Journal of Modern Science and Technology
Vol. 6. No. 3. September 2018 Issue. Pp.13-24

Assembly Line Balancing Using ACO Algorithm and RPW Method: A Comparative Case Study

*Khairun Nahar, **Md. Ahasan Habib, **Md. Ashraful Alam Nayon and ***Md. Mosharraf Hossain

Assembly Line balancing is one of the widely used basic principles in production system which improves the throughput of assembly line while reducing non value-added activities, cycle time and also ensures maximization of labor efficiency. Line balancing problem deals with the distribution of activities among the workstations for large scale production so that there will be maximum utilization of human resources and facilities without disturbing the work sequence. In an industrial environment to make certain standardized commodities it is assumed that operation times on the machines, and the precedence relationship existing between the operations which results from the technology of the production line and the cycle time or the number of machines are known. This paper focuses on minimization of the number of workstation and to maximize the balancing efficiency by applying Ant Colony Optimization (ACO) algorithm for the simple assembly line balancing problem. Besides using fixed cycle time trial cycle time also used to obtain the maximized output. The balancing efficiency have analyzed by assigning each task to the workstation for every of the ranged cycle time and finally concluded that the balancing efficiency is inversely related to the idle time of an assembly line. Rank Positional Weight (RPW) method is also used here to determine the desired findings. Finally a comparison has been made between ACO & RPW and it is found that when the cycle time minimum then balancing efficiency is maximum if the number of workstation is unchanged.

Field of Research: Management

1. Introduction

The designing of a production system has always been an important issue in industrial engineering. As a result of international competition and an extremely rapid progress in manufacturing technologies this problem becomes even more important. Productively systems are characterized by extremely short production times, the high level of automation, and the needs of new technologies, and high expenditures for the construction of the assembly lines. Assembly line balancing is concerned with the allocation of tasks to work stations on a production line. Simple assembly line balancing problems are classified into two types, type I and type II. In type I problems, the cycle time, assembly tasks, tasks times, and precedence requirements are given. The objective of type I problem is to minimize the number of workstations.

*Corresponding Author: Khairun Nahar, Assistant Professor, Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh. Email: shapla05.ipe@gmail.com
**Md. Ahasan Habib and Md. Ashraful Alam Nayon, Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh.
***Prof. Dr. Md. Mosharraf Hossain, Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi-6204, Bangladesh.

A line with fewer stations results in lower labor costs and reduced space requirements. Type I problems generally occurs at the time of designing new assembly lines. In type II problems, when the number of workstations or number of employees is fixed, the objective is to minimize the cycle time. This leads to maximize the production rate. Type II balancing problems generally occurs, when the organization wants to produce the optimum number of items by using a fixed number work stations without expansion. In 1986 Bay bars proposed the following assumptions for the problem of simple assembly line balancing- All input is known and certain, Tasks are indivisible (cannot be separated into several machines), Tasks must be performed in accordance with the requirements of the manufacturing process, All tasks must be performed, Each station can perform any task, Task times are independent of the filling stations which are carried out, Tasks can be performed on any of the stations, Line is designed for the unique model of the product. Cycle time is known and unchanging or Number of stations is known and unchanging.

In this study, a comparison has been made between ACO & RPW to identify the number of workstation when the cycle time is minimum and the balancing efficiency is maximum. This type of problem is not particularly reflected in previous researches as discussed in the following literature review.

This paper arranged as follows- Section 2 presents the literature review to identify the research scope of assembly line balancing problems in real time cases. In Section 3, the methodology of mathematical model formulations for both of the comparable models are demonstrated. Section 4 focuses on data analysis, section 5 presents the result to summarize the findings, and section 6 provides the conclusion of the study.

2. Literature Review

Krishnaiyer and Cheraghi et al (2002) present an overview of ant algorithms in their paper and they propose a review of ant applications for real life problems faced in business and industrial environments. McMullen and Tarasewich et al (2003) present a heuristic, based on ant techniques. This heuristic uses concepts derived from ACO techniques. They state that their approach effectively address the assembly line balancing problem with complicating factors (parallel workstations, stochastic task times, and mixed models). The assembly line layouts obtained by the proposed heuristic are used for simulated production runs in order to collect some output performance measures. In the paper, (Blum & Dorigo, 2004) they propose a new way of implementing ACO algorithms, which explicitly defines the hyperspace for the pheromone values as the convex hull of the set of 0-1 coded feasible solutions of the combinatorial optimization problem under consideration. This leads to a repeated resetting of these values, which could potentially disturb the dynamics of the system. In the paper of Gokcen et al (2005) a shortest route formulation of simple U-type assembly line balancing (SULB) problem is presented and illustrated on a numerical example. This model is based on the shortest route model developed in for the traditional single model assembly line balancing problem. Researchers (Scholl & Becker, 2006) refer that assembly line balancing problem can be solved when an assembly line has to be configured or redesigned. It consists of distributing the total workload for manufacturing any unit of the product to be assembled among the work stations along the line. Hirotani et al (2006) works on analysis and design of self-balancing production line. In a self-balancing production line each worker was assigned work dynamically. Simple and U-type assembly line balancing problems with a learning effect was presented by Toksari et al (2008). In this reported work, they introduced learning effect into assembly line balancing problems. Ege et al. (2009) works on Assembly line balancing with station paralleling. In their study they assume an arbitrary number of parallel workstations can be assigned to each stage. Ozcan and Toklu et al (2009) works on multiple criteria decision-making in two-sided assembly line balancing: A goal programming and a fuzzy goal programming model. They presented a mathematical model, a pre-emptive goal programming model for precise goals and a fuzzy goal programming model for imprecise goals for two-sided assembly line balancing. Yagmahan et al (2011) presents mixed-model assembly line balancing using a multi objective ant colony optimization approach. This work deals with the mixed-model assembly line balancing problem and objective for this problem was to minimize the number of stations for a given cycle time. Grzechca et al (2011) focuses on cycle time and importance of its value. Different measures of final results of assembly line balance are presented and also a numerical example is calculated. Researchers (Otto & Scholl, 2011) highlight that in manufacturing, control of ergonomic risks at manual workplaces is a necessity commanded by legislation, care for health of workers and economic considerations. A work was published by Chica et al (2011) which show their work on different kinds of preferences in a multi-objective ant algorithm for time and space assembly line balancing on different Nissan scenarios. A work on stability measure for a generalized assembly line balancing problem was published by Gurevsky et al (2013). A generalized formulation for assembly line balancing problem (GALBP) was considered, where several workplaces were associated with each workstation. In the paper (Ghutukade, Santosh & Sawant, 2013) a problem of line balancing in cashew nut shelling machine production has been discussed using ranked position weighted method. Researchers (Amardeep, Rangaswamy, & Gautham, 2013) show that LB is the problem of assigning operation to workstation along an assembly line, in such a way that assignment is optimal in some sense. This paper mainly focuses on improving overall efficiency of single model assembly line by reducing the non-value added activities, cycle time and distribution of work load at each work station by line balancing. Hamta et al (2013) addresses multi-objective (MO) optimization of a single-model assembly line balancing problem (ALBP) where the operation times of tasks are unknown variables and the only known information is the lower and upper bounds for operation time of each task. Hong et al (2015) consider the problem of balancing the assembly line, which is a flow-oriented production system suitable for mass production products such as home appliances and automobiles, etc. Since large capital investments are required for the installation of an assembly line, they investigate various design alternatives as possible.

From the above research summaries it is evident that in plenty of studies assembly line balancing problems in real time cases are analyzed and resolved with different solution techniques. But there are no researches found so far that explain the solution with comparative solution technique. In this paper a comparative analysis between the solution technique ACO and RPW is demonstrated accordingly. The hypotheses to test in this study is to conclude that meta-heuristic approach like ACO gives better results in compare to direct approach RPW.

3. Methodology

The following notations are used-

n : Number of task

cs : Ant colony size

m : Index for ant (1 ≤ m ≤ cs)

i : Index for task (1 ≤ i ≤ n)

k : Index for station

cl : Candidate tasks list.

nc : Number of candidate task in candidate list.

tf : Total pheromone quantity

gf(i,k) : Global pheromone quantity for assigning i^{th} task to k^{th} station

pw(i) : i^{th} task positional weight

r(i) : i^{th} task selection probability

p(i) : Cumulative probability (I → i)

α : Important rates of global pheromone quantity of decision $0 < \alpha \leq 1$

β : Important rates of decision without pheromone $0 < \beta \leq 1$

δ : Important rates of positional weight $1 \leq \delta \leq 10$

T_i : Task time

C : Cycle time

C_t : Trial cycle time

N_{min} : Minimum Number of workstation

The following terms are used

Cycle time, C = (Production time per day)/ (Output per day)

It may be noted that minimum number of workstation must satisfy the following constraints:

$$= (T_i / C) \leq N_{min} \leq (T_i / C) + 1$$

Trial cycle time must satisfy this condition $C_{min} \leq C_t \leq C$

Where, $C_{min} = T_i / N_{min} + 1$

3.1 Steps of the ACO Based Algorithm

1. Set initial values, start iteration.

2. Create a new ant m = m+1;

3. Open k^{th} station, k = k+1;

4. Form the initial candidate tasks list. cl = {1,…, nc}

5. Determine all task(s) selection probability in the candidate list according to the global pheromone quantities and positional weight values of the tasks.

$$tf = \sum_{i=cl}^{n} gf(i,k) , \quad tpw = \sum_{i=cl}^{n} pw(i)$$

$$r(i) = \frac{\left[gf(i,k)*\alpha + \left[pw(i)*\frac{\delta}{tpw}\right] + \beta\right]}{[(\alpha*tf)+(\beta*nc)+\delta]}$$

6. Choose a task randomly from the list, according to the selection probability.

$p(l) = p(l-1)+r(i)$, p(0) = 0, p(nc) = 1

Randomly generate q∈(0,1)

Choose the i^{th} task whose cumulative probability satisfy $p(l-1) \le q \le p(l)$ rule.

7. Assign the selected task to the k^{th} station and update the candidate according to the remaining time. x (m,i,k) = 1

8. Deposit pheromone for the chosen task and assigned station.

$gf(i,k) = x(m,i,k)+ gf(i,k)$

9. Repeat step 3 until candidate list is empty

10. Repeat step 5 until all the tasks are assigned to the stations

3.2 Steps Involved in RPW Method

Step 1: Draw the precedence diagram.
Step 2: For each work element, determine the positional weight. It is the total time on the longest path from the beginning of operation to the last operation of the network.
Step 3: Rank the work elements in descending order of ranked positional weight (R.P.W).
Step 4: Assign the work element to a station. Choose the highest RPW element. Then, select the next one. Continue till cycle time is not violated. Follow the precedence constraints also.
Step 5: Repeat step 4 till all operations are allotted to the station.
In this paper, both aforementioned methodologies provide solution to the line balancing problem and compare to have the best results.

4. Data Analysis

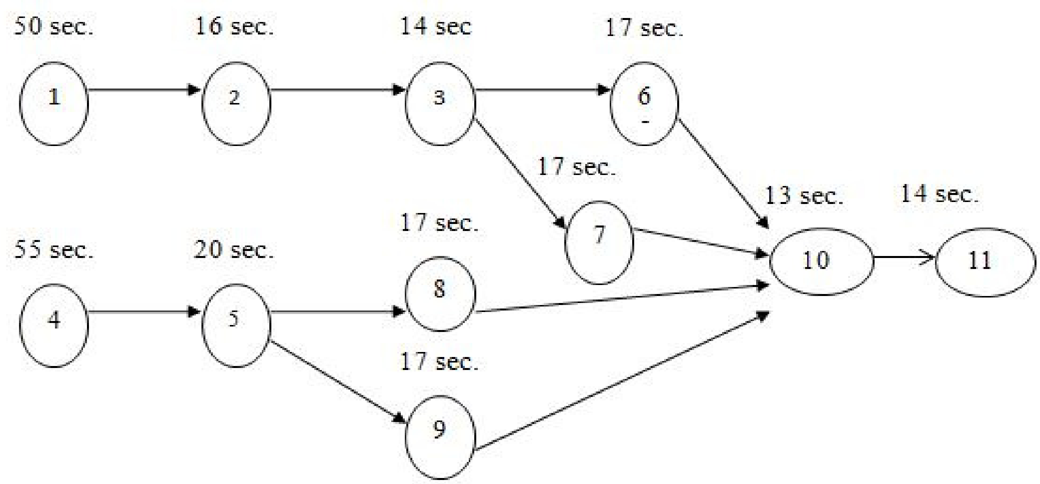
Primary data collected from the Transworld Bicycle Company Ltd. summarization and analysis are given below.

Table 1: Details of Work Elements

Task	Task Time (in seconds)	Task Description	Task that must precede
1	50	Connect the front tire to the bicycle frame	-
2	16	Insert the handle bar	1
3	14	Tighten handle bar with two screws and nuts	2
4	55	Connect the rear tire to the bicycle frame	-
5	20	Position chain mechanism to the frame	4
6	17	Attach right hand brake to handle bar	3
7	17	Attach left hand brake to handle bar	3
8	17	Attach right side pedal	5
9	17	Attach left side pedal	5
10	13	Position chain onto chain mechanism	6,7,8,9
11	14	Attach seat post	10
Total	250		

The precedence diagram is given by

Figure 1: Precedence Diagram



Cycle time, C = 60 sec
Minimum number of workstation, N_{min} = 5
Trial cycle time = 51 ≤ C_r ≤ 60

Table 2: Final Configuration for ACO Based Algorithm

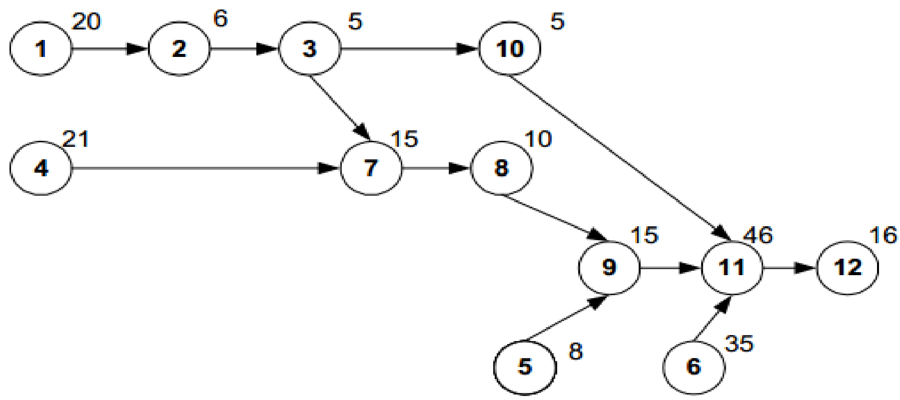
Trial cycle time	Work station 1		Work station 2		Work station 3		Work station 4		Work station 5		Balancing efficiency (%)
	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	
60	1	10	4	5	2,3,5	10	6,7,8	9	9,10,11	16	83.33
59	1	9	4	4	2,3,5	9	6,7,8	8	9,10,11	15	84.75
58	1	8	4	3	2,3,5	8	6,7,8	7	9,10,11	14	86.21
57	1	7	4	2	2,3,5	7	6,7,8	6	9,10,11	13	87.72
56	1	6	4	1	2,3,5	6	6,7,8	5	9,10,11	12	89.29
55	1	5	4	0	2,3,5	5	6,7,8	4	9,10,11	12	90.91

Table 3: Final Configuration for RPW Method

Trial cycle time	Work station 1		Work station 2		Work station 3		Work station 4		Work station 5		Balancing efficiency (%)
	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	
60	1	10	4	5	2,3,5	10	6,7,8	9	9,10,11	16	83.33
59	1	9	4	4	2,3,5	9	6,7,8	8	9,10,11	15	84.75
58	1	8	4	3	2,3,5	8	6,7,8	7	9,10,11	14	86.21
57	1	7	4	2	2,3,5	7	6,7,8	6	9,10,11	13	87.72
56	1	6	4	1	2,3,5	6	6,7,8	5	9,10,11	12	89.29
55	1	5	4	0	2,3,5	5	6,7,8	4	9,10,11	12	90.91

We have also considered a secondary data. The precedence diagram of this secondary data is given by-

Figure 2: Precedence Diagram for Secondary Data



Cycle time, C = 70 sec
Minimum number of workstation, N_{min} = 3
Trial cycle time = 68 ≤ C_t ≤ 70

Table 4: Final Configuration for Secondary Data (ACO)

Trial cycle time	Workstation 1		Workstation 2		Workstation 3		Workstation 4		Balancing efficiency (%)
	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	
70	4,5,1,2,3, 10	5	7,6,8	10	9,11	9	12	54	72.14
69	4,5,1,2,3, 10	5	7,6,8	10	9,11	9	12	54	74.29
68	4,5,1,2,3, 10	5	7,6,8	10	9,11	9	12	54	75.36

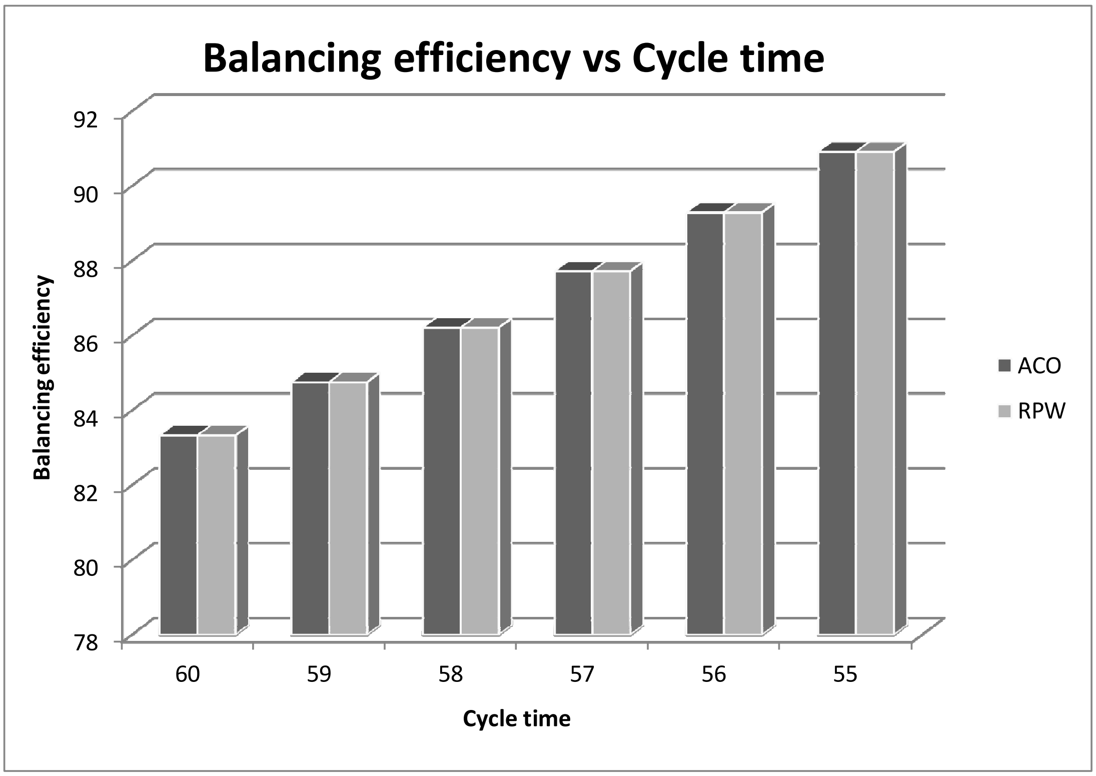
Table 5: Final Configuration for Secondary Data (RPW)

Trial cycle time	Workstation 1		Workstation 2		Workstation 3		Workstation 4		Balancing efficiency (%)
	Elements	Idle time	Elements	Idle time	Elements	Idle time	Elements	Idle time	
70	1,4,2,3,7	3	6,8,5,9	2	10,11	9	12	54	74.29
69	1,4,2,3,7	3	6,8,5,9	2	10,11	9	12	54	75.36
68	1,4,2,3,7	3	6,8,5,9	2	10,11	9	12	54	76.47

5. Results

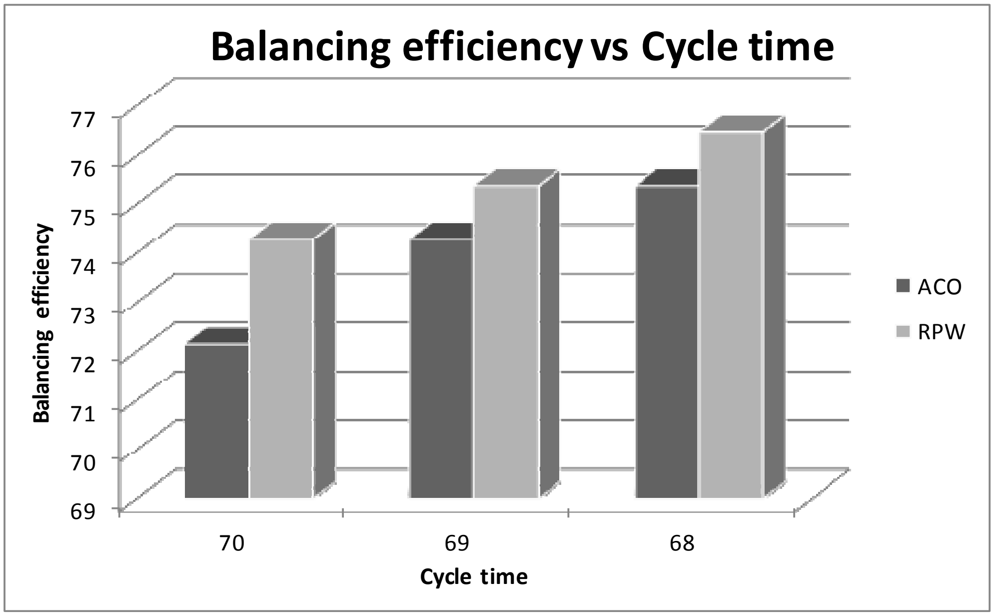
For primary data, it is apparent that the minimum number of workstation is five. By using Ant Colony Optimization (ACO) Algorithm and Rank Positional Weighted (RPW) Method we have found the maximized balancing efficiency with minimization of idle time. Transworld Bicycle Company Ltd. produces four hundred and twenty bicycles every day. Production time per day is 420 minutes. Research investigation shows that if Transworld Bicycle Company Ltd. produces 455 bicycles per day then balancing efficiency would be 90.91%.The balancing efficiency versus cycle time graph is shown below-

Figure 3: Balancing Efficiency versus Cycle Time Graph with Primary Data



In the secondary data we have found that the balancing efficiency is more in RPW Method than ACO Algorithm. So we can conclude that RPW Method gives more precise result than ACO Algorithm. The Balancing efficiency versus cycle time graph is given below-

Figure 4: Balancing Efficiency versus Cycle Time Graph with Secondary Data



In first case, with primary data, the result comparison shows the same results with both methods but the both method have suggested how balancing efficiency of the can be improved. And in second case, with secondary data, the comparison in figure 5.2 shows that the balancing efficiency is greater in RPW method than ACO method. That depicts the hypothesis made from literature review is not accepted neither rejected for primary data and is rejected for secondary data. Other research works do not provide that kind of comparisons in line balancing problems.

6. Conclusions & Future Scope

The key objective of this paper is to reduce the number of workstations for simple model assembly line and to increase the efficiency by reducing non value added activities. The important aspect of this paper is to represent the use of ACO & RPW method to develop the assembly line and balancing that line. With this study it is found that ACO algorithm is more complex and time consuming with the increase of the problem size. On the other hand RPW method is a useful technique of finding out the way to synchronize the work stations for the work flow and sequencing when less data is available and RPW method is capable of representing more précised output than ACO algorithm. By applying both of these methods the bottlenecking of the assemblies can be reduced. In this study numbers of workstations have been selected and balancing efficiency has also been improved. The significance of this study relies on the decisions taken over the primary data collected from Transworld Bicycle Company Ltd. balancing efficiency could be raised up to 90.91% thus increases the throughput. Although this work is limited in the deterministic simple assembly line balancing problem, it represents a good start point for further studies focusing on more difficult assembly line balancing problem such as the stochastic or the dynamic ALBP with U-Type Assembly Line Balancing like parallel lines, two sided assembly lines with some problem specific modifications. In reality, tasks' processing times are rarely deterministic and may vary more or less. Application of other heuristic such as PSO, SA etc. can also be considered as a useful future work to solve assembly line balancing problems.

References

Abdolreza, R., Arezoo, R., Roshani, A., Mohsen, S. and Azadeh, E. 2013, 'A simulated annealing algorithm for multi-manned assembly line balancing problem', *Journal of Manufacturing Systems,* Vol. 32, Pp. 238– 247.

Amardeep, Rangaswamy, T.M. and Gautham, 2013, 'Line balancing of single model assembly line', *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 2, issue 5.

Baykasoglu, A. and Dereli, T. 2009, 'Simple and u-type assembly line balancing by using ant colony based algorithm', *Mathematical and Computer Applications,* Vol. 14, No.1, Pp. 1-12.

Becker, C. and Scholl, A. 2004, 'A survey on problem and methods in generalized assembly line balancing', *European Journal of Operational Research*, Vol. 168, Pp. 694-715.

Blum, C. and Dorigo, M. 2004, 'The hyper-cube framework for ant colony optimization', *IEEE Transactions on Systems, Man, and Cybernetics*, Part B Vol. 34, No. 2, Pp. 1161- 1172.

Boysen, N., Fliedner, M. and Scholl, A. 2007, 'A classification of assembly line balancing problems', *European Journal of Operational Research*, Vol. 183, No. 2, Pp. 674-693.

Chica, M., Cordon, O., Damas, S. and Bautista, J. 2012, 'Multi objective memetic algorithms for time and space assembly line balancing', *Engineering Applications of Artificial Intelligence*, Vol. 25, Pp. 254–273.

Ghutukade, Santosh, T. and Sawant, D.S.M. 2013, 'Use of ranked position weighted method for assembly line balancing', *International Journal of Advanced Engineering Research and Studies*, Pp. 01-03.

Giard, V. and Jeunet, J. 2010, 'Optimal sequencing of mixed models with sequence dependent setups and utility workers on an assembly line', *International Journal of Production Economics*, Vol. 123, No. 2, Pp. 290-300.

Gokcen, H., Agpak, K., Gencer, C. and Kizilkaya, E. 2005, 'A shortest route formulation of simple U-type assembly line balancing problem', *Applied Mathematical Modeling*, Vol. 29, Pp. 373-380.

Hong, J.M., Lee, G.C., Kim, K. and Choi, S.H. 2015, 'An Ant Colony Algorithm for Assembly Line Balancing Problems with relax able Constraints', *Indian Journal of Science and Technology*, Vol. 8, Pp. 424–427.

Kriengkorakot, N. and Pianthong, N. 2007 'The assembly line balancing problem review articles', *KKU Engineering Journal*, Vol. 34, No. 2, Pp. 133 - 140.

Krishnaiyer, K. and Cheraghi, S.H., 2002, 'Ant Algorithms: Review and Future Applications', *Proceeding of the second annual meeting of Industrial Engineering Research Conference*, Industrial Engineering Research Conference, Orlando, Florida, USA.

Kumar, N. and Mahto, D. 2013, 'Assembly Line Balancing: A Review of Developments and Trends in Approach to Industrial Application', *Global Journal of Researches in Engineering Industrial Engineering*, Vol. 13, Issue. 2, Version 1.

McMullen, P.R. and Tarasewich, P. 2003, 'Using ant techniques to solve the assembly line balancing problem', *IIE Transactions*, Vol. 35, Pp. 605–617.

Nakade, K. and Ohno, K. 2003, 'An Optimal Worker Allocation Problem for a U shaped Production Line', *International Journal of Production Economics*, Vol. 60, No.1, Pp. 353-358.

Nearchou, A.C. 2008, 'Multi-objective balancing of assembly lines by population heuristics', *International Journal of Production Research*, Vol. 46, No. 8, Pp. 2275-2297.

Otto, A. and Scholl, A. 2011 'Incorporating ergonomic risks into assembly line balancing', *European Journal of Operational Research*, Vol. 212, No. 2 Pp. 277-286.

Ozcan, U. and Toklu, B. 2009, 'Multiple-criteria decision-making in two-sided assembly line balancing: A goal programming and a fuzzy goal programming models', *Computers & Operations Research*, Vol. 36, Pp. 1955-1965.

Purnomo, H.D., Wee, H.M. and Rau, H. 2013, 'Two-sided assembly lines balancing with assignment restrictions', *Mathematical and Computer Modelling*, Vol. 57, Pp.189 199.

Roy, D. and Khan, D. 2010, 'Assembly line balancing to minimize balancing loss and system loss', *Journal of Industrial Engineering International*, Vol. 6, No.11, Pp.1-5

Scholl, A & Becker, C 2006, 'State-of-the-art exact and heuristic solution procedures for simple assembly line balancing', *European Journal of Operational Research*, vol.168, no. 3, pp. 666–693.

Toksari, MD, Isleyen, SK, Guner, E & Baykoc, OF 2008, 'Simple and U-type assembly line balancing problems with a learning effect', *Applied Mathematical Modelling*, vol. 32, pp. 2954–296

Tuncel, G & Topaloglu, S 2013, 'Assembly line balancing with positional constraints, task assignment restrictions and station paralleling: A case in an electronics company', *Computers & Industrial Engineering,* vol. 64, pp. 602–609.

Yagmahan, B 2011, 'Mixed-model assembly line balancing using a multi-objective ant colony optimization approach', *Expert Systems with Applications*, vol. 38, pp. 12453–12461.