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The discrete Unconscious search and its application to uncapacitated facility location problem

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ABSTRACT

In this paper a discrete variant of Unconscious search (US) for solving uncapacitated facility location problem (UFLP) is proposed. Unconscious search mimics the process of psychoanalytic psychotherapy in which the psychoanalyst tries to access the unconscious of a mental patient to find the root cause his/her problem, which is encapsulated in unconsciousness. Unconscious search is a multi-start metaheuristic which has three main stages, namely construction, construction review and local search. In construction phase a new solution is generated. In construction review the generated solution in construction phase is used to produce more starting points for using in the local search phase. The results of applying US to UFLP shows that this metaheuristic can determine high quality solutions in short processing time comparing to other heuristics.

1. Introduction

Facility location is an important strategic decision in designing a supply chain network (Klose & Drexl, 2005). Facility location problems can have many different forms based on the objective function, time horizon, deterministic or stochastic nature of elements, number of stages, and capacity of facilities (Galvão, 2004). Most of these problems are categorized as combinatorial optimization problems (Sun, 2006). Uncapacitated facility location problem (UFLP) – also known as simple plant or simple warehouse location problem – is one of the most fundamental problems in location theory (Beltran-Royo, Vial, & Alonso-Ayuso, 2012). Many instances of UFLP application are reported in literature (Cornuejols, Nemhauser, & Wolsey, 1983; Gen, Tsujimura, & Ishizaki, 1996; Sun, 2005). After the conception of UFLP in the articles of Stollsteimer (1963) and Kuehn and Hamburger (1963), there has been an extensive effort to generalize the mathematical model and improve the solving methods.

A UFLP can be shown on a graph with $m+n$ nodes and mn vertices (Daskin, 1995) in which m is the number customers and n is the number of candidates' facilities. UFLP can be modeled as a generalized assignment problem. It has also been shown that via some transformations UFLP can be represented as a set packing, set covering, or set partitioning problem (Krarup & Pruzan, 1983). The UFLP model can be represented as follows;

$$Min \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij} + \sum_{j=1}^{n} f_j y_j$$

$$s.t. \sum_{j=1}^{n} x_{ij} = 1 \quad i = 1,\dots,m,$$

$$x_{ij} \leqslant y_j \quad i = 1,\dots,m \text{ and } j = 1,\dots,n,$$

$$x_{ij} \geqslant 0 \quad i = 1,\dots,m \text{ and } j = 1,\dots,n,$$

$$y_j = 0 \text{ or } 1 \quad j = 1,\dots,n.$$

In which c_{ij} is the cost of covering customer i demand from facility j. x_{ij} is 1 if customer i is assigned to facility j, and 0 otherwise. f_j is the fixed charge of opening facility j. y_j is 1 if facility j is opened, and 0 otherwise.

The remainder of this paper is organized as follows: Section 2 is devoted to the literature review. In Section 3, Unconscious search (Ardjmand & Amin-Naseri, 2012) is recapitulated. In Section 4, the procedure of applying Unconscious search (US) to UFLP is explained. In Section 5, some benchmarks of UFLP are solved and results are compared against existing solutions in literature. Section 5 also contains a parameter analysis. Finally, in Section 6 the overall conclusion is stated.

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2. Literature review

UFLP has been extensively reviewed and many different methods have been proposed for solving it. These methods can be classified under three main categories: exact, heuristic, and metaheuristic methods.

2.1. Exact methods

Balinski (1964) introduced the first exact method for solving UFLP by using the partitioning theorem of Benders. Efroymson and Ray (1966) were the first who solved UFLP, with branch-and-bound as an exact method. Their algorithm was able to solve the problems up to a dimension of 50 plants. Spielberg (1969) developed an implicit-enumeration algorithm that could solve some special cases of UFLP up to 100 plants and 100 customers. Later, Khumawala (1972) improved the branch-and-bound algorithm of Efroymson and Ray (1966). Bilde and Krarup (1977) proposed a method in which they used branch-and-bound when they reached a solution near lower-bound. Erlenkotter (1978) developed a dual-based algorithm that—although it was an exact method—could also be used for generating good solutions for branch-and-bound methods. Galvão and Raggi (1989) proposed a three-stage exact method for solving general 0–1 formulation of UFLP that was able to solve the problem up to 200 facilities and 200 customers. Conn and CornuéJols (1990) developed a flexible projection method that could handle side constraints and takes advantage of the exact solution of the condensed dual via orthogonal projections.

2.2. Heuristics

The first heuristic for tackling the UFLP was proposed by Kuehn and Hamburger (1963). Later, Khumawala (1973) improved his branch-and-bound algorithm (Khumawala, 1972) as a basis for creating a heuristic. Cornuejols, Fisher, and Nemhauser (1977) applied the UFLP formulation to specify the location of bank accounts in order to minimize the float. For this purpose, they proposed a simple greedy heuristic. The first constant factor heuristic was proposed by Shmoys, Tardos, and Aardal (1997). Later, Chudak (1998) proposed a $(1+\frac{2}{e})$-approximation heuristic that outperformed Shmoys et al. (1997) method. Guha and Khuller (1998) gained a better lower-bound on the best possible approximation ratio of Shmoys et al. (1997) method by embedding a simple greedy in the heuristic procedure. An 0.828-approximation heuristic was later introduced by Ageev and Sviridenko (1999). Charikar and Guha (2005) proposed an $2.414+\epsilon$-approximation heuristic with $O\left(\frac{n^2}{\epsilon}\right)$ time. Other constant approximation heuristics for UFLP include Shmoys (2000), Korupolu, Plaxton, and Rajaraman (2000), Mahdian, Ye, and Zhang (2002), Chudak and Shmoys (2003) and Li (2013). Comparison of some of these heuristics is conducted by Arya et al. (2004). Resende and Werneck (2006) proposed a hybrid multi-start heuristic based on their previously-developed heuristic for the *p*-median problem (Resende & Werneck, 2004). Later Beltran-Royo et al. (2012) used a mixed-integer programming method enhanced by a semi-Lagrangian method for solving large instances of UFLP.

2.3. Metaheuristics

Many metaheuristic methods have been applied to the UFLP in the literature among which there is tabu search (Al-Sultan & Al-Fawzan, 1999; Michel & Van Hentenryck, 2004; Sun, 2005; Sun, 2006), genetic algorithm (Kratica, Tošic, Filipović, & Ljubić, 2001; Tohyama, Ida, & Matsueda, 2011), variable neighborhood search (Ghosh, 2003; Hansen, Brimberg, Urošević, & Mladenović, 2007), simulated annealing (Yigit, Aydin, & Turkbey, 2006), particle swarm optimization (Guner & Sevkli, 2008), multiple trajectory search (Lin-Yu & Chih-Sheng, 2009), a cooperative and self-adaptive metaheuristic (Meignan, Cr, & Koukam, 2009), a population-based hybrid metaheuristic (Pullan, 2009), and artificial bee colony (Kashan, Nahavandi, & Kashan, 2012).

Tabu search is among the most used metaheuristics for solving UFLP. Considering the structure of UFLP, tabu search can easily be implemented for solving it. Two main key points of tabu search are memory and neighborhood structure (Glover & Kochenberger, 2003). Sun showed that use of three memory structure, namely short-term, medium-term and long-term memory can enhance the ability of a structured search in UFLP (Sun, 2006). In US also memory feature is incorporated. The main distinction in terms of memory application between tabu search and US memory is in the way it is represented and used. In tabu search memory is mostly used as a tool for avoiding exploration of search space which has been searched before and also finding new high quality starting points for search. In US memory, besides helping to find starting points guides the search directly without considering any solution as tabu. The unique application of memory in US is in a way that gives an approximation of search space which the search procedure is easier in it.

Variable neighborhood search (VNS) takes advantage of more complicated neighborhood structure in the course of search and hence can also be considered as a search process which can be incorporated in other metaheuristics to improve the performance (Glover & Kochenberger, 2003). The experimental results in this paper show that using a simple neighborhood structure for search can be quite satisfactory in presence of memory and there is no need for more complicated structures as of VNS although it can improve the quality of solutions.

Although simulated annealing (SA) can be implemented as a multi-start algorithm but since it does not use memory and decides based on Boltzman function to move on is quite different from US. US is a construction based multi-start algorithm which differs in nature from population based metaheuristics such as genetic algorithm, particle swarm optimization and bee colony optimization.

Unconscious search (US) is originally proposed for solving continuous optimization problems such as optimization of unbounded and bounded function optimization (Ardjmand & Amin-Naseri, 2012) and training feed-forward neural networks (Amin-Naseri, Ardjmand, & Weckman, 2013). In this paper a new discrete variant of US is proposed which can be used for solving supply chain related optimization problems like UFLP.

One of the advantages of US for solving UFLP is easiness of parameter tuning. As our experiments shows the solution quality is not sensitive to parameters of US. However, the run time of US is sensitive to one of the parameters of Unconscious search, namely *MS*. Further discussion on this parameter can be found in Section 5. In the next two sections, Unconscious search and the method of applying it to UFLP instances will be explained.

3. Unconscious search (US)

Unconscious search (US) is a metaheuristic for solving continuous engineering optimization problems, and is based on the theory of psychoanalysis. The theory of psychoanalysis was first introduced in the beginning of 20th century by Sigmund Freud in his book *Interpretation of Dreams* (Freud, 1913). According to the theory of psychoanalysis, the human psyche is made up of two main parts, the conscious and unconscious. "Consciousness is the subject's immediate apprehension of mental activity" (De Mijolla,