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Examining Rebalancing Considers of the Mixed-Model Assembly Line Type-II for the Straight and U-shaped Layout Using the Taguchi Method

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K E Y W O R D S

Assembly line, Consecutive Heuristic algorithm, Recursive Heuristic algorithm, Cycle time

A B S T R A C T

Facing the increasingly competitive market environment, assembly lines are gained attention because of the assembly process expenditure consumes more than 20 % of the manufacturing cost, and also improve its products to meet demand. In this paper, an attempt has been made to develop worker-task assigned to workstation heuristic (W-TAWH) approach for solving mixed-model assembly line balancing problem (M-MALBP), in which the assembly tasks have to be assigned to workstations, and each workstation needs to select only one of the available operators to perform the assigned tasks corresponding to the straight and U-shaped assembly lines with the objective minimum cycle time. The performance of the developed approach was evaluated and validated through applying the practical case in the Dayla State Company for Electrical Industries (DSCEI) particularly in the electric transformer factory (ETF). Taguchi method was used to evaluate the contribution of each one of the considerations in the assembly line are solution approach, layout, sequence vector (SV), and workstation numbers. All results proved the stated considerations have impact significant in any trying to re-balance the assembly line.

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1. INTRODUCTION

An assembly line is a mechanism in which the raw material passes through a conveyer system, different operator and machines perform work on it and eventually, raw material converted into the final product [1]. The key challenge is to assign tasks between workstations in the predefined sequence so that processing time of each workstation exist on line does not excess the predefined cycle time (CT) defined as assembly line balancing problem (ALBP) [2,3]. A problem of the balancing assembly line divides into the simple and generalized assembly line balancing problem. A simple assembly line balancing problem (SALBP) can be classified according to its objective function where SALBP-1, SALBP-2, SALBP-F, and SALBP-E are the problem versions. The objective of the SALBP-1 is to minimize the number of workstations for a given cycle time, whilst the SALBP-2 problem is to minimize the cycle time given the number of workstations. Unlike the previous two versions, SALBP-F determines whether or not there is a feasible assembly configuration that exists for a given combination of cycle time and number of workstations. Lastly, the SAMLB-E attempts to maximize the line efficiency by minimizing the number of workstation and cycle time simultaneously [4,5]. While another one generalize assembly line balancing problem (GALBP) includes the different types such as these classified according to the shape layout are straight assembly line balancing problem (S-ALBP) allows forward assignment only, and U-shaped assembly line balancing problem (U-ALBP) allows both forward allocating and backward [6]. Figure (1) shows the difference between both S – ALBP and U-ALBP. In general, the ALBP is a problem of the combinatorial optimization problem and extensive research has been carried out to solve this problem and so its variants. Exact approaches proposed to allow an optimum solution to be generate so that ALBP is classified as the NP-hard problem, most approaches are not practical in the real-world or big-size-problem. Thus, a number of researchers shift their focus towards heuristic approaches as a popular way of talking about hard problems. Heuristics are efficient, because they are fast and easy to implement [7].

Due to satisfy a customer need with a wide variety of products in a timely manner and rapidly changing market, the assembly line becomes a switching to a mixed model due to the produce different models on the same line in small batches [8]. Mixed model assembly line balancing (MM-ALB) problem dealing with multi products models simultaneously, for a set of tasks, task time and set of precedence relationships between tasks for each model. General purpose machines with automated tools changes and highly flexible operators are required to release a mixed sequence of different models of a product with similar process requirements to be assembled at the same line [9]. Recently, mixed -model and the different layout to solve the problem of balancing assembly line are the focuses of researchers. In addition, the classification of operators according to their skills and experiences based on qualifications as employment and training duration used in the assigned tasks to workstation. Therefore, how to assign suitable a worker and tasks to workstation in such a way that improve assembly line efficiency and reduce cycle time by is considered as a complex problem in assembly line balancing problem [10,11]. In this paper, an attempt has been made to develop worker – task assigned to workstation heuristic (W-TAWH) approach for solving mixed-model assembly line balancing problem (M-MALBP), in which the assembly tasks have to be assigned to workstations, and each workstation needs to select only one of the available operators to perform the assigned tasks corresponding to straight assembly line and U-shaped assembly line with the objective minimum cycle time.

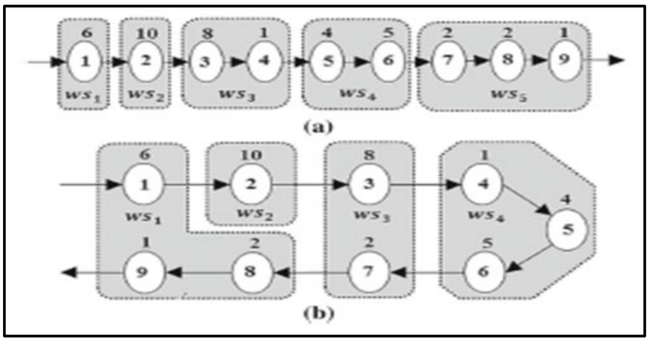

Figure 1: (a) Straight assembly line (b) U – shaped assembly line [12]

2. RELATED STUDIES

ALBP has becomes a matter of concern for academicians and researchers for a long time. There are numerous heuristic approaches, exact algorithms, and optimization methods that have been developed for solving the examined problem. However, majority of the studies have been reported in literature focus on the heuristic approach and type of model. Özcan U. (2009) [6] introduced a novel hybrid heuristic approach based on the adaptive learning strategy simple straight and U-shaped ALBP. Results of the computational studies showed that a novel approach performance superiority over benchmark problems taken from literature. Mamun A.A. (2012) [13] developed a heuristic procedure to re-balance the assembly tasks into workstations after crossover that violates the imposed constraints. The proposed procedure improves efficiency with minimizing a number of workstations and is more suitable for the small and big-size-problem. Avikal S. (2013) [14] applied a critical path method-based approach for evaluating labor productivity in U – shaped ALBP. Experimental results indicated U-shaped layout are able to enhance labour productivity. Krenczyk D. (2020) [15] presented a proposal of the new hybrid heuristic algorithm that integrated a modified ranking positional weight with local search of task order on assembly workstation zones. The obtained results of experimental study indicated to the effectiveness and reliability of the proposal. Aufy and Kassam (2020) [11] presented a proposal a new methodology for balancing a mixed-model assembly line using a worker-assigned heuristic workstation (W-TAWH) model to handle straight and U-shaped problems. The proposal enhanced performance measures depending on the number of suitable workers and tasks that assigned to the given workstation. Finally, these measures are integrated and optimized by employing the desirability function approach for optimization. This paper presented consecutive and recursive heuristic algorithms with the main objective is the minimum cycle time for solving both S-ALBP and U-ALBP in a first attempts to study an effect of the design considerations represented solution approach, layout, sequence vector, and number of the workstations simultaneously in the re-balancing assembly line.

3. PROPOSAL OF THE MATHEMATICAL MODEL FORMULATION FOR W-TAWH PROBLEM

In this paper, problem statement generally can be structured by assigning a proper task and worker that subjected to imposed constraints into a given workstation in order to minimize the main objective of cycle time in another words to improve the efficiency of total throughput. Therefore, the extension of the mixed-model assembly line balancing problem type-2 (W-TAWH) for straight and U-shaped models is developed.

The general framework to solve the W-TAWH problem is described by three stages illustrated in Figure (2). Under the following conditions:

1. The sequence between tasks is vital; hence, their precedence relations constraints meet among them.
2. A task must be assigned to only one workstation.
3. Only one worker must be assigned to each workstation. That means, Workstations number and worker's number are identical that indicates the high utilization as much as possible of available resources at hand.
4. Task time differs among workers based on work experiences and capabilities.

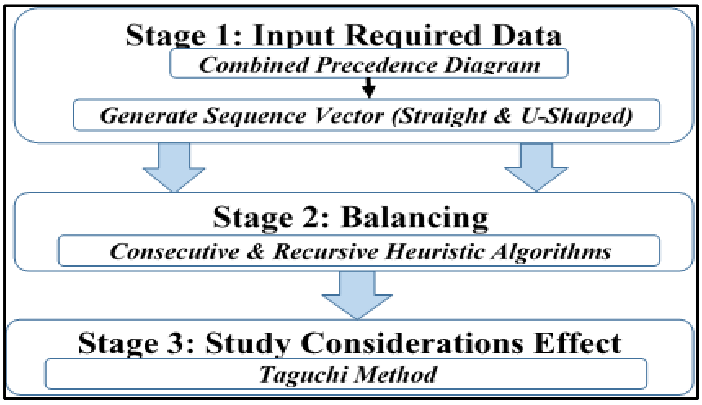

Figure 2: The Framework of the W-TAWH problem model

3.1 Stage One: Input Required Data

Input required data is necessary to combine mix models into combined mix different product models precedence graph and to generate sequence vector (SV). Before assigning worker-task for the mixed assembly line model to a constant number of workstations, a proper procedure must be created to form SV for precedence relations imposed to capture a feasible solution. Heuristic priority rules are used to rank the series of tasks in the form SV according to their priority function and precedence among them. Table (I) shows the priority rules for the S-ALBP model, while Table (II) shows the priority rules for the U-ALBP model.

TABLE I: Heuristic priority rules for S - ALBP model

Heuristic Rules	Priority Function
Maximum total number of successor tasks	$p_{st\,(max)} = \max \sum_{i\in s} i$
Minimum total number of predecessor task	$P_{tp\,(min)} = \min \{\sum_{i\in p} i$

TABLE II: Heuristic priority rules for U - ALBP model

Heuristic Rules	Priority Function
Max total number of successor or predecessor tasks	$p_{maxf\,(c)} = \max \{\text{number of task} \in \mu_c^s, \text{number of tasks} \in \mu_c^p \}$
Min total number of successor or predecessor tasks	$p_{minf\,(c)} = \min \{\text{number of tasks} \in \mu_c^s, \text{number of tasks} \in \mu_c^p \}$

Where
μ_c^p set of tasks (p) that precede task c,
μ_c^s set of tasks (s) which succeed task c.

3.2 Stage Two: Balancing

This stage aims to capture a feasible solution with the objective of minimizing cycle time associated with the task-worker ALBP. To attain minimize cycle time of the W–TAWH problem is conducted by developing consecutive and recursive heuristic algorithms.

3.2.1 Consecutive Heuristic Algorithm: This algorithm is to attempt of assigning tasks to a workstation using worker that allows a maximizing number of tasks at each workstation, this achieved by one worker under load variation to approach the minimum cycle time (CT) with maximal number of tasks assigned to the workstation, The stepwise procedure of the developed algorithms are detailed below:

Step 1: Calculate initial cycle time (CTi) that can be described as a mean of the worker's minimum processing time for all products could be conducting the tasks.

$$CT_i = \sum_{i=1}^{N} \min_{1<k<W} TT_{ik}/W \quad (1)$$

Step 2: Calculate Ts(w) workstation time for all available workers by summing up the maximum number of tasks performed by available workers within or lower bound the initial cycle time.

$$T_{s(w)} = \sum_{c=P1_s}^{P1_s+m(k)} TT_{ik} < CT_i \leq \sum_{c=P1_s}^{P1_s+m(k)+1} TT_{ik} \quad (2)$$

Where, Ts(w) is a workstation time for the worker (k)(k=1,…., W), $P1_s$ is the first position for assigned tasks to the workstation, and m(k) defines the maximal number of tasks a worker (k) could operate in the given sequence during a time less than CTi.

Step 3: Preferred workers $P_{m(w)}$ for each workstation (s) (where 1≤s≤S) is described for all workers can operate the allocating tasks within the value of CTi to meet the condition $(w_k \in P_{m(w)};\ if\ m(c) \geq m(k),\ where\ 1 \leq k \leq W)$.

Where,w_k is worker selected, $P_{m(w)}$ is the set of available workers could perform a maximal number of tasks in the given sequence during a time less than CTi, and m(c) is the maximal number of choose tasks (c) could operate by the worker (k) in the set$P_{m(w)}$.

Step 4: In case workers with the same number of tasks, select one that minimizes the total processing time of the workstation as $(w(s) = k,\ \ if\ \ T_{s(k)} \leq T_{s(w)}\ \ \ \forall\ k \in w)$.

Where, w(s) is the worker to be assigned to the workstation (s), and Ts(k) is the time of workstation (s) for the worker (k).

Step 5: Check that all workstations are complete then progress, otherwise a new workstation will be opened and the initial position for the next workstation is computed as equation (3), then go to (steps 2–5) to allocate remaining tasks in the specified sequence.

$$P1_{s+1} = PL_{ps} + 1 \quad (3)$$

Let $P1_{s+1}$ is the start position for the next workstation, and PL_{ps} is the last position of that precedence workstation.

Step 6: Check if all tasks are allocated in the specified sequence, and if so progress, otherwise go to increase unit step of CT.

Step 7: Find the minimum cycle time (CT) that is the cumulative total time of workstation assigned tasks, and expressed in equation (4).

$$\mathrm{CT} = \max\ (\mathrm{Ts}\ (\mathrm{w})) \quad \text{for } \forall\ \mathrm{s}\ \in \mathrm{S} \quad (4)$$

***3.2.2 Recursive Heuristic Algorithm*:** The basic idea of the searching process based on maximum equality in total processing time across all workstations, so to achieve maximum equality between workstations in the partition sequence vector (SV) data. Hence a slight difference in workstation time among workstations will be occur. The stepwise procedure of the developed algorithms is detailed below:

Step 1: Separating the SV into A & B parts by dividing the number of workstations given by 2.

Step 2: Specify the ratio of the workstation (WR), which shows the ratio of the number of workstations allocated to each part, which is subject to the impost condition, that is, WR less or equal 1.

Step 3: Calculate time ratio (TR), displays the data ratio allocated to each part of the A & B (workstation) and the concept is based on separating the SV into two parts called cross-vector. At this point, the left position (PL) and the right position (PR) can represent each cross-vector as shown in equation (5).

$$\mathrm{TR} = \sum_{j=\mathrm{PL}}^{i} \mathrm{APT}_j \Big/ \sum_{j=i+1}^{\mathrm{Pr}} \mathrm{APT}_j \quad (5)$$

Step 4: Checking the condition that says (TR≤ WR) if valid, adding a new position (i+1), and if not valid go to step (6), which ensures the amount of time allocated to cross-vectors in minimizing variation.

Step 5: The last position (i) should be erased from the cross-vector (A), to ensure not violating TR ≤ WR condition.

Step 6: Steps (1-6) were repeated until the remainder of the specified workstations become 1, in other words each cross-vector refers to the workstation filled with a number of tasks.

3.2.2.1 Assigning Worker to workstation and Evaluation

This assignment aims to minimize cycle time associated with processing time for worker assembly line balancing problem. Workers assigned to given workstations have been summarized in the following procedure:

Step 1: Evaluate workstation time (WT), as formulated in equation (6), it represents the total time needed to complete the allocated tasks to the workstation.

$$\mathrm{T}_{\mathrm{sw}} = \sum_{i=1}^{n} \sum_{i \in s} \mathrm{TT}_{\mathrm{ki}}\, \mathrm{A}_{\mathrm{si}} \quad \text{for } \mathrm{k} = 1, \ldots, \mathrm{W} \quad (6)$$

Step 2: Repeat step (1) for all workers till all available workers have been allocated according to minimize Tsw to a workstation.

Step 3: Repeated steps above for all workstations.

Step 4: And then, assembly line minimum cycle time is determined using equation (7).

$$\mathrm{CT} = \max\ (\mathrm{Tsw}) \quad \text{for } \forall\ \mathrm{s}\ \in \mathrm{S} \quad (7)$$

3.3 Stage 3: Study of Considerations Effect Using Taguchi Method

Taguchi's experimental design technique is valuable for studying an effect of the considerations as the solution approach (SOA), sequence vector (SV), workstation numbers (WSN), and layout (L). The orthogonal array design (L16) was chosen and the experimental design. In order to analyse the experimental data and to determine the relative importance of each factor with respect to its main impacts on the objective function (cycle time in our illustrative example) a robust design criterion entitled Signal – to – Noise (S/N) ratio [16,17]. In present study, the objective function belong to smaller – the – better, and the experimental results of the objective function with robust design criteria being based on the combination of experimental considerations are shown in Tables (III) and (IV). Finally, the magnitude of the effect of these various considers and their interactions were achieved by applying analysis of variance (ANOVA). MINITAB 17 was used for the Taguchi method implementation.

TABLE III: Re-balancing considerations, types and their levels

Assignment Limited	Type	Level
Solution Approach (SOA)	Consecutive, Recursive	[1,2]
Sequence Vector (SV)	Priority Rules	[1,2]
Workstations Number (WSN)	15 , 21	[1,2]
Layout (L)	Straight , U-shaped	[1,2]

TABLE IV: Standard L16 (24) Orthogonal array

Exp. No.	Re-balance Considerations			
	Solution approach	Sequence Vector	Workstations Number	Layout
1	SOA1	SV1	WSN1	L1
2	SOA1	SV1	WSN2	L1
3	SOA1	SV2	WSN1	L1
4	SOA1	SV2	WSN2	L1
5	SOA1	SV1	WSN1	L2
6	SOA1	SV1	WSN2	L2
7	SOA1	SV2	WSN1	L2
8	SOA1	SV2	WSN2	L2
9	SOA2	SV1	WSN1	L1
10	SOA2	SV1	WSN2	L1
11	SOA2	SV2	WSN1	L1
12	SOA2	SV2	WSN2	L1
13	SOA2	SV1	WSN1	L2
14	SOA2	SV1	WSN2	L2
15	SOA2	SV2	WSN1	L2
16	SOA2	SV2	WSN2	L2

4. PRACTICAL APPLICATION

In order to demonstrate the applicability and effective solution of the developed approach, this case under study is taken from a production line that produced an electric transformer in the Dayla State Company for Electrical Industries (DSCEI). Particularly, six transformer models of rating 100 KVA, 250 KVA, 400 KVA, 630 KVA, 1000 KVA, and 1600 KVA were selected to execute the study due to its importance since any fluctuation work conditions already will effects on the production quantity. These products mixed an assembly line with a snap shoot is given in Table (V). The precedence graph given in Figure (3), all six products required 71 tasks to be finished. According to the assumptions any one of 15 workers (wi) with different capabilities of processing time can process tasks. The rank given for each task was ordered by heuristic priority rules, a sample of data is shown in Table (VI), each column represents ranking of 71 tasks in form sequence vector (SV). In this research, four different priority heuristic rules as minimum total number of predecessors tasks and maximum total number of successors tasks for a straight line, where a maximum total number of successors tasks or precedence tasks and minimum total number of successors tasks or precedence tasks for U-shaped are investigated. The obtained results associated with the assignment stage were done using MATLAB SOFTWARE and Table (A.1) in appendix A summarized these results represented assigned tasks, assigned workers, and cycle time.

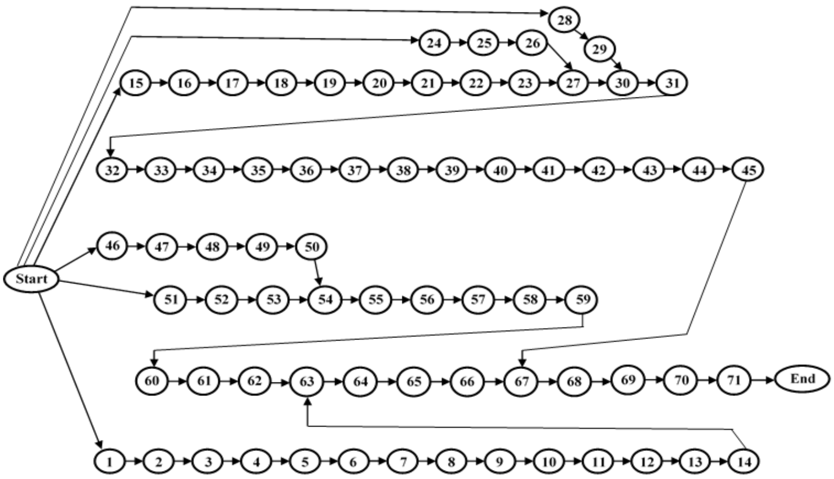

Figure 3: Combined diagram of the mix product

TABLE V: Processing time for each task performed by worker

Task No.	w1	w2	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	w13	w14	w15
1	1.41	0.93	0.99	0.53	0.48	0.93	0.93	1.24	0.85	0.36	0.45	0.48	0.48	0.59	0.48
2	3.53	2.33	1.98	0.91	0.91	2.34	2.33	3.11	2.09	0.91	0.91	0.91	0.91	1.12	0.91
3	2.82	1.09	1.46	0.73	0.73	1.1	1.09	1.70	0.92	0.73	0.73	0.73	0.73	0.73	0.73
4	1.41	0.93	0.79	0.36	0.36	0.93	0.93	1.24	0.83	0.36	0.36	0.36	0.36	0.44	0.36
5	20.8	13.7	11.6	5.40	5.39	13.8	13.7	18.3	12.3	5.39	5.40	5.40	5.40	6.62	5.40
≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀
≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀	≀
68	6.36	4.20	3.56	1.65	1.64	4.22	4.20	5.59	3.77	1.64	1.64	1.64	1.65	2.02	1.65
69	1.41	0.61	0.79	0.36	0.36	0.61	0.61	0.95	0.54	0.36	0.36	0.36	0.36	0.42	0.36
70	1.41	0.93	0.79	0.36	0.36	0.93	0.93	1.24	0.83	0.36	0.36	0.36	0.36	0.44	0.36
71	4.24	1.64	2.2	1.1	1.09	1.65	1.64	2.56	1.38	1.09	1.09	1.09	1.1	1.09	1.1

TABLE VI: Ranking assembly tasks in form SV

Task NO.	UAL			
	Rule 1	*Rule 2*	*Rule 3*	*Rule 4*
1	1	15	71	1
2	2	16	70	2
3	3	17	15	3
4	4	18	16	4
5	5	19	17	5
≀	≀	≀	≀	≀
≀	≀	≀	≀	≀
68	68	68	54	56
69	69	69	55	57
70	70	70	56	58
71	71	71	57	59

4.1 Analysis and Discussion

Based on the S/N ratio results depicted in Figures (4) and (5) and that say S/N ratio value has maximum and the means has minimum is the better. The predicated consider levels combination that must be selected to minimize the cycle time are SOA2, SV1, L2, WSN2 in comparison with others levels. From this table the SOA ranked in the most fundamental consider with respect to the CT value because of the searching process; which designed to main objective is minimum cycle time. Whilst L second the second rank important with P – value equal to 0.022 comes from U – shape requires at most or lower number of workstations workers that straight line in contract with the original concept in re – balancing assembly line that says; increase workstation will be reduce cycle time. The same analysis come in handy for Table (VII) related with WSN consider. The reason why SV has an insignificant effect on the cycle time relates which type of layout must be utilize. Thus, it has considered as an independent variable in our illustrative study. Usually, the obtained conclusion from the analysis results of ANOVA employed to the experiments in our example can only serves as a guideline. Reality, it's required more levels of variables for experimenting on the example problem.

TABLE VII: Results of ANOVA analysis for re-balancing considerers on illustrative study

Factors	SS	MS	Df	F	P - value
SOA	16.973	16.973	1	31.84	0.000
SV	1.268	1.268	1	2.38	0.151
WSN	2.689	2.689	1	5.04	0.046
L	3.802	3.802	1	7.13	0.022

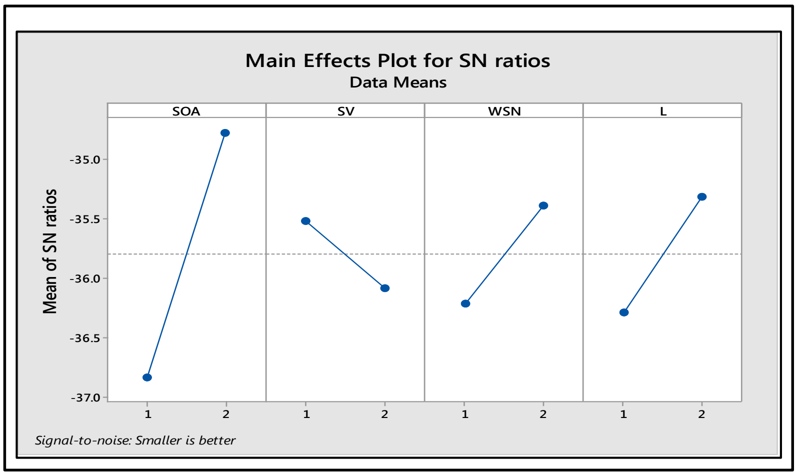

Figure 4: Mean of S/N ratio for each consider in re-balancing ALBP

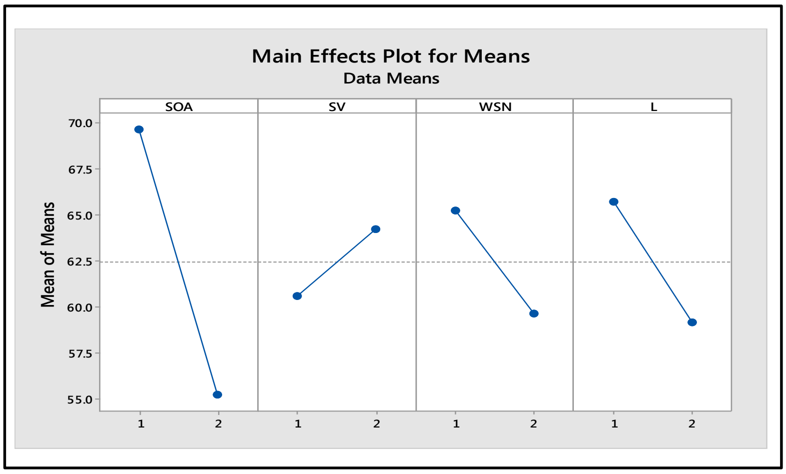

Figure 5: Mean of mean for each consider in re-balancing ALBP

5. CONCLUSIONS

In this study, the M-MALBP of straight and U-shaped assembly line balancing have been considered. Processing time for assigned task was consistent with the accumulated experience of workers presented in assumption that say each worker can perform the assembly task with difference processing time. The main objective as minimizing the cycle time with secondary objective is reducing number of workstations and workers. Consecutive and recursive heuristic algorithms were adopted in solving ALBP and then the problem considerations were calibrated by employing the Taguchi method. Finally, the proposed approach was examined in the practical application taken from the DSCEI Company. The obtained results were proof its validity in studying and identifying the importance relative of the stated re-balance considerations as well as its can be descending ordered as SOA, L, WSN, and SV respectively according to their important calculated by using ANOVA analysis.

Appendix-A

TABLE I: Computational results of combinational of assignment considerations

Exp. NO.	Workstation NO.	7	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Objective
1	Worker Assigned	W5	W8	W3	W6	W7	W4	W9	W2	W10	W1						CT
	Assigned Tasks	1	23	35	7	10	59	36	38	40	63						77.52
		2	24	46	8	11	60	37	39	41	64						
		3	25	47	9	56	61			42	65						
		4	26	48		57	12			43	66						
		5	27	49		58	13			44	67						
		6	28	50			14			45	68						
		15	29	51			62				69						
		16	30	52							70						
		17	31	53							71						
		18	32	54													
		19	33	55													
		20	34														
		21															
		22															
2	Worker Assigned	W8	W11	W2	W1	W10	W6	W7	W13	W15	W4	W9	W12	W3	W14	W5	CT
	Assigned Tasks	1	16	27	47	52	7	10	61	14	38	40	41	64	71		59.78
		2	17	28	48	53	8	11	12	62	39		42	65			
		3	18	29	49	54	9	56	13	36			43	66			
		4	19	30	50	55		57		37			44	67			
		5	20	31	51			58					45	68			
		6	21	32				59					63	69			
		15	22	33				60						70			
			23	34													
			24	35													
			25	46													
			26														
3	Worker Assigned	W5	W8	W3	W6	W7	W4	W9	W2	W10	W1						
	Assigned Tasks	15	4	47	8	11	61	36	38	40	63						70.21
		16	5	48	9	56	12	37	39	41	64						
		17	6	49	10	57	13			62	65						
		18	28	50		58	14			42	66						
		19	29	51		59				43	67						
		20	30	52		60				44	68						
		21	31	53						45	69						
		22	32	54							70						

		23	33	55							71					
		24	34	7												
		25	35													
		26	46													
		27														
		1														
		2														
		3														
4	**Worker Assigned**	**W8**	**W11**	**W2**	**W1**	**W10**	**W6**	**W7**	**W13**	**W15**	**W4**	**W9**	**W12**	**W3**	**W14**		
	Assigned Tasks	15	23	5	46	52	7	10	61	14	38	40	41	63	68		
		16	24	6	47	53	8	11	12	36	39		62	64	69		
		17	25	28	48	54	9	56	13	37			42	65	70		
		18	26	29	49	55		57					43	66	71		
		19	27	30	50			58					44	67			
		20	1	31	51			59					45				**68.02**
		21	2	32				60									
		22	3	33													
			4	34													
				35													
5	**Worker Assigned**	**W8**	**W5**	**W3**	**W6**	**W7**	**W9**	**W4**	**W2**	**W10**	**W1**						
	Assigned Tasks	71	24	36	52	66	10	14	60	54	56						
		70	25	37	53	65	11	64	46	55	57						
		15	26	38	1	7	12	63	47								
		16	28	39	2	8	13	62	59								
		17	29	40	3	9		61	58								
		18	27	41	4				48								
		19	30	42	5				49								
		69	31	43	6				50								**74.47**
		68	32	44													
		67	33	45													
		20	34	51													
		21	35														
		22															
		23															
6	**Worker Assigned**	**W15**	**W11**	**W1**	**W2**	**W6**	**W3**	**W10**	**W8**	**W13**	**W9**	**W4**	**W14**				
	Assigned Tasks	71	68	31	38	44	6	10	63	61	47	54	56				
		70	67	32	39	45	66	11	62	60	59	55	57				
		15	20	33	40	51	65	12		46	58						
		16	21	34	41	52	7	13			48						
		17	22	35	42	53	8	14			49						
		18	23	36	43	1	9	64			50						
		19	24	37		2											**73.81**
		69	25			3											
			26			4											
			28			5											
			29														
			27														
			30														
7	**Worker Assigned**	**W9**	**W4**	**W3**	**W8**	**W2**	**W10**	**W1**	**W6**	**W5**	**W7**						

	Assigned Tasks	1	10	18	62	37	40	61	47	53	56						71.22
		2	68	19	31	38	41	60	48	54	57						
		3	67	20	32	39	42	46	49	55	58						
		4	11	21	33		43		50		59						
		5	12	22	34		44		51								
		6	13	23	35		45		52								
		71	14	24	36												
		70	66	25													
		69	15	26													
		7	16	28													
		8	17	29													
		9	65	27													
			64	30													
				63													
8	**Worker Assigned**	**W8**	**W11**	**W1**	**W2**	**W6**	**W10**	**W5**	**W13**	**W15**	**W9**	**W4**	**W3**				
	Assigned Tasks	1	8	68	15	23	32	38	42	46	50	54	55				62.43
		2	9	67	16	24	33	39	43	47	51		56				
		3	10	11	17	25	34	40	44	48	52		57				
		4		12	65	26	35	41	45	49	53		58				
		5		13	64	28	36		61				59				
		6		14	18	29	37		60								
		71		66	19	27											
		70			20	30											
		69			21	63											
		7			22	62											
						31											
9	**Worker Assigned**	**W9**	**W4**	**W3**	**W8**	**W10**	**W1**	**W2**	**W6**	**W5**	**W7**						
	Assigned Tasks	1	16	24	34	51	7	10	61	37	40						60.14
		2	17	25	35	52	8	11	12	38	41						
		3	18	26	46	53	9	56	13	39	42						
		4	19	27	47	54		57	14		43						
		5	20	28	48	55		58	62		44						
		6	20	29	49			59	36		45						
		15	21	30	50			60			63						
			22	31							64						
			23	32							65						
				33							66						
											67						
											68						
											69						
											70						
											71						
10	**Worker Assigned**	**W9**	**W4**	**W11**	**W10**	**W12**	**W14**	**W3**	**W13**	**W8**	**W15**	**W2**	**W1**	**W6**	**W5**	**W7**	
	Assigned Tasks	1	5	18	24	34	47	52	54	9	58	12	38	40	63		50.78
		2	6	19	25	35	48	53	55	10	59	13	39	41	64		
		3	15	20	26	46	49		7	56	60	14		42	65		
		4	16	21	27		50		8	57	61	62		43	66		
			17	22	28		51					36		44	67		
				23	29							37		45	68		
					30										69		

					31										70		
					32										71		
					33												
11	**Worker Assigned**	**W9**	**W4**	**W3**	**W8**	**W10**	**W1**	**W2**	**W6**	**W5**	**W7**						
	Assigned Tasks	15	23	5	34	51	7	10	61	37	40						**55.14**
		16	24	6	35	52	8	11	13	38	41						
		17	25	28	46	53	9	56	14	39	62						
		18	26	29	47	54		57	36		42						
		19	27	30	48	55		58			43						
		20	1	31	49			59			44						
		21	2	32	50			60			45						
		22	3	33							63						
			4								64						
											65						
											66						
											67						
											68						
											69						
											70						
											71						
12	**Worker Assigned**	**W9**	**W4**	**W10**	**W11**	**W12**	**W14**	**W3**	**W13**	**W8**	**W15**	**W2**	**W1**	**W6**	**W5**		
	Assigned Tasks	15	18	26	5	34	47	52	54	9	10	58	12	38	40		**43.37**
		16	19	27	6	35	48	53	55		11	59	13	39	41		
		17	20	1	28	46	49		7		56	60	14		62		
			21	2	29		50		8		57	61	36		42		
			22	3	30		51						37		43		
			23	4	31										44		
			24		32										45		
					33												
13	**Worker Assigned**	**W9**	**W4**	**W3**	**W2**	**W8**	**W1**	**W10**	**W6**	**W5**	**W7**						
	Assigned Tasks	71	68	29	36	39	52	5	10	61	48						**59.55**
		70	67	27	37	40	53	6	11	60	49						
		15	20	30	38	41	1	66	12	46	50						
		16	21	31		42	2	65	13	47	54						
		17	22	32		43	3	7	14	59	55						
		18	23	33		44	4	8	64	58	56						
		19	24	34		45		9	63		57						
		69	25	35		51			62								
			26														
			28														
14	**Worker Assigned**	**W9**	**W4**	**W11**	**W10**	**W3**	**W12**	**W14**	**W13**	**W15**	**W8**	**W2**	**W1**	**W6**	**W5**	**W7**	
	Assigned Tasks	71	16	67	26	36	38	40	51	5	8	10	11	61	46	54	**65.96**
		70	17	20	28	37	39	41	52	6	9		12	60	47	55	
		15	18	21	29			42	53	66			13		59	56	
			19	22	27			43	1	65			14		58	57	
			69	23	30			44	2	7			64		48		
			68	24	31			45	3				63		49		
				25	32								62		50		
					33												

					34												
					35												
15	**Worker Assigned**	**W9**	**W4**	**W3**	**W8**	**W10**	**W1**	**W2**	**W6**	**W5**	**W7**						**57.57**
	Assigned Tasks	1	69	10	16	23	32	36	40	47	53						
		2	7	68	17	24	33	37	41	48	54						
		3	8	67	65	25	34	38	42	49	55						
		4	7	11	64	26	35	39	43	50	56						
		5		12	18	28			44	51	57						
		6		13	19	29			45	52	58						
		71		14	20	27			61		59						
		70		66	21	30			60								
				15	22	63			46								
						62											
						31											
16	**Worker Assigned**	**W4**	**W10**	**W11**	**W3**	**W14**	**W15**	**W8**	**W1**	**W2**	**W6**	**W12**	**W13**				**49.12**
	Assigned Tasks	50	54	32	8	55	46	1	68	15	23	38	42				
		51		33	9	56	47	2	67	16	24	39	43				
		52		34	10	57	48	3	11	17	25	40	44				
		53		35		58	49	4	12	65	26	41	45				
				36		59		5	13	64	28		61				
				37				6	14	18	27		60				
								71	66	19	30						
								70		20	63						

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