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Comparing Heuristic and Simulation Methods Applied to the Apparel Assembly Line Balancing Problem

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Abstract
In this study, general information on assembly line and simulation and researches on assembly line balancing are theoretically analysed. Afterward time studies with respect to blouse production, which will be analysed in assembly line balancing, are conducted and information, which is necessary for assembly line balancing, is obtained. In parallel with the data obtained, the assembly line is firstly balanced by the Hoffman method, which is one of the heuristic methods. Then the assembly line is balanced again using the Arena Simulation program and results which belong to two different assembly line balancing resolutions are given. The aim of the study is to create an assembly line which has highest line efficiency by using an optimum number of machines and operators as well as highlight the applicability of the Hoffman method to ready-to-wear assembly lines.

Key words: *assembly line balancing, simulation, clothing industry, Hoffman method, heuristic line balancing.*

Introduction

Assembly lines are places where the parts and components of 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], which is called assembly line balancing or line balancing, used to attain operations needed during product formation at assembly stations in the 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, and they are divided into groups according to the way they are produced. Assembly line balancing methods are divided 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].

Simulation, in other word analogy, is to minimise the real size and to transfer it to a computer [7]. Shanon described it as a method of managing experiments to design a computerised system model and to understand system models with this model or to evaluate different strategies which can be used to manage the system [8]. Simulation is an important tool to analyse the current situation and determine what is necessary to be done later on. Simulation also has important advantages in foreseeing the results of the investment decision while a company is determining investments and in enabling to make a choice between the two current situations. These specialties of the simulation make it a method that can be used as a decision making tool without having any risks when it is considered that ready-to-wear sewing lines necessitate capital-incentive.

In this study, time studies of knitted blouse production examined in assembly line balancing were carried out and data necessary for balancing obtained. In the parallel with this information, the assembly line was balanced by both the Hoffman method, which is an Heuristic assembly line balancing method, and the simulation method.

Although the Hoffman method is one of the easiest to understand and apply among the heuristic line balancing methods, it is hardly ever used in clothing assembly line balancing, as far as previous studies are concerned. Hence it was interesting to see the effects with this study.

The Arena simulation program was used in applying the simulation method. After line balancing practices, the results of two different assembly line balancing resolutions are compared.

The aim of the study was to create an assembly line which has the highest line efficiency and to especially indicate the applicability of the Hoffman method to apparel assembly lines by comparing results which belong to both assembly line methods. For this reason there was no need to select a complex product.

Literature review

The Hoffman method is one of the heuristic line balancing methods, and it is named after the man who founded it. The idea of assembly line balancing by the Hoffman Method was first suggested by Thomas R. Hoffman in his article called "Assembly Line Balancing with a Precedence Matrix" in 1963 [9].

When the studies on assembly line balancing in the apparel industry are reviewed, the first that comes to mind is the study conducted by Baskak, in which

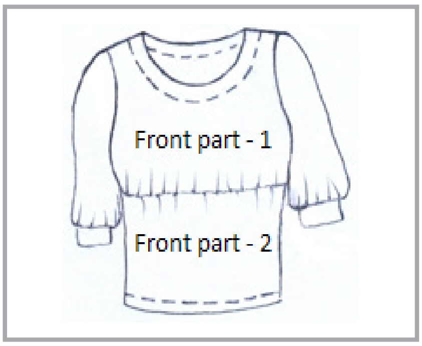

__Figure 1.__ Model of knitted blouse.

a new method was developed for the assembly line balancing problem [10]. In a study conducted by Kayar and his colleague, the Hoffman Method was also used. [11].

As regards studies on line balancing by the simulation method, Cocks and Harlock made a simulation of the sewing department of an apparel company using a program named Fortran 77 [12]. Fozzard and his colleagues made a simulation of flow line in a clothing company [13]. In his study, Kayar designed two separate assembly lines which had different technology to produce jean trousers by using the promodal simulation program and compared differences between those assembly lines. [7]. Rajakumar and his colleagues tried to an balance assembly line by using a simulation program written in C++ [14]. In the studies conducted by Kursun, Kaloğlu and their colleagues between 2007 and 2010, the simulation method was used for production line modelling, determining ideal workflow, and assembly line balancing [15 - 19]. In the study conducted by Eryuruk, a dress assembly line was modelled using a simulation program [20]. Assembly line balancing practices which were applied by using the simulation method were also conducted by Guner and his colleagues [21, 22].

Experimental

A knitted blouse was used in this study. A model of the blouse is shown in ***Figure 1***.

A model of the blouse, which shown in ***Figure 1***, consists of 8 parts, including the front part 1 and 2, back, sleeves (2), cuffs (2) and collar (1). The blouse was produced on appropriate machines according to an operation order. ***Figure 2*** shows the production flow that is necessary for producing the blouse.

Assembly line balancing

The Hoffman method, which is one of the heuristic methods, and the simulation method were used for assembly line balancing.

The duration of a workstation cannot be shorter than the longest duration of a work unit, and it cannot be longer than the cycle time [3]. Because of this principle, the cycle time in assembly line balancing studies is accepted as 0.887 minutes. The loss of balance of assembly lines as well as their efficiency and daily total production amount is estimated using the formulas below.

- $LB = [(nC - \sum C_o)/nC)]\ 100$
- $LE = (1 - LB)\ 100$
- $PA = T/C$

where, LB is the loss of balance, LE the line efficiency, C the cycle time, n the total number of work stations, $\sum C_o$ the total time, PA the daily total production amount and T the daily total production time [23].

In all assembly line balancing studies carried out within the scope of this study, it was supposed that *hand-made operations are done by all operators* on condition that operations are done by same type of machine.

An assembly line balancing study was carried out according to the blouse production, which consists of 19 operations. shown in ***Figure 3*** with its diagram.

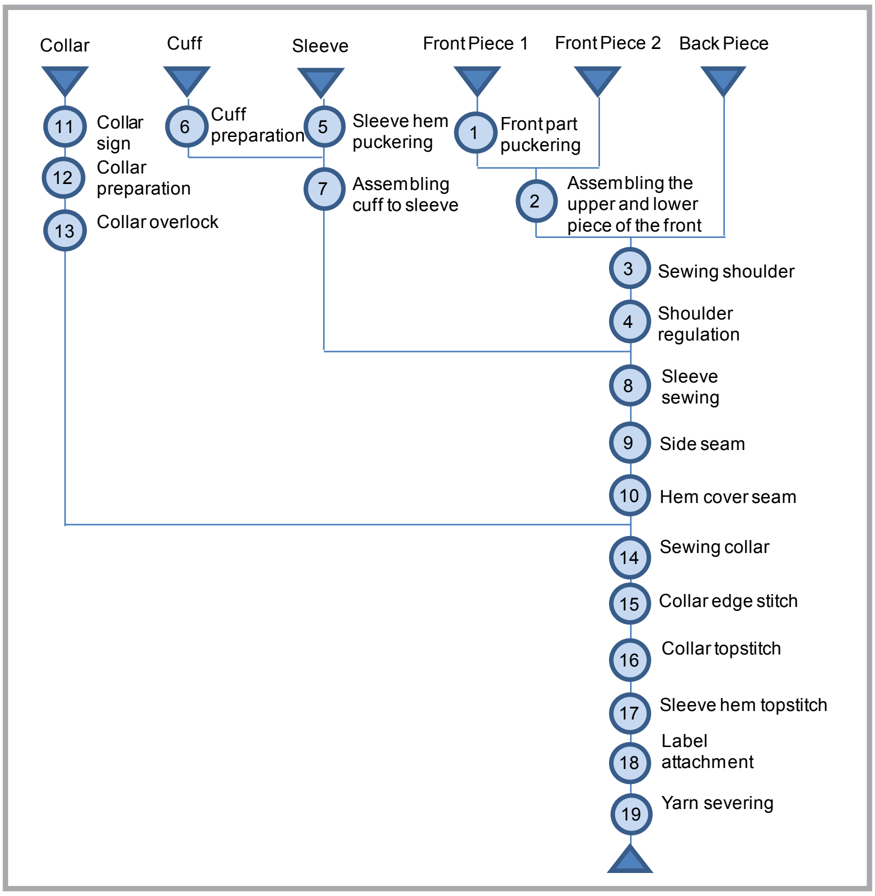

__Figure 2.__ Operations and flow chart of the operations in the blouse production.

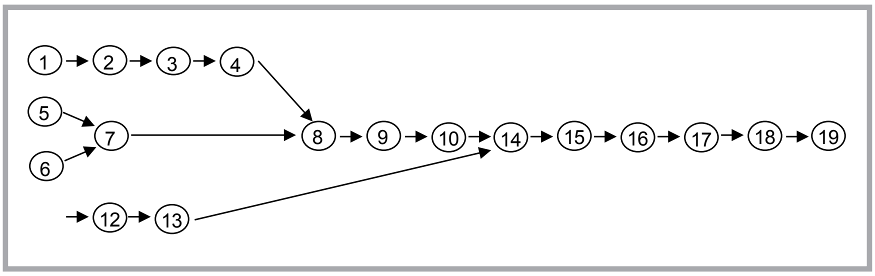

__Figure 3.__ Precedence diagram for blouse sewing.

The operation time for the blouse production, machines used during this operation and previous operations are shown in ***Table 1***.

__Table 1.__ Operation times for machine types and previous operations for blouse sewing

Op. N.	Operations	Machine Type	Operation times, min.	Previous operations
1	Front part (1) puckering	Lock-stitch sewing machine	0.462	-
2	Assembling the upper (1) and lower (2) piece of the front	3 thread overlock	0.408	1
3	Sewing shoulder	3 thread overlock	0.383	2
4	Shoulder Regulate	Hand-made	0.193	3
5	Sleeve hem puckering	Lock-stitch sewing machine	0.341	-
6	Cuff preparation	3 thread overlock	0.151	-
7	Assembling cuff to sleeve	3 thread overlock	0.205	5 – 6
8	Sleeve sewing	3 thread overlock	0.541	4 – 7
9	Side seam	3 thread overlock	0.837	8
10	Hem cover seam	Cover stitch machine	0.588	9
11	Collar sign	Hand-made	0.229	-
12	Collar preparing	Lock-stitch sewing machine	0.450	11
13	Collar overlock	3 thread overlock	0.292	12
14	Sewing collar	3 thread overlock	0.517	10 – 13
15	Collar edge stich	Lock-stitch sewing machine	0.481	14
16	Collar topstitch	Lock-stitch sewing machine	0.887	15
17	Sleeve hem topstitch	Lock-stitch sewing machine	0.373	16
18	Label attachment	Lock-stitch sewing machine	0.536	17
19	Yarn severing	Hand-made	0.791	18
		Total time	**8.665**	

As can be seen from ***Table 1***, four different sewing machines were used for the blouse production. As a general rule, it is considered that the chain stitch machine should be used in the production of knitted garments. However, in the blouse production, lock stitch machines were used for 7 (1, 5, 12, 15, 16, 17, 18) operations because no force affects the sewing area.

Hoffman method process

Firstly a priority matrix is designed as the assembly line is being constituted by the using Hoffman method (***Table 2.a***). There are 4 operations (1, 5, 6 and 8) which have a 0 rate in the code number array. The operation numbered 1, which is the first one among them, is assigned to the 1st work station. The remaining time of the 1st work station is calculated as $C - t_1 = 0.887 - 0.462 = 0.425$ minutes. The time of the second operation which has a 0 rate (operation number 5) is 0.341 minutes. As it is shorter than the remaining time of the 1st work station, in which the same type of are used, operation number 5 is assigned to the 1st work station. The remaining time of the 1st work station is calculated as $C - t_5 = 0.425 - 0.341 = 0.084$ minutes.

To make an assignment to the 2nd work station, a new priority matrix is obtained by crossing - out lines and columns numbered 1 and 5 in the priority matrix (***Table 2.b***). There are 3 operations (2, 6, and 11) which have a 0 rate in the code number array. The first rate of 0, which is left to right in the code number array, can be seen in the operation numbered 2. As this operation cannot be assigned to the 1st work station, it is given to the 2nd work station. The remaining time of the 2nd work station is calculated as $C - t_2 = 0.887 - 0.408 = 0.479$ minutes. The time of the second operation which has rate 0 (operation numbered 6) is 0.151 minutes. As it is shorter than the remaining time of the 2nd work station, in which the same type of are used, the operation numbered 6 is assigned to the 2nd work station. The remaining time of the 2nd work station is calculated as $C - t_6 = 0.479 - 0.151 = 0.328$ minutes. The time of the third operation which has a 0 rate (operation number 11) is 0.229 minutes. As it is shorter than the remaining time of the 2nd work sta-

__Table 2.__ Solution matrix 1 – 3.

a)

Op.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
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																1			
16																	1		
17																		1	
18																			1
19																			
Code No	0	1	1	0	0	2	2	1	1	1	0	1	1	2	1	1	1	1	1

b)

Op	2	3	4	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2		1															
3			1														
4						1											
6					1												
7						1											
8							1										
9								1									
10												1					
11										1							
12											1						
13												1					
14													1				
15														1			
16															1		
17																1	
18																	1
19																	
Code No	0	1	1	0	1	2	1	1	0	1	1	2	1	1	1	1	1

c)

Op	3	4	7	8	9	10	12	13	14	15	16	17	18	19
3		1												
4				1										
7				1										
8					1									
9						1								
10									1					
12								1						
13									1					
14										1				
15											1			
16												1		
17													1	
18														1
19														
Code No	0	1	0	2	1	1	0	1	2	1	1	1	1	1

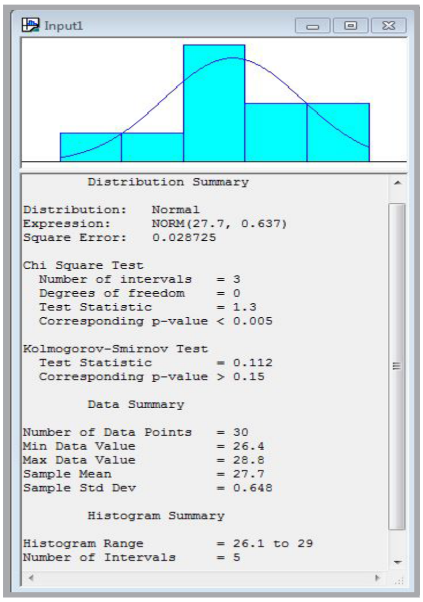

Figure 4. *Dispersion belonging to the front part puckering operation.*

tion, in which the same type of are used, the operation numbered 11 is assigned to the 2nd work station. The remaining time of the 2nd work station is calculated as C - t_{11} = 0.328 - 0.229 = 0.099 minutes.

To make an assignment to the 3rd work station, a new priority matrix is designed by crossing out the lines and columns numbered 2, 6 and 11 in the priority matrix (***Table 2.c***, see page 133).

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 according to the assembly line designed by using the Hoffman Method are shown ***Table 2*** in the results section.

Simulation process

The Arena simulation program was used to create the simulation model. Each operation which belongs to the operators is programmed as shown in ***Figure 2***.

Data obtained from the work study was used for setting of the simulation model. The dispersion rates of thirty time studies are obtained as a result of work studies calculated by an input analyser, and the first test is performed. In the graphic below, dispersion belonging to front part puckering operations is shown as an example.

In the model designing step, some situations that will be encountered in the real production system are accepted and some considered not to be encountered. Not only are these assumptions accepted, but also tolerances related to them are reflected in the data. The assumptions accepted in this application are given below.

1. The daily production time is accepted as 540 min.
2. It is not taken into consideration that operators have a break because of their individual needs, machine checks and stoppages.
3. It is assumed that there is no power outage or defective manufacturing, and that every operation proceeds as is required.
4. All operation durations are approached stochastically
5. In each machine, only one operator works.
6. The system of handling the parts of the blouse among the machines is made by middle men and the number of the middle men is accepted as being infinite.
7. The assembly line operates based on the propulsion system. When a follow up machine confronts a narrow pass, the former machine stops its production and does not deliver parts to the next one.
8. It is accepted that the parts composing the blouse are ready for the sewing process as having been cut.

Table 3. *Line balancing results.*

Workstation number	Op. No	Time, min.	Total time for work station, min.	Remaining time, min.
1	1 5	0.462 0.341	0.803	0.084
2	2 6 11	0.408 0.151 0.229	0.788	0.099
3	3 4 7	0.383 0.193 0.205	0.781	0.106
4	12 17	0.450 0.373	0.823	0.064
5	8 13	0.541 0.292	0.833	0.054
6	9	0.837	0.837	0.050
7	10	0.588	0.588	0.299
8	14	0.517	0.517	0.370
9	15	0.481	0.481	0.406
10	16	0.887	0.887	0
11	18	0.536	0.536	0.351
12	19	0.791	0.791	0.096
	Total	**8.665**	**8.665**	**1.979**

Considering the assumptions above, a simulation model is firstly designed as one operator for each operation. In this simulation model, 608 pieces blouses were obtained by using 19 work stations and the assembly line efficiency was received as 51%.

The same simulation model of the assembly line in the work study performed was set in the next stage. The daily output number was obtained by running the simulation, and the average daily output number of the real system was compared. Validation of the system was performed and the reality of the simulation model observed. In this model, 679 pieces blouse were obtained by using 16 work stations, and the assembly line efficiency was obtained as 68%.

The bottlenecks of the simulation model of the existing system determined were eliminated by the operation and operator to meet regulations and optimum machine and operator balance for the production line was achieved.

According to results of the simulation, which are given in detail in the results section,the workstation number was 10, the total time 8.6764 min (min = 8.4268 min, max = 9.0158 min – ***Table 5***), and the average cycle time was found as 0.8864 (min = 0.8140 min, max = 0.9601 min – ***Table 6***). According to these results, the average assembly line efficiency was found to be 97.88%.

According to the simulation results, the firm's assembly line was balanced and the assembly line efficiency was measured as 92% at the end of the day. The applicability of the simulation model was tested according to the results. The reason for the 6% difference is igno-

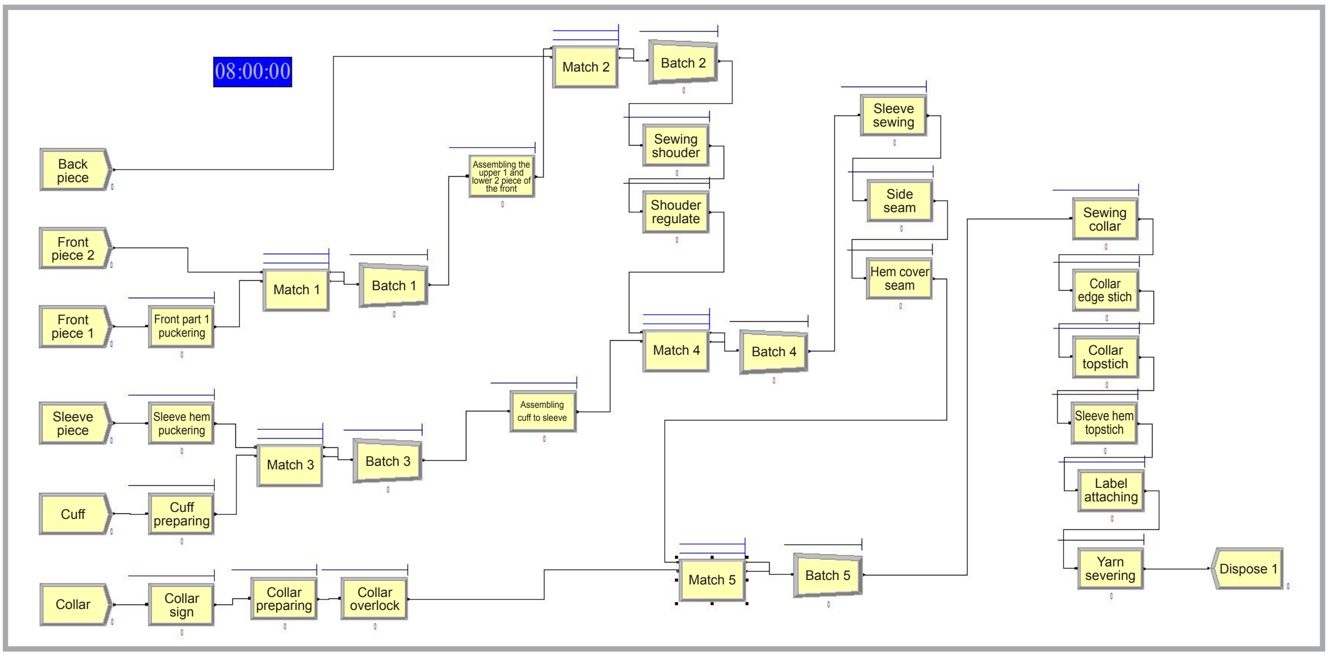

Figure 5. *Modelling of blouse production with the Arena Simulation programme.*

Table 4. *Number of operators and machines which are used in the assembly line (a) & operation assignment (b)*

a)

Number Scheduled	Average	Minimum value	Maximum value
3 Thread overlock machine 1	1.0000	1.0000	1.0000
3 Thread overlock machine 2	1.0000	1.0000	1.0000
3 Thread overlock machine 3	1.0000	1.0000	1.0000
Cover stitch machine	1.0000	1.0000	1.0000
Hand made	1.0000	1.0000	1.0000
Lock stitch sewing machine 1	1.0000	1.0000	1.0000
Lock stitch sewing machine 2	1.0000	1.0000	1.0000
Lock stitch sewing machine 3	1.0000	1.0000	1.0000
Lock stitch sewing machine 4	1.0000	1.0000	1.0000
Lock stitch sewing machine 5	1.0000	1.0000	1.0000
Operator 1	1.0000	1.0000	1.0000
Operator 10	1.0000	1.0000	1.0000
Operator 2	1.0000	1.0000	1.0000
Operator 3	1.0000	1.0000	1.0000
Operator 4	1.0000	1.0000	1.0000
Operator 5	1.0000	1.0000	1.0000
Operator 6	1.0000	1.0000	1.0000
Operator 7	1.0000	1.0000	1.0000
Operator 8	1.0000	1.0000	1.0000
Operator 9	1.0000	1.0000	1.0000

b)

Op.	Machines	Operations Assigned		
		1st assign	2nd assign	3rd assign
1	3 thread overlock machine	Front part 1 puckering	Sleeve hem puckering	Label attachment
2		Collar preparation	Sleeve hem topstitch	Label attachment
3		Sleeve sewing	Collar overlock	Yarn severing
4	Cover stitch machine	Hem cover seam	Yarn severing	
5	Hand made	Shoulder regulation	Collar sign	Yarn severing
6	Lock stitch machine	Collar edge stitch	Label attaching	
7		Collar topstitch		
8		Side seam	Yarn severing	
9		Cuff preparing	Assembling cuff to sleeve	Sewing collar
10		Assembling the upper 1 and lower 2 piece of the front	Sewing shoulder	Collar sign

rance of the events of the real assembly line in the firm.

Results

The results for the methods used in assembly line balancing in this study are given below.

Hoffman method

Solution results according to the assembly line designed using the Hoffman method are shown in ***Table 3***.

As can be deduced from the table above, the assembly line is designed according to a 0.887 minute cycle time with 12 work stations. The loss of balance, assembly line efficiency and daily total production amount of the assembly line designed are shown below.

LB = [[(12 x 0.887) – (8.665)] / (12 x 0.887)] x 100 = 18.59%

LE = (1 – 0.1859) x 100 = 81.41%

PA = 540 / 0.887 = 608 pcs / day

Simulation method

The results of the modelling of blouse production with the Arena simulation programme is shown below (***Figure 5***).

Table 5. Product sewing time belonging to the blouse assembly line balanced by the simulation method.

VA Time	Average	Half Width	Minimum Value	Maximum Value
Product	8.6764	0.0090	8.4268	9.0158

Table 6. Average, maximum and minimum rates of the operations.

VA Time Per Entity	Average	Half Width	Minimum Value	Maximum Value
Assembling cuff to sleeve	0.2055	0.0017	0.1794	0.2870
Assembling the upper 1 and lower 2 piece of the front	0.4080	0.0015	0.3700	0.4478
Collar edge stitch	0.4812	0.0010	0.4617	0.5002
Collar overlock	0.2933	0.0006	0.2802	0.3083
Collar preparing	0.4567	0.0066	0.3667	0.5833
Collar sign	0.2291	0.0006	0.2212	0.2777
Collar topstitch	0.8864	0.0020	0.8140	0.9601
Cuff preparation	0.1504	0.0010	0.1245	0.1667
Front part 1 puckering	0.4612	0.0007	0.4336	0.4947
Hem cover seam	0.5877	0.0023	0.5372	0.6897
Label attachment	0.5366	0.0005	0.5179	0.5550
Sewing collar	0.5158	0.0021	0.4668	0.5500
Sewing shoulder	0.3848	0.0014	0.3348	0.4267
Shoulder regulation	0.1934	0.0009	0.1719	0.2156
Side seam	0.8347	0.0017	0.7845	0.8666
Sleeve hem puckering	0.3432	0.0016	0.3256	0.5360
Sleeve hem topstitch	0.3728	0.0011	0.3501	0.4099
Sleeve sewing	0.5433	0.0018	0.5196	0.6483
Yarn severing	0.7918	0.0004	0.7834	0.8000

Table 7. Number of operations performed.

Number In	Value	Number Out	Value
Assembling cuff to sleeve	617.00	Assembling cuff to sleeve	617.00
Assembling the upper 1 and lower 2 piece of the front	617.00	Assembling the upper 1 and lower 2 piece of the front	616.00
Collar edge stitch	613.00	Collar edge stitch	612.00
Collar overlock	617.00	Collar overlock	617.00
Collar preparation	617.00	Collar preparation	617.00
Collar sign	618.00	Collar sign	617.00
Collar topstitch	612.00	Collar topstitch	611.00
Cuff preparation	618.00	Cuff preparing	617.00
Front part 1 puckering	618.00	Front part 1 puckering	617.00
Hem cover seam	614.00	Hem cover seam	614.00
Label attachment	610.00	Label attachment	610.00
Sewing collar	614.00	Sewing collar	613.00
Sewing shoulder	616.00	Sewing shoulder	616.00
Shoulder regulation	616.00	Shoulder regulation	616.00
Side seam	615.00	Side seam	614.00
Sleeve hem puckering	618.00	Sleeve hem puckering	617.00
Sleeve hem topstitch	611.00	Sleeve hem topstitch	610.00
Sleeve sewing	616.00	Sleeve sewing	615.00
Yarn severing	610.00	Yarn severing	608.00

Table 8. Data belonging to assembly lines balanced by the Hoffman and simulation methods.

Method	Cycle time, min	PA, pcs	LE, %	Number of workstation
Hoffman	0.887	608	81.41	12
Simulation	0.8864 (average)	608	97.88 (average)	10

The number of operators and machines (***Table 4.a***) which are used in the assembly line as a result of the simulation model and the operation assignments (***Table 4.b***) are shown below.

As can be seen in the table above, in the simulation model designed, 3 thread overlock machines, 5 lock stitch sewing machines, 1 cover stitch machine and 1 handcraft station plus one operator for each of them are used.

According to the simulation results, the cycle time of the collar topstitch operation is 0.8864 which has the highest value added time.

Simulation results have shown that aproduct is sewed in an average of 8.6764 minute and in return for this average rate, the minimum time is 8.4268 minutes and maximum time 9.0158 (***Table 5***).

The time in which each operation is performed as a result of the simulation run is given ***Table 6*** as average, maximum and minimum rates.

According to simulation results, the times each operation is performed is given in ***Table** 7*.

As can be understood from the table which is given above, the "yarn severing" operation,which is the last operation in the assembly line at the end of the 540 minutes performing time, is performed 608 times. Accordingly the current output of the assembly line which is designed as a result of assembly line balancing by the simulation method becomes 608. The average efficiency of the line which is designed as a result of the assembly line balancing practice is shown below.

$$n = 10 \text{ units}$$

$$C = 0.8864 \text{ min.}$$

$$(\text{min}=0.8140 \text{ min, max}=0.9601 \text{ min})$$

$$\sum C_o = 8.6764 \text{ min}$$

$$(\text{min} = 8.4268 \text{ min, max} = 9.0158 \text{ min})$$

$$LB = [[(10 \times 0.8864) - (8.6764)]/(10 \times 0.8864)] \times 100 = 0.02116\%$$

$$LE = (1 - 0{,}02116) \times 100 = 97.88\%$$

Comparison of methods

The final results of two methods are given in the ***Table 8***.

As seen from ***Table 8***, the results of the Hoffman assembly line balancing method, daily production amount, station number and assembly line efficiency were found to be 608, 12 and 81.41, respectively. As a result of the assembly line balancing performed by the simulation method, the daily production amount, station number and assembly line efficiency were found to be 608, 10 and 97.88, respectively.

Considering the data above, it is understood that the simulation method has more advantages for assembly line balancing. Based on a similar cycle time and same production amount, by use of the simulation method, the assembly line is balanced by providing fewer work stations (2) and higher line efficiency (16.47%) than by the Hoffman method. When an assembly line with 16 work stations, 679 daily products and 68% assembly line efficiency is considered, it can be observed that the same number of blousse can be produced using the two assembly line balancing methods with less operator-machine usage and higher line efficiency.

Conclusion

Assembly line balancing is very important as an nnbalanced assembly line causes labour, machine and energy loss. That is why optimum balancing of an assembly line is crucial for ready-made garment firms.

The main purpose of the study was to create an assembly line which has the highest line efficiency with minimum machine and operator usage by using different assembly line balancing methods. For this purpose broad research was conducted on the blouse production process in a firm which has blouse production. As a result of detailed analyses conducted by the work study method, the operation turns, durations and machines used were ascertained. Later on the blouse production line was balanced by the Hoffman method and the simulation method and results which obtained.

In the light of these results, both techniques can be used efficiently for the balancing of an assembly line.

The biggest advantage of the simulation method is the capability of trying new scripts on the assembly line. Also it is important to consider the different timing possibilities of each operation. However, the application of different scripts and evaluation of the results for each model is a very time consuming process. A simulation program and programmer are required for application of the simulation method. In the Hoffman method, contrary to the simulation method, a single time is considered for each operation and the assembly line is balanced according to priority. In this method, different scripts cannot be applied, the work distribution less complicated in balanced assembly lines, and it offers great convenience, especially in the designing of assembly lines which produce complicated modelled products.

As a result, in the conditions studied, firms can use both methods according to their targets and model properties of their products.

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