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Bi-objective dependent location quadratic assignment problem: Formulation and solution using a modified artificial bee colony algorithm

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ABSTRACT

Combinatorial optimization problems arise from various real life situations and the quadratic assignment problem (QAP) to model a facility layout problem or a plant location problem is such an example. While examining the facility layout of a semi-automated bus body manufacturing unit, a bi-objective facility layout optimization problem is identified in which the solution space of the second objective function depends and changes upon the feasible solutions of the first objective function. In this paper, the said problem is first defined in the form of a bi-objective quadratic dependent location assignment problem (bi-d-QAP), a heuristic solution approach is then provided, and finally, a modified artificial bee colony algorithm is proposed while combining both the genetic and neighborhood search algorithms to solve the considered bi-d-QAP. The data obtained from the above-mentioned manufacturing unit are utilized to show how the proposed algorithm performs better in comparison to some of the popular state-of-the-art optimization algorithms.

1. Introduction

Knowles and Corne (2002) introduced the concept of multi-objective quadratic assignment problem (mQAP) in which more than one type of flow (flow matrix) can be minimized simultaneously within a common facility (distance matrix). Since then, researchers have proposed several approaches to solve mQAPs. A few examples of such approaches include Pareto local search (PLS) algorithm (Paquete & Stützle, 2006; Drugan & Thierens, 2012; Dubois-Lacoste, López-Ibáñez, & Stützle, 2015), greedy randomized adaptive search procedure (GRASP) (Li & Landa-Silva, 2009), multi-objective go with the winner (MOGWW) algorithm (Gutiérrez & Brizuela, 2007, 2011), and multi-objective ant colony optimization (mACO) algorithm (Özkale & Fığlalı, 2013). All of these approaches have mainly utilized randomly generated test problems to demonstrate the performance and efficacy of the developed algorithms. In this paper, a maiden attempt is taken to solve a complex facility layout problem (FLP) of a real time manufacturing unit in the form of an mQAP using a modified artificial bee colony (ABC) algorithm.

Real life problems often consist of multiple, dissimilar subproblems that are to be optimized or analyzed simultaneously. Typically, these subproblems are strongly connected through some criteria or variables. These kinds of problems are termed as 'interwoven systems' or 'system of systems' (Maier, 1998; Klamroth et al., 2017). Stolk, Mann, Mohais, and Michalewicz (2013) identified a water tank transport and packing problem while researching on a real time problem faced by the schedule planners for transporting water tanks for an Australian company; Bonyadi, Michalewicz, and Barone (2013) defined the 'travel and thief problem' and Klamroth et al. (2017) provided an academic example of interwoven systems. An integrated location problem is also a typical example of a system of systems.

While working on facility layout optimization of a bus body manufacturing unit, an FLP is identified which consists of two simultaneous layout optimization subproblems connected by the feasible allocation of one problem. The objectives of this paper are thus focused towards the followings:

(a) formulation of the subproblems in the form of QAP and thereby, formation of bi-objective QAP (bQAP), named as bi-d-QAP to solve the FLP.
(b) developing a heuristic approach to solve the bi-d-QAP.
(c) modification of ABC algorithm to solve the bi-d-QAP.
(d) performing a sensitivity analysis to select the most appropriate parametric settings of the modified ABC algorithm for solving the bi-d-QAP.
(e) comparing the derived results with seven other state-of-the-art multi-objective optimization algorithms to establish the efficacy of the proposed ABC-based algorithm for solving bi-d-QAP.

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These seven other state-of-the-art algorithms are (a) non-dominated sorting genetic algorithm II (NSGAII) (Deb, Agrawal, Pratap, & Meyarivan, 2000), (b) strength Pareto evolutionary algorithm (SPEA2) (Zitzler, Laumanns, & Thiele, 2001), (c) multi-objective variable neighborhood search (MOVNS) (Duarte, Pantrigo, Pardo, & Mladenovic, 2015), d) MOGWW (Gutiérrez & Brizuela, 2007, 2011), (e) PLS (Paquete & Stützle, 2006), (f) Pareto simulated annealing (PSA) (Czyzak & Jaszkiewicz, 1998) and (g) weighted robust Tabu search (W-ROTS) (Paquete & Stützle, 2006). All these algorithms are coded in Matlab and an HPC cluster of 20 nodes is used to perform the computational study. All of them are run for the same time duration. It is found that the proposed ABC-based algorithm outperforms all the other algorithms on the basis of four solution quality indicators, i.e. (a) purity (P), (b) epsilon (ε), (c) generational distance (GD) and (d) hypervolume (HV).

The rest of this paper is organized as follows. A brief discussion about the FLP identified from the semi-automated bus body manufacturing unit is first presented, followed by the problem formulation of the bi-d-QAP. Next, the heuristic approach that is developed to solve the bi-d-QAP is discussed together with the modified ABC-based algorithm. Sensitivity analysis is then performed along with comparison of the results obtained by all the algorithms to establish the efficacy of the developed approach. The last section provides conclusions and future scope of this study.

2. A study on the FLP of firm X

Firm X is a bus body manufacturing unit in India. It procures bus chassis' from the outside organizations and constructs the full bus body using its various in-house facilities. It can only manufacture passenger buses and the corresponding process flow for each bus is the same, as exhibited in Fig. 1. It can be noted from Fig. 1 that there are nine workstations, named as bus stations. Each chassis is driven through these nine bus stations sequentially and various parts/components/sub-assemblies are attached to the chassis at each bus station. These parts/components are manufactured in-house and then moved from specific locations called substations to the bus stations, as shown in Fig. 1. Thus, there are two major movements associated with bus body manufacturing, i.e. (a) bus chassis being driven sequentially through various bus stations and (b) the parts/components/sub-assemblies that are to be integrated with the bus chassis are moved from substations to the bus stations manually. Though these two movements are simultaneous, they utilize different modes. Therefore, minimization of both the movements using any of the single objective optimization techniques would not result in a feasible and good solution. Since the distance that each part/component/sub-assembly needs to move to reach the destined bus station is dependent upon the choice of locations of the bus stations with respect to substations, optimization of such movement is not possible while ignoring the chosen locations of bus stations.

Thus, it is evident that this FLP has two distinct subproblems with distinct solution spaces. The different solution spaces can be attributed to the fact that the bus station locations and substation locations are not the same. Thus, the first objective is to identify the optimal locations of the bus stations and the second objective is to determine the optimal locations of the substations. However, the solution space of the second objective function depends on the feasible solution of the first objective function, i.e. optimization of substation locations depends on the choice of bus station locations. In other words, the choice of bus stations determines the distance matrix related to the choice of substations. In addition, empty spaces left after the choice of bus station locations

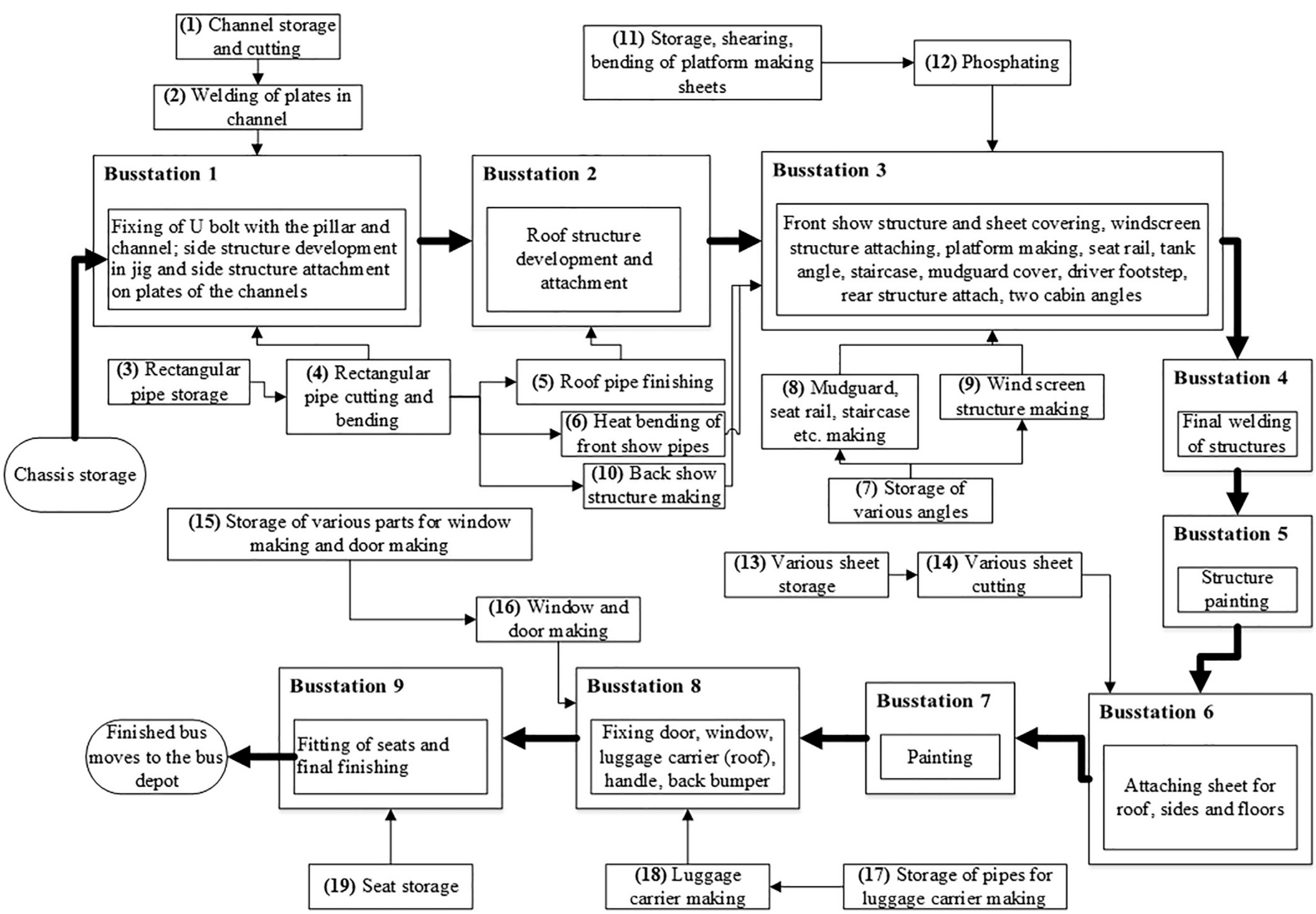

Fig. 1. Process flow in the bus body manufacturing unit.