An Improved Ant Colony Optimisation Algorithm for Type-I Parallel Two-Sided Assembly Line Balancing Problem

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An Improved ACO Algorithm for Type-I Parallel Two-Sided Assembly Line Balancing Problem

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Outline

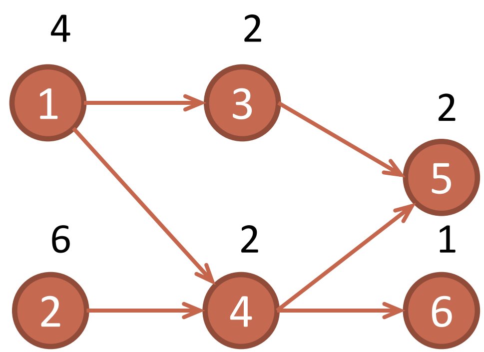
- Introduction
- Problem Description (PTALBP-I)
- Proposed Method (Improved Ant Colony Optimisation Algorithm)
- An Illustrative Example
- Discussion
- Conclusions and Future Research

Introduction

Assembly lines are mostly used flow oriented production systems in mass production environment, and it has been *over five decades* since researchers first discussed the most basic version of *Assembly Line Balancing Problem, which is Simple Assembly Line Balancing Problem* (SALBP) (Yaman, 2008; Wei and Chao, 2011).

Figure 1. A view from GM automobile factory which shows assembly line workers attach tires to GM vehicles (http://bentley.umich.edu/research/guides/automotive/workers.php).

Introduction



$$\text{Cycle Time} = \frac{\text{Planning Period}}{\text{Production Quantity}}$$

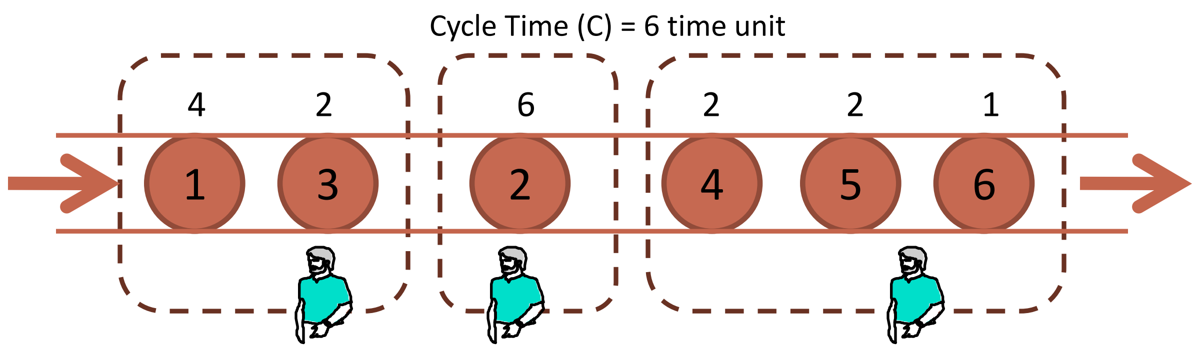


Figure 2. Illustration of an assembly line
(adapted from: Kara et al., 2010)

Introduction

Problem types

		Cycle Time (C)	
		Given	Minimise
Number of Stations (m)	Given	ALBP-F	ALBP-2
	Minimise	ALBP-1	ALBP-E

Four types of line balancing problems are defined by using different objectives (adapted from Scholl and Becker 2006):
ALBP-1 minimises the number (m) of stations given the cycle time (c),
ALBP-2 minimises c given m,
ALBP-E maximises the line efficiency E,
ALBP-F seeks for a feasible solution given m and c.

Introduction

- Two-sided assembly lines are usually utilised to produce standardised high-volume large-sized products such as trucks and buses. However, there are only a few researchers who address this problem.

Figure 3. Two workers one on each side of the line (http://www.npr.org/blogs/thetwo-way/2011/02/14/133750236/gm-to-pay-hourly-workers-more-than-4-000-each-in-bonuses)

Introduction

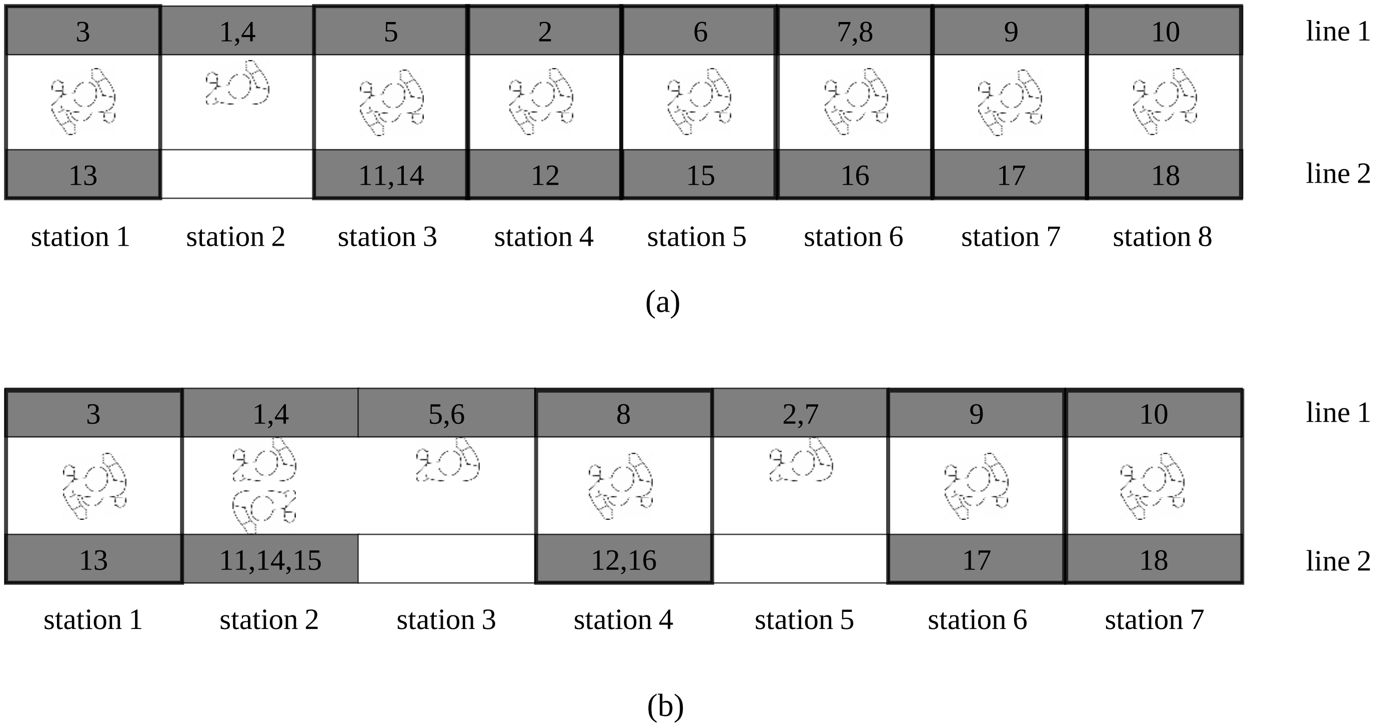


Figure 7. Two different solutions (a and b) with split and normal workplaces (Scholl and Boysen, 2009).

PROVIDES

- *shortening assembly line*
- *more flexibility*
- *split workplaces*

BUT

- *may cause more worker and equipment cost*

Literature Review

- Simple ALB problem *was defined by* Helgeson et al. (1954), and *modelled mathematically* by Salveson (1955).
- Since then, line balancing has been of continuing interest to academia and industry with the development of manufacturing systems (Ghosh and Gagnon, 1989).

Literature Review

Research	Method / Solution Approach	Main Object. (min)	Additional constraints/features
Suer (1998)	3-phase heuristic with IP and MILP model	Number of lines and workstations	Dynamic number of lines
Gokcen et al. (2006)	Heuristic procedures and a mathematical programming model	Number of workstations	Fixed number of lines
Benzer et al. (2007)	A network model	Number of workstations	Fixed number of lines
Lusa (2008)	Survey		
Baykasoglu et al. (2009)	Ant colony optimisation	Number of workstations	Fixed number of lines
Cercioglu et al. (2009)	Simulated annealing based approach	Number of workstations	Fixed number of lines
Ozcan et al. (2009)	Tabu search algorithm	Number of workstations	Fixed number of lines, workload balance between workstations
Scholl and Boysen (2009)	Binary linear programme and Salome based exact solution procedure	Number of workstations and operators	Product-line assignment considered
Kara et al. (2010)	Two goal programming approaches	Number of workstations, cycle time, and task loads of workstations	Three conflicting goals
Ozcan et al. (2010a)	Simulated annealing algorithm	Number of workstations, workload variance between workstations	Mixed-models and model sequencing considered
Ozcan et al. (2010b)	**Tabu search algorithm**	**Number of workstations**	**Two-sided PALBP**
Kucukkoc et al. (2013)	**Ant Colony Optimisation**	**Number of workstations and line length**	**Two-sided PALBP**

Introduction

- Kucukkoc at al. (2013) proposed *first Ant Colony Optimisation (ACO) algorithm* to solve *parallel two-sided assembly line balancing problem (PTALBP)*. They employed two type of pheromone release strategy:
  - Between task-last assigned task,
  - Between task-qzone in which task is assigned.

- However, they did not consider any heuristic algorithm to select tasks.

- In this study, the ant colony optimisation algorithm developed by Kucukkoc et al. (2013) is *improved* by employing *a heuristic rule* to search solution space more effectively.

Literature Review

- The conclusion that can be drawn from this literature review is that, parallel two-sided assembly line balancing problem is a new research domain.

- Although there are many studies on different types of line balancing problems, the studies on parallel two-sided assembly line balancing problem are very scarce.

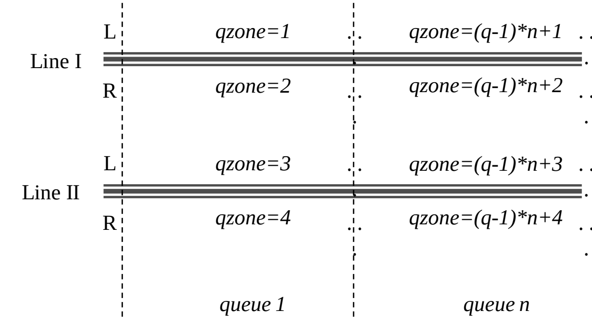
Problem Description

- The *parallel two-sided assembly line balancing problem is*, balancing more than one two-sided assembly line which are constructed in parallel by considering some constraints such as *precedence relationships*, *capacity constraints*, *positional constraints*, and *zoning constraints*.

- Parallel two-sided assembly line balancing problem (PTALBP) is *a new research domain* first described by Ozcan *et al.* (2010b).

- Parallel two-sided assembly lines carry *many advantages of both parallel assembly lines and two-sided assembly lines*.

Problem Description



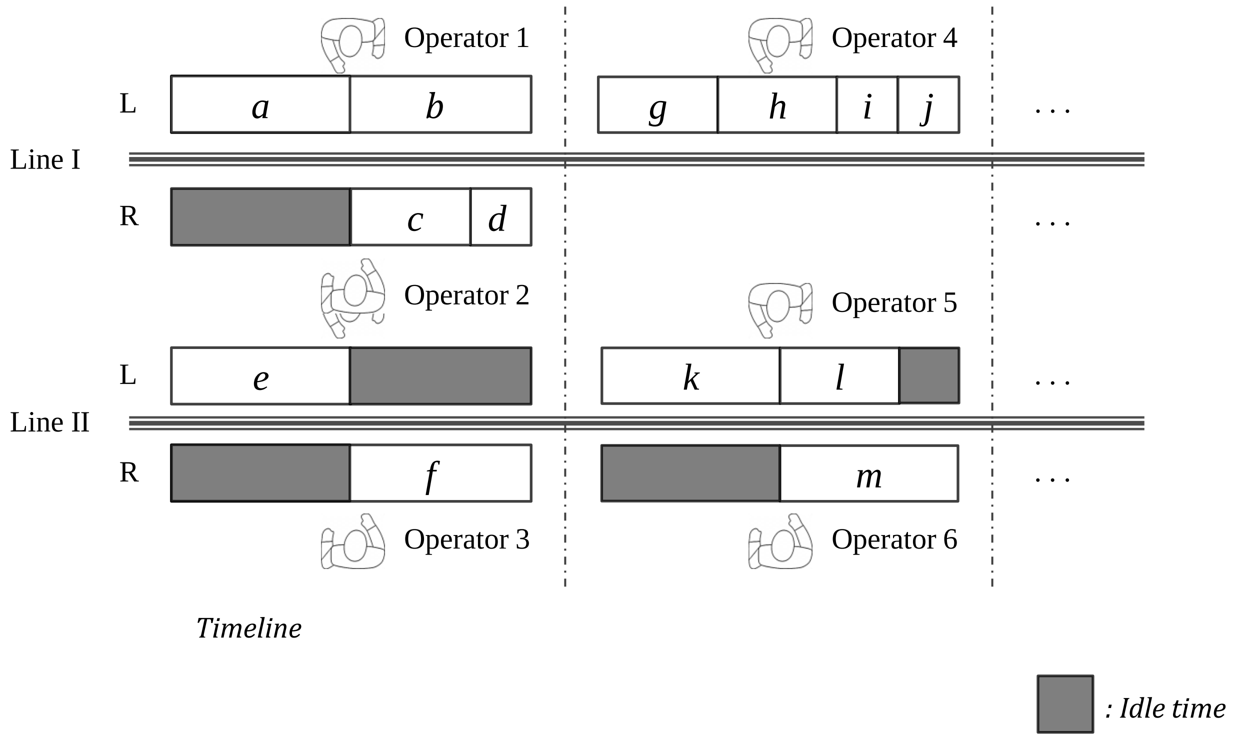


Figure 4: An illustration of parallel two-sided assembly lines (Kucukkoc et al., 2013)

PTALBP is…

Advantages

- *shortening* assembly line
- *more flexibility*
- *split workplaces*

- Ozcan et al (2010b)

Problem Description

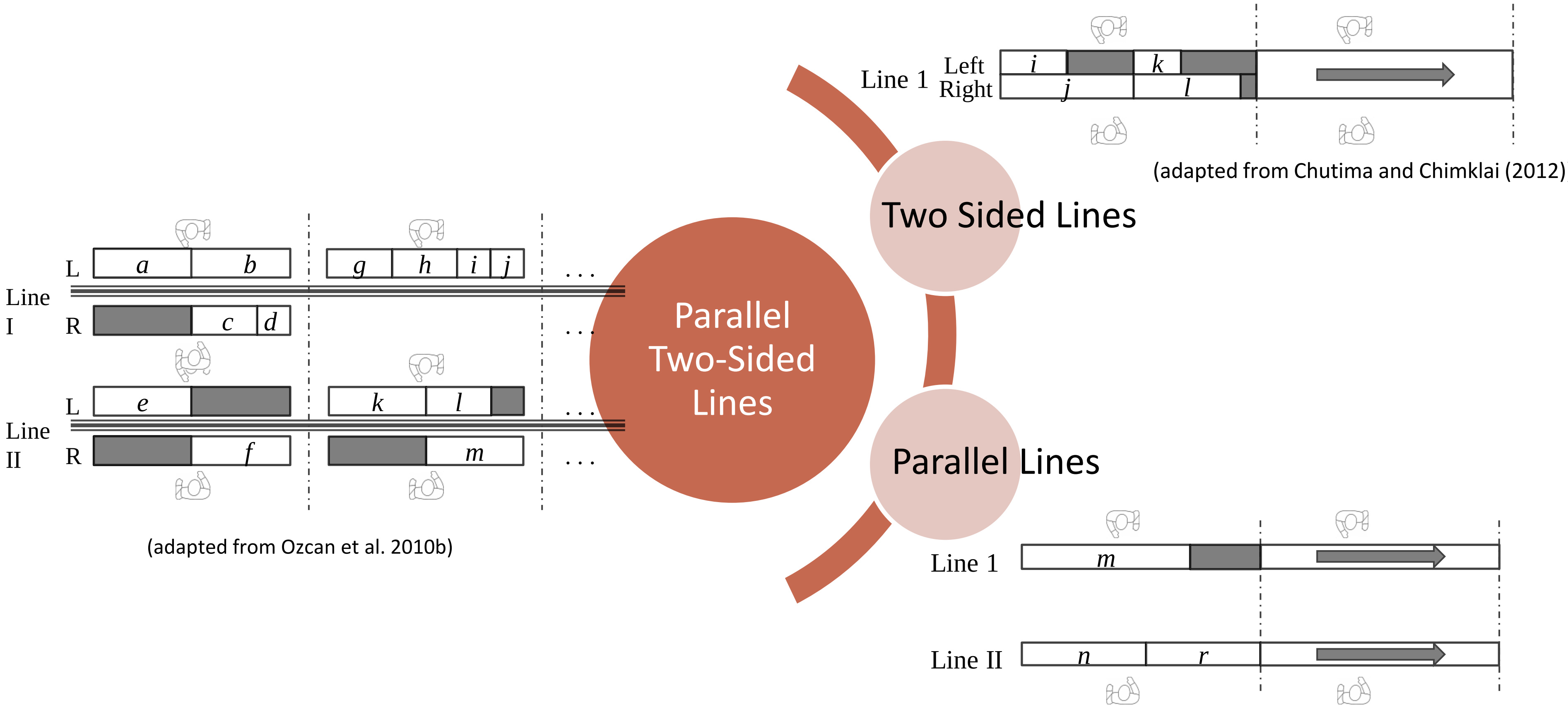


Figure 5: Main structure of parallel two-sided assembly lines (Kucukkoc et al., 2013)

Problem Description

- Minimise:
  - *total number of workstations*
  - *total line length* by considering predefined constraints.

$$\min\left(\sum_{k=1}^{S} z_k + \varepsilon \max_{k=1,\ldots,S}\{q_k\}\right)$$

where $max\{q_k\}$ demonstrates total line length, z_k is a binary variable and ε is a user defined weighting factor;

$$z_k = \begin{cases} 1 & if\ station\ k\ is\ utilised \\ 0 & otherwise \end{cases}$$

Problem Description

- The *assumptions/constraints* considered in the study are as follows (Ozcan et al., 2010b; Kucukkoc et al., 2013):
  - *Only one model (m) is assembled on each particular line* (h). So, the total number of the lines equals to total number of the models $(H = M)$,
  - Task times are known and deterministic,
  - Each task must be assigned to *exactly one workstation*,
  - *Cycle time* is larger than total workload of any workstation,
  - Each product model has its own set of tasks and precedence relationships,
  - A task can only be started if all of its *predecessor tasks have been assigned* and completed,
  - Tasks can be assigned only a predetermined side of the line (left - L, right - R, or either - E),

Proposed Method (ACO Algorithm)

- PTALBP problems are *NP-Hard* type of problems
- ACO algorithm (Dorigo et al., 1996) has been used to solve *various kind of NP-Hard problems* in a reasonable time (Zhang et al., 2007).
- First ACO to solve line balancing problem were implemented by McMullen and Tarasewich (2003).
- *First and only ACO approach to solve PTALBP* problem was developed by Kucukkoc et al. (2013) recently.
- However they did benefit from any heuristic algorithm for local search.

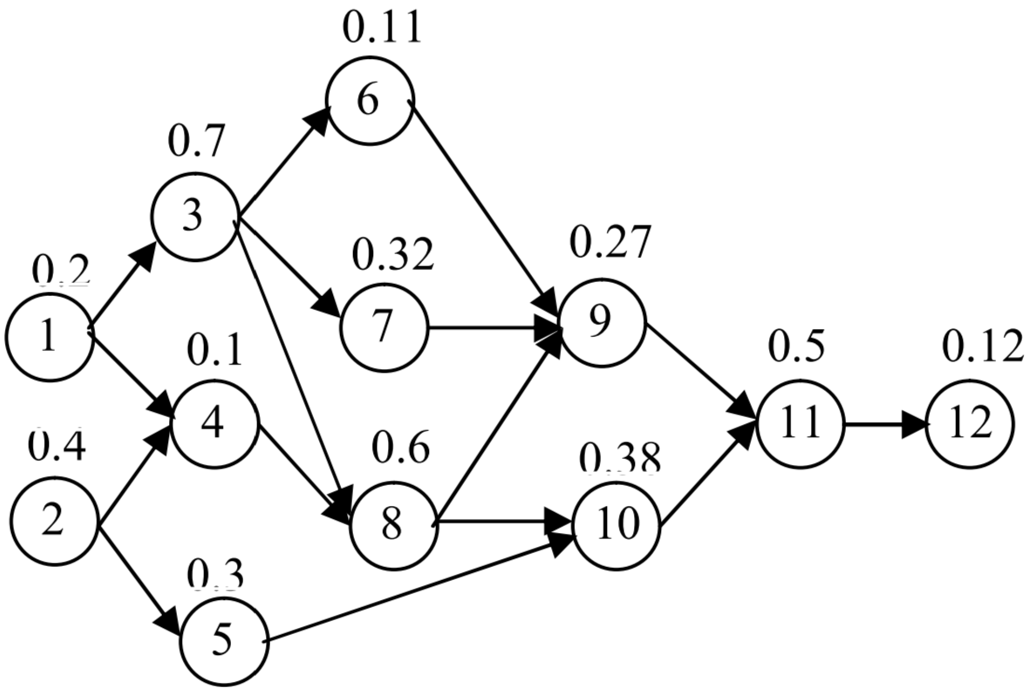
Proposed Method (ACO Algorithm)

- In the current research, we integrated *Positional Weight Method (PWM),* which is proposed by Helgeson and Birnie (1961), in order to help the convergence of the algorithm.

- In PWM, positional weights of tasks are calculated for each task. Positional weight of a task is defined as "*time of the longest path from the beginning of the operation through the remainder of the network* (Ponnambalam *et al*., 1999).

Proposed Method (ACO Algorithm)

- Calculation of Positional Weights



Work element	RPW
1	3.3
3	3
2	2.67
4	1.97
8	1.87
5	1.3
7	1.21
6	1.00
10	1.00
9	0.89
11	0.62
12	0.12

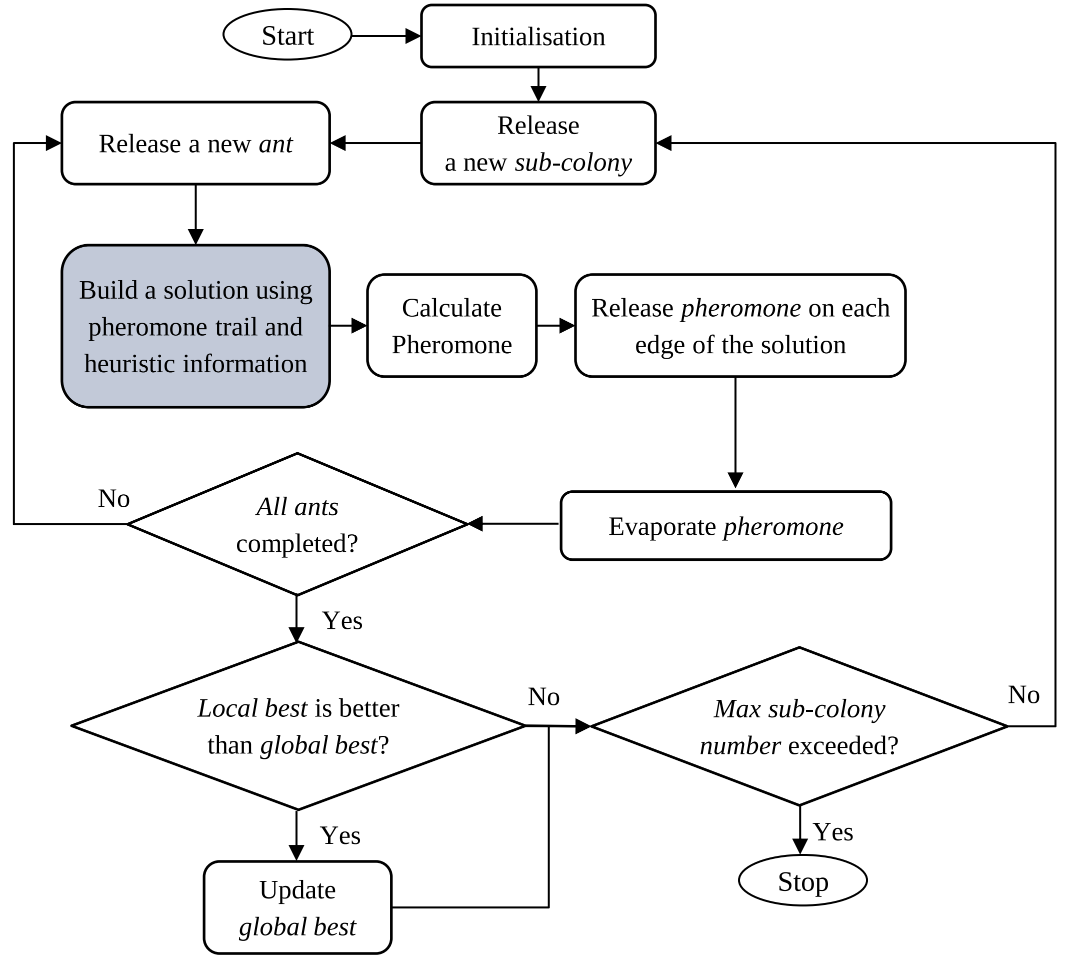


Figure 8.
Flowchart of proposed ACO
(adapted fromKucukkoc et al. 2013)

Proposed Method (ACO Algorithm)

- The probability of selection task i for ant k in qzone z while in t^{th} tour is:

$$p_{iz}^{k}(t) = \frac{[\tau_{iz}(t)]^{\alpha}[\eta_i(t)]^{\beta}}{\sum_{y \epsilon Z_i^k}\left[\tau_{iy}(t)\right]^{\alpha}[\eta_i(t)]^{\beta}}$$

- The amount of virtual pheromone between *task - qzone is represented with* $\tau_{iz}(t)$.

- The heuristic information of task i that comes from *Positional Weight Method is represented by* $\eta_i(t)$.

Proposed Method (ACO Algorithm)

- The pheromone update rule used in this research is:

$$\tau_{iz}(t+1) = (1-\rho)\tau_{iz}(t) + \Delta\tau_{iz}(t)$$

$$\Delta\tau_{iz}(t) = \frac{\mu}{Objective\ Function\ Value}$$

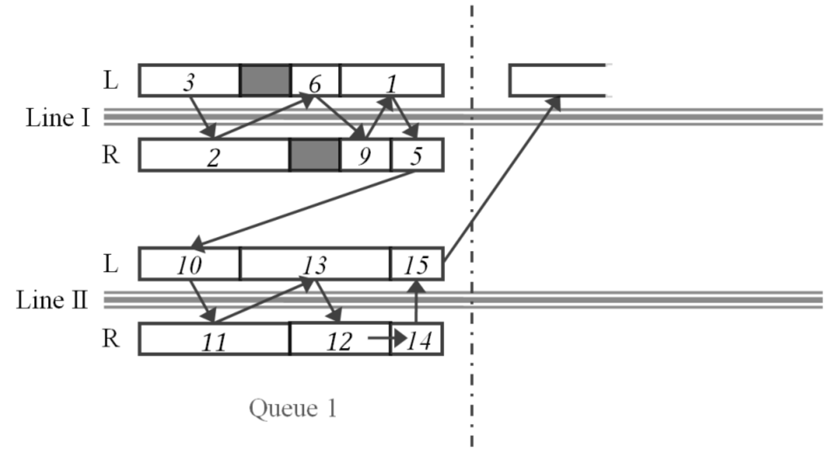
where μ is a user defined value between 40-100.

α and β values, and other parameters are selected after a set of preliminary experiments.

Parameter	Value
α	0.1
β	0.3
ρ	0.1
Initial pheromone level	15
Number of ants in each colony	10
Total number of colonies	10
Significance of line length (ε)	0.5
User defined value (μ)	40-100

Proposed Method (ACO Algorithm)

Select the first line
Start from left side of the line
While there are unassigned tasks
    Determine available tasks (in terms of precedence, capacity, and other constraints)
    Select an available task using *pheromone trail* and *heuristic information*
    Assign selected task into the current workstation
    Increase station workload as task time
        If $st(k) > st(\underline{k})$ **then**
            Change side (left or right)
        End if
        If both sides do not have enough capacity to assign available tasks **then**
            Select other line
            Start from left side of the line
        End if
        Update unassigned tasks list
End while



Pseudo Code of building a balancing solution (Kucukkoc et al. 2013)

An Illustrative Example

- For this aim, the problem (P16) of Lee et al. (2001) is selected and adapted by changing task time of task 16 from 4 to 3.

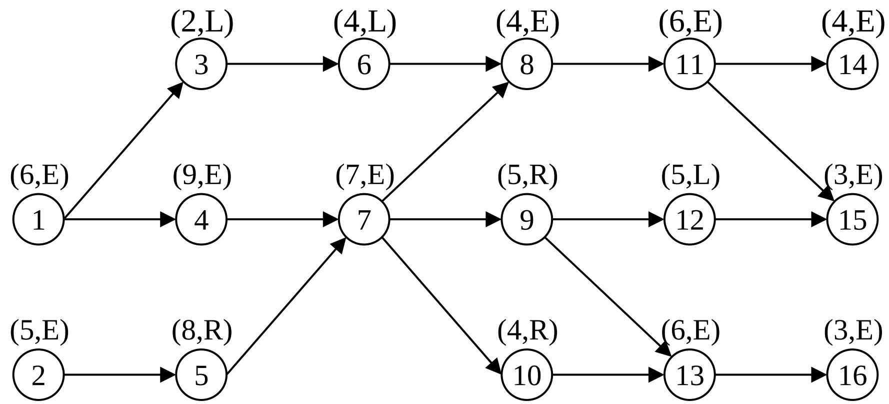


Figure 9. Precedence relationship diagram for illustrative example (adapted from Lee et al., 2001)

- Two same product models that have *same precedence relationships* and *same task times* are assembled on two parallel two-sided lines (one on each line).

An Illustrative Example

- In the precedence relationship diagrams, task times are given in nodes while preferred operation directions (sides) are shown over nodes.
- *Cycle time* is assumed as *16 time units* for this problem.

Assignable task lists are shown on parallel two sided assembly lines

Assignable Tasks

Line I	Left Side	*1, 2, 3, 4, 6, 7, 8, 11, 12, 13, 14, 15, 16*
	Right Side	*1, 2, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15, 16*
Line II	Left Side	*1, 2, 3, 4, 6, 7, 8, 11, 12, 13, 14, 15, 16*
	Right Side	*1, 2, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15, 16*

Figure 10. Assignable tasks are shown on the lines

An Illustrative Example

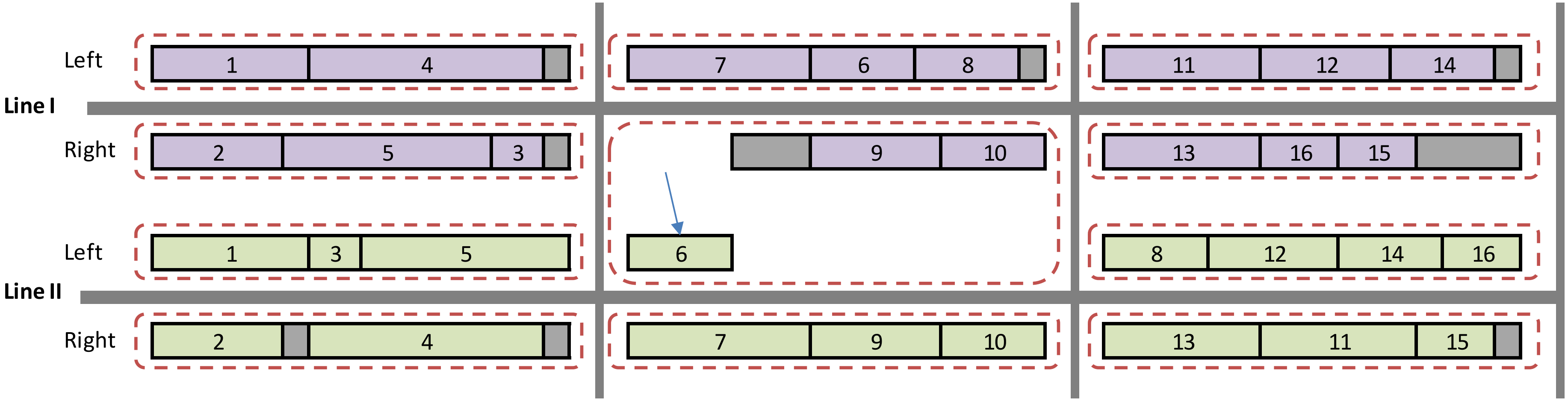


Figure 11. Obtained best solution for illustrated example

- 11 workstations
- 1 merged workstation

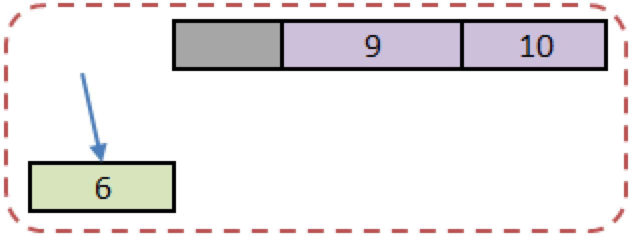
$$Balance\ Delay = \frac{11 \times 16 - 163}{11 \times 16} = 0.073$$

Discussion

- *Theoretical minimum number of workstations* for illustrated example is 11 workstations (Ozcan et al., 2010b). So, *optimal solution is found* by the proposed algorithm for given problem.

- Computed balance delay for given example is 7.5%. So, it means lines are balanced quite efficiently.

- Two workstations are merged in queue 2 and built one workstation. Thus, the operator assigned to merged workstation first completes his/her job on left side of Line II and then completes his/her job on right side of Line I.



Discussion

- A heuristic algorithm is integrated with ACO algorithm to search solution space more effectively in current research.

- The *heuristic algorithm* used in this research *provides some kind of information* for tasks about workload of their successors, and helps the algorithm *to assign tasks that play critical role as early as possible*. So that, *idle times* are trying to be minimised.

- *More experiments* could be processed on medium-large sized problems to assess the efficiency of the algorithm.

Conclusions and Future Research Directions

- The main purpose of this research is:
  - to improve the ACO algorithm, which is proposed by Kucukkoc et al. (2013) to solve PTALBP, to increase the capability of current method,
  - show how more than one two-sided assembly line, which is constructed in parallel, is balanced together using an ant colony optimisation based approach.

- There is only one published work on ACO algorithm for any type of Parallel Two-Sided Assembly Line Balancing Problem.

- The algorithm uses *task-qzone* (Kucukkoc et al., 2013) based pheromone trails and heuristic information (PWM) to build solutions.

Conclusions and Future Research Directions

- To assess the performance of the algorithm, *a set of large-sized benchmark problems can be solved with the proposed approach* and obtained results can be compared with existing tabu search algorithm in the literature.

- Additionally, *some additional constraints can also be considered* for future researches; such as positive and negative zoning constraints, synchronous tasks constraints, and positional constraints.

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Thanks for your attention.

Any Questions Please?