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A new data structure of solution representation in hybrid ant colony optimization for large dynamic facility layout problems

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ABSTRACT

A dynamic facility layout problem (DFLP) is concerned with finding a set of facility layouts across multiple time periods that minimizes the total cost of material flows and rearrangement costs. Unlike other heuristic approaches that focus mainly on the searching aspect, this research takes another approach by streamlining the data structure of solution representation to improve the solution swapping and storing activities within a meta-heuristic framework. The experimental results from testing the data encoding and decoding schemes on a DFLP data set have been quite promising in terms of solution quality and computational time.

1. Introduction

In today's rapidly changing corporate environments manufacturing facilities are going through periods of expansion and decline due to ever-moving business goals. Fast switching from one product line to another and discontinuing existing production lines is often the norm especially in the high-tech industries. To keep up with the pace, the facility layout needs to be adaptable to changes. The layout has to be "flexible enough to accommodate changes in product design, process design, and schedule design" (Tompkins et al., 2003). Heragu predicted that redesigning existing facilities will become more common than generating new facility layouts in future facility planning (Heragu, 1997).

Traditionally, researches into the facility layout problems treat all the data—the departments, areas and flows—as constant. This type of research problems is referred to as the Static Facility Layout Problem or SFLP. Recently, researches into ever-changing facilities layouts known as the Dynamic Facility Layout Problem (DFLP) have generated much interest. Unlike the traditional static facility layout where the layout is relatively constant throughout time, the concept of dynamic facility layout introduces the time dimension into the facility layout planning. To construct a dynamic facility layout, the facility planners or managers must take the time periods into account. At each time period, planners need to consider the material flow cost and rearrangement cost and evaluate whether the facility rearrangement is necessary. Therefore, the pre-determination of material flow costs is required in the dynamic facility layout.

Several factors need be considered regarding the dynamic facility layout: (1) the cost incurred due to loss in production time; (2) the costs of physically moving equipments from their existing locations to new locations: planning, dismantling, construction, movement and installation (Kochhar and Heragu, 1999).

The dynamic facility layout problem represents one type of combinatorial optimization problems since a dynamic facility layout may have $(n!)^t$ combinations for a given n departments, t periods. Many heuristic or meta-heuristic approaches to solve the DFLP may involve a significant amount of swapping and storing of candidate solutions in quest of local and global solutions. In another word, by improving solution swapping and storing may lead to a significant reduction of computational time and memory space, especially with large combinatorial optimization problems. Consider a 30-department, 10-period dynamic facility layout problem—the amount of memory it takes for a single DFLP solution is:

$$30\text{ departments} \times 4\text{ bytes (integer data type)} \times 10\text{ periods}$$
$$= 1200\text{ bytes or }300\text{ integers(based on a Visual C++ program)}$$

On the contrary, each department can be represented by only 1 byte:

$$30\text{ departments} \times 1\text{ byte} = 30\text{ bytes} \div 4\text{ bytes (integer data type)}$$
$$\cong 8\text{ integers} \quad 8\text{ integers} \times 10\text{ periods} = 80\text{ integers}$$

The encoding results in a 4-fold data storage improvement. Additionally, several nominal values may be packed into one 32-bit integer type: for 8-department and 15-department layouts, 4 nominal values are packed into an integer while 30-departments 2 nominal values are packed. With a more compacted data structure and less bytes to manipulate, the author theorizes that a shorter computational time can be achieved for the solution

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swapping, which is a major activity in local and global searches of meta-heuristics.

Therefore, this author considers improving the computational efficiency by focusing on the data structure of solution representation. Inspired by data encoding in telecommunication systems, the author investigates encoding the solution representation in DFLP to pack as much solution representation as possible into as few bits or bytes as possible.

The author proposes two Binary Coded Hybrid Ant Systems (BC-HAS), modifications of HAS I and HAS III presented by McKendall and Shang (2006) to solve the dynamic facility layout problem using encoding and decoding schemes.

This paper is organized as the follows: In the next section, the author presents the background and relevant information on the dynamic facility layout. In Section 3 the meta-heuristic framework, ant colony optimization, is discussed along with solution encoding/decoding schemes for solving the DFLP. In Section 4 the newly proposed heuristics are compared with existing approaches to the DFLP and the results are presented. Finally, the conclusion is given in Section 5.

2. Previous approaches

2.1. Dynamic facility layout problem

"The dynamic facility layout problem (DFLP) is the problem of assigning departments to locations during multi-period planning horizon such that the sum of material handling and rearrangement cost is minimized" (Liu, 2005). The concept of dynamic facility layout is first coined by Rosenblatt (1986). Essentially, DFLP involves a 'planning horizon', which can be divided into several time intervals or periods. Each time period has its own material flows and distance matrices. The changes of material flows from one time period to another time period incur the rearrangement cost (Lacksonen and Enscore, 1993). The objective function of DFLP is expressed in the following mathematical model (Shang, 2002):

$$TC = \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{t=1}^{T} f\pi_i{}^t\pi_j{}^t d_{ij} + RC \tag{1}$$

where TC is the total cost; d_{ij} is the distance between locations of departments π_i and π_j for the dynamic facility layout (π) at each time period t; $f^t_{\pi j}$ denotes the material flows between departments π_i and π_j at a given time period; RC is the rearrangement cost. The rearrangement cost can be expressed in the following mathematical model (Shang, 2002):

$$RC = \sum_{i=1}^{N}\sum_{t=2}^{T} r_{\pi_i^t} x_i^t \tag{2}$$

subject to

$$x_i^t = \begin{cases} 1 \text{ if } \pi_i^t \neq \pi_i^{t-1}, \\ 0 \text{ } otherwise \end{cases} \tag{3}$$

where RC is the total rearrangement cost; $r_{\pi_i^t}$ is the rearrangement cost for moving the department π_i at a particular time period. x_i^t signifies whether the rearrangement involving π_i has occurred between consecutive time periods.

Numerous articles have been published on the dynamic facility layout problem ranging from industrial engineering and computer science to civil engineering. Lacksonen and Enscore (1993) used five modified approaches to solve the dynamic facility layout problem, which include the dynamic programming, branch and bound algorithm, modified cutting plane algorithm, cut trees and CRAFT. Urban (1993) proposed a steep-descent pair-wise interchange procedure combined with the concept of forecast windows. Baykasoglu and Gindy (2001) took the simulated annealing approach to solve DFLP problem, while Balakrishnan and Cheng (2006, 2003) developed the hyrid genetic algorithm (GADP). Later, Balakrishnan and Cheng (2009) incorporated the concepts of rolling horizons and forecast uncertainty with the dynamic facility layout problem. Baykasoglu et al. (2006) made the first attempt to solve the DFLP with budget constraints. They set the constraints such that the layout can only be rearranged with a sufficient allocated budget. Ulutas and Islier came up with a clonal selection algorithm for the dynamic facility layout problem (2009). McKendall and Shang (2006) modified Gambardella's HAS-QAP intended for the static facility layout problem (1999) to solve the DFLP. They used the ant colony optimization (ACO) which simulates the ants' foraging behavior. The general concept of ACO is summarized in the following description. Initially, ants explore the food source from the ant colony by taking random paths. As they move along different paths, they deposit a chemical substance called pheromones on the ground. As more and more pheromones accumulated on the trails, ants would preferably take the path with the strongest pheromone concentrations. The ACO has been applied to many fields including the supply chains design (Moncayo-Martinez and Zhang, 2011) and crane scheduling (Wen et al., 2010).

3. The proposed binary hybrid ant colony optimization

In the research this author proposes modifications to HAS I and HAS III of McKendall and Shang (2006), which were extended from Gambardella's Hybrid Ant System-Quadratic Assignment Problem (HAS-QAP) for the static facility layout problem (Gambardella et al., 1999). The newly modified heuristics are herein referred to as Binary Coded HAS I (BC-HAS I) and Binary Coded HAS II (BC-HAS II). BC-HAS I differs from BC-HAS II in terms of their local search strategies. The former utilizes the pair-wise exchange heuristic for its local search while the latter utilizes the look-ahead/look-back strategy (Balakrishnan et al., 2000; Urban, 1993).

BC-HAS utilizes several parameters. Among those are:

Q: parameter used to initialize the pheromone trail matrix P.
R: parameter used to represent the number of iterations for going through pheromone trail based modification.
q: parameter used to decide whether policy 1 or policy 2 is selected in the pheromone trail based modification. q is represented as a probability.
α_1, α_2: parameters used to represent the pheromone evaporation rate and pheromone trail reinforcement, respectively.
S: parameter used to decide when to implement the diversification strategy after a number of consecutive iterations.
I^{max}: maximum number of repetitions for the heuristic.

3.1. BC-HAS heuristics

BC-HAS has inherited the framework originated from Gambardella's HAS-QAP. The major steps of the framework are described below:

Step 1: *Initialize the solutions*
At this step the solutions or layouts are initialized and associated with each ant because BC-HAS is an improvement algorithm, the initial solutions must be first "seeded". The objective function of each dynamic facility layout is calculated based on material flows and distances between departments according to Eq. (1).