

A Greedy Randomized Heuristic for U-Shaped Assembly Line Balancing

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Abstract

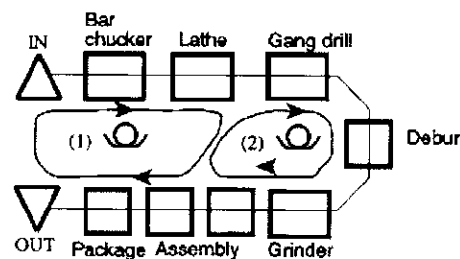
Many manufacturers have adopted a Just-in-time (JIT) approach to manufacturing in recent year. One of the important changes resulting from JIT implementation is the replacement of the traditional straight lines with U-shaped production lines. The important characteristic of these new configurations is that multiskilled workers perform various tasks at different stations along the production line. On the other hand, the problem of assigning tasks on a U-line configuration is more complex than the straight line. This paper addresses the U-shaped assembly line balancing problem type I (UALBP-1; the number of workstations is minimized for a given cycle time) using a constructive heuristic. To measure performance of the heuristic, it is applied to solve a large number of benchmark problems. The results are compared with the optimal solutions and other heuristics obtained from the previous published research. The results indicate that the proposed heuristic is able to identify better solutions and performs efficiently.

Keywords: U-shaped assembly line balancing problem (UALBP), Optimization, Greedy randomized heuristic

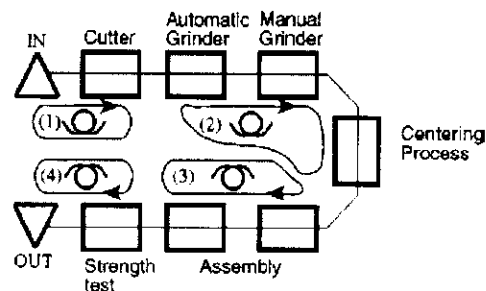
1. Introduction

A production line is often used to take advantage of mass production. As a consequence of the implement of just-in-time (JIT) principles into manufacturing, many companies are organizing their production processes into U-shaped production lines

(figure 1) rather than traditional straight production lines [3]. Such modern assembly lines are often organized as a "U-line" (figure 2 [4]). Both end of the line are close together forming a rather narrow "U". Stations may work at two segments of the line facing each other simultaneously. For example, station 1 works at the beginning and end of the line, i.e. it performs the first and the last tasks for every product unit. When compared to straight lines they typically have, better balancing, improved visibility and communications, fewer work stations, more flexibility for adjustment, minimization of operation travel, and easier material handling [5].



A. Pin and bushing line at farm implements manufacturer in Canada [1]



B. Fishing rod production line in Japan [2]

Figure 1. Actual U-shaped production lines

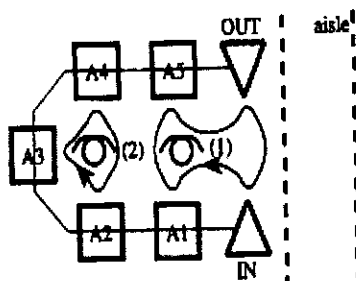


Figure 2. U-shaped production line [4]

The traditional line or straight line assembly line balancing problem considers a production line in which stations are arranged consecutively in a line. A balance is determined by grouping tasks into stations while moving forward through a precedence diagram. However, the U-line assembly line balancing problem is more complex than the straight line because tasks can be assigned by moving forward, backward, or simultaneously in both directions through the precedence diagram.

In terms of the solution of the line balancing problem, this implies that the solution of the U-shaped line configuration dominates the solution of the traditional straight line configuration due to the number of stations on a U-line is less than or equal to the number of stations required on a straight line [5].

Single model and mixed model straight line assembly line balancing have been researched since the first published work in 1955. However, the first published work on U-shaped lines was not until 1994. In comparison to the well studied straight assembly line balancing problem, there are many areas in U-line assembly line balancing which require further research [5].

The first UALBP study in the literature was by Miltenburg and Wijngaard [6], who developed a DP formulation for the single-model U-line to minimize the number of stations. The authors presented a Ranked Positional Weight Technique (RPWT)-based heuristic for larger size problems (111-tasks problems). Later, Miltenburg and Sparling [7]

developed three exact algorithms to solve the UALBP. The first was based on a reaching DP formulation, whereas the other two were breadth- and depth-first branch-and-bound (B&B) algorithms.

Later, Urban [8] developed an integer linear programming formulation to solve small- to medium-sized of UALBP with up to 45 tasks. Scholl and Klein [10] developed a branch-and-bound procedure to solve, either optimally or suboptimally, problem with up to 297 tasks. Mixed-model U-lines were studied by Sparling and Miltenburg [9]. They developed a heuristic procedure for the U-line by which different products were assembled simultaneously. Their approximate solution algorithm that merges each model's precedence diagram into a single precedence diagram solved problems with up to 25 tasks. Miltenburg [10] proposed a DP formulation for a U-line facility that consisted of numerous U-lines connected by multiline stations. Sparling [11] developed heuristic solution procedures for a U-line facility consisting of individual U-lines operating at the same cycle time and connected with multiline stations. Ajenblit and Wainwright [12] developed a genetic algorithm. Erel et al. [13] proposed simulated annealing as solution methodologies for larger U-line and for some further research directions; they stated that it would be interesting to use other metaheuristics in the U-type assembly line balancing problem. Hadi Gokcen et al. [14] presented a shortest route formulation of simple U-type assembly line balancing problem and illustrated on a numerical example.

This paper addresses the U-shaped assembly line balancing problem type 1 (UALBP-1; the number of workstations is minimized for a given cycle time) using heuristic method. To measure performance of the heuristic, it is applied to solve a large number of benchmark problems and compared with the optimal solutions and other heuristics obtained from the previous research work.

2. Problem Formulation

The U-line assembly line balancing problem (UALBP) is an extension of simple assembly line balancing problem (SALBP) which is based on a U-shaped assembly line instead of a serial line. As in the case with SALBP, it can define three problem versions of UALBP (cf. Miltenburg and Wijngaard [6]) as well as Scholl and Klein [15].

- UALBP-1 : Given the cycle time (c), minimize the number of station (m)

- UALBP-2 : Given the number of stations (m), minimize the cycle time (c).

- UALBP-E : Maximize the line efficiency (E) for c and m being variable.

Since models for UALBP differ from those for SALBP only with respect to the precedence constraints. In SALBP all (direct and indirect) predecessors of a task j performed at a station k must be assigned to one of the stations $1, \dots, k$.

In UALBP, each task in principle can share a station with any of its predecessors or successors. However, all predecessors or (and) all successors of a task j performed at a station k must be assigned to one of the station $1, \dots, k$. In many cases, a higher efficiency is possible with UALBP. Note that increasing the line efficiency has the further positive effect of smoothing the levels of station utilization, i.e., the stations get more equally loaded.

The simple U-line assembly line balancing problem defined by Miltenburg and Wijngaard [6] is given as follows: Miltenburg and Wijngaard's definition follows from that given by Gutjahr and Nemhauser [16] for the traditional line balancing problem.

Given set of tasks $F = \{i \mid i = 1, 2, \dots, n\}$, a set of precedence constraints $P = \{(x, y) \mid \text{task } x \text{ must be completed before task } y\}$, a set of task times $T = \{t_i \mid i = 1, 2, \dots, n\}$, cycle time c and a number of workstation m , find a collection of subsets of F , $(S_1, S_2, \dots, S_m)$ where $S_k = \{i \mid \text{task } i \text{ is done at a workstation } k\}$, that satisfy the following conditions:

$$\bigcup_{k=1}^m S_k = F \quad (1)$$

$$S_k \cap S_j = \emptyset \quad (2)$$

$$\sum_{i \in S_k} t_i \leq c, \quad k = 1, 2, \dots, m \quad (3)$$

For each task y ,

$$\text{if } (x, y) \in P, x \in S_k, y \in S_j, \text{ then } k \leq j, \text{ for all } x; \text{ or} \quad (4)$$

$$\text{if } (y, z) \in P, y \in S_j, z \in S_i, \text{ then } i \leq j, \text{ for all } z.$$

$$\left[mc - \sum_{k=1}^m \sum_{i \in S_k} t_i \right] \text{ is minimized.} \quad (5)$$

Condition 1 ensures that all tasks are assigned to a workstation. As a result of condition 2, each task is assigned only once. Condition 3 ensures that the work content of any workstation does not exceed the cycle time. Condition 4 ensures that the precedence constraints are not violated on the U-line. As a result of the objective function, the number of workstations will be minimized [6].

3. Heuristic Method

A greedy randomized heuristic is a proposed method to find solutions to the UALBP-1. The proposed heuristic is described below.

Let U_i^p be the set of tasks which must precede task i ,

Let U_i^s be the set of tasks which must succeed task i ,

Then at any instant the set of assignable tasks, $V = \{i \mid \text{all } x \in U_i^p \text{ or all } y \in U_i^s\}$, have already been assigned.

In this study, we use station oriented procedure for solution building. This procedure is initiated by the opening of a first station ($k = 1$). Tasks are then successively assigned to this station until more tasks cannot be assigned, in which case, said station is closed and a new station is opened. In each iteration, the candidate task with the greedy randomized

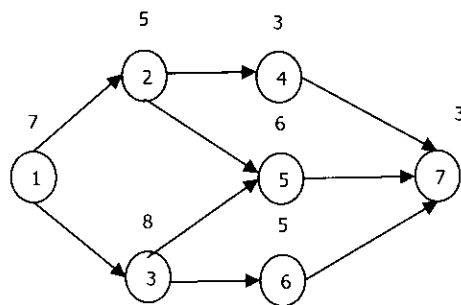
probability value is assigned to the current station; a task is a candidate when its preceding tasks have been assigned and it requires less time that available in the station under construction. When no more tasks may be assigned to the open station, this is closed and the following station ($k + 1$) is opened. The procedure finalizes when there are no more tasks left to assign.

In the case of using a probabilistic (p_{kj}) building schema, the likelihood of selecting candidate task j belonging to the set S_k of candidate tasks to be assigned to station k , is determined in the following way :

$$p_{kj} = \frac{[t_j]}{\sum_{i \in S_k} [t_i]} \quad (6)$$

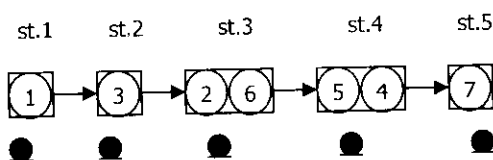
4. Numerical illustration

An example problem with 7 tasks and a cycle time of 10 units is considered. The precedence diagram and straight line configuration results are shown in Figure 3 (A), (B) respectively. It can be



Total tasks time = 37, assume $c = 10$

A. precedence diagram problem



B. straight line configuration results

seen that all tasks are performed at 5 stations in traditional line balancing. The illustration example for assigning tasks to work stations in U-line by using a greedy randomized heuristic is shown in Table 1.

Table 1 Assigning tasks to stations using a greedy randomized heuristic in U-line

St.	Cand. list	Assign	t_j	Idle time	Prob.	Acc. Prob.
1	1*	1	7	3	1.00	1.00
	7	7	3	0	1.00	1.00
2	2,3,4,5,6					
	2		5		0.19	0.19
	3		8		0.29	0.48
	4		3		0.11	0.59
	5		6		0.22	0.81
	6		5		0.19	1.00
		3	8	2	* R=0.35, select task 3	
3	2,4,5,6					
	2		5		0.26	0.26
	4		3		0.16	0.42
	5		6		0.32	0.74
	6		5		0.26	1.00
		2	5	5	* R=0.19, select task 2	
	4,6					
	4		3		0.38	0.38
	6		5		0.62	1.00
		6	5	0	* R=0.74, select task 6	
4	4,5					
	4		3		0.33	0.33
	5		6		0.67	1.00
		5	6	4	* R=0.69, select task 5	
		4	3	1	1.00	1.00

* Task 1 is selected the first due to it is the beginning task of precedence diagram.

Table 1 shows the illustration for assigning tasks to the stations in U-line by using a greedy randomized heuristic. The assignable tasks for the first station are $V = \{1,7\}$. We assign task 1 firstly, then assign task 7 because it has the most priority and sufficient cycle time remaining, it is also assigned to workstation 1, the remaining assignment process is described on Table 1. From the results, the U-line configuration is depicted in Figure 4.

Figure 3. An example problem (A) and straight line result

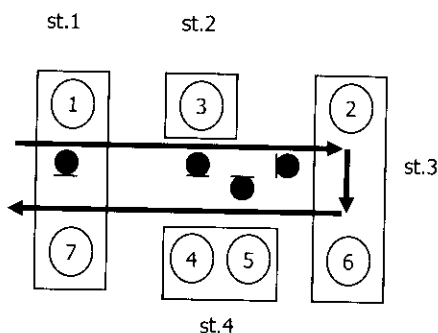


Figure 4. U-line configuration results of example problem

Figure 4 illustrates the solution of UALBP-1 with four stations : $S_1 = \{1,7\}$, $S_2 = \{3\}$, $S_3 = \{2,6\}$, $S_4 = \{5,4\}$ and with station times of 10, 8, 10 and 9, respectively. In U-line, stations can include tasks located on different parts of the production line. For example the first station consists of tasks 1 and 7, where task 1 is located at the beginning of the line while task 7 is located at the end of the line. In this case, the number of stations required on a U-line is less than one stations on a straight line. From the example problem, it shows that the U-line configuration frequently improves the line efficiency and has fewer work stations compared to traditional lines.

5. Computational Results

Several test problems were considered by Miltenburg and Wijngaard [6]. We consider only the larger problems (21 or more tasks) in U-line. Table 2 presents the results of the proposed heuristic (greedy randomized method) and compares the results with [6] by using a maximum ranked positional weight heuristic, other heuristics [17] and the optimal solutions of the U-shaped line balancing problem [8].

By the results, problems of up to 45 tasks can be solved with the proposed heuristic. The problems were solved on a personal computer using FoxPro 6.0 with a Pentium 4, 3.0 GHz, 512 MB RAM and the operating system on windows XP. The computational results indicated that the greedy

randomized heuristic was able to identify better solutions than other heuristics and the calculation time were not high. It found 17 optimal solutions out of 25 instances whereas Max. task time, Maximum RPW and Min. task time heuristics reached only 13, 11 and 4 respectively. Concerning the average relative deviations (%) from the best known solution, the greedy randomized heuristic was the best ranking when compared with other heuristics.

6. Conclusions

Recently, U-shaped line have been utilized in many production lines in place of the traditional straight line configuration due to the use of just-in-time principle. The shape of U-lines improves visibility and allows the construction of stations containing tasks on both sides of the line. This arrangement, combined with cross-trained operators, provides greater flexibility in station construction than is available on a comparable straight production line.

This paper studies the U-shaped assembly line balancing problem and the greedy randomized heuristic for assigning tasks to stations are presented. The performance of the heuristic is applied to solve a large number of benchmark problems and compare results with the optimal solutions and other heuristics which obtained from the previous research work. The computational results indicated that the proposed heuristic can produce good solutions and the computational requirements are not high. This study has taken a step in the direction of finding good heuristic rule to solve the UALBP. It is possible that different heuristic rules with different problems may produce different results. Because there are a large variety of UALBP.

For further research, it would be interesting to use other heuristics, metaheuristics and find more flexible solution approaches in the larger U-shaped assembly line balancing problem.

Table 2. Solutions of the test problems for U-shaped line balancing

Prob.	C	IP solution ¹	Max. ²		Max. task time ³			Min. task time ³			Greedy Randomized Heuristic		
		m	m	%	m	%	Cal. Time (sec.)	m	%	Cal. Time (sec.)	m	%	Cal. Time (sec.)
Mitchell 21	14	8	8	0	8	0	0.03	10	25	0.04	8	0	0.17
	15	8	8	0	8	0	0.03	8	0	0.04	8	0	0.17
	21	5	6	20	6	20	0.03	6	20	0.04	5	0	0.31
Heskiaoff 28	114	9	10	11.11	10	11.11	0.06	11	22.22	0.07	10	11.11	0.21
	128	8	9	12.50	9	12.50	0.08	11	37.50	0.06	9	12.50	0.20
	138	8	8	0	8	0	0.08	9	12.50	0.06	8	0	0.23
	205	5	6	20	5	0	0.10	6	20	0.08	5	0	0.31
	216	5	5	0	5	0	0.08	6	20	0.08	5	0	0.26
	256	4	4	0	5	25	0.09	5	25	0.07	4	0	0.43
	324	4	4	0	4	0	0.09	4	0	0.08	4	0	0.30
	342	3	3	0	3	0	0.08	4	33.33	0.08	3	0	0.31
	342	3	3	0	3	0	0.08	4	33.33	0.08	3	0	0.31
Sawyer 30	25	14	15	7.14	14	0	0.08	17	21.42	0.06	14	0	0.28
	27	13	14	7.69	13	0	0.08	15	15.38	0.06	13	0	0.33
	30	11	12	9.09	12	9.09	0.08	13	18.18	0.08	12	9.09	0.23
	33	10	11	10	11	10	0.07	12	20	0.08	11	10	0.28
	36	10	10	0	10	0	0.08	12	20	0.08	10	0	0.25
	41	8	9	12.50	9	12.50	0.07	9	12.50	0.06	9	12.50	0.28
	54	6	7	16.67	7	16.67	0.08	7	16.67	0.08	7	16.67	0.27
	75	5	5	0	5	0	0.06	5	0	0.07	5	0	0.26
	75	5	5	0	5	0	0.06	5	0	0.07	5	0	0.26
Kilbridge & Wester 45	57	10	10	0	10	0	0.20	12	20	0.18	10	0	0.41
	79	7	8	14.28	8	14.28	0.17	9	28.57	0.24	8	14.28	0.47
	92	6	7	16.67	7	16.67	0.19	7	16.67	0.17	7	16.67	0.53
	110	6	6	0	6	0	0.17	6	0	0.19	6	0	0.47
	138	4	5	25	5	25	0.17	5	25	0.18	4	0	1.24
	184	3	4	33	4	33	0.15	4	33	0.19	3	0	1.08
	184	3	4	33	4	33	0.15	4	33	0.19	3	0	1.08
Total optimal solutions (or lower bound) found from 25 instances			11	8.63	13	8.35	0.096	4	18.52	0.097	17	4.11	0.37
				/inst.		/inst.	/inst.		/inst.	/inst.		/inst.	/inst.

¹ Integer Programming solution, results from Urban [8] (in table 1, p.740)

² Maximum Ranked Positional Weight heuristic researched by Miltenburg and Wijngaard [6], calculation time and spec. of computer were not indicated.

³ Maximum task time and Minimum task time heuristics researched by Nuchara, et al. [17]

m is the number of stations.

% is the average relative deviation from the best known solution

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