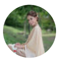
A Hybrid Tabu Search Method for Assembly Line Balancing



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Abstract: - A new hybrid tabu search (HTS) method for solving assembly line balancing problems is proposed in this paper. The tabu search (TS) method is combined with the genetic algorithm (GA) to identify and provide solutions for assembly line balancing problems. With the proposed HTS method, the TS method can well address the number of tasks assigned for each workstation, while the GA can also assign the sequence of tasks for each workstation according to precedence constraints. In this paper, four single-model assembly line balancing problems from literature are tested against the proposed method. From the simulation results compared with the conventional method, it was found that the proposed HTS method is capable of producing solutions superior to the conventional method. It can be concluded that the HTS method is an alternative potential algorithm to solve assembly line balancing problems.

Key-Words: - assembly line balancing, tabu search, genetic algorithm, hybrid tabu search

1 Introduction

In the early 1900's, the manufacturing assembly line balancing was first introduced by Henry Ford. It was designed to be an efficient, highly productive way of manufacturing a particular product. The principle of an assembly line balancing consists of a set of workstations assigned in a linear fashion. The basic movement of material through an assembly line begins with a part being fed into the first workstation. A workstation is considered any point on an assembly line, in which a task is performed on the part. Once the part enters a workstation, a task is then performed on the part, and the part is fed to the next operation. The time it takes to complete a task at each operation is known as the processing time [1].

The cycle time of an assembly line is predetermined by a desired production rate. Such the production rate is set so that the desired amount of end product is produced within a certain time period [2]. In order for an assembly line to maintain a certain production rate, the sum of the processing times at each workstation must not exceed the workstations' cycle time. If the sum of the processing times within a workstation is less than the cycle time, the idle time is said to be present at that workstation [3].

The assembly line balancing (ALB) problem is one of the classic problems in industrial engineering and considered as the class of NP-hard combinatorial optimization problems [4]. This means that an optimal solution is not guaranteed. Therefore, heuristic methods have become the most popular techniques for solving such the problems [5],[6].

To date, artificial intelligent (AI) techniques have become potential candidates to various industrial applications. The tabu search (TS) [7],[8] and the genetic algorithm (GA) [9],[10], two of the most powerful AI search techniques, have been widely used for solving industrial problems. In this paper, the TS and the GA are developed and proposed to be an alternative potential algorithm to solve assembly line balancing problems. The TS is used to address the number of tasks assigned for each workstation, while the GA is conducted to arrange the sequence of tasks according to the precedent constraints. The novel proposed method is called the hybrid tabu search (HTS) method.

This paper consists of five sections. The assembly line balancing problem formulation is illustrated in Section 2. The proposed HTS method is described in Section 3. Results and discussions are given in Section 4, while conclusions are provided in section 5.

2 ALB Problem Formulation

An assembly line is a sequence of workstations connected together by a material handling system. It is used to assemble components into a final product. The problem of balancing an assembly line is considered as one of the classic industrial engineering problems. The assembly line balancing problem is assigning tasks (work elements) to workstations that minimize the amount of the idle time of the line, whereas satisfying specific constraints. The first constraint is that the total processing time assigned to each workstation should be less than or equal to the cycle time. The second one is that the task assignments should follow the sequential processing order of the tasks (precedent constraints). In this paper, the single-model assembly line balancing problem is considered. The objective of line balancing is to assign tasks to each workstation according to the precedence relationships. The variable of interest for an assembly line balancing consists of number of tasks, processing time, precedence relationships, and the cycle time. The goals of an assembly line balancing are to minimize the number of workstations, to minimize the workload variance, to minimize the idle time, and to maximize the line efficiency as shown in (1)-(4), respectively, where n is the number of workstations, $n_{\max}$ is the maximum number of workstation allowance, W is the total processing time, ct is the cycle time, ct_r is the actual cycle time, T_i is the processing time of the i^{th} workstation, L_{eff} is the line efficiency, w_v is the workload variance, and T_{id_T} is the total idle time.

$$\frac{W}{ct} \le min\, n \le n_{\max} \tag{1}$$

$$min\, T_{id\_T} = min \sum_{t=1}^{n} \left(ct - T_i \right) \tag{2}$$

$$min\, w_v = min \sum_{t=1}^{n} \left(T_i - \left(\frac{W}{n} \right) \right)^2 \Big/ n \tag{3}$$

$$max\, L_{eff} = max \frac{\sum_{i=1}^{n} T_i}{\left(n \times ct\_r \right)} \times 100 \tag{4}$$

3 The Proposed HTS Method

In this paper, the tabu search (TS) and the genetic algorithm (GA) are used to solve assembly line balancing problems. The algorithms of the TS and the GA are briefly described as follows.

3.1 Tabu Search (TS)

The TS [7],[8] is a stochastic search technique based on iterative neighborhood search approach for solving combinatorial and nonlinear problems. The tabu list is used to record a history of solution movement for leading a new direction that can escape a local minimum trap. The TS algorithm is summarized as follows.

(1) Initialize a search space.
(2) Randomly select an initial solution x_o from the search space. Let x_o be a current local minimum.
(3) Randomly generate N solutions around x_o within a certain radius R. Store the N solutions, called neighborhood, in a set X.
(4) Evaluate a cost function of each member in X. Set x_1 as a member that gives the minimum cost in X.
(5) If $x_1 < x_0$, put x_0 into the tabu list and set $x_0 = x_1$, otherwise, store x_1 in the tabu list instead.
(6) If the termination criteria are met, stop the search process. x_0 is the best solution, otherwise go back to step (2).

3.2 Genetic Algorithm (GA)

The GA [9],[10] is also a stochastic search technique based on two natural processes, i.e. selection and genetic operation. The search process of the GA is similar to the nature evolution of biological creatures in which successive generations of organisms are given birth and raised until they themselves are able to breed. The GA algorithm is summarized as follows.

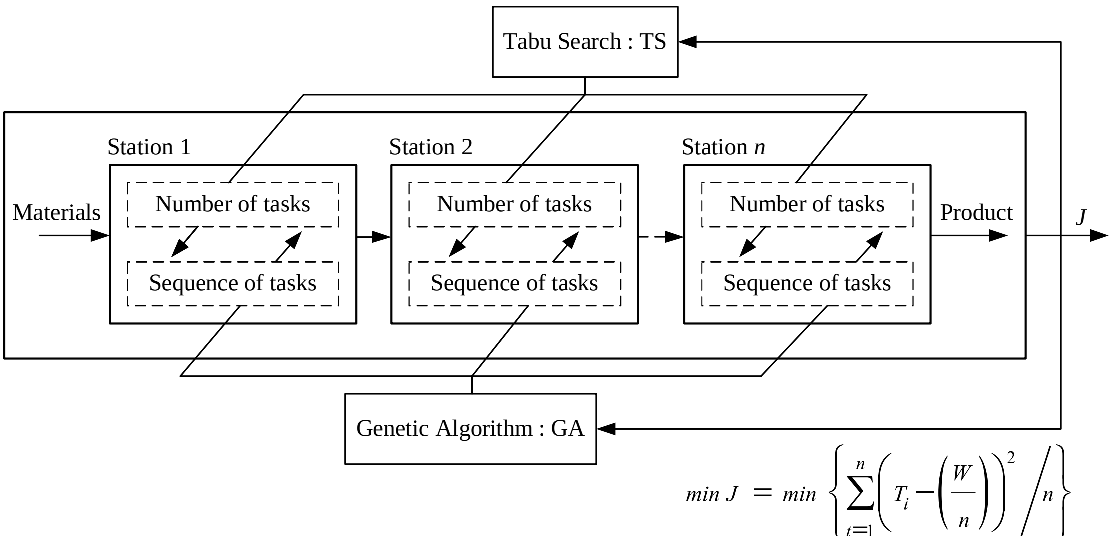

Fig. 1 The HTS method for assembly line balancing.

(1) Randomly initialize populations or chromosomes and set them as a search space.
(2) Evaluate the fitness value of each chromosome via the objective function.
(3) Select some chromosomes giving better fitness value to be parents.
(4) Reproduce new generation (offspring) by genetic operations, i.e. crossover and mutation.
(5) Compute the fitness value of each new chromosome via the objective function.
(6) If the termination criteria are met, stop the search process. The optimum solution found is the best chromosome in a search space, otherwise replace old chromosomes by new ones and go back to step (2).

$$min\ J = min\left\{\sum_{i=1}^{n}\left(T_i-\left(\frac{W}{n}\right)\right)^2 \Big/ n\right\} \qquad (5)$$

The proposed HTS method for the assembly line balancing problems is represented by the block diagram as shown in Figure 1. Referring to Figure 1, the TS is employed to address the number of tasks assigned for each station. The summation of all tasks assigned by the TS for each station is equal to the total task of the problem of interest. The GA is used to arrange the sequence of tasks according to the precedent constraints. The workload variance, w_v, is set as the objective value, J, of the search process. In each search round, the TS will search the appropriate number of tasks for each station, whereas the GA will search the sequence of tasks according to the precedent constraints. J will be fed back to the TS and the GA boxes to be minimized as expressed in (5), while the maximum number of search round is set as the termination criterion.

4 Results and Discussions

To perform the effectiveness of the proposed HTS method, four single-model assembly line balancing problems from a survey of literature are used for test against the proposed approach. In this work, The TS method is coded by MATLAB v.7.0. For all tests, the parameter settings of the TS are as follows: N = 500 and R = 2. The GA is employed from the genetic algorithm toolbox of MATLAB v.7.0. For all tests, the parameter settings of the GA are as follows: number of populations = 60 and maximum generation = 5,000. The maximum search round of the HTS method = 50 is set as the termination criteria for all tests.

The first single-model assembly line balancing problem [11] as shown in Table I consists of 11 tasks. The predetermined parameters are set as follows: ct = 10 min., W = 46 min., $n = W/ct = 4.6 \cong 5$, and n_{max} = 6 workstations. The boundaries of number of tasks for each workstation are set to perform the search space as follows: Station#1$\in$[1, 3], Station#2$\in$[1, 2], Station#3$\in$[1, 3], Station#4$\in$[1, 2], Station#5$\in$[1, 3], and Station#6$\in$[1, 2]. Once the search process of the HTS method stopped, Table II shows the results obtained from the proposed HTS method comparing with the ones obtained from the COMSOAL method [5], one of the conventional methods widely used to solve assembly line balancing problems. From Table II, it shows that the proposed HTS method is capable of producing much better solution. The workload variances, w_v, of the solution obtained from the proposed HTS method and the COMSOAL method are 0.56 and 4.89, respectively, and the line efficiencies, L_{eff}, obtained from the proposed HTS method and the COMSOAL method are 85.19% and 76.67%, respectively.

Table I Task, time, and precedence of the first ALB problem.

Task	Task time (min)	Task that must precede
1	6	-
2	2	1
3	2	2
4	6	3
5	5	4
6	5	1
7	7	1
8	1	1
9	3	6,7,8
10	5	9
11	4	10

Table II Results obtained from the HTS and the COMSOAL methods for the first ALB problem

Results obtained from the COMSOAL method			
Station	Assigned Task	Processing time (min)	Idle time (min)
1	1,2,8	9	1
2	7	7	3
3	6,3,9	10	0
4	4	6	4
5	10,5	10	0
6	11	4	6
The total idle time = 14 min. The workload variance = 4.89 The line efficiency = 76.67%			
Results obtained from the proposed HTS method			
Station	Assigned Task	Processing time (min)	Idle time (min)
1	1,8	7	3
2	7	7	3
3	6,2	7	3
4	3,4	8	2
5	9,5	8	2
6	10,11	9	1
The total idle time = 14 min. The workload variance = 0.56 The line efficiency = 85.19%			

The second single-model assembly line balancing problem [12] as shown in Table III consists of 11 tasks. The predetermined parameters are set as follows: ct = 50.4 sec., W = 195 sec., $n = W/ct \cong 4$, and $n_{\max}$ = 5 workstations. The boundaries of number of tasks for each workstation are set to perform the search space as follows: Station#1∈[1, 3], Station#2∈ [1, 3], Station#3∈[3, 6], Station#4∈[3, 6], and Station#5∈[1, 3]. Once the search process of the HTS method stopped, Table IV shows the results obtained from the proposed HTS method comparing with the ones obtained from the COMSOAL method. From Table IV, the workload variances, w_v, of the solution obtained from the proposed HTS method and the COMSOAL method are 133.20 and 229.20, respectively, and the line efficiency, L_{eff}, obtained from both methods is 78.00%.

Table III Task, time, and precedence of the second ALB problem.

Task	Task time (sec)	Task that must precede
1	45	-
2	11	1
3	9	2
4	50	-
5	15	4
6	12	3
7	12	3
8	12	5
9	12	5
10	8	6,7,8,9
11	9	10

Table IV Results obtained from the HTS and the COMSOAL methods for the second ALB problem

Results obtained from the COMSOAL method			
Station	Assigned Task	Processing time (sec)	Idle time (sec)
1	1	45	5.4
2	4	50	0.4
3	2,5,3,6	47	3.4
4	7,8,9,10	44	6.4
5	11	9	41.4
The total idle time = 57 sec. The workload variance = 229.20 The line efficiency = 78.00%			
Results obtained from the proposed HTS method			
Station	Assigned Task	Processing time (sec)	Idle time (sec)
1	1	45	5.4
2	4	50	0.4
3	2,3,7,6	44	6.4
4	5,8,9	39	11.4
5	10,11	17	33.4
The total idle time = 57 sec. The workload variance = 133.20 The line efficiency = 78.00%			

The third single-model assembly line balancing problem [13] as shown in Table V consists of 11 tasks. The predetermined parameters are set as follows: ct = 15 min., W = 50 min., $n = W/ct \cong 4$, and $n_{\max}$ = 4 workstations. The boundaries of number of tasks for each workstation are set to perform the search space as follows: Station#1∈[1, 5], Station#2∈ [1, 5], Station#3∈[1, 5], and Station#4∈[1, 4]. Once the search process of the HTS method stopped, Table VI shows the results obtained from the proposed HTS method comparing with the ones obtained from the COMSOAL method. From Table VI, the workload variances, w_v, of the solution obtained from the proposed HTS method and the COMSOAL method are 0.75 and 5.25, respectively, and the line efficiencies, L_{eff}, obtained from the proposed HTS method and the COMSOAL method are 96.15% and 83.33%, respectively.

Table V Task, time, and precedence of the third ALB problem.

Task	Task time (min)	Task that must precede
1	3	-
2	6	-
3	7	1
4	5	1,2
5	2	2
6	4	3
7	5	6
8	7	4,5
9	1	8
10	6	5
11	4	7,9,10

Table VI Results obtained from the HTS and the COMSOAL methods for the third ALB problem

Results obtained from the COMSOAL method			
Station	Assigned Task	Processing time (min)	Idle time (min)
1	1,2,4	14	1
2	3,5,10	15	0
3	6,8,9	12	3
4	7,11	9	6
The total idle time = 10 min. The workload variance = 5.25 The line efficiency = 83.33%			
Results obtained from the proposed HTS method			
Station	Assigned Task	Processing time (min)	Idle time (min)
1	2,5,1	11	4
2	10,3	13	2
3	4,8,9	13	2
4	6,7,11	13	2
The total idle time = 10 min. The workload variance = 0.75 The line efficiency = 96.15%			

Table VII Task, time, and precedence of the forth ALB problem.

Task	Task time (min)	Task that must precede
1	0.1	-
2	0.1	1
3	0.1	2
4	0.2	2
5	0.1	2
6	0.2	3,4,5
7	0.1	1
8	0.1	7
9	0.2	8
10	0.1	9
11	0.2	6
12	0.2	10,11
13	0.1	12

Table VIII Results obtained from the HTS and the COMSOAL methods for the forth ALB problem

Results obtained from the COMSOAL method			
Station	Assigned Task	Processing time (min)	Idle time (min)
1	1,7,8,9	0.5	0
2	2,5,4,3	0.5	0
3	10,6,11	0.5	0
4	12,13	0.3	0.2
The total idle time = 0.2 min. The workload variance = 0.0075 The line efficiency = 90.00%			
Results obtained from the HTS method			
Station	Assigned Task	Processing time (min)	Idle time (min)
1	1,2,5,4	0.5	0
2	7,3,6,8	0.5	0
3	11,9	0.4	0.1
4	10,12,13	0.4	0.1
The total idle time = 0.2 min. The workload variance = 0.0025 The line efficiency = 90.00%			

The last single-model assembly line balancing problem [13] as shown in Table VII consists of 13 tasks. The predetermined parameters are set as follows: ct = 0.5 min., W = 1.8 min., $n = W/ct \cong 4$, and $n_{\max}$ = 4 workstations. The boundaries of number of tasks for each workstation are set to perform the search space as follows: Station#1∈[1, 6], Station#2∈ [1, 6], Station#3∈[1, 6], and Station#4∈[1, 6]. Once the search process of the HTS method stopped, Table VIII shows the results obtained from the proposed HTS method comparing with the ones obtained from the COMSOAL method. From Table VIII, the workload variances, w_v, of the solution obtained from the proposed HTS method and the COMSOAL method are 0.0025 and 0.0075, respectively, and the line efficiency, L_{eff}, obtained from both methods is 90.00%. Figure 2 shows the convergence rate of the workload variance, w_v, obtained from the HTS method for the last problem, as an example. The search convergence rate curves of previous three problems are omitted because they have a similar form to that of the last problem shown in Figure 2.

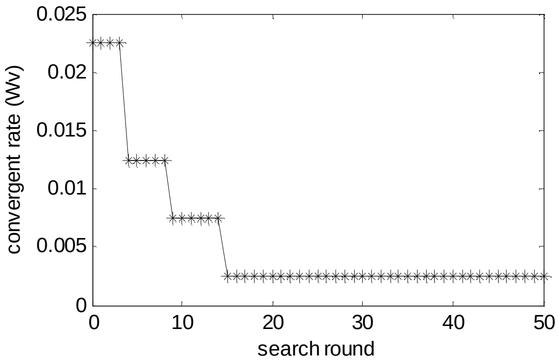

Fig. 2 The convergence rate obtained from the HTS method for the last ALB problem.

5 Conclusions

The hybrid tabu search (HTS) method has been proposed in this paper for solving assembly line balancing problems. Such the method consists of the TS method used to address the number of tasks assigned for each workstation and the GA used to assign the sequence of tasks according to the precedent constraints. Four single-model assembly line balancing problems from a survey of literature have been tested against the proposed approach. Comparing with the conventional method (COMSOAL), it was found that the proposed HTS method is capable of producing much better solutions than the conventional method. It can be concluded that the proposed HTS method is an alternative potential algorithm to solve assembly line balancing problems.

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