Discrete Optimization 14 (2014) 126–146

Contents lists available at ScienceDirect

Discrete Optimization

journal homepage: www.elsevier.com/locate/disopt

Towards an efficient resolution of printing problems

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ARTICLE INFO

Article history:
Received 13 September 2012
Received in revised form 1 September 2014
Accepted 3 September 2014
Available online 29 September 2014

Keywords:
Combinatorial optimization problem
Metaheuristics
GRASP

ABSTRACT

This paper addresses two different problems coming from the printing industry: the label printing problem and the cover printing problem. In both cases, the problem consists in the assignment of a fixed number of labels on different templates in order to fulfill the printing requirements and to minimize the waste of excessive printed labels in the first case or to minimize the total production cost in the second case. In these problems, allocating suitable labels to each template is a strategical task to improve the efficiency of the printing process. As the considered problems are hard, we propose a new GRASP algorithm to solve these problems. The proposed algorithm is tested on some reference instances, comparing the obtained results with those found in the literature. The results prove that the GRASP algorithm is particularly well suited to these problems.

1. Introduction

Printing problems have many applications in real-world industries. In various sectors, different types and quantities of labels are required: labels on clothes, labels on a variety of consumer products, labels presenting candidates for an election, and so on. In this paper, we consider two different printing problems: the label printing problem and the cover printing problem. These two problems have common elements but are considered separately in the literature.

In a printing factory, templates are composed before the printing process starts. We have to determine the number of templates needed and the assignment of a fixed number of labels on these different templates. A printing frequency is then determined for each template in order to fulfill the printing requirements. Poor template designs may produce excessive printed labels and therefore allocating suitable labels to each template is a strategical task to improve the efficiency of the printing process. The label printing problem aims to minimize the total waste of excessive printed labels under a fixed number of templates while the cover printing problem aims to minimize the total production cost (cost of the templates used and the printing cost).

Both problems have been treated in some previous published works. In [1], a two-level approach is presented to solve the label printing problem. For each template, the outer level optimizes the combination of labels by applying a simulated annealing approach while the inner level optimizes on the allocation of the assigned labels using a heuristic approach. More works exist for the cover printing problem. After the failure of the use of exact resolution methods [2], a simulated annealing combined with linear programming is proposed in [3], a tabu search metaheuristic is tested in [4] and two approaches of genetic algorithms with linear programming solver are presented in [5]. In [6], a branch and price algorithm is presented but the results are not quite satisfactory since only bounds on the optimal solution are provided. More recently, a GRASP method has been proposed in [7] and an ad hoc original heuristic has been developed in [8].

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http://dx.doi.org/10.1016/j.disopt.2014.09.001
1572-5286/

Both problems can be formulated as a combinatorial optimization problem. It has been established in [9] that although some very special cases of these problems can be polynomially solved, in general these problems are strongly $\mathcal{NP}$-hard problems. Moreover, in [9] a Multi-Run Heuristic is presented and the authors proved that this heuristic finds a 2-approximation solution.

Combinatorial optimization problems [10,11] involve finding optimal solutions from a large but finite set of feasible solutions. Many of these problems cannot be solved to optimality in reasonable computation times, due to their inner nature or to their size. It is the case of the label printing problem and the cover printing problem treated in this paper. The use of heuristic methods is then the natural choice for solving these problems. The goal of heuristics [12] is to quickly produce good approximate solutions, without necessarily providing any guarantee of solution quality. The effectiveness of these methods depends upon their ability to adapt to a particular realization, avoid entrapment at a local optimum, and exploit the basic structure of the problem.

Metaheuristics are techniques that have widespread success in providing high-quality near-optimal solutions to many real-life difficult combinatorial optimization problems in various industrial, economic, and scientific domains. Among them, we find simulated annealing, tabu search, GRASP, genetic algorithms, scatter search, VNS, ant colonies, and others. We refer to [13,12] for an introduction, [14] for a bibliography and [15,16] for an overview. Based on the success of metaheuristics [17,18], we already proposed a GRASP procedure to solve the cover printing problem [7]. In this paper, we completely redesign the GRASP procedure in order to solve both the label printing and the cover printing problems. Moreover new numerical instances are considered and the obtained results are not only compared with the previous GRASP results but also with those of two existing methods in the literature [1,8].

The remaining parts of the paper are organized as follows. In Section 2 we give a formal statement of the label printing problem and we present in details the greedy random adaptive procedure. In Section 3 the cover printing problem is considered. In both sections, we illustrate the efficiency of the proposed method by comparing the obtained results to the best-known results available in the literature. Conclusions are drawn in Section 4.

2. The label printing problem

In a typical order arriving at a printing factory, a number L of different labels of equal size are requested. For each label, a given number $d_l,\ l = 1, \dots, L$ of copies has to be printed. A fixed set of T templates are used for printing the required labels. A template is made of a fixed number S of slots and a label is assigned to each slot. Empty labels are allowed on a template. The printing process consists in composing the T templates of S labels (which may be similar, different or empty) and in making a certain number of imprints of them. Each imprint produces one large printed sheet of paper, once properly cut into S parts, yields S copies.

The mathematical model presented here is not new and is similar to the model described in [1]. Let n_{lt} be the number of label l assigned to template t and p_t be the number of imprints of template t. To minimize the total waste of labels under a fixed number of templates, the optimization problem (LPP) can be formulated as a non-linear optimization problem with integer variables. A weight $0 < \epsilon \le 1$ is introduced to differentiate the empty label from the others.

$$(LPP)\ \begin{cases} \min\ \displaystyle\sum_{l=1}^{L}\left(\sum_{t=1}^{T} n_{lt}\, p_t - d_l\right) + \epsilon \sum_{t=1}^{T} p_t \left(S - \sum_{l=1}^{L} n_{lt}\right) \\ \displaystyle\sum_{t=1}^{T} n_{lt}\, p_t \ \ge\ d_l \qquad l = 1, \dots, L \\ \displaystyle\sum_{l=1}^{L} n_{lt} \ \le\ S \qquad t = 1, \dots, T \\ n_{lt} \in \{0, 1, \dots, S\} \qquad l = 1, \dots, L\ \ t = 1, \dots, T \\ p_t \ge 0 \text{ and integer} \qquad t = 1, \dots, T. \end{cases}$$

The first constraints of (LPP) indicate that the customer order is fulfilled. The second constraints mean that the capacity of the templates are not exceeded.

2.1. Solving the LPP problem

In this study, we first propose to customize and implement a greedy random adaptive search procedure (GRASP) to solve the label printing problem. This method is a multistart metaheuristic [19–23], in which each iteration returns a feasible solution to the problem and consists of two phases: a construction phase and a local search phase. The best solution over all iterations is kept as the final result. A generic GRASP pseudo-code is given in Algorithm 1. One of the major advantages of the GRASP metaheuristic is how easy this general scheme may be adapted to the solution of particular problems. This method has been used with success to provide solutions for several difficult combinatorial optimization problems [24,25, 19,26–29,14].