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Multi-objective multi-layer congested facility location-allocation problem optimization with Pareto-based meta-heuristics

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ABSTRACT

Facility location-allocation problems arise in many practical settings from emergency services to telecommunication networks. We propose a multi-objective multi-layer facility location-allocation (MLFLA) model with congested facilities using classical queuing systems. The goal is to determine the optimal number of facilities and the service allocation at each layer. We consider three objective functions aiming at: (1) minimizing the sum of aggregate travel and waiting times; (2) minimizing the cost of establishing the facilities; and (3) minimizing the maximum idle probability of the facilities. The problem is formulated as a multi-objective non-linear integer mathematical programming model. To find and analyze the Pareto optimal solutions, we propose a Pareto-based multi-objective meta-heuristic approach based on the multi-objective vibration damping optimization (MOVDO) and the multi-objective harmony search algorithm (MOHSA). We demonstrate the effectiveness of the proposed model and exhibit the efficacy of the procedures and algorithms by comparing MOVDO and MOHSA with two well-known evolutionary algorithms, namely, the non-dominated sorting genetic algorithm (NSGA-II) and multi-objective simulated annealing (MOSA).

1. Introduction

Facility location-allocation (FLA) problems, originally introduced by Cooper [1], are concerned with locating multiple facilities in a Euclidian plane and allocating customers to a facility while minimizing the total costs, mainly composed of transportation costs. In a typical FLA problem, suppliers, warehouses, and producers are considered as facilities, and retailers, purchasers, and service users are treated as customers. Researchers have studied multi-objective

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location-allocation problems extensively (see, among others, [2–8]). In particular, FLA problems and the corresponding solution methods play an important role in many and different areas such as: local clinics and hospitals centers; emergency medical service (EMS) systems; rescue helicopter locations, relief distribution centers and reconstruction center locations; education systems; police stations; truck terminals; hotels; city logistics terminals; press delivery networks, locating post boxes, post delivery services and fast delivery packing companies; solid waste disposal system; air ports; telecommunication systems; fuel/gasoline service stations; blood banking centers; libraries; retail outlets; and so forth.

The inclusion of multiple and conflicting objectives enhances the analysis of FLA problems by replacing the concept of an optimal solution with an efficient (also referred to as non-dominated, non-inferior, or Pareto-optimal) solution [9].

1.1. Congested facilities: a short review on queuing theory and evolutionary algorithms

The facilities are often used to meet average demands in a given production or service system. However, a facility may not be able to fulfill all of the customers' needs when the demand is at the maximum level. Facilities that cannot cope with the additional demands are called congested facilities [10].

Queuing theory is a useful method for studying congested facilities [11]. Berman and Larson [12] proposed a nonlinear congested facility location model with $M/G/1$ queues. Wang et al. [13] proposed a facility location model within an $M/M/1$ queuing system that minimizes the aggregation of traveling and waiting times. Wang et al. [14] presented a constrained location problem with the possibility for opening and closing of some facilities. They proposed three heuristic algorithms including greedy interchange, Tabu search, and Lagrangian relaxation approximation to solve the problem.

Silva and Figuera [15] considered demand as stochastic and formulated each of the facilities as an independent queue. They combined stochastic models of manufacturing systems with deterministic location models to obtain a formula for the backlogging probability at a potential facility location. A heuristic based on the greedy search procedure was proposed to solve their model. Berman and Drezner [16] developed a single-objective facility location model within $M/M/m$ queues. Syam [17] proposed a nonlinear multiple server location-allocation model with relevant costs and other considerations. Aboolian et al. [18] investigated a multiple-server center location problem with a nearest-facility constraint. Their goal was to minimize the maximum time spent by any customer including travel time and waiting time. Raman et al. [19] hybridized a queuing model with a genetic algorithm (GA) to solve the layout problem. This combination provides a unique opportunity to consider the stochastic variations while achieving a good layout. Zarrinpoor and Seifbarghy [20] developed a competitive location model with capacitated queues to minimize the total cost of the system and solve their model with GA and Tabu search.

Zanjirani Farahani et al. [21] reviewed recent developments in multi-criteria location problems and classified them into three categories: bi-objective, multi-objective, and multi-attribute problems. Pasandideh and Niaki [22] proposed a bi-objective facility location problem within the $M/M/1$ queuing framework. Chambari et al. [23] presented two Pareto-based algorithms including non-dominated sorting genetic algorithms (NSGA-II) and non-dominated ranking genetic algorithms (NRGA) to solve a bi-objective facility location problem with $M/M/1/k$ queues. Hajipour and Pasandideh [24] presented an adaptive particle swarm optimization to optimize a bi-objective facility location model with batch arrivals. Pasandideh et al. [7] developed a new multi-objective facility location problem with batch arrivals and utilized two meta-heuristics known as simulated annealing (SA) and GA to solve the problem with integrated objectives using the LP-metric technique. LP-metric method is a rigorous multi-objective technique used to navigate the search direction of GA.

A large number of closed form and approximation methods have been used in the literature to find Pareto fronts in multi-criteria NP-hard location problems. Sherali and Nordai [25] showed that a multi-facility Weber problem (where the facilities can be placed at any point in the Euclidian plane) with limited capacity and deterministic parameters is NP-hard even if all the customers are located on a straight line. Therefore, the only reasonable approach for solving large-scale problems is to use heuristics and meta-heuristics [7,13]. Farahani and Hekmatfar [26], Farahani et al. [21], Boloori et al. [27], and Farahani et al. [28] present a comprehensive overview of these heuristics and meta-heuristics.

Several solution procedures involving simultaneous optimization of multiple objectives are proposed to find the Pareto solution sets [29]. The multi-objective optimization algorithm based on GA and SA algorithms like NSGA-II [30] and the multi-objective SA (MOSA) [31] are the meta-heuristics commonly used to find the Pareto front solutions in NP-hard multi-objective problems [32].

Two alternative approaches to solving FLA problems have been recently proven to be quite efficient, namely, the vibration damping optimization (VDO) algorithm and the harmony search algorithm (HSA).

VDO is a meta-heuristic algorithm that uses the concept of vibration-damping in mechanical vibration improvisation of musicians [33]. Mehdizadeh and Tavakkoli-Moghaddam [33] used the VDO algorithm to solve the parallel machine scheduling problems. Mehdizadeh et al. (2011) proposed a hybrid VDO algorithm to solve multi-facility stochastic-fuzzy capacitated location allocation problems. Mousavi et al. [34] developed a special type of VDO algorithm to solve capacitated multi-facility location-allocation problems with probabilistic customers' locations and demands.

Harmony search algorithm (HSA) is a music-inspired algorithm, conceptually simple and with very few parameters. HSA is easy to implement and has been successfully applied to different problems including the Sudoku puzzle [35], mechanical structure design [36], pipe network optimization [37], inventory models [38], and facility location [39,40].