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Discrete Optimization

Solving a bi-objective Transportation Location Routing Problem by metaheuristic algorithms

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ABSTRACT

In this work we consider a Transportation Location Routing Problem (TLRP) that can be seen as an extension of the two stage Location Routing Problem, in which the first stage corresponds to a transportation problem with truck capacity. Two objectives are considered in this research, reduction of distribution cost and balance of workloads for drivers in the routing stage. Here, we present a mathematical formulation for the bi-objective TLRP and propose a new representation for the TLRP based on priorities. This representation lets us manage the problem easily and reduces the computational effort, plus, it is suitable to be used with both local search based and evolutionary approaches. In order to demonstrate its efficiency, it was implemented in two metaheuristic solution algorithms based on the Scatter Tabu Search Procedure for Non-Linear Multiobjective Optimization (SSPMO) and on the Non-dominated Sorting Genetic Algorithm II (NSGA-II) strategies. Computational experiments showed efficient results in solution quality and computing time.

1. Introduction

Distribution systems in Supply Chain Management comprise all operations related to the transportation of final products from plants to clients, considering all intermediate steps, such as the ones relating to warehouses and distribution centers.

The location of distribution facilities and the distribution of products from these facilities to clients are two key components of a distribution system (Tunzun & Burke, 1999). The problem, which combines the facility location and the vehicle routing decisions, is known in operations research context as the Location Routing Problem (LRP). Both, the facility location (FLP) and the Vehicle Routing Problem (VRP) are in general, NP-Hard (Cornuejols, Fischer, & Nemheuser, 1977; Karp, 1972, as cited in Tunzun & Burke, 1999). Therefore, the integration of both problems (LRP) is even more complex (Garey & Johnson, 1979; Megiddo & Supowit, 1984; Shen, 2007).

Efforts to solve FLP and VRP separately have proven to generate sub-optimal results (Prins, Prodhon, & Wolfler Calvo, 2006; Salhi & Rand, 1989). The fact is that the location of facilities in a supply chain, strategic level, and the vehicle routing decisions, tactical level, interact. Both are part of the supply chain system, and different designs of facility location affect the routing arrangement. It is necessary to view the problem holistically. An overall solution for both problems is required.

This research focuses on strategic and operational issues of a soft drinks' distribution industry. There exists several production plants and a group of clients located in cities. These clients (hotels, restaurants, mini-markets, and others) demand a fixed and stable amount of products. Due to traffic regulations, trucks from plants cannot arrive at clients locations in the cities. City Distribution Centers (CDCs) on the city's outskirts are required. The organization needs to determine the quantity and location of these logistic platforms, the number of trucks from each plant to each City Distribution Center (CDC) and the sequence to visit clients for product delivery. This problem can be seen as an extension of the two stage Location Routing Problem, in which the first stage corresponds to a transportation problem and the second one to a routing stage.

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Distribution costs have a significant impact on the overall costs of an organization (Toth & Vigo, 2002; Srivastava & Benton, 1990). Therefore, in their strategic and operational decisions, organizations have to take into account the objective of minimizing the overall distribution system's cost. Because of this, most efforts have focused in dealing with cost minimization.

However, in a complex industry system, other stakeholders are required to be taken into account in processes design and decision making. For instance, issues such as work equity and fairness might be considered in order to generate balanced workloads for employees (Kritikos & Ioannou, 2010). In this work, we considered a balance objective in order to even up the work load of the transportation staff in the routing stage.

In order to tackle the problem addressed in this work, an extension for the two stage Location Routing Problem is considered, which could be seen as the integration of three sub-problems: the location of the CDC (FLP), the transportation of product from plants to CDCs (transportation problem with truck capacity) and the design of the vehicle routes to visit clients for each CDC (VRP). We call this problem a Transportation–Location-Routing Problem (TLRP). Additionally, two objectives are considered in the problem definition, minimize the total operation cost of the system and maintain balance in vehicle (city freighters) operators' workload.

At least within the reviewed literature, multiple objectives in a TLRP have never been analyzed.

This paper is organized as follows, in Section 2 a brief discussion about previous related works is presented, the problem description and its mathematical formulation are comprised in Section 3. The solution approach description is given in Section 4, while the generation of data instances and computational results are presented in Section 5. In Section 6 some concluding remarks are offered.

2. Literature review

The first efforts of LRP studies date back to 1970s and early 1980s. One of the first authors to analyze a LRP was Watson-Gandy and Dohrn in 1973 (Min, Jayaraman, & Srivastava, 1998), and ever since, several efforts have been done in this field. For detailed information about development, classification and applications for the LRP see Nagy and Salhi (2007) and Min et al. (1998).

In recent years, the emphasis in LRP studies has been in the design and implementation of metaheuristic, such as Tabu Search (TS) (Albareda-Sambola, Díaz, & Fernández, 2001, 2005; Caballero, González, Guerrero, Molina, & Paralera, 2007; Lin & Kwok, 2006; Melechovský, Prins, & Wolfler Calvo, 2005; Tunzun & Burke, 1999; Wang, Sun, & Fang, 2005), Simulated Annealing (Wu, Low, & Bai, 2002), Particle Swarm Optimization (PSO) (Peng & Bai, 2006), clustering analysis (Barreto, Ferreira, Paixão, & Sousa Santos, 2007), multiple ant colony optimization algorithm (MACO) (Ting & Chen, 2013), variable neighborhood search (VNS) (Jarboui, Derbel, Hanafi, & Mladenović, 2013), and some hybrids metaheuristics, such as an hybrid PSO with Path Relinking (Marinakis & Marinaki, 2008), an algorithm combining Simulated Annealing with an Ant Colony System (Bouhafs, Hajjam, & Koukam, 2006), a GRASP algorithm complemented by Path Relinking (Prins et al., 2006) and a heuristic including Lagrangian relaxation and granular TS (Prins, Prodhon, Ruiz, Soriano, & Wolfler Calvo, 2007). Even though there exists several studies in the LRP field, most of them are focused on the single stage single objective LRP.

Related to multiple stages LRP studies, only few works are found: Ambrosino & Scutellà, 2005; Boccia, Crainic, Sforza, & Sterle, 2010; Contardo, Hemmelmayr, & Crainic, 2012; Lashine, Fattouh, & Issa, 2006. Ambrosino and Scutellà (2005) designed a model for a four layer LRP. Obtaining optimum solution for one instance, after a limit processing time of 25 hours for small instances and some days for large instances. Lashine et al. (2006) presented a model for a two stage LRP. The authors solved the model with a Lagrangian relaxation in the demands constraints, divided the problem into a location/allocation module and a routing module, obtaining good results for small instances but with computational time growing rapidly. Boccia et al. (2010) proposed a TS for solving a two echelon LRP, they decomposed the problem in four subproblems, one capacitated FLP and one multi-depot VRP for each echelon. Subproblems are solved sequentially and iteratively and then combined to generate a global solution. For comparison purposes, they considered for small instances, mathematical model results (within 2 hours limit) and for medium and large instances, a decomposition approach, sequentially solving a two echelon FLP and two MDVRP (one for each echelon), they could only obtained exact results for 19 out of 63 small instances. Contardo et al. (2012) considered a two-echelon capacitated LRP, they obtained lower bounds for the problem with the design and implementation of a two-index vehicle-flow formulation and several families of valid inequalities embedded into a branch-and-cut (B&C) solver. They also proposed an adaptive large neighborhood search (ALNS) capable of obtaining good upper bounds for the problem. The ALNS outperfomed previous heuristics for the two echelon capacitated VRP (single-sourcing). Lower bounds obtained with B&C lie no further than 2.77% on average below the best solution found by the ALNS which, according to Contardo et al. (2012) validates the robustness of both approaches.

Within the literature reviewed only two works that considered a multiple objective approach for the single stage LRP were found. One considered multiple objectives in a global problem (Caballero et al., 2007), while the other only in some sections of the problem (Lin & Kwok, 2006). And one work considering multiples objective in a multiples stage LRP Samanlioglu (2013).

Based on TS, Caballero et al. (2007) designed a multiobjective metaheuristic using an adaptative memory procedure (MOAMP) for the resolution of multiobjective combinatorial problems (MOCO). The authors analized the problem of determining the location of two incineration plants to dispose of solid animal waste, and to design routes to serve clients in the region of Andalusia, contrasting economic and social objectives.

On the other hand, Lin and Kwok (2006), considered the objective of minimizing total cost with a workload balance criteria in a single stage capacitated LRP. The authors applied TS and simulated annealing on real data and simulated data, while using two versions for the solution algorithm about the way routes are assignment to vehicles.

Lately, Samanlioglu (2013) proposed a mathematical model for a three objective (one economic and two social criteria) two stage LRP, for an industrial hazardous waste management system in a region of Turkey. They used a lexicographic weighted Tchebycheff formulation to obtain 16 different representative Pareto optimal solutions.

After an extensive literature review, no publications that consider multiple objective approaches for a TLRP, as the one proposed here, were found. Considering this situation, we proposed a mathematical model and a new representation for the problem, based on priorities, implemented in two solution algorithms based on metaheuristic approaches, in order to obtain good solutions for the multiobjective TLRP.

3. Problem description and mathematical formulation

The TLRP considers a set of clients with known demands. The client's product demands must be supplied from a set of plants. Each client i has a known demand h_i and each plant k can supply