0.09
6	9		0.43	0.43	0.02
7	10	Blade cover sawing machine	0.42	0.42	0.03
8	11	Lock - stitch sawing machine	0.13	0.44	0.01
	13		0.06		
	14		0.25		
9	12	Lock - stitch sawing machine	0.33	0.33	0.12
10	15	Iron	0.45	0.45	0.00
Total time			**3.91**	**3.91**	**0.59**

__Table 4.__ Solution of problem using the ranked positional weight method.

Operation No	Time, min	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Ranked positional weight value
1	0.29			1	+	+	+	+		+	+	+	+	+	+	+	3.74
2	0.08			1	+	+	+	+		+	+	+	+	+	+	+	3.53
3	0.34				1	+	+	+		+	+	+	+	+	+	+	3.45
4	0.25					1	+	+		+	+	+	+	+	+	+	3.11
5	0.35						1	+		+	+	+	+	+	+	+	2.86
6	0.08							1		+	+	+	+	+	+	+	2.51
7	0.36									1	+	+	+	+	+	+	2.43
8	0.09									1	+	+	+	+	+	+	2.16
9	0.43										1	+	+	+	+	+	2.07
10	0.42											1	+	+	+	+	1.64
11	0.13												1	+	+	+	1.22
12	0.33													1	+	+	1.09
13	0.06														1	+	0.76
14	0.25															1	0.70
15	0.45																0.45

__Table 5.__ Line balancing results.

Workstation number	Operation No	Machine type	Time, min	Total time for workstation (x)	Remaining time (C - x)
1	1	4 thread overlock machine	0.29	0.29	0.16
2	2 8	Lock – stitch sewing machine	0.08 0.09	0.17	0.28
3	3	4 thread overlock machine	0.34	0.34	0.11
4	4	Lock – stitch sewing machine	0.25	0.25	0.20
5	5 6	Chain stitch sewing machine hand-made	0.35 0.08	0.43	0.02
6	7	4 thread overlock machine	0.36	0.36	0.09
7	9	4 thread overlock machine	0.43	0.43	0.02
8	10	Blade cover stitch machine	0.42	0.42	0.03
9	11	Lock – stitch sewing machine	0.13	0.13	0.32
10	12	Blade cover stitch machine	0.33	0.33	0.12
11	13 14	Lock – stitch sewing machine	0.06 0.25	0.31	0.14
12	15	Iron	0.45	0.45	0.00
		Total Time	**3.91**	**3.91**	**1.49**

As can be deduced from ***Table 3***, the assembly line is designed for a`` 0.45 minute cycle time with 10 work stations. The loss of balance and assembly line efficiency of the assembly line designed are shown below.

$$LB = [[(10 \times 0.45) + – (3.91)]/(10 \times 0.45)] \times 100 = 13.11\% \quad (6)$$

$$LE = (1 – 0.1311) \times 100 = 86.89\% \quad (7)$$

Ranked positional weight method

To be able to apply this method to assembly line balancing, a table as shown below must be created (***Table 4***).

In ***Table 4***, operation numbers are shown in the first column and operation times in the second. In the mid section of the table factor priorities are given.

For instance, the 1st operation is followed by the 3rd, 7th, 8th and 9th operations. "1", which is written in the midsection, represents the action which immediates an operation, and "+" represents that which immediates an operation because of its relation with another operation. In the last column positional weights for each factor are given. Positional weights are estimated by adding the operation time of each factor to the standard time of all operations that follow this one [3].

For instance, the positional weight of operation number 8 is the total of its own operation time and that of those numbered 9, 10, 11, 12, 13, 14 and 15, which follow operation number 8.

$$(0.09 + 0.43 + 0.42 + 0.13 + 0.33 + + 0.06 + 0.25 + 0.45 = 2.16) \quad (8)$$

While making the valuation, firstly operation number 1, which has the highest positional weight, is assigned to the 1st work station. After operation number 1 is assigned, although the time of operation number 2 is shorter than the remaining time of the station, it can be assigned to different types of machines used. Among the rest of the operations, another one cannot be assigned to this station when precedence and the types of machines used are considered. The remaining time of the 1st work station is calculated as $C - t_1 = 0.45 - 0.29 = 0.16$ minutes. Operation number 2 is assigned to the 2nd work station. The residual time of the 2nd work station is $C - t_2 = 0.45 - 0.08 = 0.37$ minutes. After the assignment of operation number 2, since the time of operation number 3, which has a higher position weight, is longer than the remaining time of this operation, where different types of machines are used, it cannot be assigned. Among the rest of the operations, where precedence and the types of machines are considered, only operation number 8 is assigned to the 2nd work station and the remaining time of the 2nd work station is calculated as $C - t_8 = 0.37 - 0.09 = 0.28$ minutes. Operation number 3 is assigned to the 3rd work station. After the assignment, since the time of operation number 4, which has a higher positional weight, is longer than the operation's residual time and different types of machines are used, it cannot be assigned. Among the rest of the operations where precedence and the type of machine are considered, another operation cannot be assigned to this station. The remaining time of the 3rd station is $C - t_3 = 0.45 + - 0.34 = 0.11$ minutes.

As can be seen in the assignment example done for the 1st, 2nd and 3rd work stations, one can achieve a solution. The solution results for designing an assembly line using the ranked positional weight method are shown in ***Table 5***.

As can be deduced from ***Table 5***, the assembly line is designed for a 0.45 minute cycle time with 12 work stations. The loss of balance and assembly line efficiency of the assembly line designed are shown below.

$$LB = [[(12 \times 0.45) + – (3.91)]/(12 \times 0.45)] \times 100 = 27.59\% \quad (9)$$

$$LE = (1 – 0.2759) \times 100 = 72.41\% \quad (10)$$

COMSOAL method

To be able to apply this method, a table as shown below must be designed (***Table 6.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, the operation without a previous one (OWPO) takes place.

While assignments for the work stations are being made, any operation among those in the 3rd column is chosen randomly. The operation selected is deleted from the 1st column and the ***Table 6.a*** is formed again. Factors which initiate the operation chosen and have no anoth factors that follow them are added to the 3rd column. This procedure continues until the cycle time at the station and work factors run short and are not able to be assigned new factors. After then the making of assignments starts at the next stations.

In ***Table 6***, the first 3 steps of applying the method are given, as in the examples.

In ***Table 6***, which is formed while applying the method, operation number 1, which is written in the 3rd column, is selected for first work station assignment. The remaining time of the 1st work station is calculated as $C - t_1 = 0.45 - 0.29 =$ $= 0.16$ minutes. In table 6-b operation number 2 in the 3rd column is selected. The time of the operation is shorter than the residual time of the 1st work station (0.16). It cannot be assigned to the 1st work station since different types of machines are used during the operation. Therefore operation number` 2 is assigned to the 2nd work station and the remaining time of the 2nd work station is calculated as $C - t_2 = 0.45 - 0.08 =$ $= 0.37$ minutes. Afterwards operation number 2 is deleted from ***Table 6.b*** and ***Table 6.c*** is derived. In ***Table 6.c*** operation number 3 in the 3rd column is selected. The type of machine which is used during the operation is same as that at the first work station though its operation time is 0.349 minutes. An assignment cannot be made as it is higher than the residual time of the 1st work station (0.26). The operation time (0.34) is shorter than the remaining time of the 2nd work station (0.37) though different times of the machine is used and it cannot be assigned to the work station. As a result operation number 3 is assigned to the 3rd work station. The remaining time of the 3rd work station is calculated in minutes. By deleting operation number 3 from ***Table 6.c***, ***Table 6.d*** is derived.

As can be seen in the assignment example, which is done for the 1st, 2nd and 3rd work stations, one can achieve a solution. The solution results for designing an assembly line using the COMSOAL method are shown in ***Table 7***.

Table 6. *Solution stages of problem using the COMSOAL method.*

a)

Op. No	APO	OWPO
1	0	1
2	0	2
3	2	8
4	1	
5	1	
6	1	
7	1	
8	0	
9	2	
10	1	
11	1	
12	1	
13	1	
14	1	
15	1	

b)

Op. No	APO	OWPO
2	0	2
3	1	8
4	1	
5	1	
6	1	
7	1	
8	0	
9	2	
10	1	
11	1	
12	1	
13	1	
14	1	
15	1	

c)

Op. No	APO	OWPO
3	0	3
4	1	8
5	1	
6	1	
7	1	
8	0	
9	2	
10	1	
11	1	
12	1	
13	1	
14	1	
15	1	

d)

Op. No	APO	OWPO
4	0	4
5	1	8
6	1	
7	1	
8	0	
9	2	
10	1	
11	1	
12	1	
13	1	
14	1	
15	1	

Table 7. *Line balancing results.*

Workstation number	Operation No	Machine Type	Time, min	Total time for workstation (x)	Remaining time (C - x)
1	1 6	4 thread overlock machine hand-made	0.29 0.08	0.37	0.08
2	2 4 8	Lock – stitch sewing machine	0.08 0.25 0.09	0.42	0.03
3	3	4 thread overlock machine	0.34	0.34	0.11
4	5	Chain stitch sewing machine	0.35	0.35	0.10
5	7	4 thread overlock machine	0.36	0.36	0.09
6	9	4 thread overlock machine	0.43	0.43	0.02
7	10	Blade cover stitch machine	0.42	0.42	0.03
8	11 13 14	Lock – stitch sewing machine	0.13 0.06 0.25	0.44	0.01
9	12	Blade cover stitch machine	0.33	0.33	0.12
10	15	Iron	0.45	0.45	0.00
		Total time	**3.91**	**3.91**	**0.59**

As can be deduced from ***Table 7*** above, the assembly line is designed with a 0.45 minute cycle time for 10 work stations. The loss of balance and assembly line efficiency of the assembly line designed are shown below.

$$LB = [[(10 \times 0.45) + – (3.91)]/(10 \times 0.45)] \times 100 = 13.11\% \quad (11)$$

$$LE = (1 – 0.1311) \times 100 = 86.89\% \quad (12)$$

Moddie & Young method

To be able to apply this method, first a table as must be formulated (***Table 8.a,*** see page 14). In the first column of the table, the operation number(s) are shown. In the second column the previous operation(s) are given. In the third column the next operation(s) and in the fourth processing times are shown. While formulating this table, if one process is not followed by another, the "–" symbol is written in the second column. In the beginning, the same symbols are written in the control column [29].

The operation which has the longest time is selected as (1) and is assigned to work station number 1. And the residual time of the 1st work station is calculated as $C - t_1 = 0.45 - 0.29 = 0.16$ minutes. A new table (***Table 8.b***) is formulated by deleting operation number 1 from ***Table 8.a***.

The operation which has the longest time is chosen among the available operations (2 and 8) in ***Table 8.b***. The time of the operation is 0.09. Although it is shorter than the remaining time of the 1st work station (0.16), it cannot be assigned because of the difference between machines which are used during the operation. Operation number 8 is assigned to the 2nd work sta-

Table 8. Solution stages of problem using the Moodie & Young method.

a)

Operation No	Previous operation(s)	Next operation(s)	Time, min	Control
1	-	3	0.29	-
2	-	3	0.08	-
3	1 - 2	4	0.34	
4	3	5	0.25	
5	4	6	0.35	
6	5	7	0.08	
7	6	9	0.36	
8	-	9	0.09	-
9	7 - 8	10	0.43	
10	9	11	0.42	
11	10	12	0.13	
12	11	13	0.33	
13	12	14	0.06	
14	13	15	0.25	
15	14	-	0.45	

b)

Operation No	Previous operation(s)	Next operation(s)	Time, min	Control
2	-	3	0.08	-
3	2	4	0.34	
4	3	5	0.25	
5	4	6	0.35	
6	5	7	0.08	
7	6	9	0.36	
8	-	9	0.09	-
9	7 - 8	10	0.43	
10	9	11	0.42	
11	10	12	0.13	
12	11	13	0.33	
13	12	14	0.06	
14	13	15	0.25	
15	14	-		

tion and the remaining time of the 2nd work station is C - t_8 = 0.45 - 0.09 = = 0.36 minutes.

By considering this result, the only available operation is operation number 2. The time of operation number 2 (0.08) is shorter than the remaining time of the second work station and these operations are carried out by the same type of machine, therefore it can be assigned to the 2nd work station, with the remaining time of the second work station found to be 0.28 minutes.

After the assignment of operation number 2, since the operations which come before operation number 3 are assigned, operation number 3 becomes available; its remaining time is longer than the 1st and 2nd work stations' remaining time and it is carried out by different types of machines, assigned to the 3rd work station. The remaining time of the 3rd work station is calculated as 0.11 minutes.

As can be seen in the assignment example, which is done for the 1st, 2nd and 3rd work stations, one can achieve a solution.. Solution results for designing an assembly line using the Moodie & Young Method are shown in ***Table 9***.

Table 9. Line balancing results.

Workstation number	Operation No	Machine type	Time, min	Total time for workstation (x)	Remaining time (C - x)
1	1	4 thread overlock machine	0.29	0.29	0.16
2	2 8	Lock – stitch sewing machine	0.08 0.09	0.17	0.28
3	3	4 thread overlock machine	0.34	0.34	0.11
4	4	Lock – stitch sewing machine	0.25	0.25	0.20
5	5 6	Chain stitch sewing machine hand-made	0.35 0.08	0.43	0.02
6	7	4 thread overlock machine	0.36	0.36	0.09
7	9	4 thread overlock machine	0.43	0.43	0.02
8	10	Blade cover stitch machine	0.42	0.42	0.03
9	11	Lock – stitch sewing machine	0.13	0.13	0.32
10	12	Blade cover stitch machine	0.33	0.33	0.12
11	13 14	Lock – stitch sewing machine	0.06 0.25	0.31	0.14
12	15	Iron	0.45	0.45	0.00
		Total time	**3.91**	**3.91**	**1.49**

As can be deduced from ***Table 9***, the assembly line is designed with a 0.45 minute cycle time for 12 work stations. The loss of balance and assembly line efficiency of the assembly line designed are shown below.

$$LB = [[(12 \times 0.45) + - (3.91)]/(12 \times 0.45)] \times 100 = 27.59\% \quad (13)$$

$$LE = (1 - 0.2759) \times 100 = 72.41\% \quad (14)$$

Kilbridge & Western method

To be able to apply this method, ***Figure 4*** is formed according to the priority diagram in ***Figure 3***.

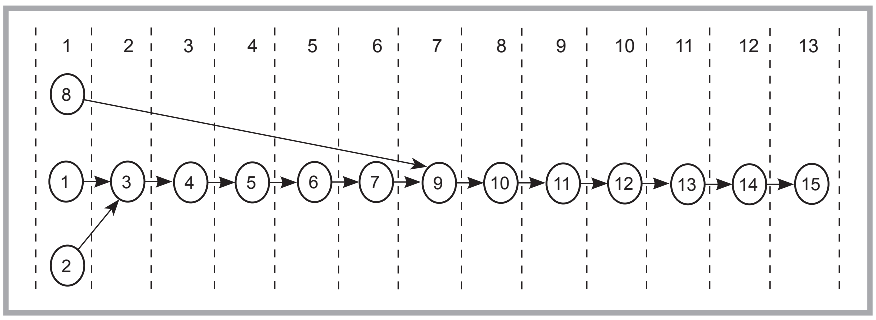

Figure 4. *Priority diagram for Kilbridge & Wester method.*

As can be interpreted from ***Figure 4***, 13 work stations are initially required. In other words 13 columns correspond to 13 work stations. If 13 work stations are used, assembly line productivity decreases since the total time of the work stations is below their cycle time. Consequently the operations which can be carried out in different columns without disordering the process must be taken into account. In the c column of ***Table 10***, the columns which a operation can be assigned to are shown.

To assign elements to workstations, start with column 1 elements. Continue the assignment procedure in order of column number until the cycle time is reached. Results of the solution for the assembly line balancing study are shown in ***Table 11***.

As can be deduced from ***Table 11***, the assembly line is designed with a 0.45 minute cycle time for 12 work stations. The loss of balance and assembly line efficiency of the assembly line designed are shown below.

$$LB = [[(12 \times 0.45) + - (3.91)]/(12 \times 0.45)] \times 100 = 27.59\% \quad (15)$$

$$LE = (1 - 0.2759) \times 100 = 72.41\% \quad (16)$$

Largest candidate rule method

To be able to apply this method, ***Table 12.a*** must firstly be formulated. In this table operations are ordered from the longest to the shortest . When ordering the operations, the one which is of the first priority among them with the same operation time is written first.

The most appropriate operations to be assigned are numbered 1, 8 and 2.

The operation which has the longest time is operation number 1. Operation number 1 is assigned to the 1st work station and its remaining time is calculated as C - t_1 = 0.45 - 0.29 = 0.16 minutes. Although the times of operations 2 and 8 are shorter than for the 1st work station, they can not be assigned to the 1st work station because of the difference in the machine types. ***Table 12.b*** is derived by crossing out operation number 1 from ***Table 12.b***.

The operation which has the longest time is chosen among the available operations (2 and 8) in ***Table 12.b***. The operation numbered 8 is assigned to the 2nd work station. The remaining time of the 2nd work station is calculated as C - t_8 = 0.45 - 0.09 = 0.36 minutes. The time of operation number 2 is shorter than the remaining time of the 2nd work station and is carried out by the same type of machine. This operation is also assigned to the 2nd work station. The remaining time is found to be C - t_2 = 0.36 + - 0.08 = 0.28 minutes. ***Table 12.c*** is derived by crossing out operations number 8 and 2 in ***Table 12.b***.

Table 10. *Operations arranged according to columns.*

Column number (a)	Operation(s) No (b)	Transfer (c)	Time, min (d)	Total time for workstation (e)	Cumulative time, min (f)
1	1 2 8	- - 3-4-5-6-7	0.29 0.08 0.09	0.46	0.46
2	3	-	0.34	0.34	0.80
3	4	-	0.25	0.25	1.05
4	5	-	0.35	0.35	1.40
5	6	-	0.08	0.08	1.48
6	7	-	0.36	0.36	1.84
7	9	-	0.43	0.43	2.27
8	10	-	0.42	0.42	2.69
9	11	-	0.13	0.13	2.82
10	12	-	0.33	0.33	3.15
11	13	-	0.06	0.06	3.21
12	14	-	0.25	0.25	3.46
13	15	-	0.45	0.45	3.91

Table 11. *Line balancing results.*

Workstation number	Operation No	Machine type	Time, min	Total time for workstation (x)	Remaining time (C - x)
1	1	4 thread overlock machine	0.29	0.29	0.16
2	2	Lock – stitch	0.08	0.08	0.37
3	3	4 thread overlock machine	0.34	0.34	0.11
4	4 8	Lock – stitch sewing machine	0.25 0.09	0.34	0.11
5	5 6	Chain stitch sewing machine hand-made	0.35 0.08	0.43	0.02
6	7	4 thread overlock machine	0.36	0.36	0.09
7	9	4 thread overlock machine	0.43	0.43	0.02
8	10	Blade cover stitch machine	0.42	0.42	0.03
9	11	Lock – stitch sewing machine	0.13	0.13	0.32
10	12	Blade cover stitch machine	0.33	0.33	0.12
11	13 14	Lock – stitch sewing machine	0.06 0.25	0.31	0.14
12	15	Iron	0.45	0.45	0.00
		Total time	**3.91**	**3.91**	**1.49**

Table 12. *Solution stages of the problem using of the largest candidate method.*

a)			b)			c)		
Op. No	Time, min	Previous operation(s)	Op. No	Time, min	Previous operation(s)	Op. No	Time, min	Previous operation(s)
15	0.45	14						
9	0.43	7 - 8	15	0.45	14			
10	0.42	9	9	0.43	7 - 8			
7	0.36	6	10	0.42	9	15	0.45	14
5	0.35	4	7	0.36	6	9	0.43	7
3	0.34	1-2	5	0.35	4	10	0.42	9
12	0.33	11	3	0.34	2	7	0.36	6
1	0.29	-	12	0.33	11	5	0.35	4
4	0.25	3	4	0.25	3	3	0.34	-
14	0.25	13	14	0.25	13	12	0.33	11
11	0.13	10	11	0.13	10	4	0.25	3
8	0.09	-	8	0.09	-	14	0.25	13
2	0.08	-	2	0.08	-	11	0.13	10
6	0.08	5	6	0.08	5	6	0.08	5
13	0.06	12	13	0.06	12	13	0.06	12

As can be seen in the assignment example, which is done for the 1st and 2nd work stations, one can achieve a solution.

The solution results for designing an assembly line using the largest candidate rule method are shown in ***Table 13***.

Table 13. Line balancing results.

Workstation number	Operation No	Machine type	Time, min	Total time for workstation (x)	Remaining time (C - x)
1	1	4 thread overlock machine	0.29	0.29	0.16
2	2 8	Lock – stitch sewing machine	0.08 0.09	0.17	0.28
3	3	4 thread overlock machine	0.34	0.34	0.11
4	4	Lock – stitch sewing machine	0.25	0.25	0.20
5	5 6	Chain stitch sewing machine Hand-made	0.35 0.08	0.43	0.02
6	7	4 thread overlock machine	0.36	0.36	0.09
7	9	4 thread overlock machine	0.43	0.43	0.02
8	10	Blade cover stitch machine	0.42	0.42	0.03
9	11	Lock – stitch sewing machine	0.13	0.13	0.32
10	12	Blade cover stitch machine	0.33	0.33	0.12
11	13 14	Lock – stitch sewing machine	0.06 0.25	0.31	0.14
12	15	Iron	0.45	0.45	0.00
		Total time	**3.91**	**3.91**	**1.49**

Table 14. Number of machines – operators required for the operations.

Operation No	Operation	Machine type	Operation time, min	Number of required machine-operator
1	Shoulder sewing	4 thread overlock machine	0.29	0.644 machine
2	Collar inseam	Lock – stitch sewing machine	0.08	0.178 machine
3	Collar sewing	4 thread overlock machine	0.34	0.756 machine
4	Neck label sewing	Lock – stitch sewing machine	0.25	0.556 machine
5	Neck binding sewing	Chain stitch sewing machine	0.35	0.778 machine
6	Binding control – regulated	Hand-made	0.08	0.178 operator
7	Sleeve sewing	4 thread overlock machine	0.36	0.800 machine
8	Care label preparing	Lock – stitch sewing machine	0.09	0.200 machine
9	Side seam	4 thread overlock machine	0.43	0.956 machine
10	Sleeve hem cover seem	Blade cover stitch machine	0.42	0.933 machine
11	Sleeve hem reinforcement	Lock – stitch sewing machine	0.13	0.289 machine
12	Hem cover seam	Blade cover stitch machine	0.33	0.733 machine
13	Hem reinforcement	Lock – stitch sewing machine	0.06	0.133 machine
14	Flag label sewing	Lock – stitch sewing machine	0.25	0.556 machine
15	Ironing	Iron	0.45	1.000 machine
		Total time	**3.91**	**8.700 m-o**

As can be deduced from **Table 13**, the assembly line is designed with a 0.45 minute cycle time for 12 work stations. The loss of balance and assembly line efficiency of the assembly line designed are shown below.

$$LB = [[(12 \times 0.45) + -(3.91)]/(12 \times 0.45)] \times 100 = 27.59\% \quad (17)$$

$$LE = (1 - 0.2759) \times 100 = 72.41\% \quad (18)$$

Classical method

In the assembly line balancing study conducted using this method, the number of machines and operators required to carry out each operation based on the daily total production amount (PA = 1200) is calculated firstly (***Table 14***) using the formula which is given below [10].

$$RMO = (OP \times PA)/T \quad (19)$$

Where: RMO is the number of machines – operators required, OP the operation time, PA the daily total production amount and T is the daily total production time.

For example, the standard time of operation 1 is 0.19 minutes.

$$RMO = (0.29 \times 1200)/540 = 0.644. \quad (20)$$

Secondly operations are classified according to the types of machines, and the total number of machines required is determined (***Table 15***).

As can be seen in ***Table 15***, 10 machines/operators including 2 lock–stitch machines, 4 thread overlock machines, 2 blade cover stitch machines, 1 chain stitch machine and 1 iron are required to set up an assembly line. No assignment will be made for handwork operations. A handwork operation will be carried out using appropriate machines as the assembly line is being balanced.

After the calculations, each operator is given a task in such a way that they work 540 minutes (daily total working time). Giving such a task, at the same time, points out that the operation which is carried out by the same type of machine must be assigned according to the number of machines required. In this way each operator is given a task in a such way that they will work for 540 minutes. The narrow gap that can result from the difference between the numbers of machines required is resolved. The assignments of the assembly line can be seen in ***Table 16***.

Table 15. Number of machines – operators required for the operations based on machine type.

Lock – stitch sewing machine		4 thread overlock machine		Blade cover stitch machine		Chain Stitch sewing machine		Hand-made		Iron	
Op. No	Quantity	Op. No	Quantity	Op. No	Quantity	Op. No	Quantity	Op. No	Quantity	Op. No	Quantity
2	0.178	1	0.644	10	0.933	5	0.778	6	0.178	15	1.000
4	0.556	3	0.756	12	0.733						
8	0.200	7	0.800								
11	0.289	9	0.956								
13	0.133										
14	0.556										
Total	**1.912**		**3.156**		**1.666**		**0.778**		**0.178**		**1.000**
Total	**2**		**4**		**2**		**1**		**-**		**1**

Table 16. *Line balancing result.*

Work-station	Assigned operations			Work load (Time, minute)					
	1	2	3	1. Assign	Remaining time	2. Assign	Remaining time	3. Assign	Remaining time
1	Shoulder sewing - 1	Binding control / regulated - 6		0.29 × 1200 = 348	192	0.08 x 975 = 78	114		
2	Collar inseam – 2	Neck label sewing – 4	Care label preparing - 8	0.08 × 1200 = 96	444	0.25 × 1200 = 300	144	0.09 × 1200 = 108	36
3	Collar sewing – 3	Binding control / regulated - 6		0.34 × 1200 = 408	132	0.08 × 225 = 18	114		
4	Neck binding sewing - 5			0.35 × 1200 = 420	120				
5	Sleeve sewing – 7			0.36 × 1200 = 432	108				
6	Side seam - 9			0.43 × 1200 = 516	24				
7	Sleeve hem cover seam - 10			0.42 × 1072 = 450	89.76				
8	Sleeve hem cover seam - 10	Hem cover seam – 12		0.42 × 128 = 53.8	486.24	0.33 × 1200 = 396	90.24		
9	Sleeve hem reinforcement – 11	Hem reinforcement – 13	Flag label sewing - 14	0.13 × 1200 = 156	384	0.06 × 1200 = 72	312	0.25 × 1200 = 300	12
10	Ironing – 15			0.45 × 1200 = 540	0				

Table 17. *Results of studies for assembly line balancing.*

Workstation	Assembly line balancing methods													
	Ranked positional weight		Moodie & Young		Largest candidate rule		Kilbridge & Wester		Hoffman		Comsoal		Classic	
	Op.	Eff., %	Op.	Eff., %	Op.	Eff., %	Op.	Eff., %	Op.	Eff., %	Op.	Eff., %	Op.	Eff.. %
1	1	64.44	1	64.44	1	64.44	1	64.44	1 6	82.22	1 6	82.22	1 6	93.33
2	2 8	37.77	2 8	37.77	2 8	37.77	2	17.77	2 4 8	93.33	2 4 8	93.33	2 4 8	93.33
3	3	75.55	3	75.55	3	75.55	3	75.55	3	75.55	3	75.55	3 6	78.88
4	4	55.55	4	55.55	4	55.55	4 8	75.55						
5	5 6	95.55	5 6	95.55	5 6	95.55	5 6	95.55	5	77.77	5	77.77	5	77.77
6	7	80.00	7	80.00	7	80.00	7	80.00	7	80.00	7	80.00	7	80.00
7	9	95.55	9	95.55	9	95.55	9	95.55	9	95.55	9	95.55	9	95.55
8	10	93.33	10	93.33	10	93.33	10	93.33	10	93.33	10	93.33	10	83.37
9	11	28.88	11	28.88	11	28.88	11	28.88	11 13 14	97.77	11 13 14	97.77	11 13 14	97.77
10	12	73.33	12	73.33	12	73.33	12	73.33	12	73.33	12	73.33	10 12	83.28
11	13 14	68.88	13 14	68.88	13 14	68.88	13 14	68.88						
12	15	100.00	15	100.00	15	100.00	15	100.00	15	100.00	15	100.00	15	100.00
Line eff., %	**72.41**		**72.41**		**72.41**		**72.41**		**86.89**		**86.89**		**86.89**	

As can be observed from ***Table 16***, the assembly line is designed for 1200 amounts of the daily total production amount with 10 work stations. The loss of balance and the assembly line efficiency are shown below.

$$LB = [[(10 \text{ x } 0.45) + – (3.91)]/(10 \times 0.45)] \times 100 = 13.11\% \quad (21)$$

$$LE = (1 – 0.1311) \times 100 = 86.89\% \quad (22)$$

Results

In this study six different methods used in assembly line balancing were analysed. Additionally the results of assembly line balancing methods applied to production lines were compared with that of the "classical" method. It is determined that the six different line balancing methods have different efficiency values for a t-shirt production line with between 10 and 12 workstations.

The results of the assembly line studies carried out by using the heuristic and classical methods are shown in ***Table 17***.

As can be concluded from ***Table 17*** the results of the studies conducted using the ranket positional weight Moodie &

Table 18. *Comparison of the lowest workstation efficiency values of the line balancing methods.*

Methods	The lowest workstation efficiency values, %
Ranked positional weight	28.88
Moodie & Young	28.88
Largest Candidate Rule	28.88
Kilbridge & Wester	17.77
Hoffman	73.33
Comsoal	73.33
Classical	77.77

Young and largest candidate rule methods are same. The only difference of the Kibridge & Western method, which is another method with 12 work station, is that operation number 8 is assigned to the 4th work station rather than the 2nd work station. The reason for this difference is that applicability steps are different. Among the 3 methods with 12 work stations, the lowest work station efficiency is 28.88%, belonging to work station number 9. The lowest work station efficiency on an assembly line by Kibridge & Western is 17.77%, belonging to work station number 2, since operation number 8 is carried out at a different work station for the first 3 methods.

As can be seen from ***Table 17***, the results of assembly line balancing studies conducted by the Hoffman and COMSOAL method are the same.

The difference between the classical method, which consists of 10 operations, from the others is that operations number 3 and 10 are assigned to different work stations. The reason why these operations are assigned to more than one work station is to make the efficiency of the work stations the same. For instance, when the operation assignments shown in ***Table 9*** are considered, it can be understood if operation number 10 is assigned to the 7th work station, it has to wait 36 minutes to operate. Consequently the 8th work station, which the second operation is assigned to, has to wait 144 minutes to operate. As a result of these assignments, the time which 7th work station has to wait to operate again is 89.76 (work station efficiency 83.37%), and the time of 8th is - 90.24 (work station efficiency 83.28%).

On the other hand operations number 6, which are handwork operations, are carried out with operations number 5 on an assembly line which consists of 12 work stations and on an assembly line which consists of 10 work stations, carried out with the 1st work station, which affects the 1st work station's efficiency positively. Data obtained from the analyses done by considering the lowest work station efficiency are shown in ***Table 18***. The classical method is the most advantageous with 77.77% and the Killbridge & Wester method is the most disadvantageous with 17.77% from among the other methods.

Conclusions

the aim of this study was to design assembly lines which have the highest performance, compare the classical method which is used widely in ready-to-wear companies with other methods used in assembly line balancing and examine their applicability.

In this context the methods which are named according to the researchers that conducted the study were applied and results analysed.

When the results of the study are examined, it can be stated that almost all of the heuristic assembly line balancing methods can be applied in a ready-to-wear assembly line though some have lower efficiency because of the basic obstacle of applicability. When the classical method used in ready-to-wear companies these days is considered, the Hoffman and COMSOAL method gives nearly the same results.

The highest efficiency loss results from the fact that different operations cannot be assigned to machines used for only one operation, as can be seen from the example of an operation where chain stitch machines are used. On the other hand the problem that the same operation cannot be assigned to a different work station in the methods except from the classical method affects assembly line efficiency negatively.

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