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Bi-objective vibration damping optimization for congested location–pricing problem

Vahid Hajipour [a], Reza Zanjirani Farahani [b,*], Parviz Fattahi [c]

[a] Industrial Engineering Department, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran
[b] Kingston Business School, Kingston University, Kingston Upon Thames, Surrey, UK
[c] Department of Industrial Engineering, Faculty of Engineering, Alzahra University, Tehran, Iran

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ABSTRACT

This paper presents a bi-objective mathematical programming model for the restricted facility location problem, under a congestion and pricing policy. Motivated by various applications such as locating server on internet mirror sites and communication networks, this research investigates congested systems with immobile servers and stochastic demand as $M/M/m/k$ queues. For this problem, we consider two simultaneous perspectives; (1) customers who desire to limit waiting time for service and (2) service providers who intend to increase profits. We formulate a bi-objective facility location problem with two objective functions: (i) maximizing total profit of the whole system and (ii) minimizing the sum of waiting time in queues; the model type is mixed-integer nonlinear. Then, a multi-objective optimization algorithm based on vibration theory (so-called multi-objective vibration damping optimization (MOVDO)), is developed to solve the model. Moreover, the Taguchi method is also implemented, using a response metric to tune the parameters. The results are analyzed and compared with a non-dominated sorting genetic algorithm (NSGA-II) as a well-developed multi-objective evolutionary optimization algorithm. Computational results demonstrate the efficiency of the proposed MOVDO to solve large-scale problems.

1. Introduction

The traditional goal in facility location problems (FLPs) is to locate the facilities in the best locations to minimize fixed location and transportation costs. Hakimi [24], Toregas et al. [45], Love et al. [27], Marianov and Revelle [29], and Hodgson and Berman [26] proposed various models and solutions methodologies for FLPs. Farahani and Hekmatfar [17], Melo et al. [31], Farahani et al. [16], Boloori Arabania and Farahani [9], and Farahani et al. [18] provided more detail on FLPs and their solving methodologies. In addition to FLPs, several other streams of research such as queuing, pricing and multi-objective heuristics techniques are related to this paper which will be explained in detail as follows.

In the many real-life applications of FLPs such as gas stations and car parking, customer demand on arrival at facilities is heavy; these facilities are called congested [8]. Therefore, queues are formed in these systems; consequently, waiting time will be a key parameter in such FLPs. Thus, the combination of queuing theory with FLPs emerges to create queuing facility location problems (QFLPs) which are more realistic in some applications. Berman and Larson [3] proposed a nonlinear location problem with congested facilities which behaves like a $M/G/1$ queue. Wang et al. [46] presented a congested FLP to minimize aggregate traveling and waiting times. Wang et al. [47] presented several heuristic algorithms to solve location problems with budget limitations. Berman and Drezner [4] formulated a facility location problem within a $M/M/m$ (multi-server) queuing framework. Syam [43] presented a nonlinear multi-server location–allocation problem to minimize total costs of the system. Zarrinpoor and Seifbarghy [49] developed FLPs in competitive environments to determine a specific percentage of the market share in the context of cost minimization. Hajipour and Pasandideh [21] proposed a multi-objective congested FLP which behaves as a $M^{[x]}/M/1$ queuing system. Chambari et al. [11] presented two Pareto-based algorithms based on a genetic algorithm (GA) for a facility location model with two conflicting objectives for $M/M/1/k$ queues. Pasandideh and Niaki [38] applied a GA and desirability function approach to solve a bi-objective facility location model with classical queues. Hajipour and Pasandideh [22] optimized a bi-objective congested facility location problem by an adaptive multi-objective particle swarm optimization. Pasandideh et al. [39] presented a multi-objective facility location model in which batch demands arrive on the

* Corresponding author. Tel.: +44 20 8417 5098; fax: +44 20 8417 7026.
E-mail addresses: Zanjiranireza@gmail.com, R.Zanjiranifarahani@kingston.ac.uk (R.Z. Farahani).

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system; they solved the problem by a multi-objective GA and SA (simulated annealing) algorithm. Rahmati et al. [42] presented multi-objective FLPs considering multiple servers at each facility. They solved the model with multi-objective Pareto-based meta-heuristic algorithms.

Another aspect of real-world applications is that demand nodes are mainly influenced by pricing strategy. Some researchers have focused on hybridizing thepricing concept with FLPs [19,15,28] and also with queuing theory [41,2]. Since these problems are chiefly multi-objective, the majority of solving methods are applied to find Pareto solutions for multi-objective FLPs. Additionally, since exact or hard computing approaches cannot solve NP-hard problems [47,38,39], soft computing approaches are applied. Unlike hard computing techniques, soft computing approaches deal with imprecision, uncertainty, and approximation to determine robustness and low-cost solutions. Neural networks, fuzzy logic and evolutionary computations may help in such approaches. Among these, evolutionary algorithms are more popular for developing algorithms to solve the FLP models [10]. Evolutionary algorithms are divided into two classifications, namely single and multi-objective models. Interested readers may refer to Farahani et al. [16] to see a survey of these studies in FLPs.

Berman et al. [5] combined location, pricing and queuing concepts in a single facility location problem on a network to maximize profit. They considered, simultaneously, decision making on location, pricing and service capacity, where the demand depends on price, distance and waiting time at the facilities. They presented an algorithm to achieve the optimal price and capacity. Later, Berman et al. [6] extended their previous research to a multi-facility location model. In these two research works, they assumed that customers have a prior knowledge about the expected waiting times at the facilities. Abouee-Mehrizi et al. [1] extended these models to locating m facilities on a network with n demand nodes. They assumed a $M/M/1$ queuing system in which (a) customers may balk the system upon their arrival and (b) all the facilities charge the same price for service.

Among multi-objective algorithms, the non-dominated sorting genetic algorithm (NSGA-II) is one of the commonly used Pareto-based approaches proposed by Deb et al. [14]. This algorithm is applied to various operations research applications including FLPs and their variations. Bhattacharya and Bandyopadhyay [7] applied NSGA-II to solve FLPs with two conflicting objectives. Chambari et al. [11] solved an $M/M/1/k$ queue model by using both NSGA-II and non-dominated ranking genetic algorithms (NRGA). Chambari et al. [12] implemented NSGA-II to optimize cost and reliability of the whole system in a redundancy allocation problem. Mehdizadeh and Tavakkoli-Moghaddam [32] proposed a new meta-heuristic optimization algorithm, namely vibration damping optimization (VDO) to solve the parallel machine scheduling problem; VDO is based on the concept of vibration damping in mechanical vibration. Zhang and Lu [52] proposed a multi-objective decision support system to consider how to help users select and use the proposed algorithms. This algorithm simulates the vibration phenomenon. Mehdizadeh et al. [33] proposed a hybrid VDO algorithm to solve the multiple facilities stochastic-fuzzy capacitated location–allocation problem. Mousavi et al. [35] developed a special type of the VDO algorithm to solve the capacitated multi-facility location–allocation problem with probabilistic customer locations and demands. Recently, Hajipour et al. [23] introduced a multi-objective version of VDO for solving multi-objective optimization problems.

In this paper, a hybrid problem of location, pricing, and queuing in a network with M customer nodes and N potential server nodes is developed. We model the problem mathematically; the model contains two simultaneous objectives of (i) maximizing the profit and (ii) minimizing the sum of waiting time in the whole network. The model is formulated for a system in which each facility behaves as a $M/M/m/k$ queuing system; m is the number of servers in each facility and k is the capacity in the queuing system. We have assumed that various prices at different service facilities are provided. Furthermore, the capacity constraints are considered to make the problem more realistic. This assumption is known as the "mill pricing"; petrol stations and paid car parking areas are examples of mill pricing application.

The closest research paper to this work is Aboouee Mehrizi et al. [1]. However, the contributions of this research to the research literature are as follows:

- This research considers a $M/M/m/K$ queuing system at each facility, whereas the previous literature is mainly based upon a $M/M/1$ queuing system.
- Various prices are considered for each facility, while the simplifying assumption in the existing literature is based on the same price for all facilities.
- Our mathematical model contains two objectives and is presented in the form of a bi-objective model; in the literature, only single-objective models have been considered to date.
- A multi-objective VDO (MOVDO) is developed to find Pareto solutions. The VDO algorithm is extended, using fast non-dominated sorting and ranking procedures to find Pareto-optimal solutions for multi-objective optimization problems with conflicting and competing objectives. In fact, fast non-dominated sorting and crowding distances have been used to find and manage the Pareto-optimal front. The MOVDO is also analyzed and compared with the best-developed NSGA-II on some standard metrics. To block the impact of algorithm operators, the Taguchi approach is applied.

The rest of the paper is organized as follows: Section 2 details the problem. Section 3 formulates the problem as a non-linear integer programming mathematical model. Section 4 presents the proposed MOVDO algorithm as well as the NSGA-II. Section 5 discusses the tuning parameters of the algorithms. Section 6 analyzes the computational results and investigates the efficiency of the algorithm. Finally, conclusions and future research directions are provided.

2. Problem definition

We consider a firm that intends to locate several multi-server facilities in a region. The system under study contains two networks: (1) a customers' network with demand on nodes and (2) a facilities network in which nodes represent candidate location for facilities. The arcs indicate the allocation of demand nodes to facility nodes. Each customer node has a potential number of users which refers to facilities traveling certain distances to receive the service/goods. In order to receive the service/goods, users refer to the facility that provides the highest utility. User utility is a function of service/good pricing and the distance between customer nodes and facility nodes. It is rational to assume that potential users refrain from receiving the service/goods if a desirable price and distance are not provided. Obviously, sensitivity in each customer node toward price and distance is different. Therefore, pricing for service/goods and location of facilities are the most important determinants for firms, in order to maximize both profit and customer satisfaction levels. Since waiting time in queues is one of the satisfaction factors, firms intend to optimize profit and waiting time simultaneously. To obtain an efficient waiting time, queue length in each facility is controlled by an appropriate pricing policy to obtain the appropriate number of servers at the facility. Fig. 1 illustrates the network that is used in this paper. The idea is to achieve the following objectives:

- optimal number of facilities;