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Shortest path based simulated annealing algorithm for dynamic facility layout problem under dynamic business environment

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ABSTRACT

This paper studies a new kind of dynamic multi-stage facility layout problem under dynamic business environment, in which new machines may be added into, or old machines may be removed from the plant. We define this problem first on the basis of unequal area machines and continual presentation of layouts. Compared with nodes and arcs of the flow chart, we convert this problem into a shortest path problem by studying its cost function and machine adding/removing heuristic rules, and the corresponding mathematical model for this problem is established. An auction algorithm is proposed here to solve the shortest path problem. Finally, a shortest path based simulated annealing algorithm is presented to solve the optimization problem. Parameters of the SP based SA algorithm are discussed to improve the performance of the algorithm. Some cases are used to verify the proposed algorithm.

1. Introduction and literature review

Today's manufacturing facility needs to be responsive to the frequent changes in product mix and demand while minimizing material handling and machine re-location costs. The dynamic plant layout problem (DPLP) extends the static plant layout problem (SPLP) by considering the changes in material-handling flow over multiple periods and the costs of rearranging the layout (Balakrishnan, Cheng, Conway, & Laub, 2003; Kusiak & Heragu, 1987). Different from the traditional DPLP, this paper investigates a dynamic facility layout problem with a characteristic of adding/removing machines in each period. That is, not only changes in material-handling flow and re-locations of existing machines, but also the new machines' adding and old machines' removing should be considered. The motivation behind this study is that, under dynamic business environment, as continuously introducing a wide range of products whose demands are variable and lifecycles are short, static facility layout is vulnerable to dynamic changes in requirements of products or machines, which will cause material handling inefficiency, prohibitive re-location costs (including production shutdown) and poor plant operational performances (Benjaafar, Heragu, & Irani, 2002). With the rapid introduction of new products, new machines need to be installed in the plant, and old machines will be removed from the plant when some products are eliminated from the current product line. For example, in semiconductor industry under fast changing business environment, life cycles of products become very short and types and amounts of products vary very fast, new machines and old machines may need to be added into/removed from the plant in multi-stages.

A layout plan for the DFLP can be represented as a series of layouts, and each layout is associated with a period. Therefore, the total cost of a layout plan consists of the sum of the material handling costs for all periods and the sum of the rearrangement costs. As indicated by McKendall and Shang (2006a, 2006b), the DPLP is not just a series of SPLPs/quadratic assignment problems. In traditional dynamic layout problems, the "dynamic" is resulted from the changes in the flow-to matrix of the materials between processes. This paper deals with a new type DPLP in which the number of machines in different planning periods is changing due to machines' adding/removing in each planning period. This machine changing data for each period are forecasted and can be obtained from so called PTL (POR Tool List, i.e., Plan of Record Tool List). Rosenblatt (1986) developed a dynamic programming (DP) model and solution procedure with branch and bound scheme for determining an optimal layout for each of several pre-specified future planning periods. This model takes into consideration material handling cost as well as cost of re-locating machines from one period to the next. In the heuristic DP method only a few layouts from each period are included. This procedure is to select the layouts in a period randomly. However this is not very effective. A better method is to select some of the better quality layouts in each period to form part of the DP. The DPLP is a combinatorial problem for which the optimal solution can be found only for very small problems. Heuristic procedures such as genetic algorithm for the dynamic layout problem can be found in a number of papers

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including Conway and Venkataramanan (1994), Kochhar and Heragu (1999), and Urban (1998). Urban (1998) proposed an approach using a steepest-descent pairwise exchange heuristic similar to CRAFT (Armour & Buffa, 1963). Conway and Venkataramanan (1994), and Balakrishnan and Cheng (2000) make use of genetic algorithms (GA) for the DPLP while Kaku and Mazzola (1997) use Tabu Search. Baykasoglu and Gindy (2001) have developed a simulated annealing algorithm (SA) for the DPLP. Using the test problems from Balakrishnan et al. (2003), they showed that their algorithm performed better than the GA's of Conway and Venkataramanan, and Balakrishnan and Cheng (2000). The parameter settings in their SA algorithm involve determining the initial temperature (the probability that in the neighborhood search, an inferior solution will be accepted), the rate at which the temperature decreases (the decrease in the acceptance probability of an inferior solution), and the number of iterations. Wu, Chung, and Chang (2008) proposed a hybrid simulated annealing algorithm with mutation operator to solve the manufacturing cell formation problem considering multiple process routings for parts, so that either the intercellular movements are minimized or the grouping efficacy is maximized, depending on the definition of the decision objective.

Many previous studies of dynamic facility layout optimization problem are based on the changes in the material flow matrix. The problem is modeled as a QAP or bay structure problem using discrete presentation of facility layouts, which is difficult to be applied into the real world. While the quadratic assignment formulation of the layout problem has been deeply investigated there are very few papers solving it for departments of unequal size (Dunker, Radons, & Westkämper, 2005). Dunker et al. (2005) presented an approach which can handle unequal sizes of departments, which in addition may change from one period to the next. Their algorithm combines genetic search and dynamic programming. They described a representation of layouts which can be used as genetic code.

The representation of a DPLP solution forms the basis for a mathematical model and significantly impacts the structure and efficiency of the applied optimization algorithms (Liu & Meller, 2007). With a discrete representation, the facility is represented by an underlying grid structure with fixed dimensions and all departments are composed of an integer number of grids. However, shapes of the machines are not concerned for discrete representation, so it's difficult to define the real locations of machines. By representing the layout in a discrete fashion, the DPLP is simplified, but at the penalty of eliminating many solutions from consideration (Bos, 1993). Continual representation means that the locations of machines are represented continuously with the coordinates (x, y) of the machines (Drira, Pierreval, & Hajri-Gabouj, 2007). In a continuous representation, department dimensions are not restricted to an underlying grid structure. Continuous representation is more accurate and realistic than discrete representation, and thus, is capable of finding the "real optimal" layout solution. However, the continuous representation also increases the complexity of the DPLP (Cui & Huang, 2006; Das, 1993; Liu & Meller, 2007).

While there exist some literatures on DPLP investigation, up to our knowledge, there are no research has been implemented for this dynamic layout problem with unequal size machines and machines' adding/removing in each period. Machines' adding/removing in each period increases the complexity of DPLP. The aim of this research is to develop an effective method for DPLP with machines' adding/removing in each period. In order to obtain realistic layouts, continuous layout representation is adopted in this study.

The remainder of this article is organized as follows. In Section 2, a shortest path based mathematical model is presented. The machines' adding/removing heuristic rules are presented in Section 3. In Section 4, a hybrid simulated annealing algorithm with shortest path solution algorithm and heuristic rule is developed to find the optimal solution. Section 5 shows the computational results on a real-world application problem, and Section 6 concludes the paper.

2. Mathematical model

The result of dynamic layout problem is a series of layouts from initial layout to the last stage layout. The solution procedure can be regarded as how to choose a path with shortest distance (or minimal total cost for DPLP). A flow graph of n-period dynamic layout problem is shown in Fig. 1, in which directions of arrows are consistent with the planning time horizon. Assume that there are m feasible layouts chosen by some heuristic rules in each period. In Fig. 1, nodes represent feasible layouts in each period and values of edges are associated costs from current layout to the layout in the next period. Let s_0 be the initial layout. ($s_{11}, s_{12}, \ldots, s_{1m}$) represents m feasible layouts chosen by some heuristic rules in planning stage 1 and ($s_{21}, s_{22}, \ldots, s_{2m}$) and ($s_{n1}, s_{n2}, \ldots, s_{nm}$) are m feasible layouts chosen by some heuristic rules in planning stage 2 and stage n, respectively. In order to construct a shortest path optimization problem, a virtual node s_e is added at the rear of the nth period. Assume that layouts in the nth period can be transferred into the virtual layout without any cost. Now the dynamic layout problem becomes a $s_0 \to s_e$ shortest path problem.

Define 0–1 variable μ_{ij} as follows:

$$\mu_{ij} = \begin{cases} 1, & \text{if node } i \text{ and } j \text{ are directly connected} \\ 0, & \text{else} \end{cases} \tag{1}$$

Then the mathematical model for the shortest path based dynamic layout problem becomes:

$$\min C_t = \sum_{i,j} \mu_{ij} e_{ij} \tag{2}$$

s.t.

$$\mu_{ij} \in \{0, 1\}, \quad \forall (i,j) \in E \tag{3}$$

$$\sum\nolimits_j \mu_{ij} = m, \quad \forall (i,j) \in E \text{ and node } i \in P \tag{4}$$

$$\sum\nolimits_i \mu_{ij} = m, \quad \forall (i,j) \in E \text{ and node } j \in Q \tag{5}$$

$$e_{ij} \geqslant 0, \quad \forall (i,j) \in E \tag{6}$$

$$\sum\nolimits_i e_{ij} = 0, \quad \text{if node } j \text{ is virtual node } s_e \tag{7}$$

where C_t is total cost and μ_{ij} is a 0–1 variable indicating the direct connection relationship between node i and j. e_{ij} represents the cost of the edge between node i and j, and m is number of feasible layouts chosen by some heuristics in each stage. E and Ω are sets of all the edges and nodes, respectively. Let P be the set of all the nodes except the virtual node and nodes at the last period, Q be the set of all the nodes except the initial node and nodes at the first period,

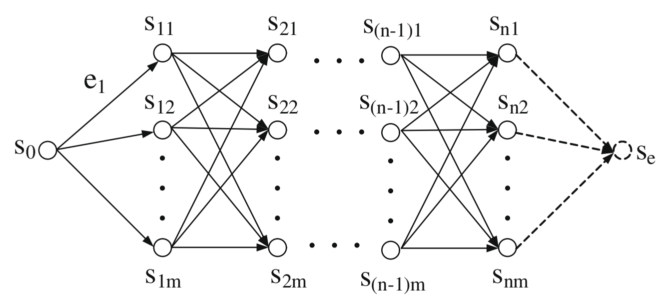

Fig. 1. A shortest path based representation of n-period dynamic layout problem.