(REFEREED RESEARCH)

A COMPARATIVE STUDY ON DESIGNING OF A CLOTHING ASSEMBLY LINE

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ABSTRACT

Assembly line balancing has taken the attention of researchers. There are many theoretical studies which propose mathematical or heuristic methods and some of these studies compare the performances of different assembly line balancing techniques. However, there are few practical studies which solve real world assembly line problem. Besides it is not often to meet a study that compares the performance of proposed heuristics with real world practical assembly line balancing techniques. In this study, the sewing line of a woman blouse was balanced with two different real world practical assembly line balancing techniques (PT-1 and PT- 2) and Rank Positional Weight heuristic(RPW) with different objectives. Firstly, this study aimed to contribute to decrease the deficiency of practical applications on assembly line balancing in literature. The second purpose was to compare the performances of practical techniques PT-1 and PT- 2 with the performance of RPW heuristic. Apart from that, PT-1/RPW and PT-2/RPW combinations were made and the performances of these newly developed techniques, together with the performances of PT-1, PT-2 and RPW were discussed in order to outline some points that can improve the efficiency of assembly lines as the third objective.

Key Words: Assembly line balancing, Rank positional weight, Clothing industry, Operation management.

ÖZET

Montaj hattı dengeleme araştırmacıların ilgisini çeken bir konudur. Bu konuda matematiksel ve sezgisel yöntemler öneren çalışmalar bulunmaktadır ve bu çalışmaların bazıları farklı montaj hattı dengeleme yöntemlerinin performanslarını birbiri ile karşılaştırmaktadır. Gerçek montaj hattı problemlerini çözen uygulama çalışmalarına az rastlanılmaktadır. Bunun yanında, önerilen sezgisel yöntemlerin performansını pratik hat dengeleme yöntemlerinin performansı ile karşılaştıran çalışmalarla çok sık karşılaşılmamaktadır. Bu çalışmada, bir bayan bluzu iki pratik hat dengeleme yöntemi(PT-1 ve PT-2) ve Göreceli Pozisyon Ağırlıkları (RPW) sezgiseli ile farklı amaçlar hedeflenerek dengelenmiştir. Öncelikle, bu çalışma montaj hattı dengeleme konusunda gerçek problem uygulama örneği eksiğini azaltmaya katkıda bulunmayı amaçlamaktadır. İkinci amaç, uygulanan pratik yöntemlerin performanslarının göreceli poziyon ağırlıkları yönetiminin performansı ile karşılaştırmaktır. Bunun dışında, PT-1/RPW ve PT-2/RPW kombinasyonu geliştirerek, elde edilen bu iki yeni yöntem, PT-1, PT-2 ve RPW yöntemlerinin performanslarını toplu olarak karşılaştırıp montaj hattının performansını arttırmaya yönelik bazı önemli noktalar çıkarmak bu çalışmanın üçüncü amacıdır.

Anahtar Kelimeler: Montaj hattı dengeleme, Göreceli pozisyon ağırlıkları, Konfeksiyon sanayi, Üretim yönetimi.

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1. INTRODUCTION

The increasing trend of product variability and shorter cycle times has been enhancing the importance of production lines. Production lines are composed of a number of workstations and the work pieces (jobs) are consecutively launched down the line and are moved from station to station. At each station, certain operations are repeatedly performed regarding the cycle time. The cycle time is the maximum available time for the production of a job at any workstation and it is the key competitiveness of a firm as it affects both price and schedule (1).

The allocation of jobs to workstations is based on the objective of minimizing the workflow among the workstations, reducing the throughput time as well as the work in progress and thus increasing productivity (2). If the jobs are not allocated in balance, this will cause idle workstations and waste of workforce besides the loss of overall efficiency.

Assembly line balancing aims to determine the allocation of the tasks to an ordered sequence of stations such that each task is assigned to exactly one station, no precedence constraint is violated and some selected performance measures are optimized like minimizing the number of stations. It consists of distributing the total workload for manufacturing any unit of the product to be assembled among the workstations along the line. In other words, assembly line balancing is trying to allocate the works equally to each work station along the line (3).

Assembly line balancing has taken the attention of researchers since its first introduction and many studies have been submitted about this topic since then. There are many theoretical studies which propose mathematical and heuristic methods and the comparisons of their performances in assembly lines literature. However, we see few practical studies which solve real world assembly line problem. Scholl& Becker (4) and Boysen et al. (5) emphasize the fewness of practical assembly line balancing studies and the considerable gap between the academic discussion and practical applications. At the same time, in literature, many types of assembly lines have been examined but there are a few studies about sewing lines in clothing industry despite its labor intense and complex structure (6). In fact, clothing industry has been in a huge competition because of the small lot sizes and short lead times. Therefore the companies should be productive and flexible and meet the demands on time in order to be competitive. Examples of studies that tackled a real world assembly line balancing problem of clothing industry in literature were summarized below.

Eryuruk, Kalaoglu, Baskak (7) compared the performance of two heuristics named rank positional weight and probabilistic line balancing techniques by applying in a clothing company.

Eryuruk, Kalaoglu, Baskak (8) used probabilistic line balancing technique developed by El-Sayed and Boucher to maximize the line efficiency for a constant cycle time.

Yao (9) showed two realistic application of line balancing for apparel industry.

Eryuruk (10) applied two heuristic line balancing techniques known as probabilistic line balancing by El-Sayed and Boucher and largest set rule algorithm by Agrawal to design a multi-model assembly line in apparel industry.

Atan and Foong (1) reduced the cycle time in a garment manufacturing company by using simulation technique.

Unal (6) proposed a new algorithm in order to be used in apparel industry.

Guner, Yucel, and Unal (11) investigated the efficiencies of five different line balancing methods such as longest operation time, ranked positional weight, shortest operation time, most following task, fewest following task. They used parallel stations to see its effect on the efficiency of line.

In examined studies, some heuristics were applied to real world sewing line problems and the performances of these heuristics were compared with each other. We have not met a study that compares the performance of these heuristics with the performance of practical real world line balancing techniques. Rank Positional Weight technique was mostly used in given studies and it was compared with the other heuristics and it was seen that this technique gives considerable results. Therefore, in this work, performance of RPW technique was compared with the performances of two real world practical techniques (PT-1 and PT-2) by using real data of a blouse. Besides Rank Positional Weight technique was combined with these practical methods. One of the aims of this study is to give real world assembly line balancing application from apparel industry as a practical contribution to literature. The other aim is to compare the performances of RPW, PT-1 and PT-2. Finally, two new techniques were developed by combining RPW with PT-1 and PT-2. The applications and balancing results of all techniques were compared to deduce some points that improve the efficiency of assembly lines.

2. ASSEMBLY LINE BALANCING and BASIC CONCEPTS

Manufacturing a product on an assembly line requires partitioning the total amount of work into a set of elementary operations named tasks V = {1,...,n}. Performing a task j takes a task time tj and requires certain equipment of machines and/or skills of workers. Due to technological and organizational conditions precedence constraints between the tasks have to be observed. These elements can be summarized and visualized by a precedence graph. It contains a node for each task, node weights for the task times and arcs for the precedence constraints (4).

Most of the researches on assembly line balancing has been focused on modeling and solving the simple assembly line balancing problems in two types which have a dual relationship. While the first type minimizes the number of workstations for a given fixed cycle time, the second one minimizes cycle time for a given fixed number of workstation (4).

There are three types of assembly line balancing. If only one product is assembled, all work pieces are identical and a single-model line is present. In mixed-model production, set-up times between models could be reduced sufficiently enough to be ignored, so that intermixed model sequences can be assembled on the same line. In multi-model production, the homogeneity of assembled products and their production processes is not sufficient to allow for facultative production sequences. In order to avoid set-up times and/or costs the assembly is organized in batches (5).

Primary terms which are used in assembly lines and their definitions are as follows (9, 12).

Cycle Time(C)

Cycle time is the maximum amount of time allowed at each station. This can be found by dividing required units to production time available per day.

$$Cycle\ time(C) = \frac{Production\ Time\ per\ day}{Unit\ required\ per\ day}$$

$$C = \frac{T(total\ standard\ processing\ time\ of\ a\ piece)}{N(the\ number\ of\ workstations)}$$

Bottleneck

Bottleneck is the delay in transmission that slow down the production rate. This can be overcome by balancing the line.

Bottleneck Cycle Time

Bottleneck cycle time determines the production rate of a production line. The cycle time lasting longest or exceeding average time is called bottleneck cycle time.

Lead Time

It is total production times along the assembly line.

Precedence

It can be represented by nodes or graph. In assembly line the products have to obey this rule. The product can't be moved to the next station if it is not completed at the previous station. The products flow from one station to the other station.

Idle Time

Idle time is the time specified as period when system is not in use but is fully functional at desired parameters.

Smoothness Index(SI)

This is the index to indicate the relative smoothness of a given assembly line balance. When smoothness index is zero it indicates perfect balance.

$$SI = \sqrt{\sum_{i=1}^{k}(STmax - STi)^2}$$

where STmax is maximum station time (in most cases cycle time) and STi is station time of station i.

Line efficiency (E)

It shows the percentage utilization of the line.

$$E = \frac{T(standard\ total\ processing\ time)}{C \times N(the\ n\ umber\ of\ workstations)} \times 100\%$$

The number of workstations (N)

The number of workstations is the required amount of equipment/operator.

$$N = \frac{T(standard\ total\ processing\ time)}{Cycle\ time}$$

3. METHODOLOGY

In this study, a blouse model was examined. The operations and standard times of the operations were defined in a factory prior to the study. In this study, Rank Positional Weight heuristic and two real world line balancing methods (PT-1 and PT-2) were used in order to balance the sewing line of a woman blouse model. The real world practical methods have been being applied by some clothing companies (9, 13). Additionally, two new techniques were obtained by combining RPW with PT-1 and PT-2 separately. Application procedures of the RPW, PT-1, PT-2 and newly developed techniques were given below.

The number of workstation represents the number operators since apparel industry is labor intense and efficiency of workers defines the efficiency of the line. Minimization of workstations for a given cycle time was the goal of this study.

Line efficiency (E), smoothness index (SI) and number of workstations (N) were chosen to be performance measures for comparison of the techniques.

As maximum station times could exceed cycle time in practical methods, which were displayed in this study, bottleneck cycle time was used as cycle time while the line efficiencies were evaluated in these methods.

After assigning the tasks according to the steps of each method, balancing results of the techniques were given in tables 3, 4, 5, 6, 7.

The steps of Rank Positional Weight, the other two practical balancing techniques and combination applications are as following.

Rank positional weight method (RPW)

The assignment is done according the following steps (3).

Step1. Determine the positional weight (PW) for each task. The positional weight value of an operation is obtained by summing the operation time considered with the time of other operations that follows in series (7).

Step 2. Rank the work elements based on the PW. The work element with the highest PW is ranked first.

Step 3. Proceed to assign work elements (tasks) to the workstations, where elements of the highest positional weight and rank are assigned first.

Step 4. If at any workstation additional time remains after assignment of an operation, assign the next succeeding ranked operation to the workstation, as long as the operation does not violate the precedence relationships and the station times do not exceed the cycle time.

Step 5. Repeat steps 3 and 4 until all elements are assigned to the workstations.

Practical technique 1 (PT –1)

In this technique, the required amount of workstation shows the percentage workload of the workstation at the same time. For example, if number of workstation is calculated as 0,45, it means the workload is 45%. While applying this technique the number of workstation can be slightly over 1, in other words maximum station time can be over cycle time if it is needed during assignments. The assignment steps are seen below.

Step 1. The number of workstations should be calculated for each operation.

$$N_i = \frac{ti}{C}$$

where N_i is the required amount of workstations on the i^{th} operation.

Step 2. Assign tasks to workstations considering precedence relations and calculated number of workstations (workload) given in Table 1.

Step 3. If, at any workstation, workload is fewer than 100% after assignment of a task, assign the next succeeding ranked task to the workstation and as long as the task does not violate the precedence relationships and the station workload does not exceed 110% workload.

Step 4. Repeat steps 2 and 3 until there is no unassigned task left.

Practical technique 2 (PT-2)

In this technique, the design of the line is made according to expected line of efficiency. The main principle of this method is that maximum station times of workstations should be between lower and upper limits.

Step1. Calculate cycle time, lower limit and upper limit.

$$Cycle\ time(C) = \frac{Production\ Time\ per\ day}{Unit\ required\ per\ day}$$

$$Upper\ Limit(UL) = \frac{C}{E(Desired\ efficiency)}$$

$$Lower\ Limit(LL) = 2 \times C - UL$$

Step 2. Assign tasks to workstations considering precedence relationships given in Table 1.

Step 3. If, at any workstation, station time is under lower limit after assignment of an operation, assign the next succeeding operation to the workstation, as long as the operation does not violate the precedence relationships and maximum station times do not exceed upper limit.

Step 4. Repeat steps 2 and 3 until all elements are assigned to the workstations.

Combination of PT-1 and RPW

Step1. Determine the positional weight (PW) and needed number of workstations for each task

Step 2. Rank the work elements based on the PW. The work element with the highest PW is ranked first.

Step 3. Proceed to assign work elements (tasks) to the workstations, where elements of the highest positional weight and rank are assigned first.

Step 4. If at any workstation workload is fewer than 100% after assignment of a task, assign the next succeeding ranked task to the workstation, as long as the task does not violate the precedence relationships and the station workload does not exceed 110% workload.

Step 5. Repeat steps 3 and 4 until all elements are assigned to the workstations.

Combination of PT-2 and RPW

Step1. Determine the positional weight (PW) for each task, upper limit and lower limit

Step 2. Rank the work elements based on the PW. The work element with the highest PW is ranked first.

Step 3. Proceed to assign work elements (tasks) to the workstations, where elements of the highest positional weight and rank are assigned first.

Step 4. If at any workstation station time is under lower limit after assignment of a task, assign the next succeeding ranked task to the workstation, as long as the task does not violate the precedence relationships, and maximum station times do not exceed upper limit.

Step 5. Repeat steps 3 and 4 until all elements are assigned to the workstations.

4. PROBLEM DESCRIPTION

In this study, a blouse model was selected to be examined and it includes 26 tasks (operations). The task times are deterministic and they were obtained by using time study works. This study was conducted considering the assembly line as a single model assembly line type.

The production time available per day is 480 minutes and the daily demand is considered to be 500 pieces. Cycle time and the other needed data were calculated according these data. Lead time (total task time) of a unit is 1268.7 sec/piece. It was assumed that the operators were able to do all kinds of jobs and could use all types of machines.

The work flow (Figure 1) and the table (Table 1) which contains operation times, calculated number of workstations and precedence relations of tasks are seen below.

Table 1. Task times, calculated number of workstations and precedence relations of the model

Tasks/ Operation No	Operations/Tasks	Standard time (sec)	Calculated Workstation for 500 pcs/day	Precedence Relations
1	Interlining upper back facing	24.1	0.42	-
2	Ironing upper back facing	21.1	0.37	1
3	Interlining upper front facing	59.2	1.03	-
4	Ironing upper front facing	54.4	0.94	3
5	Interlining lower back facing	24.1	0.42	-
6	Interlining lower front facing	59.2	1.03	-
7	Assembling lower back and front facings	31.3	0.54	5,6
8	Assembling upper back and front facings	31.3	0.54	2,4
9	Overall lower and upper facing	114.5	1.99	8,7
10	Edge stitching of facing	91	1.58	9
11	Stitching label to facing	31.5	0.55	10
12	Ironing of facing	20.5	0.36	11
13	Stitching rubber to sleeves	22.4	0.39	-
14	Stitching the dart of front yoke	30.4	0.53	-
15	Joining the sleeve to yoke	30.4	0.53	13,14
16	Assembling the backs	33.2	0.58	15
17	Assembling the facing	114.3	1.98	12,16
18	Edge stitching of facing	110.3	1.91	17
19	Pick stitching of front yoke from the facing	12	0.21	18
20	Assembling the front	2.5	0.04	19
21	Edge stitching of front	21.8	0.38	20
22	Side seams	39.7	0.69	21
23	Hemming the trimming	39.3	0.68	22
24	Overlock trimming of sleeve hem	35.9	0.62	23
25	Trimming of sleeve hem	60.3	1.05	24
26	Attaching rivet	154	2.67	25

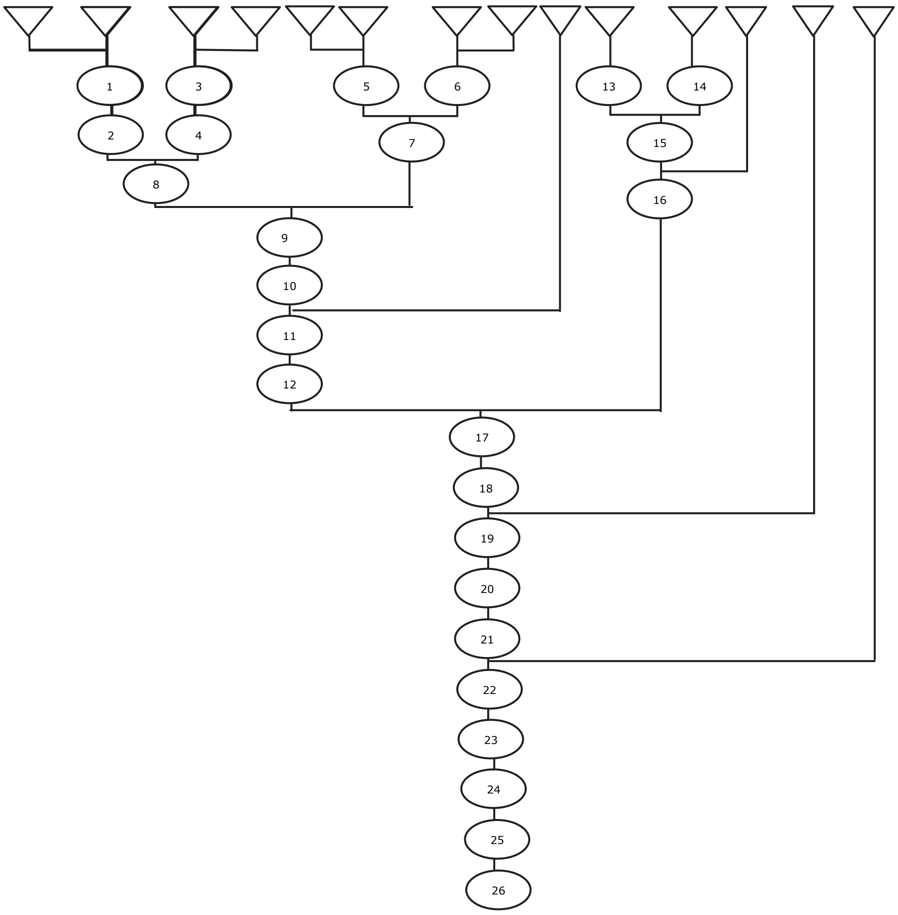

Figure 1. Workflow of the woman blouse model

5. RESULTS

C= (480 minutesX60 sec)/500 pieces= 57.6 sec ≈58 sec

N=1268.7sec/58 sec=22 workstations (theoretical)

Rank positional weight

The positional weights of the tasks were calculated (Table 2) and were ranked in descending order. Then the assignments were done according to this order as mentioned above. The balancing results are given in Table 3.

Table 2. Positional weights of the operations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Positional Weight
1		1						*	*	*	*	*					*	*	*	*	*	*	*	*	*	*	924.1
2								1	*	*	*	*					*	*	*	*	*	*	*	*	*	*	900
3				1				*	*	*	*	*					*	*	*	*	*	*	*	*	*	*	992.5
4								1	*	*	*	*					*	*	*	*	*	*	*	*	*	*	933.3
5							1		*	*	*	*					*	*	*	*	*	*	*	*	*	*	903
6							1		*	*	*	*					*	*	*	*	*	*	*	*	*	*	938.1
7									1	*	*	*					*	*	*	*	*	*	*	*	*	*	878.9
8									1	*	*	*					*	*	*	*	*	*	*	*	*	*	878.9
9										1	*	*					*	*	*	*	*	*	*	*	*	*	847.6
10											1	*					*	*	*	*	*	*	*	*	*	*	733.1
11												1					*	*	*	*	*	*	*	*	*	*	642.1
12																	1	*	*	*	*	*	*	*	*	*	610.6
13															1	*	*	*	*	*	*	*	*	*	*	*	676.1
14															1	*	*	*	*	*	*	*	*	*	*	*	684.1
15																1	*	*	*	*	*	*	*	*	*	*	653.7
16																	1	*	*	*	*	*	*	*	*	*	623.3
17																		1	*	*	*	*	*	*	*	*	590.1
18																			1	*	*	*	*	*	*	*	475.8
19																				1	*	*	*	*	*	*	365.5
20																					1	*	*	*	*	*	353.5
21																						1	*	*	*	*	351
22																							1	*	*	*	329.2
23																								1	*	*	289.5
24																									1	*	250.2
25																										1	214.3
26																											154

Table3. Balancing results of rank positional weight method

Workstation/ Operators	Assigned Operation Numbers	Ranked Positional Weight Value	Standard Times (sec)	Station Time(sec)	Leisure Time (sec)
1, 2	3	992.5	59.2	59.2+54.4=113.6	2.4
	4	933.3	54.4		
3, 4	6	938.1	59.2	59.2+24.1+24.1=107.4	8.6
	1	924.1	24.1		
	5	903	24.1		
5,6	2	900	21.1	21.1+31.3+31.3+30.4=114.1	1.9
	7	878.9	31.3		
	8	878.9	31.3		
	14	684.1	30.4		
7,8	9	847.6	114.5	114.5	1.5
9, 10	10	733.1	91	91+22.4=113.4	2.6
	13	676.1	22.4		
11,12	15	653.7	30.4	30.4+31.5+33.2+20.5=115.6	0.4
	11	642.1	31.5		
	16	623.3	33.2		
	12	610.6	20.5		
13,14	17	590.1	114.3	114.3	1.7
15,16	18	475.8	110.3	110.3	5.7
17,18	19	365.5	12	12+2.5+21.8+39.7+39.3=115.3	0.7
	20	353.5	2.5		
	21	351	21.8		
	22	329.2	39.7		
	23	289.5	39.3		
19, 20	24	250.2	35.9	35.9+60.3=96.2	19.8
	25	214.3	60.3		
21,22,23	26	154	154	154	78

In order to assign the tasks according to the given steps, 23 workstations were used. Cycle time and $STmax$ is 58 sec.

$$E = \frac{T(standard\ total\ processing\ time)}{C\times N(the\ n\ umber\ of\ workstations)} \times 100\% =$$

1268.7 sec / (58X23)= 95.1%

$$SI = \sqrt{\sum_{i=1}^{k}(STmax - STi)^2} = 19.84$$

Output= Daily Demand X E= 500X95.1%= 475 pieces

Practical technique 1 (PT –1)

Assignments were made by following the steps mentioned before and the results are in Table4.

22 workstations were used to balance the line with this technique and the bottleneck stations are 19, 20, 21, 22 with 108.5% workload. $STmax$ is 62.55 seconds.

35.9+60.3+154=250.2 sec(total operation time of 24^{th}, 25^{th}, 26^{th} tasks.)

250.2/4=62.55 sec (actual operation times of bottleneck stations 19, 20, 21, 22)

$$E = \frac{T(standard\ total\ processing\ time)}{C\times N(the\ n\ umber\ of\ workstations)} \times 100\% =$$

1268.7/ (22X62.55sec) X100%= 92.19%

$$SI = \sqrt{\sum_{i=1}^{k}(STmax - STi)^2} = 30.8$$

Output= Daily Demand X E= 500X92.19%= 460 pieces

Practical technique 2 (PT –2)

C=58 sec

Desired Efficiency (E)= 90%

UL=C/E=58/0.90=64.4 sec

LL=2XC-UL=2X58-64.4= 51.6 sec

The tasks were assigned to the workstation considering the calculated UL and LL and balancing results are seen in Table 5.

Table 4. Balancing results of practical technique 1 (PT –1)

Workstation/ Operators	Assigned Tasks	Calculated Number of Workstation	Needed Number of Workstation/Operators	Workload of each station
1	1	0.42	(0.42+0.37)=0.79	79%
	2	0.37		
2	3	1.03	1.03≈1	103%
3	4	0.94	0.94≈1	94%
4	6	1.03	1.03≈1	103%
5,6	5	0.42	(0.42+0.54+0.54+0.53=2.03≈2	101.50%
	7	0.54		
	8	0.54		
	14	0.53		
7,8	9	1.99	1.99≈2	99.50%
9, 10	10	1.58	(1.58+0.55)=2.13≈2	106.50%
	11	0.55		
11,12	12	0.36	(0.36+0.39+0.53+0.58=1.86≈2	93%
	13	0.39		
	15	0.53		
	16	0.58		
13,14	17	1.98	1.98≈2	99%
15,16	18	1.91	(1.91+0.21)=2.12≈2	106%
	19	0.21		
17,18	20	0.04	(0.04+0.38+0.69+0.68)=1.79≈2	89.50%
	21	0.38		
	22	0.69		
	23	0.68		
19,20,21,22	24	0.62	(0.62+1.05+2.67=4.34≈4	**108.50%**
	25	1.05		
	26	2.67		

Table 5. Balancing results of practical technique 2(PT –2)

Workstation/ Operators	Assigned Tasks	Operation Times(sec)	Actual Cycle Time (sec) per workstation
1	3	59.2	59.2
2, 3	1	24.1	(54.4+24.1+21.1+24.1)/2=123.7/2=61.85
	2	21.1	
	4	54.4	
	5	24.1	
4	6	59.2	59.2
5	7	31.3	**(31.3+31.3)=62.6**
	8	31.3	
6, 7	9	114.5	114.5/2=57.25
8, 9	10	91	(91+31.5)/2=61.25
	11	31.5	
10, 11	13	22.4	(22.4+30.4+30.4+33.2)/2=58.2
	14	30.4	
	15	30.4	
	16	33.2	
12,13,14,15	12	20.5	(20.5+114.3+110.3)/4=61.275
	17	114.3	
	18	110.3	
16,17	19	12	(12+2.5+21.8+39.7+39.3)/2=57.65
	20	2.5	
	21	21.8	
	22	39.7	
	23	39.3	
18,19,20,21	24	35.9	(35.9+60.3+154)/4=62.55
	25	60.3	
	26	154	

In this technique, 21 workstations were enough to balance the line. The bottleneck cycle time and $STmax$ is 62.6 sec.

$$E = \frac{T(standard\ total\ processing\ time)}{C \times N(the\ number\ of\ workstations)} \times 100\% =$$

1268.7/(21X 62.6 sec)X100%= 96.5%

$$SI = \sqrt{\sum_{i=1}^{k}(STmax - STi)^2} = 14.21$$

Output= Daily Demand X E= 500X96.5%= 482 pieces

Combination of PT-1 and RPW

After finishing the assignments regarding the application steps we obtained Table 6.

In this technique, 22 workstations were enough to balance the line. The bottleneck stations are 1st and 2nd stations with 103% workload. $STmax$ is 59.2 seconds.(operation times of 3rd and 6th tasks assigned to these stations)

$$E = \frac{T(standard\ total\ processing\ time)}{C \times N(the\ number\ of\ workstations)} \times 100\% =$$

1268.7/ (22X 59.2sec) X100%= 97.4%

$$SI = \sqrt{\sum_{i=1}^{k}(STmax - STi)^2} = 11.84$$

Output= Daily Demand X E= 500X97.4%= 487 pieces

Combination of PT-2 and RPW

Results of this application are given in Table 7.

Table 6. Balancing results of combination of PT-1 and RPW

Workstation/ Operators	Assigned Tasks	Ranked Positional Weight Value	Calculated Number of Workstation	Needed Number of Workstation/ Operators	Workload of each station
1	3	992.5	**1.03**	**1.03≈1**	**103%**
2	6	938.1	**1.03**	**1.03≈1**	**103%**
3,4,5	4	933.3	0.42	(0.94+0.42+0.42+0.37+0.54+0.39)=3.08≈3	102.60%
	1	924.1	0.37		
	5	903	0.94		
	2	900	0.42		
	7	878.9	0.54		
	13	676.1	0.39		
6,7,8	8	878.9	0.54	(0.54+0.53+1.99)=3.06≈3	102%
	14	684.1	1.99		
	9	847.6	0.53		
9, 10,11	10	733.1	1.58	(1.58+0.53+0.55+0.36=3.012≈3	100.40%
	15	653.7	0.55		
	11	642.1	0.36		
	12	610.6	0.53		
12, 13, 14,15,16	16	623.3	0.58	(0.58+1.98+1.91+0.21+0.04+0.38)=5.10≈5	102%
	17	590.1	1.98		
	18	475.8	1.91		
	19	365.5	0.21		
	20	353.5	0.04		
	21	351	0.38		
17,18	22	329.2	0.69	(0.69+0.68+0.62)=1.99≈2	100%
	23	289.5	0.68		
	24	250.2	0.62		
19,20,21,22	25	214.3	1.05	(1.05+2.67)=3.72≈4	93%
	26	154	2.67		

Table 7. Balancing results of combination of PT-2 and RPW

Workstation/ Operators	Assigned Operation Numbers	Ranked Positional Weight Value	Operation Times(sec)	Actual Cycle Time (sec) per workstation
1	3	992.5	59.2	**59.2**
2	6	938.1	59.2	**59.2**
3,4,5	4	933.3	54.4	(54.4+24.4+24.1+21.1+31.3+22.4)/3=59.13
	1	924.1	24.1	
	5	903	24.1	
	2	900	21.1	
	7	878.9	31.3	
	13	676.1	22.4	
6,7,8	8	878.9	31.3	(31.3+114.5+30.4)/3=58.73
	9	847.6	114.5	
	14	684.1	30.4	
9, 10,11	10	733.1	91	(91+30.4+31.5+20.5)/3=57.8
	15	653.7	30.4	
	11	642.1	31.5	
	12	610.6	20.5	
12, 13, 14,15,16	16	623.3	33.2	(33.2+114.3+110.3+12+2.5+21.8)/5=58.82
	17	590.1	114.3	
	18	475.8	110.3	
	19	365.5	12	
	20	353.5	2.5	
	21	351	21.8	
17,18	22	329.2	39.7	(39.7+39.3+35.9)/2=57.45
	23	289.5	39.3	
	24	250.2	35.9	
19,20,21,22	25	214.3	60.3	(60.3+154)/4=53.575
	26	154	154	

In this technique, 22 workstations were enough to balance the line. The bottleneck cycle time and $STmax$ is 59.2 sec.

$$E = \frac{T(standard\ total\ processing\ time)}{C \times N(the\ n\ umber\ of\ workstations)} \times 100\% =$$

1268.7/ (22X 59.2 sec) X100%= 97.4%

$$SI = \sqrt{\sum_{i=1}^{k}(STmax - STi)^2} = 11.84$$

Output= Daily Demand X E= 500X97.4%= 487 pieces

6. DISCUSSION

The sewing line of woman blouse was balanced with RPW, PT-1, PT-2 and the developed techniques and the balancing results are given in Table 8.

Table 8. Comparison of the performance indicators

	Workstation/Operators	Efficiency	Output	Smoothness Index
Rank Positional Weight(RPW)	23	95.1	475	19.84
Practical Technique I (PT-1)	22	92.2	461	30.89
Practical Technique II(PT-2)	21	96.5	482	14.21
Combination of PT-1 and RPW	22	97.4	487	11.84
Combination of PT-2 and RPW	22	97.4	487	11.84

PT-2 method's efficiency value is better than RPW and PT-1 and 21 workstations were used to balance the assembly line with PT-2. RPW's efficiency value is better than PT-1 but 23 workstations were used in RPW while 22 workstations were used in PT-1. Besides, the smoothness index of PT-2 is the best among the three methods. The main feature of PT-1 and PT-2 is their allowance to maximum station time to exceed the cycle time unlike RPW. In fact, maximum station time cannot exceed the cycle time and the number of workstations used for balancing the line cannot be under the theoretical number of workstations according to literature. Although the theoretical number of workstation was calculated as 22 workstations, 21 workstations were enough to balance the line since most of maximum station times were over cycle time (58 sec) in PT-2. Maximum station time can fluctuate between lower and upper limits in PT-2 so the assignments were more balanced as seen from the smoothness indexes given in Table 8. There was not a lower limit in PT-1 method and 1st workstation was loaded with 79% workload and the maximum workload was 108.5% in workstations 19, 20, 21, 22 (Table 4). As the range of 79%-108.5% workload was so wide, the values of efficiency and smoothness index of PT-1 method were not good compared to the values in PT-2. When the newly developed methods of combination were examined, it is seen that both efficiency values and smoothness indexes have good performances compared to PT-1, PT-2 and RPW. In these two combination methods, assignments were made according the positional weights and precedence relationships but the station times could pass the cycle time. As the station time can exceed the cycle time in an allowed limit, more parallel workstations were able to be used in combination practical applications and this lessened the number of workstations compared to RPW and increased the efficiency of the line. Assigning according to the positional weights improved the performance of practical methods. As we consider that line balancing applications are made manually in clothing industry in real world, it can be said that RPW is also easy to apply on line balancing problems in the industry.

As a result, it can be deduced that tolerating maximum station time to exceed cycle time in some limits instead of not to pass a rigid cycle time, provides flexibility during balancing. This offers reducing the idle times and number of workstation. Especially, when the wide range of task times of a garment is considered, flexibility is important to prevent the idle times of operators during assignment. However, it should not be forgotten that to define wide ranges for the fluctuations of the maximum station time can cause the decrease of efficiency at the same time. There should be a good balance between maximum station time, bottleneck cycle time and the number of workstations. Additionally, using positional weight as precedence relationship improved the performance of practical methods.

7. CONCLUSION

Assembly line balancing is trying to allocate the works equally to each work station along the line and it has taken the attention of researchers since its first introduction. The increasing competition, rapidly changing customer demands and reduction in lead time forces the companies to be flexible and productive and assembly line balancing affects the efficiency of the assembly line directly.

In this study, a woman blouse sewing line was balanced with two different real world practical assembly line balancing techniques (PT-1 and PT- 2) and Rank Positional Weight heuristic (RPW) with the aim of comparing the performances of these three techniques. Besides, two new techniques were developed by combining PT-1 and PT-2 with RPW separately and the performances of these newly developed techniques were also compared with the performances of PT-1, PT-2 and RPW. Some points were driven from the results and were discussed in results and discussion section. We hope these points will help both the assembly line balancing practitioners and the researchers who are studying on developing new heuristics.

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