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Heuristics comparison for u-shaped assembly line balancing in the apparel factory

Nuchsara Kriengkorakot* and Preecha Kriengkorakot

Department of Industrial Engineering, Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani, Thailand, 34190.

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Abstract

In recent year, many industries have adopted a Just-in-time (JIT) approach to manufacturing. One of the important changes resulting from JIT implementation is the replacement of the traditional straight lines with U-shaped assembly lines. The important characteristic of these new configurations is that multiskilled workers perform various tasks of different stations along the production line. This research is to improve the assembly line balancing in apparel factory in case study of T-shirt style 53287. The efficiency of production line was 55.48%, the factory balanced line with the traditional method in straight line. Then, the u-shaped assembly line balancing problem (UALBP) is to be performed instead of straight line. By using the heuristics of Maximum Task Time, Minimum Task Time, Maximum Ranked Positional Weight (RPWmax) and Greedy Randomized to determine the optimal solutions related to the number of stations and line efficiency. The results indicate that two heuristics have given the good solution which have produced by the use of Maximum Task Time and Greedy Randomized. The minimum number of stations have reduced from 17 stations to 11 stations in UALB and the line efficiency was increased from 55.48% to 85.75%. The U-line configuration frequently improves the line efficiency and has fewer work stations compared to the traditional lines.

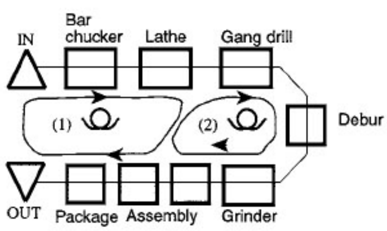
Keywords: Heuristics, U-shaped assembly line balancing, Apparel factory

[1] *Corresponding author. Tel.: +66-4535-3300 ext.3357 ; fax: +66-4535-3333

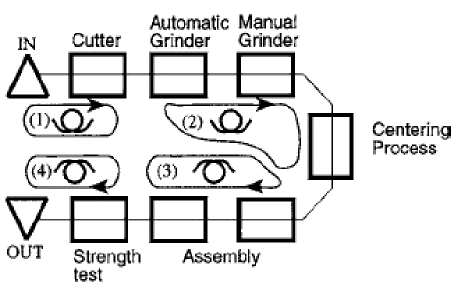
Email address: ennuchkr@ubu.ac.th

1. Introduction

A production line is often used to take advantage of mass production. By just-in-time (JIT) principles, many companies are organizing their production processes into U-shaped production lines (figure 1[1],[2]) 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

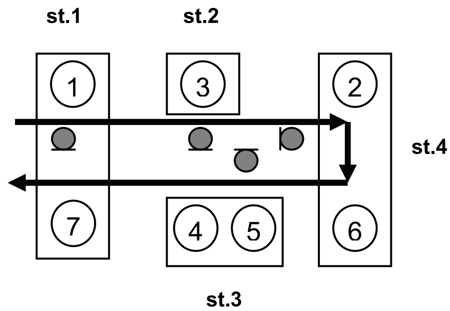


Figure 2 U-shaped production line, [4]

The 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, Miltenburge 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. 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. Hadi Gokcen et al. [14] presented a shortest route formulation of simple U-type assembly line balancing problem and illustrated on a numerical example. Scholl and Klein [15] developed a branch-and-bound procedure to solve, either optimally or sub-optimally, problem with up to 297 tasks.

This research is to improve the assembly line balancing in apparel factory in case study of T-shirt style 53287. The efficiency of production line was 55.48%, the factory balanced line with the traditional method by supervisor in straight line. In this research, the u-shaped assembly line balancing is to be performed by using the heuristics of Maximum Task Time, Minimum Task Time, Maximum Ranked Positional Weight and Greedy Randomized to determine the number of work stations and line efficiency.

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. 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,…,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,…,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 $P = \{(x,y) \mid$ task x must be completed before task $y\}$, a set of task times $T = \{t_i \mid$

$i = 1,2,\ldots,n\}$, cycle time c and a number of workstation m, find a collection of subsets of F, $(S_1, S_2,\ldots,S_n)$ where $S_k = \{i|$ task i is done at a workstation $k\}$, that satisfy the following conditions:

$$\bigcup_{k=1}^{m} S_k = F \tag{1}$$

$$S_k \bigcap_{k \neq j} S_j = \varnothing \tag{2}$$

$$\sum_{i \in S_k} t_i \leq c, \quad k = 1,2,\ldots,n \tag{3}$$

For each task y,

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

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

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

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].

This research is to improve the assembly line balancing in apparel factory in case study of T-shirt style 53287. There are 17 tasks in sewing process. The cycle time is 0.81 minutes. The picture of T-shirt style, the precedence diagram and task time in each element (minute) are shown in figure 3 and 4 respectively. The factory balanced line with the traditional method in straight line. Then, the u-shaped assembly line balancing (UALBP-1) is to be proposed for production line improvement.

Figure 3 Picture of T-shirt style

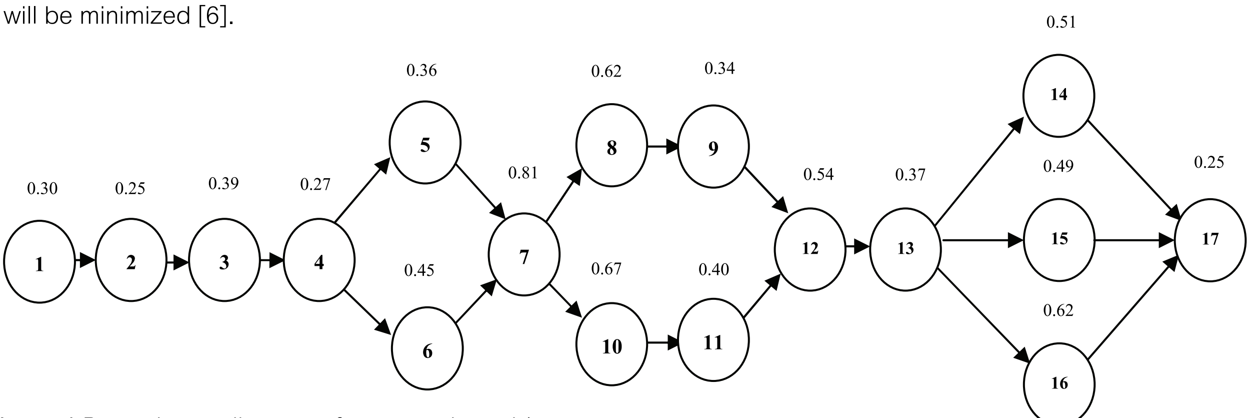


Figure 4 Precedence diagram of case study problem

3. Heuristics

Four heuristic methods (maximum task time, minimum task time, Maximum Ranked Positional Weight and Greedy randomized) are used in this research to find solutions to the UALBP-1 in case study. These heuristic rules were previously used to solved the SALBP. However, to allow them to work for UALBP some modifications were made because each task in principle can share a station with any of its predecessors or successors. The proposed heuristics are 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| all $x \in U_i^p$ or all $y \in U_i^s$ have already been assigned}.[6]

Determined the task priority, $p(i)$, for each task i. Set s =0

s-loop : consider the next station, $s=s+1$; set C^R =0.

1. Determine the set of assignable tasks, V. When $V = \emptyset$ then all tasks have been assigned; procedure ends.

Sort the tasks in V in decreasing order of task priority.

Assign the first task $i \in V$ for which $C^R + t(i) \leq C$ to station S, set $C^R = C^R - t(i)$; go to 1. If there is no such task, then station s is filled. Go to s-loop

3.1 Maximum task time

The priority function $p_{maxt}(i)$, called the U-line maximum task time.

$$p_{maxt}(i) = t(i) \qquad (6)$$

3.2 Minimum task time

The priority function $p_{mint}(i)$, called the U-line minimum task time.

$$p_{mint}(i) = t(i) \qquad (7)$$

These 2 procedures are quite the same concept. The maximum task time 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 each iteration, the candidate task with the maximum task time (but for the minimum task time method we use minimum time of each task for the priority assigning) is assigned to the current station; a task is a candidate when its preceding or succeeding 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.

3.3 Maximum ranked positional weight (RPW max)

One priority function, $p(i)$, called the U-line maximum ranked positional weight is defined as, [6]

$$p(i) = \max\left\{ t(i) + \sum_{x \in U_i^s} t(x), t(i) + \sum_{y \in U_i^p} t(y) \right\} \qquad (8)$$

That is, the priority of each task is either the time required to complete both that task and all the tasks that must succeed or must precede it, whichever is larger (*p(i) value*). In this way tasks that, in combination with their successors or predecessors, require a long time to complete are assigned as soon as possible to stations. It is possible to define *p(i)* in many other ways, including the minimum, sum, product etc. In this research, We use the maximum ranked positional weight for the priority assigning.

3.4 Greedy randomized

A greedy randomized heuristic, 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 or succeeding 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 :

$$p_{kj} = \frac{[t_j]}{\sum_{i \in S_k} [t_i]} \tag{9}$$

4. Computational results

By the results, in case study problem with 17 tasks can be solved with the heuristics of Maximum Task Time, Minimum Task Time, Maximum Ranked Positional Weight (RPWmax) and Greedy Randomized to determine the number of stations and line efficiency in the UALBP-1 and compare the solution with the traditional method. The problem can be 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 results indicate that the U-shaped assembly line balancing frequently improves the line efficiency and has fewer work stations compare to straight line and two heuristics have given the good solution which have produced by the Maximum Task Time and Greedy Randomized. The U-line configuration are depicted in figure 5-6 respectively. The minimum number of work stations can be reduced from 17 stations to 11 stations and the line efficiency can be increased from 55.48% to 85.75%. In table 1 is the heuristics comparison data of the UALBP-1 in this case study.

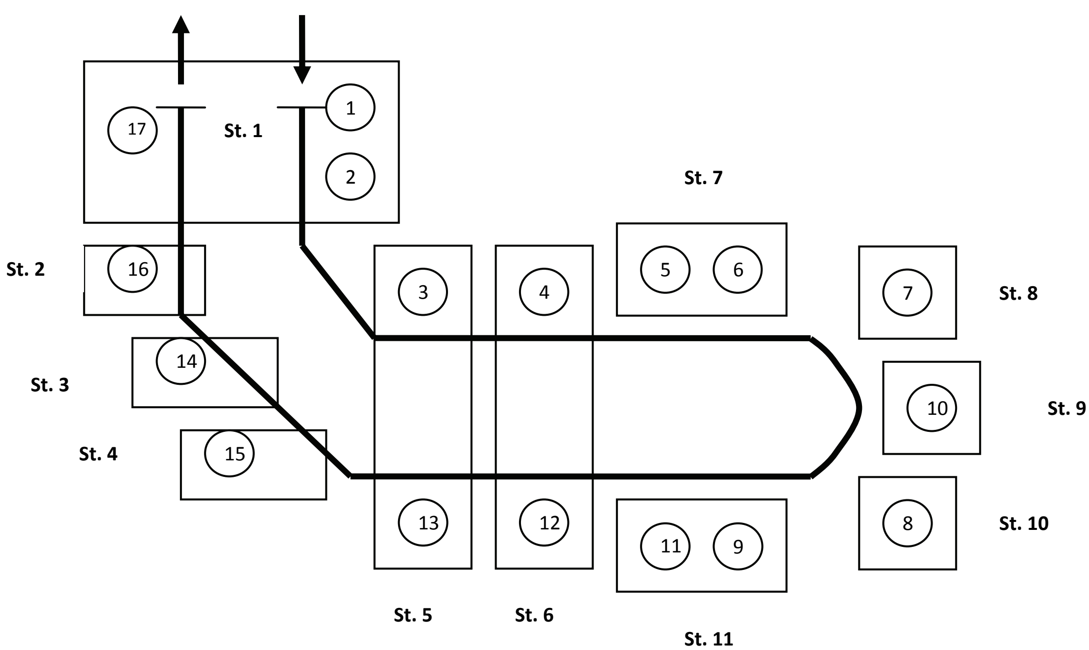


Figure 5 U-line configuration of the Maximum Task Time heuristic

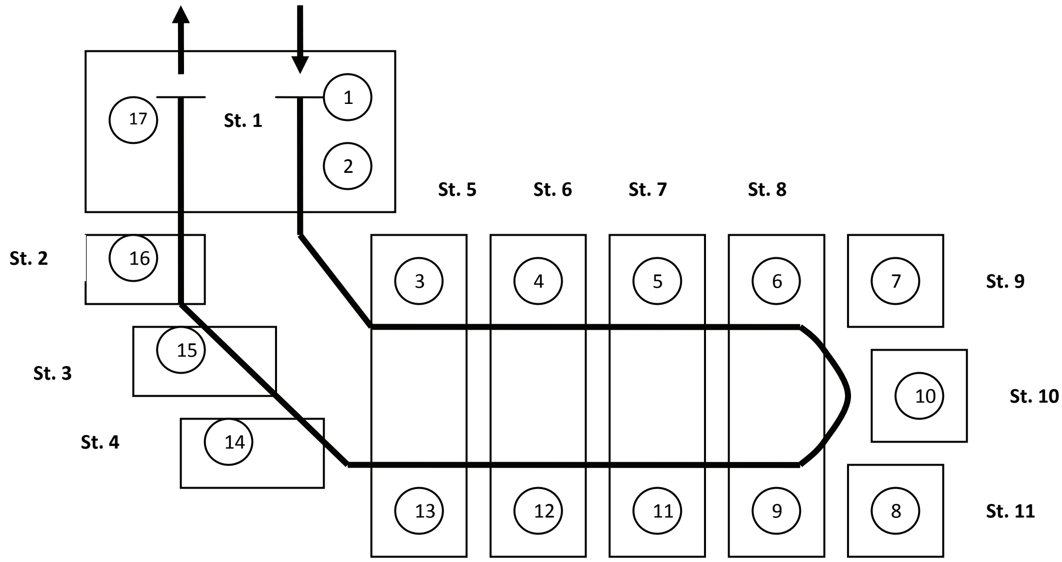


Figure 6 U-line configuration results of the Greedy Randomized heuristic

Table 1 Heuristics comparison data of the UALB-1 in this case study

	SALBP-1	UALBP-1			
solutions	Traditional method	Max. task time	Min. Task time	RPW	Greedy Random.
No. of station	17	11	12	12	11
E (%)	55.48	85.75	78.60	78.60	85.75
Balance Delay (%)	44.52	14.25	21.40	21.40	14.25

5. Conclusions

Presently, U-line layouts have been utilized in many production lines in place of the traditional straight-line configuration due to the use of just-in-time principles.

The computational results indicated that the proposed heuristics can produce good solutions. This study has taken a step in the direction of finding good heuristic rule to solve the UALBP-1 in case study of the apparel factory. 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, meta-heuristics and find more flexible solution approaches in the larger U-shaped assembly line balancing problem.

6. Acknowledgements

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