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On Applications of Ant Colony Optimisation Techniques in Solving Assembly Line Balancing Problems

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Abstract

Recently, there is an increasing interest in applications of meta-heuristic approaches in solving various engineering problems. Meta-heuristics help both academics and practitioners to get not only feasible but also near optimal solutions where obtaining a solution for the relevant problem is not possible in a reasonable time using traditional optimisation techniques. Ant colony optimisation algorithm is inspired from the collective behaviour of ants and one of the most efficient meta-heuristics in solving combinatorial optimisation problems. One of the main application areas of ant colony optimisation algorithm is assembly line balancing problem.

In this paper, we first give the running principle of ant colony optimisation algorithm and then review the applications of ant colony optimisation based algorithms on assembly line balancing problems in the literature. Strengths and weaknesses of proposed algorithms to solve various problem types in the literature have also been discussed in this research. The main aim is to lead new researches in this domain and spread the application areas of ant colony optimisation techniques in various aspects of line balancing problems. Existing researches in the literature indicate that ant colony optimisation methodology has a promising solution performance to solve line balancing problems especially when integrated with other heuristic and/or meta-heuristic methodologies.

Keywords: Ant colony optimisation; assembly line balancing; manufacturing systems; survey; meta-heuristics; artificial intelligence

1. Introduction

Ant algorithm, proposed by Dorigo et al. (1996), is one of the nature inspired algorithms. They developed an ant system (AS) meta-heuristic, initial form of ant colony optimisation (ACO) technique, to solve small-sized travelling salesman problem with up to 75 cities. Since then, several researchers carried out a substantial amount of research in ACO algorithm, which demonstrates a better performance than AS.

ACO algorithm is inspired by observation of real ant colonies in the nature and their capability of finding the shortest path between the nest and food sources. Foraging behaviour of ants help them find the shortest path by depositing a substance called pheromone on the

ground while they are walking. In this way, a pheromone trail is formed and ants smell pheromone to choose their way in probability. Paths involve strong pheromone levels have more chance to be selected by ants (Dorigo et al., 1999). The pheromone trail is favourable to the succeeding ants which are intended to follow it. When a set of possible paths are given to the ants, each ant choses one path randomly, and apparently some ants picking the shortest path will return faster. Then, there will be more pheromone on the shortest path, influencing later ants to follow this path, after their completion of one tour. By time, the path has high level pheromone will be most often selected and considered as the shortest route (Leung et al., 2010). The famous double bridge experiment (Dorigo et al., 1999) depicts the selection of shortest path by ants (see Figure 1).
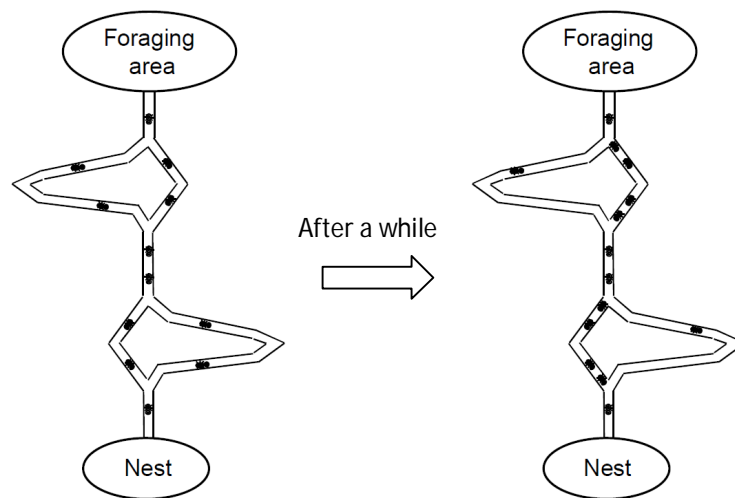

Figure 1 Double bridge experiment, adapted from (Dorigo et al., 1999)

There exist some rules in the ACO algorithms to determine:

- the amount of pheromone deposited on edges,
- the edge chosen by on its way,
- the pheromone evaporation speed.

The transition probability of moving from node i to node j for an ant a located at node i is computed as follows (Ilie and Badica, 2013):

$$p_{(i,j)} = \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}]^\beta}{\sum_j [\tau_{ij}]^\alpha [\eta_{ij}]^\beta}$$

where τ_{ij} is the amount of pheromone deposited on edge (i,j); η_{ij} is the weight of edge (i,j) or heuristic information provided by an integrated heuristic procedure; α and β are parameters to control the influences of τ_{ij} and η_{ij} respectively; and j is a non-visited node reachable from node i.

The algorithm converges with the help of pheromone update rules. So, more pheromone is laid on each edge of tour when a better solution is found than the best known, with cost C_a.

$$\Delta \tau_{ij} = \begin{cases} 1/C_a & \text{if edge } (i,j) \text{ belongs to found tour} \\ 0 & \text{otherwise} \end{cases}$$

When each ant completes its tour, it will update the pheromone by laying down pheromone on the edges of the travelled path. Additionally, an amount of pheromone will be evaporated from each nodes either visited or not. Evaporation and pheromone updates are calculated as follows (Ilie and Badica, 2013):

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

where ρ is pre-determined evaporation rate $(0 \leq \rho < 1)$.

Figure 2a gives a flowchart of proposed ant colony optimisation approach for parallel two-sided assembly line balancing problem. The proposed algorithm starts with initialisation of pheromones. A new colony is released and different solutions (paths) are obtained by each ant in the colony. The basic idea is selection of tasks to be added to the current workstation by artificial ants. Pheromone level determines the probability of a task being selected by an ant. Pheromones, a measure of each path's relative desirability, are calculated according to the quality of the drawn path by each ant.

In the algorithm a new pheromone releasing strategy has been used instead of a heuristic search. So, two types of pheromone have been released by each ant according to the quality of the drawn path: (i) between *task* and *last assigned task*, and (ii) between *task* and *qzone* number. A constant value of pheromone is evaporated after each tour. When a colony is completed their tour, global best solution is updated if a better solution is found and double pheromone is laid to the edges of global best solution. The algorithm continues until all colonies complete their tour and stops when a predetermined maximum colony (*Max Colony*) number has been exceeded.

Pseudo code of building a balancing solution procedure is given below (see Figure 4). Each ant draws a path using this code to build a balancing solution.

In the code, $st(k)$ means workload of current workstation while $st(\underline{k})$ represents workload of its mated workstation (Simaria and Vilarinho, 2009).

While allocating tasks to line I, if both sides do not have enough capacity to assign available tasks from line I (product model 1), efficiency of right side workstation is checked whether more tasks can be assigned from line II (product model 2). If yes, tasks are assigned from line II until right side workstation gets full, to decrease idle times.
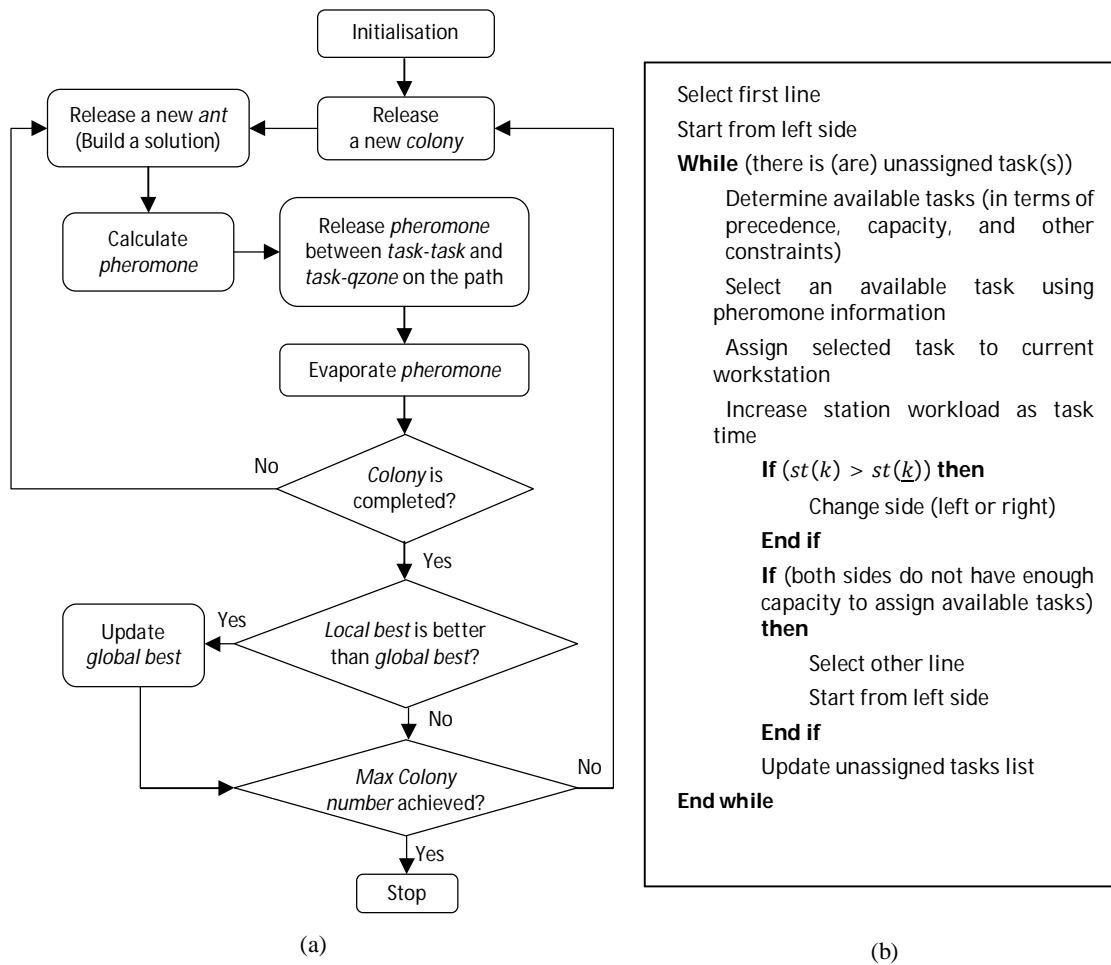
Figure 2 (a) Flowchart of ACO algorithm and (b) pseudo code of balancing a solution procedure for parallel two-sided assembly line balancing problem, adapted from (Kucukkoc et al., 2013a)

One of the main application areas of ACO algorithm is assembly line balancing problem. Previous researches that involve ACO techniques to solve various kinds of ALB problems are summarised in Table 1 and briefly extracted below.

As could be seen from the table, the first technique that uses concepts derived from ant colony optimisation to solve line balancing problem was implemented by McMullen and Tarasewich (2003). Then, ACO techniques have been applied to wide range of line balancing problems, from straight lines to parallel lines. Many different performance measures were sought in these problems like number of workstations, cycle time, design cost, completion on time, workload smoothness, work relatedness and so on. However, still some types of assembly lines utilised in industry, i.e. mixed-model parallel two-sided assembly lines have not been addressed by any research in the literature. So, the authors' on-going work focusses on this topic.

Table 1 Summary of the literature review on ACO based approaches to solve ALB problems

Research	Line Configuration				Mixed-Models	Parallel Stations	Main Obj. (min)			Additional Constraints				Additional Features / Keywords
	Straight	U-Shaped	Parallel L.	Two-Sided			N	C	S	Zoning	Positional	Synch. Tasks	Space	
McMullen and Tarasewich (2003)	●				●	●		●						Stochastic task times, design cost, completion on time
McMullen and Tarasewich (2006)	●					●			●					Multiple objectives considered, (i) crew size, (ii) design cost, and (iii) probability of completing tasks on time used as objective
Vilarinho and Simaria (2006)	●				●	●	●			●				Workload smoothness, line length
Bautista and Pereira (2007)	●						●						●	
Zhang et al. (2007)	●						●							Pheromone summation rules
Baykasoglu and Dereli (2008)				●			●			●				Work relatedness
Baykasoglu and Dereli (2009)	●	●					●							
Baykasoglu et al. (2009)			●				●							
Khaw and Ponnambalam (2009)	●	●					●							Workload smoothness
Sabuncuoglu et al. (2009)		●					●							
Simaria and Vilarinho (2009)				●	●		●			●		●		Workload smoothness
Chica et al. (2010)	●						●						●	
Chica et al. (2011)	●						●	●					●	Multi-objective, labour cost, space cost
Fattahi et al. (2011)	●						●							Multi-manned stations, stochastic mechanism help ants
Ozbakir et al. (2011)			●				●							Bi-objective evaluation function
Sulaiman et al. (2011)	●						●							Look forward ant
Yagmahan (2011)	●				●									Workload smoothness
Kucukkoc et al. (2013a)			●	●			●	●						Line length
Kucukkoc et al. (2013b)			●	●			●	●						RPWM heuristic, line length

N: Number of workstations, C: Cycle time, S: Special

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