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An ant colony algorithm for solving budget constrained and unconstrained dynamic facility layout problems ☆

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Abstract

The main characteristic of today's manufacturing environments is *volatility*. Under a volatile environment, demand is not stable. It changes from one production period to another. To operate efficiently under such environments, the facilities must be adaptive to changing production requirements. From a layout point of view, this situation requires the solution of the *dynamic layout problem* (DLP). DLP is a computationally complex combinatorial optimization problem for which optimal solutions can only be found for small size problems. It is known that classical optimization procedures are not adequate for this problem. Therefore, several heuristics including taboo search, simulated annealing and genetic algorithm are applied to this problem to find a good solution. This work makes use of the *ant colony optimization* (ACO) algorithm to solve the DLP by considering the budget constraints. The paper makes the first attempt to show how the ACO can be applied to DLP *with* the budget constraints. In the paper, example applications are presented and computational experiments are performed to present suitability of the ACO to solve the DLP problems. Promising results are obtained from the solution of several test problems.

Keywords: Dynamic facility layout; Ant colony optimization; Heuristics

1. Introduction

Facility layout studies usually result from the changes that occur in the requirements for space, equipment and people. If requirements change frequently, then it is desirable to plan for change and to develop a flexible layout that can be modified, expanded, or reduced easily [1]. Flexibility can be achieved by utilizing modular equipment, general-purpose production equipment and material handling devices, etc. The change in the design of existing products, the processing sequences for existing products, quantities of production and associated schedules, and the structure of organization and/or management philosophies (e.g. centralized, decentralized, hierarchical, etc.) can lead to changes in layout. When these changes occur frequently, it is important for the layout to accommodate them [2]. Impact of change on the design of the facility pointed to the need for a facility that can respond to change. An important part of the response to change is the need to rearrange workstations or modify the system structure based on changing functions, volumes, technology, product mix and so on. The dynamic layout problem (DLP) arises when the location of an existing facility is a decision variable. With the introduction of new parts and changed demands, new locations for the facilities might be necessary in order to reduce excessive material handling costs. Gupta and Seifoddini [3] concluded that one-third of USA companies undergo major dislocation of production facilities every 2 years.

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Over time the mix of parts, the volume of production for each part and the routing for each part in the system is generally subjected to change in a dynamic production environment. If everything remains constant for long period of time, a dedicated set of facilities would be more appropriate, but where this is not the case, there is a need to focus on a re-layout issue. The objective function in a DLP is generally defined as the minimization of flow costs plus rearrangement cost for a series of static layout problems [4–6]. In a DLP, rearrangement costs are added whenever an area contains different departments in consecutive time periods. According to Lacksonen and Enscore [6], the DLP is required when we must balance the trade-off between increased flow cost of inefficient layouts and added rearrangement costs. Afentakis et al. [7] stated that when system characteristics change, it can cause a significant increase in material handling requirements; consequently, it shows a need to consider re-layout. They defined two cost components for relayout, i.e. cost of reconfiguration or relocation of equipment and cost of lost production. The cost of reconfiguration depends on the number of machines moved and/or the number of links in material handling changed.

Traditionally, the effectiveness of layout problems has been connected to the flow of materials. Material handling cost is commonly used to evaluate alternative layout designs. The relative location of facilities in a functional layout has been determined under the criterion of material handling cost minimization. Usually, the material handling cost is assumed to be an incremental linear function of the distances between the components of the system under study. Total estimated annual material handling cost for a particular design is used to provide a quantitative measure of the flexibility of design [2]. There is a massive amount of literature available about facility layout problem [8]. But, the research effort is generally on the static facility layout problems. In recent years, research has also focused on the dynamic case. The work done by Rosenbaltt [5] has generally been accepted as the first serious approach to model and solve DLP. He developed an optimal solution methodology for DLP using a dynamic programming approach. The stages of the dynamic programming problem correspond to the periods in the planning horizon and the states correspond to specific layout arrangements. The main problem with his model is the determination of alternative layouts (states) to use in each stage. Lacksonen and Enscore [6] also studied the DLP. They modelled the problem as a modified quadratic assignment problem. Their model can be considered as a general quadratic assignment formulation of the basic DLP. They modified various static layout algorithms to solve the dynamic version of the quadratic assignment model. Lacksonen [9,10] also extended his DLP model by considering departments with unequal areas. He applied branch-and-bound routine and the cut tree algorithm to solve the mixed integer linear programming model. Urban [11] proposed a heuristic algorithm that is based on the CRAFT (steepest descent pair-wise interchange) procedure for DLP. Conway and Venkataramanan [12] applied genetic algorithms to solve DLP. Balakrishnan and Cheng [13] also proposed a genetic algorithm for DLP. Kaku and Mazzola [14] developed a taboo search-based heuristic for the DLP. The application of simulated annealing to the DLP is shown by Baykasoglu and Gindy [2]. Erel et al. [15] also purposed several heuristics for the dynamic layout problem by using dynamic programming and simulated annealing. They plan to arrive at the optimal sequenced of layouts by implicitly enumerating over subset of all possible layouts. Given all possible layouts, they claim that the DLP can be viewed as a shortest path problem. A good survey on the DLP is published by Balakrishnan and Cheng [16] that explains the state of the research on DLP. They gave detailed explanations about some of the available algorithms on DLP alongwith their comparisons.

Good heuristic techniques are necessary for solving DLP due to its high computational complexity (i.e. for an N location T period problem, $(N!)^T$ solutions are possible). Modern heuristic techniques, namely *genetic algorithms taboo search*, *simulated annealing and ant colony optimization*, can be good candidates for this problem. As discussed in the previous paragraphs, the applications of genetic algorithms, taboo search and simulated annealing to the DLP has been shown in the literature. However, we should mention here that in all of these applications budget constraints are not taken into account. It is also possible to take into account budget constraints in other modern heuristics by using some forms of penalty functions or not allowing unfeasible moves during the search, etc. This might be considered as a future work in re-implementing these algorithms for DLP. But it is a well-known fact that in some production periods due to budget limitations the reconfiguration may not be possible. Balakrishnan et al. [17] considered budget constraints in their studies of DLP and presented how this constraint can be taken into account. They add the constraint of a budget for total rearrangement costs over the entire horizon and presented a solution procedure that is based on constrained shortest path algorithms.

In this research, ant colony optimization (ACO) heuristic is used for solving the unconstrained and budget-constrained DLP. The main research contribution of the present paper is to make the first attempt in the published literature to show how the ACO algorithm can be applied to DLP *with* the budget constraints.

In the following sections of this paper, the ant colony heuristic algorithm for DLP is explained then the computational results are reported.

2. The problem statement and the mathematical program for the budget constrained DLP

The DLP problem extends the well-known static layout problem where a group of departments are arranged into a layout such that the sum of the costs of flow between