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A simulated annealing heuristic for the dynamic layout problem with budget constraint

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ABSTRACT

Facility layout problem has been extensively studied in the literature because the total material handling cost can be a significant portion in the operational costs for a company and in the manufacturing cost of a product. Today's severe global competition, rapid changes in technology and shortening life cycle of products force companies to evaluate and modify their facility layout in a periodic fashion. This type of layout problems is categorized as the dynamic facility layout problem (DFLP). As a realistic dimension of the problem, one has to consider also the limited budget to cover the cost of changing the layout. In this study, we propose a simulated annealing heuristic for the DFLP with budget constraint, and show the effectiveness of this heuristic on a set of numerical experiments.

1. Introduction and literature review

Facility layout problem has been intensively studied in the literature because the material handling costs can be a significant portion in the operational costs for a company, and in the manufacturing costs of a product. According to Tompkins, White, Bozer, and Tanchoco (2003), between 20% and 50% of the total operating expenses within a manufacturing setting is attributed to material handling, and it is generally agreed that effective facilities can reduce the material handling costs by at least 10–30%. Static version of the problem, called static facility layout problem (SFLP), is about locating resources, i.e. machines, departments, etc., within a facility in order to achieve a well-coordinated workflow among these resources. A good solution for the facility layout problem leads to the overall efficiency of operations where the right amount of material flows among resources in a right and safe manner, while a poor layout will result in the accumulation of the work-in-process inventory, the overloading of the material handling systems, the inefficient set-ups, and the longer queues. The SFLP has been generally modeled as a quadratic assignment problem (QAP).

The facility layout decisions are very costly decisions and they affect the production systems for long terms. Thus, one has to consider the long terms when making the facility layout decisions. If one takes a long term as the planning horizon, it is easy to see that there can be changes over time in the flow rates among departments, which is the main factor in making layout decisions. These changes in the material flow rates can be due to several reasons such as, changes in the design of an existing product, elimination of some products from a production line, and introduction of new products. As a result of these changes, one-third of the companies in USA carry out a major relocation of production facilities in every 2 years (Gupta & Seifoddini, 1990). The problem that considers the dynamic changes in the flow rate over time is called the dynamic facility layout problem (DFLP), and it has received attention starting with the work of Rosenblatt (1986), where the author formulated DFLP using a dynamic programming approach, and suggested both heuristic and optimal solution procedures.

DFLP is modeled by discretizing the time into the planning periods. The flow rates for each period are forecasted and assumed constant during each period. The total cost of a solution to DFLP involves two parts; material handling costs in each period and the rearrangement costs for the facilities that need to be relocated from one period to the next. It will be sub-optimal to solve a DFLP as a series of static layout problems, one problem for each period separately, since this approach does not consider the cost of relocating facilities from a period to the next.

Rosenblatt (1986) developed an optimization approach for the DFLP based on a dynamic programming (DP) model as we mention above. But this approach is computationally intractable for real life

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problems. The number of the layouts to be evaluated in order to guarantee the optimality for a DFLP with N departments and T periods is $(N!)^T$. Because of the computational difficulty of solving real life problems various heuristic algorithms have been proposed. Rosenblatt (1986) suggested two heuristic procedures. These procedures are dynamic programming based heuristics that consider only limited set of good layouts for each period. Urban (1993) developed a steepest-descent heuristic based on pair-wise-exchange idea, similar to CRAFT. Lacksonen and Enscore (1993) introduced and compared five heuristics to solve the DFLP. The heuristics considered in this study are based on dynamic programming, branch and bound, cutting plane algorithm, cut trees, and CRAFT.

There have been several meta-heuristics suggested for DFLP as well. Balakrishnan and Cheng (2000) presented a genetic algorithm (GA) to solve the DFLP, while Kaku and Mazzola (1997) used a tabu search (TS) heuristic. Their TS heuristic is a two-stage search process that incorporates the diversification and intensification strategies. Baykasoglu and Gindy (2001) presented a simulated annealing (SA) heuristic for the DFLP where they utilize an upper and a lower bound of the solution of a given problem instance to determine SA parameters. Balakrishnan, Cheng, Conway, and Lau (2003) presented a hybrid genetic algorithm for the DFLP. Erel, Ghosh, and Simon (2003) proposed a new heuristic to solve the DFLP. They used weighted flow data from the various time periods to developed viable layouts, and they suggested a shortest path for the DFLP. McKendall and Shang (2006) developed three hybrid ant systems (HAS) for the DFLP. Also McKendall, Shang, and Kuppusamy (2006) presented two simulated annealing (SA) heuristics. The first SA heuristic (SA I) is a direct adaptation of SA to the DFLP. The second SA heuristic (SA II) is the same as SA I, except that it has an added look-ahead/look-back strategy. Rodriguez, MacPhee, Bonham, and Bhavsar (2006) presented hybrid meta-heuristic algorithm based on the genetic algorithm and tabu search for the DFLP. Krishnan, Cheraghi, and Nayak (2006) developed a new tool 'Dynamic From Between Chart', for the analysis of redesigning layouts. It models the production rate changes using a continuous function. Balakrishnan and Cheng (2009) investigate the performance of algorithms under fixed and rolling horizons, under different shifting costs and flow variability, and under forecast uncertainty for the DFLP. Şahin and Türkbey (2009) proposed a new hybrid meta-heuristic algorithm based on the simulated annealing approach supplemented with a tabu list. For an extensive review on DFLP one can check Balakrishnan and Cheng (1998) and Kulturel-Konak (2007).

The studies included above share a common assumption that all the departments are of equal size. There are some other studies that do not make this assumption. Two recent examples of such studies are Dunker, Radons, and Westkamper (2005) and McKendall and Hakobyan (2010).

None of the studies mentioned above considers a budget constraint. As we mentioned before, the layout changes are difficult and costly activities, and companies must operate within a given budget. Therefore, as a realistic aspect, one has to take the budget constraint into account when solving DFLP. In this study we propose an effective simulated annealing based heuristic approach for DFLP with budget constraints. To the best of our knowledge, there have been only two studies on DFLP with the budget constraints; (Balakrishnan, Jacobs, & Venkataramanan, 1992; Baykasoglu, Dereli, & Sabuncu, 2006).

In Balakrishnan et al. (1992), they incorporated a budget constraint for the total rearrangement cost during the entire planning horizon. To solve the DFLP with the budget constraint they utilized a constrained shortest path algorithm in their heuristic solution procedure.

In Baykasoglu et al. (2006), the authors used a budget constraint for each period separately instead of restricting the total cost of rearrangements for the entire planning horizon. Since period-base budget constraints are more common in practice we considered the budget constraints in Baykasoglu et al. (2006) more appropriate, and used this budgeting structure in our computational experiments. The details of the budgeting structure used in the experiments are explained in the computational part.

Next section describes the mathematical formulation of the problem. Section 3 addresses the SA based heuristic developed in this study. Computational testing and comparison with the results from the literature are given in Section 4. Section 5 concludes our work with a summary of the study and future research directions.

2. Problem formulation

The DFLP can be modeled as a modified QAP similar to SFLP. The notation used in the model is given below:

Variables;

$$X_{tij} = \begin{cases} 1 & \text{if department} i \text{ is assigned to location } j \text{ in period} t, \\ 0 & \text{otherwise}, \end{cases}$$

$$Y_{tijl} = \begin{cases} 1 & \text{if department } i \text{ is shifted from location } j \\ & \text{to } l \text{ at the beginning of period } t, \\ 0 & \text{otherwise}. \end{cases}$$

LB_t: Left-over budget from period t to period $t+1$,
B_t: Available budget for period t.
Parameters;
N: Both the number of departments and the locations,
T: The number of periods in the planning horizon,
AB_t: Allocated budget for period t,
C_{tijkl}: Cost of material handling between department i in location j and the department k in location l in period t, and
A_{tijl}: Cost of rearrangement department i from j to l at beginning of period t.

We adapted the basic formulation of the DFLP from McKendall et al. (2006) and Baykasoglu et al. (2006). We revised the budget constraints and added some relevant variables to the basic model as given below:

$$Min\ TC = \sum_{t=2}^{T}\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{l=1}^{N} A_{tijl}Y_{tijl} + \sum_{t=1}^{T}\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N}\sum_{l=1}^{N} C_{tijkl}X_{tij}X_{tkl} \quad (1)$$

$$s.t. \quad (2)$$

$$\sum_{i=1}^{N} X_{tij} = 1 \quad j = 1,2,3,\ldots N, \; t = 1,2,3,\ldots T \quad (3)$$

$$\sum_{j=1}^{N} X_{tij} = 1 \quad i = 1,2,3,\ldots N, \; t = 1,2,3,\ldots T \quad (4)$$

$$Y_{tijl} = X_{(t-1)ij}X_{til} \quad i,j,l = 1,2,3,\ldots N, \; t = 2,3,\ldots T \quad (5)$$

$$LB_t = B_t - \sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{l=1}^{N} A_{tijl}Y_{tijl} \quad t = 1,2,3,\ldots T \quad (6)$$

$$B_t = AB_t + LB_{t-1}t = 1,2,3,\ldots T \quad (7)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{l=1}^{N} A_{tijl}Y_{tijl} \leqslant B_t \quad t = 1,2,3,\ldots T \quad (8)$$

$$LB_t, B_t \geqslant 0 \quad t = 1,2,3,\ldots T \quad (9)$$

$$X_{tij}, Y_{tijl} \in \{0,1\} \quad t = 1,2,3,\ldots T, \; i,j,l = 1,2,3,\ldots N \quad (10)$$