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Assembly Line Balancing in a Clothing Company

Abstract
In this study, two heuristic assembly line balancing techniques known as the "Ranked Positional Weight Technique", developed by Helgeson and Birnie, and the "Probabilistic Line Balancing Technique", developed by El-Sayed and Boucher, were applied to solve the problem of multi-model assembly line balancing in a clothing company for two models. Information about definitions and solution methods related to assembly line balancing problems is given. The aim of this article is the comparison of the efficiencies of two different procedures applied for the first time to solve line balancing in a clothing company. By using both methods, different restrictions are taken into consideration and two different line balancing results are reached. The balancing results are compared with each other.

Key words: *assembly line, balancing techniques, multi-model assembly line, clothing company, balancing procedure efficiency.*

Introduction

Assembly lines are production systems developed to meet the requirements of mankind, which continue to grow day by day. The demand for greater product variability and shorter life cycles has caused traditional production methods to be replaced with assembly lines. The aims of these systems are to manufacture products at production rates in the shortest time, in the most productive way, cheaply and with the quality required. Since assembly line balancing is an NP-hard problem, some heuristic methods are still needed to solve large scale assembly line balancing problems.

An assembly line consists of a number of workstations which are arranged along a conveyor belt, or similar material transportation equipment, in order to obtain a sequence of finished product types. The work pieces are moved from station to station and at each one certain operations are performed in view of some constraints. The first primary constraint is the cycle time. The cycle time is the time interval between finishing two units or the maximum available time for the production of any work piece at any workstation. When assigning work tasks to the stations, care must be taken that the total station time, which equals the sum of the processing times of each task performed at the station, should not exceed the cycle time [1]. Besides cycle time, precedence relations are the other primary constraints. Some tasks can only be started after other tasks have been finished [2].

An assembly line can be defined as a system which is formed by arranging workstations along a line. At these workstations, work pieces can be transferred by using labour force as well as equipment, and tasks are assembled taking into consideration precedence constraints and cycle time. The decision problem of optimally balancing the assembly work among the workstations is known as the assembly line balancing problem.

Assembly lines can organise production in three different ways: single model, multi-model and mixed-model assembly lines [1, 3]. The design of a single model assembly line is very simple because this type of line is constructed for only one type of product. Different products or different models of the same type of product are assembled on multi-model assembly lines. In this situation, the assembly line balancing problem is solved independently in order to manufacture every lot of the product. In mixed-model assembly lines, different models of a product are produced at the same time. Mixed-model lines, unlike the single model assembly environment, are designed to assemble more than one model concurrently. Studies of mixed model sequencing have tried to resolve the problem by suggesting sequencing procedures that optimise various system measures, such as throughput, cycle time, number of stations, idle time, flow time, line length, work-in-process and raw material demand deviation developed heuristics for the balancing–sequencing problem [4].

Assembly line balancing problems can be classified into two groups: stochastic and deterministic assembly lines. When an assembly line is fully automated, all the tasks will have a fixed operation time. Variability (or stochasticity) comes into the picture when tasks are performed manually at the workstations [5].

There can be two main goals while balancing an assembly line [6, 7]:
1. Minimisation of the number of workstations for a given cycle time.
2. Minimisation of the cycle time for a given number of workstations.

In this study, two heuristic assembly line balancing techniques known as the "Ranked Positional Weight Technique", developed by Helgeson and Birnie, and the "Probabilistic Line Balancing Technique", developed by El-Sayed and Boucher, were applied to solve the problem of multi-model assembly line balancing in a clothing company for two different models. The aim of this article is the comparison of the efficiencies of two different procedures applied for the first time to solve assembly line balancing in a clothing company.

Literature review

The assembly line balancing problem has received considerable attention in the literature, and many studies have been made on this subject since 1954.

The assembly line balancing problem was first introduced by Bryton in his graduate thesis. In his study, he accepted the amount of workstations as constant, the workstation times as equal for all stations and work tasks as moving among the workstations [8]. The first article was published in 1955 by Salveson [9]. He developed a 0-1 integer programming model to solve the problem.

COMSOAL (Computer Method of Sequencing Operations for Assembly Lines) was first used by Arcus [10] in 1966 as a solution approach to the assembly line balancing problem.

Helgeson ve Birnie [11] developed the "Ranked Positional Weight Technique". In this method, the "Ranked Positional Weight Value" is determined. It is the sum of a specified operation time and the working times of the other operations that can not be assembled without considering the operation finished. While taking into consideration the cycle time and technological precedence matrix, the operation having the largest ranged weight is assigned to the first workstation, and other operations are assigned to workstations in accordance with their ranked positional weight value.

For the multi-model assembly line, Kilbridge and Wester [12] developed a simple method to solve line balancing. In the first stage they formed an appointment table, and then they made necessary workload balance among workstations, taking into consideration precedence relationships and cycle time.

Nicosio et. al. [13] studied the problem of assigning operations to an ordered sequence of non-identical workstations, which also took precedence relationships and cycle time restrictions into consideration. The aim of the study was to minimise the cost of workstations. They used a dynamic programming algorithm, and introduced several fathoming rules to reduce the number of states in the dynamic program.

Kim et. al. [14] used a genetic algorithm to solve the assembly line balancing problem of how to minimise the number of workstations and cycle time, and how to maximise workload smoothness and work relatedness. A performance comparision was made between the Gas proposed and the heuristic algorithms known.

Experimental procedures

Test materials

In this study, the production of two models: command pocket and welt pocket pants (Figure 1) were investigated to solve the problem of assembly line balancing in a clothing company.

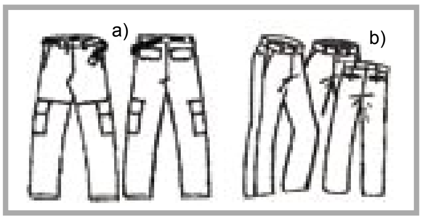

Figure I. *Pant model; a) command pocket, b) welt pocket.*

Medhods used

By using the "Ranked Positional Weight Technique" and the "Probabilistic Line Balancing Technique", the assembly line balancing problem was solved. The solution steps of these methods are explained as follows.

Ranked positional weight technique

This heuristic method was developed by Helgeson and Birnie of the General Electric Company in 1961 [11]. In this method, the ranked positional weight value of each operation is determined. The procedures below are applied in order to assign operations to workstations.

The ranked weight value of an operation is obtained by summing the operation time considered with the time of other operations that come after that in series. After all of the ranked positional weights of the operations are determined, they are arranged in decreasing order. Then tasks are assigned to each workstation starting from the task with the highest ranked positional weight. Before this the operation having the second highest ranked value should be selected from the remaining working operations in order to assign to the workstation; the precedence constraints, the operation time, the unused workstation time should be controlled. The assignment procedure is continued until one of conditions below is obtained;

1. If all the operations are assigned to the stations,
2. If there are no operations having either precedence or unassigned time constraints.

Probabilistic line balancing technique

In this method, a P (predecessor elements) and F (follower elements) matrix are formed and the steps below are followed [15]:

1. The line of the P matrix having zero values is selected. If there is more than one line having zero values, the operation with the highest operation time is selected (Every line corresponds to one work task). If the time of this work task is suitable, it is assigned to the workstation.
2. If the chosen work task is assigned, we go to the F matrix having the same line number and the numbers in this line are taken. Then we turn back to the P matrix and between the subsequent elements of the P matrix in the numbers taken, we write 0 value to the last work task assigned, and step 1 is repeated for the new situation. If the work task is not assigned, we turn back to step 1 in order to open a new station or select a new work task.
3. Step 1 and step 2 are repeated until all the lines in the P matrix are used, taking into consideration the constraint (Enb $t_i \leq T \leq C$).

Results

Model 1: Command pocket pant line balancing results

Model 1: Command pant model ranked positional weight balancing results

This model has fifty-two work operations and an operation list. Its standard times, precedence relations and machine types used are listed in Table 1. After the determination of the precedence relationships between operations, a technological precedence diagram is drawn like Figure 3. Then the cycle time is calculated as shown below:

$$C = T / PA \qquad (1)$$

T = Total working time in a day
PA = Total production amount in a day
C = T / PA = (540 minutes × 60 seconds) / 450 piece = 72 seconds/piece

Cycle time = 75 seconds (This value is assumed instead of 72 seconds/piece)

The next step is the calculation of the minimum theoretical number of workstations .

$$n_{min} = \text{Max}\ (n_{min};\ n_{probable}) \qquad (2)$$

$$n_{min} = [\Sigma\ t_i / C\ ]^{+} = [2744.6 /75]^{+} = 37 \qquad (3)$$

Table 1. Data of command pant model

NO	OPERATIONS	MACHINE TYPE	PRECEDENCY RELATIONS	STANDARD TIME
	PREPARATIONAL OPERATIONS			
1	Darts stitching and topstitching	Lock-stitch sewing machine	-	55,3
2	Front part stitching	3 thread overlock	-	30,5
3	Front part twin needle seam	Double needle sewing machine	2	24,3
4	Right fly piping	Lock-stitch sewing machine	-	7,7
5	Left fly piping	Lock-stitch sewing machine	-	12,0
6	Facing sewing to the front pocket	Lock-stitch sewing machine	-	31,8
7	Contrary fabric sewing to the front pocket	Lock-stitch sewing machine	6	40,1
8	Pocket covering	Lock-stitch sewing machine	-	33,4
9	Flap pocket covering	Hand made	8	53,8
10	Pocket flap twin needle seam	Double needle sewing machine	9	53,2
11	Remove shade marker	Lock-stitch sewing machine with knife	10	59,3
12	Knee pocket preparing and pocket edge stitch	Lock-stitch sewing machine	-	44,0
	BACK PREPARATION			
13	Welt overlock	3 thread overlock	-	6,6
14	Welting	Welting machine	13	48,3
15	Welt opening	Hand made	14	44,3
16	Welt top topstitching	Lock-stitch sewing machine	15	73,4
17	Welt bottom topstitching	Lock-stitch sewing machine	16	70,9
18	Back pocket bagging and fancy seam	Lock-stitch sewing machine	17	111,7
19	Back pocket bartacking	Bartack Machine	18	24,3
20	Assembling piece above back pocket	Lock-stitch sewing machine	19	90,1
	FRONT PREPARATION			
21	Assembling and topstitching of front pocket facing	Lock-stitch sewing machine	3_7	50,7
22	Drawing seam line to the front pocket	Hand made	21	19,8
23	Front pocket edge double stitch	Twin needle stitch sewing machine	22	27,4
24	Front pocket top stitch	Double needle sewing machine	23	23,0
25	Front pocket bagging	Lock-stitch sewing machine	24	35,6
26	Front pocket bag top stitch	Lock-stitch sewing machine	25	11,6
27	Front pocket assembling	Lock-stitch sewing machine	26	34,6
28	Front crotch overlock and front pocket lining correction	3 thread overlock	27	29,0
29	Left fly assembly and topstitching	Lock-stitch sewing machine	5_28	53,9
	ASSEMBLING			
30	Side stitching	3 thread overlock	20_29	43,7
31	Side chain stitching	Chain stitch sewing machine	30	46,3
32	Piece assembling above knee pocket	Lock-stitch sewing machine	31	95,8
33	Knee pocket assembling	Double needle sewing machine	12_32	73,5
34	Flap assembling and zipping	Lock-stitch sewing machine	11_33	124,0
35	Flap double stitch	Double needle sewing machine	34	97,6
36	Zipper assembling	Lock-stitch sewing machine	35	68,8
37	Fly top stitch	Double needle sewing machine	36	50,4
38	Close fly assembling	Lock-stitch sewing machine	4_37	29,1
39	Inside leg and back center stitch	3 thread overlock	38	64,2
40	Back center double stitch	Double needle sewing machine	39	26,9
41	Belt loop assembling	Lock-stitch sewing machine	40	39,7
42	Washing instruction assembling	Lock-stitch sewing machine	41	25,9
43	Attaching waistband	Lock-stitch sewing machine	42	59,8
44	Waistband end making	Lock-stitch sewing machine	43	31,4
45	Waistband back center label assembling	Lock-stitch sewing machine	44	48,3
46	Cutting and reversing waistband end	Hand made	45	34,6
47	Closing waistband	Lock-stitch sewing machine	46	112,2
48	Label assembling above the belt loop and back pocket	Lock-stitch sewing machine	47	81,6
49	Belt loop assembling	Lock-stitch sewing machine	48	115,4
50	Leg hemstitch	Double needle sewing machine	49	73,2
51	Bartacking	Bartack Machine	50	80,3
52	Bartacking	Bartack Machine	51	41,0

Table 2. Balancing Results of Ranked Positional Weight Technique for Model 1.

WORKSTATION NUMBER	WORK TASK NUMBER	RANKED POSITIONAL WEIGHT VALUE	PRECEDENCE RELATIONS	OPERATION TIME	CUMULATIVE WORK TIME (X)	REMAINING TIME (C-X)
PREPARATION BACK OPERATIONS						
1	1	1968,9	-	55,3	55,3	19,7
	13	1931,6	-	6,6	61,9	13,1
2	14	1927,0	1_13	48,3	48,3	26,7
	5	1529,9	-	12,0	60,3	14,7
	4	871,4	-	5,5	68,0	7,6
3_4	15	1878,7	14	44,3	44,3	105,7
	16	1834,4	15	73,4	117,7	32,3
5	6	1841,3	-	31,8	31,8	43,2
	7	1809,5	6	40,1	71,9	3,1
6	2	1834,3	-	30,5	30,5	44,5
	3	1790,7	2	24,3	54,8	20,2
7	17	1761,0	16	70,9	70,9	4,1
8_9	18	1690,0	17	111,7	111,7	38,3
	19	1578,4	18	24,3	136,1	13,9
10_11	20	1554,1	19	90,1	90,1	59,9
	8	1424,4	-	35,4	145,5	4,5
12	9	1388,9	8	53,8	53,8	21,2
13	10	1317,3	9	53,2	53,2	20,8
14_15	11	1263,9	10	59,3	59,3	90,7
	12	1392,1	-	44,0	143,3	6,7
FRONT PREPARATION						
16	21	1769,4	3_6_7	50,7	50,7	24,3
	22	1718,8	21	19,8	70,5	4,5
17	23	1699,0	22	27,4	27,4	47,6
	24	1671,6	23	23,0	50,4	24,6
18	25	1648,7	24	35,6	35,6	39,4
	26	1613,1	25	11,6	47,2	7,8
19	27	1581,5	26	34,6	34,6	40,4
	28	1546,9	27	29,0	63,6	11,4
20	29	1517,9	5_28	53,9	53,9	21,1
ASSEMBLING						
21	30	1464,0	20_29	43,7	43,7	31,3
22_23	31	1420,0	30	46,3	46,3	103,7
	32	1373,9	31	95,8	142,1	7,9
24	33	1278,1	32_12	73,5	73,5	1,5
25_26_27	34	1204,6	33_11	124,0	124,0	101,0
	35	1080,6	34	97,6	221,6	3,4
28_29	36	983,0	35	68,8	68,8	81,2
	37	914,1	36	50,4	119,2	30,8
	38	863,7	4_37	29,1	148,4	1,6
30	39	834,6	38	64,2	64,2	10,8
31	40	770,4	39	26,9	26,9	48,1
	41	743,5	40	39,7	66,6	8,4
32_33	42	703,8	41	25,9	25,9	124,1
	43	677,9	42	59,8	85,7	64,3
	44	618,1	43	31,4	117,1	32,9
34	45	586,7	44	48,3	48,3	26,7
35_36	46	538,4	45	34,6	34,6	115,4
	47	503,7	46	112,2	146,8	3,2
37_38_39	48	391,5	47	81,6	81,6	143,4
	49	309,9	48	115,4	197,0	28,0
40	50	194,4	49	73,2	73,9	1,1
41_42	51	121,2	50	80,3	80,3	69,7
	52	41,0	51	41,0	121,3	28,7

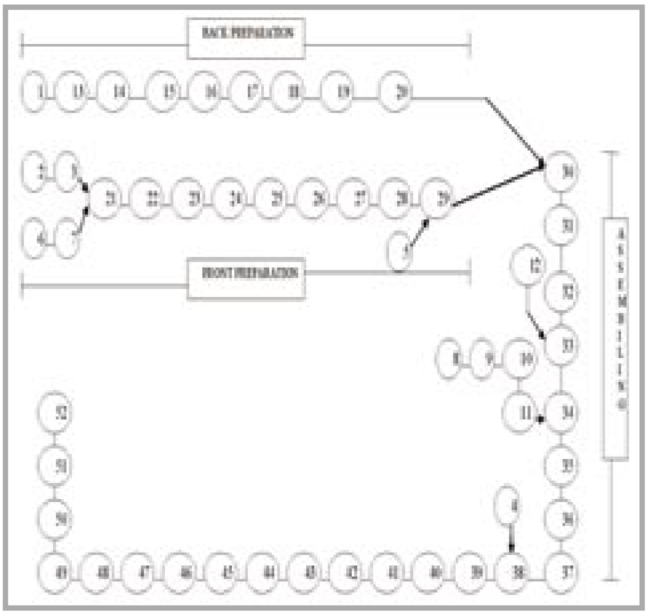

Figure 2. Technological precedence diagram of the command pocket model.

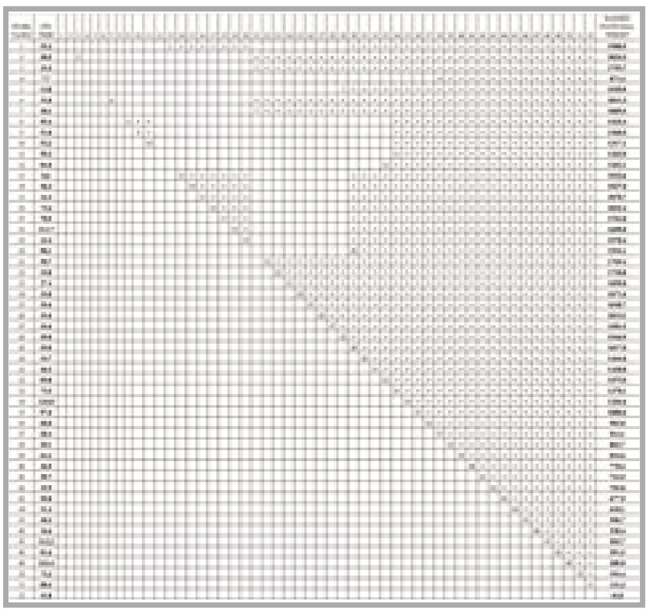

Figure 3. Ranked positional weight table for the command pocket pant model

Table 3. *Standard time, standart deviation and matrix values concerning command pant model.*

No	OPERATIONS	MACHINE TYPE	STD. TIME	STANDARD VARIATION	P(MATRIX1)	P(MATRIX2)
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
33	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
34	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
38	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
41	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
47	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
49	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
52	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 4. *Probabilistic line balancing results of the command pocket pant model.*

Station number (k)	Work task (i) Number	t_i	T_k	Unused Time
1	1	55,3		
	13	6,6	61,9	13,1
2	14	48,3		
	4	7,7		
	5	12,0	68	7
3	15	44,3	44,3	30,7
4	16	73,4	73,4	1,6
5	17	70,9	70,9	4,1
6_7	18	111,7		
	19	24,3	136,1	13,9
8_9	20	90,1		
	8	55,4	145,5	4,5
10	9	51,8	51,8	23,2
11	10	53,2	53,2	21,8
12	11	59,3	59,3	15,7
13	2	30,5		
	3	24,3	54,8	20,2
14	6	31,8	31,8	43,2
15_16	7	40,1		
	12	84,0	124,1	25,9
17	21	50,7		
	22	19,8	70,5	4,5
18	23	27,4		
	24	23,0	50,4	24,6
19	25	35,6		
	26	31,6	67,2	7,8
20	27	34,6		
	28	29,0	63,6	11,4
21	29	53,9	53,9	21,1
22	30	43,7	43,7	31,3
23_24	31	46,3		
	32	95,8	142,1	7,9
25	33	73,5	73,5	1,5
26_27	34	124,0	124	26
28_29	35	97,6	97,6	52,4
30	36	68,8	68,8	6,2
31_32	37	50,4		
	38	29,1		
	39	64,2	143,7	6,3
33_34	40	26,9		
	41	39,7		
	42	25,9	92,5	57,5
35_36	43	59,8		
	44	31,4		
	45	48,3	139,5	10,5
37_38	46	34,6		
	47	112,2	146,8	3,2
39_40_41	48	81,6		
	49	115,4	197,0	28,0
42	50	73,2	73,2	1,8
43_44	51	80,3		
	52	41,0	121,3	28,7

Table 5. *Operations, ranked positional weights and machine type used for the welt pocket pant model.*

WORK TASK NUMBER	STD. TIME	RANKED POSITIONAL WEIGHT	OPERATIONS	MACHINE TYPE
			PREPARATIONAL OPERATIONS	
3	23,6	1482,2	Front pocket facing seam	Lock-stitch sewing machine
1	41,7	1468,1	Front piece seam	Lock-stitch sewing machine
6	22,7	1458,6	Mini-zip pocket sewing	Lock-stitch sewing machine
2	40,4	1426,4	Front pocket label assembling	Lock-stitch sewing machine
4	30,7	1385,9	Welt overlock	3 thread overlock
5	3,8	1228,5	Front switch overlock	3 thread overlock
9	2,9	1098,8	Right fly sewing	3 thread overlock
7	9,6	957,8	Right fly piping	Lock-stitch sewing machine
8	3,6	947,4	Left fly piping	Lock-stitch sewing machine
			FRONT PREPARATION	
14	42,9	1435,9	Front mini-pocket assembling and top stitching	Lock-stitch sewing machine
15	37,8	1390,8	Mini-zip pocket bagging	Lock-stitch sewing machine
16	51,8	1355,2	Assemble of front pocket facing	Lock-stitch sewing machine
17	42,0	1303,9	Front pocket facing topstitching	Lock-stitch sewing machine
18	52,0	1261,9	Pocket bagging	Lock-stitch sewing machine with knife
19	40,3	1209,5	Top stitching of front pocket bag	Lock-stitch sewing machine
20	73,7	1169,6	Front pocket assembling	Lock-stitch sewing machine
21	38,1	1095,9	Left fly assembling	Lock-stitch sewing machine
			BACK PREPARATION	
10	55,4	1224,8	Back pocket welting	Welting machine
11	30,3	1169,3	Bottom topstitching of welt	Lock-stitch sewing machine
12	18,0	1119,8	Top stitching of welt	Lock-stitch sewing machine
13	63,2	1021,8	Back pocket bagging and topstitching	Lock-stitch sewing machine
			ASSEMBLING	
22	60,0	1057,8	Zipper assembling	Lock-stitch sewing machine
23	54,0	997,9	Top stitching on fly	Lock-stitch sewing machine
24	10,9	943,6	Right fly assembling	Lock-stitch sewing machine
25	74,5	912,9	Side seam	3 thread overlock
26	54,3	858,4	Side chain stitching	Chain stitch sewing machine
27	54,9	804,2	Belt loop assembling	Lock-stitch sewing machine
28	100,1	749,3	Waistband assembling	Lock-stitch sewing machine
29	44,6	649,2	Waistband lining attachment	Lock-stitch sewing machine
30	79,0	604,6	Waistband end assembling	Lock-stitch sewing machine
31	64,1	525,6	Waistband lining binding	Lock-stitch sewing machine
32	29,8	461,5	Front opening and washing instruction fitting	Lock-stitch sewing machine
33	42,2	431,8	Back centre binding seam (seat seam)	Chain stitch sewing machine
34	46,7	389,6	Inside leg binding seam	3 thread overlock
35	17,9	342,9	Back centre assembly seam	Lock-stitch sewing machine
36	61,7	325,0	Waistband end making and closure	Lock-stitch sewing machine
37	87,1	263,4	Waistband secure closure (fastening)	Lock-stitch sewing machine
38	49,3	176,3	Trouser hemstitch	Lock-stitch sewing machine
39	61,2	126,9	Pocket bartacking	Bartack Machine
40	65,7	65,7	Belt loop bartacking	Bartack Machine

Table 6. *Model 2: Ranked positional weight balancing results of the welt pocket pant model.*

WORKSTATION NUMBER	WORK TASK NUMBER	RANKED POSITIONAL WEIGHT VALUE	PRECEDENCE RELATIONS	OPERATION TIME	CUMULATIVE WORK TIME (X)	REMAINING TIME (C-X)
			PREPARATIONAL OPERATIONS			
1	3	1482,2	-	23,6	23,6	41,4
	9	1098,8	-	2,9	26,5	38,5
2	1	1468,1	-	41,7	41,7	23,3
3	6	1458,6	3	22,7	22,7	42,3
	5	1228,5	-	3,8	26,5	38,5
	7	957,8	-	9,6	36,1	28,9
4	2	1426,4	1	40,4	40,4	24,6
5	4	1385,9	2	30,7	30,7	34,3
	8	947,4	7	3,6	34,3	30,7
			FRONT PREPARATION			
6	14	1435,9	1_6	42,9	42,9	22,1
7	15	1390,8	14	37,8	37,8	27,2
8	16	1355,2	1_2_4_15	51,3	51,3	13,7
9	17	1303,9	16	42,0	42,0	23,0
10	18	1261,9	17	52,0	52,0	13,0
11	19	1209,5	18	40,3	40,3	24,7
12_13	20	1169,6	19	73,7	73,7	56,3
	21	1095,9	9_20	38,1	111,8	18,2
			BACK PREPARATION			
14	10	1224,8	5	55,4	55,4	9,6
15	11	1169,3	10	30,3	30,3	34,7
	12	1119,8	11	18,0	48,3	16,7
16	13	1021,8	12	63,2	63,2	1,8
			ASSEMBLING			
17	22	1057,8	13_21	60,0	60,0	5,0
18	23	997,9	22	54,0	54,0	11,0
	24	943,6	8_23	10,9	64,9	0,1
19	25	912,9	24	74,5	74,5	55,5
	26	858,4	25	54,3	128,8	1,2
20	27	804,2	26	54,9	54,9	10,1
21_22	28	749,3	27	100,1	100,1	29,9
23_24	29	649,2	28	44,6	44,6	85,4
	30	604,6	29	79,0	123,6	6,4
25	31	525,6	30	64,1	64,1	0,9
26	32	461,5	31	29,8	29,8	35,2
27	33	431,8	32	42,2	42,2	22,8
28	34	389,6	33	46,7	46,7	18,3
	35	342,9	34	17,9	64,6	0,4
29	36	325,0	35	61,7	61,7	3,3
30_31	37	263,4	36	87,1	87,1	42,9
32	38	176,3	37	49,3	49,3	15,7
33_34	39	126,9	38	61,2	61,2	68,8
	40	65,7	39	65,7	126,9	3,1

Table 7. *Model 2: Welt pocket pant probabilistic line balancing results.*

Station number (k)	Work task (i) Number	t_i	T_k	Unused Time
1	1	41,7	41,7	23,3
2	2	40,4	40,4	24,6
3	3	23,6		
	4	30,7	54,3	10,7
4	5	3,8		
	6	22,7		
	7	9,6		
	8	3,6		
	9	2,9	42,6	22,4
5	10	55,4	55,4	9,6
6	11	30,4		
	12	18,0	48,4	16,6
7	13	63,2	63,2	1,8
8	14	42,9	42,9	22,1
9	15	37,8	37,8	27,2
10	16	51,3	51,3	13,7
11	17	42,0	42,0	23,0
12	18	52,0	52,0	13,0
13	19	40,3	40,3	24,7
14-15	20	73,7		
	21	38,1	111,8	18,2
16	22	60,0	60,0	5,0
17	23	54,0	54,0	11,0
18-19	24	10,9		
	25	74,5	85,4	44,6
20	26	54,3	54,3	10,7
21	27	54,9	54,9	10,1
22-23	28	100,1	100,1	29,9
24-25	29	44,6		
	30	79,0	123,6	6,4
26-27	31	64,1		
	32	29,8	93,9	36,1
28	33	42,2	42,2	22,8
29	34	46,7	46,7	18,3
30-31-32	35	17,9		
	36	61,7		
	37	87,1	166,7	28,3
33	38	49,3	49,3	15,7
34-35	39	61,2		
	40	65,7	126,9	3,1

Table 8. *Line balancing results.*

Model	The number of workstation	Theoritical line efficiency, %	Line efficiency, %	Balancing loss, %
Command and pocket pant-ranked positional weight method balancing results	n = 42	98.9	87.1	12.9
Command and pocket pant-probabilistic method line balancing resuits	n = 44	98.9	83.2	16.8
Welt pocket pant-ranked positional weight method balancing results	n = 34	97.9	80.6	19.4
Welt pocket panl-probabilistic method line balancing resuits	n = 35	97.9	78.3	21.7

$n_{probable}$ = The number of work tasks that have the condition of t_i > (C/2 = 75/2 = = 37.5) = 33 (1,7,8,9,10,11,12,14,15,16, 17,18,20,21,29,30,31,32,33,34,35,36,37, 39,41,43,45,47, 48,49,50,51,52)

n_{min} = Max (37; 33) = 37

Then ranked positional weights of operations are calculated by using the method explained above and listed in a descending order, as shown in Figure 4. As a result of balancing, it is found that (n = 42) workstations are needed to balance the line. This situation is convenient for the condition ($n \geq n_{min}$). Balancing results of the ranked positional weight technique are given in Table 2.

Balancing loss is calculated:

$$BL = (n\times C - \Sigma t_i)/(n\times C)\times 100\% = = (42\times 75 - 2744.6)/(42\times 75)\times 100\% = = 12.9\% \quad (4)$$

For this assembly line, theoritical and real line efficiency values are calculated:

$$TE = [\sum_{i=1}^{N} t_i/(n_{min}\times C)]\times 100\% = \quad (5)$$
$$= [2744.6/(37\times 75)]\times 100\% = 98.9\ \%$$

$$LE = [\sum_{i=1}^{N} t_i/(n\times C)]\times 100\% = \quad (6)$$
$$= [2744.6/(42\times 75)]\times 100\% = 87.1\ \%$$

Model 1: Command pocket pant probabilistic line balancing results

Table 3 shows information about the standard time, standart deviation and precedence matrix of the model. By accepting the confidence interval as being 80% and the cycle time as being C=75 seconds, we can attempt to balance to balance the assembly line. After constituting P and F matrixes, the steps below are followed:

1. We start by using the first line, having only zero values in the P matrix. The first operation is assigned to the first station (t_1=55.3; T_1=55.3).
2. We take 13 from the first line of the F matrix. It is looked to the line 13 of the P matrix. There is a value of l, this means that before 13 is assigned to any workstation, operation 1 should be made. This situation is supplied above. Operation 13 is controlled in order to assign it to a workstation.
3. Z formula is used to control the suitability of operation 13 for the workstation (t_{13}=6.6, T_1=62, $Z_{20\%}$= -0.84):

As the confidence interval is 80% (= 50% + 30%), a value corresponding to 30% (= 0.3000) is sought from the normal distribution table that the value corresponding. This value is 0.84. However, here the non-confidence value which corresponds to (1 – 80%=) 20% is sought, and this value is ($Z_{20\%}$= -0.84).

$$\sigma_{w.s.} = \sqrt{\sigma_1^2 + \sigma_{13}^2} = = \sqrt{(7.1)^2 + (0.4)^2} = 7.11 \quad (7)$$

$$Z = (62 - 75)/7.11 = -1.82 < -0.84 \quad (8)$$

$$P(T > C) \approx 0 < 0.2$$
(assignment is available).

4. If there is still unused cycle time, it is sought whether or not any other work task can be assigned to the first station. If an operation can not be assigned to a station, then a new station is opened and new operations are attempted to be to assigned.

Table 4 shows command pocket pant model probabilistic line balancing results of the command pocket pant model. The balancing loss and line efficiency are also calculated below:

$$BL = (n\times C - \Sigma t_i)/(n\times C)\times 100\% = = (44\times 75 - 2744.6)/(44\times 75)\times 100\% = = 16.8\%$$

$$LE = [\sum_{i=1}^{N} t_i/(n\times C)]\times 100\% =$$
$$= [2744.6/(44\times 75)]\times 100\% = 83.2\%$$

Model 2: Welt pocket pant line balancing results

Model 2: Welt pant model ranked positional weight balancing results

First the cycle time is calculated. Table 5 shows the operations, ranked positional weights and machine types used to produce the welt pocket pant model.

$$C = T/PA = (540 \text{ minutes} \times 60 \text{ seconds}) / 500 \text{ piece} = 64.8 \text{ seconds/piece} = 65 \text{ seconds}$$

n_{min} = Max (n_{min}; $n_{probable}$) =28

The line is balanced by using (n = 34) workstations. Balancing results of the ranked positional weight technique are given in Table 6.

$$TE = [\sum_{i=1}^{N} t_i/(n_{min}\times C)]\times 100\% =$$

$$= [1781.8/(28\times 65)]\times 100\% = 97.9\%$$

$$LE = [\sum_{i=1}^{N} t_i/(n\times C)]\times 100\% =$$

$$= [1781.8/(34\times 65)]\times 100\% = 80.6\%$$

Model 2: Welt pocket pant probabilistic line balancing results

Welt pocket pant probabilistic line balancing results are shown in Table 7. Also, line balancing loss and real line efficieny values are calculated below:

$$BL = (n\times C - \sum t_i)/(n\times C) =$$

$$= (35\times 65 - 1781.8)/(35\times 65) = 21.7\%$$

$$LE = [\sum_{i=1}^{N} t_i/(n\times C)]\times 100\% =$$

$$= [1781.8/(35\times 65)]\times 100\% = 78.3\%$$

Conclusions

As a result of evaluation, it can be seen that the Ranked Positional Weight Technique gives better resuls than the Probabilistic line balancing technique, as shown in Table 8.

The Ranked Positional Weight Technique is easier to apply and has higher line efficiencies. On the other hand, it is accepted that task times are not deterministic (variable) and work element times obey a normal distribution with μ average value and σ standard deviation in the probabilistic line balancing technique. For this reason, when work elements are assigned to workstations, standard deviation values of standard time values are taken into consideration. This situation enables work elements to be assigned to workstations more sensitively, and thus more reliable assembly line balancing results can be obtained. In conclusion, both techniques have proven effective in getting successive line balancing results and it is necessary to select between them in accordance with the company's targets.

Editorial note

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