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Innovative Applications of O.R.

The Latency Location-Routing Problem

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ABSTRACT

This paper introduces the Latency Location-Routing Problem (LLRP) whose goal is to minimize waiting time of recipients by optimally determining both the locations of depots and the routes of vehicles. The LLRP is customer oriented by pursuing minimization of the latency instead of minimization of the length of routes. One of the main applications of this problem is the distribution of supplies to affected areas in post-disaster relief activities. It is also relevant in customer-oriented supply chain where latency at demand locations plays a significant role in the satisfaction of the customers. The problem is formulated mathematically and two heuristics, the Memetic Algorithm (MA) and the Recursive Granular Algorithm (RGA), are proposed. An extensive experimental study shows that both algorithms are able to produce promising results in reasonable time.

1. Introduction

Transportation and delivery of products and services are inherent in most manufacturing and service systems. The delivery is generally performed by a fleet of vehicles from multiple depots to customers. To design an efficient distribution system, whether for emergency situations or commercial systems, several types of decisions need to be carefully examined: locating the depots, allocating vehicles to depots, and routing vehicles. While these decisions in emergency and disaster situations seek to achieve minimum loss and damage, profit maximization is the primary goal in commercial delivery systems.

One of the main post-disaster activities is the distribution of commodities from distribution centers to affected areas. Commodities may encompass a range of different supplies, such as food, water, clothing, and medical supplies. Affected areas with their associated demand size are examined and estimated after disaster. To effectively distribute supplies to the victims despite limited resources, it is important to answer the three aforementioned questions. The locations of temporary distribution centers (DCs) must be appropriately selected among a set of potential locations that are usually predetermined before a disaster happens. As time passes after disaster, deaths and losses increase due to the lack of supplies. Therefore, the focus of the disaster relief operations is on minimizing waiting time of the recipients which eventually leads to enhanced safety and welfare of the victims. The limited capacity of the vehicles and depots should also be taken into account to handle the relief logistics operations realistically.

In commercial environments, product/service is delivered with the goal of maximizing profit, which can be achieved by reducing customers' waiting time and thereby improving customer satisfaction. This satisfaction will eventually lead to more profit for the company by receiving more orders from the existing and new customers due to good reputation. The same decisions mentioned above, therefore, contribute to the commercial systems as well. These customer-oriented systems with focus on minimum waiting time are different from the server-oriented systems in which minimum travel distance is the primary objective.

According to the literature of disaster relief location-routing, no article has assumed minimization of the total latency although it plays an important role in reducing deaths and losses. The common objective in the literature of disaster relief location-routing problems that involve the three types of decisions is maximizing the amount of satisfied demands (Ceselli, Righini, & Tresoldi, 2014; Rath & Gutjahr, 2014). However, this objective does not satisfy the need for disaster delivery systems as discussed above. For example, it does not guarantee maximum survival of victims because it may lead to the delivery of supplies to the victims who are no longer alive at the time of delivery. Hence, minimizing latency should be taken into account as a primary goal of the LRP in disaster relief logistic.

The purpose of this paper is to introduce a problem called the *Latency Location-Routing Problem (LLRP)* whose objective is to minimize latency by optimally determining location, allocation, and routing decisions at the same time. This problem can be viewed

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as a hybrid of two optimization problems. The first problem is the Facility Location Problem (FLP) (Bramel & Simchi-Levi, 1997; Klose & Drexl, 2005) which determines the locations of depots, and the second problem is the Cumulative Capacitated Vehicle Routing Problem (CCVRP) (Lysgaard & Wøhlk, 2014; Ngueveu, Prins, & Wolfler Calvo, 2010; Ribeiro & Laporte, 2012), which allocates vehicles to depots and obtains the sequences of visits to customers. The FLP and CCVRP are closely interrelated and best results can be obtained when both are solved simultaneously instead of sequential problem solving. Because of the complexity of the LLRP, two efficient algorithms are proposed to deal with the problem practically. The first approach is a Memetic Algorithm with elitism which executes several local search operators, while the second approach is a recursive granular search algorithm with different neighborhood search strategies. The performances of the two proposed algorithms are carefully examined in several ways. We compare them with a sequential approach that solves the decisions in a natural, sequential manner, as well as comparisons with two different lower bounds. We also evaluate it by analyzing performance enhancement over the conventional Location-Routing Problem settings. The evaluation results indicate the importance of considering latency in designing distribution systems and the effectiveness of the two proposed algorithms in minimizing the latency.

The remainder of the paper is organized as follows. Section 2 presents the literature review of recent location-routing problems and solution approaches. Section 3 describes the problem and its assumptions, and presents a mathematical model of the problem based on a network flow model. Section 4 describes the proposed algorithms and the results of the implementation are presented in Section 5. Finally, Section 6 concludes the paper.

2. Related literature

Many authors have studied different variants of location routing problems. In the context of disaster relief operations, Wang, Du, and Ma (2014) presented a multi-objective formulation of the open location routing problem in post-disaster earthquake relief. The model seeks to minimize the total depot locating and vehicles' travel costs, minimize the maximum travel time of the vehicles, and maximize the minimum route reliability. Two heuristic algorithms based on Non-dominating Sorting Genetic Algorithm II (NSGA-II) and Non-dominated Sorting Differential Algorithm (NSDE) were developed and implemented in a case study on Great Sichuan Earthquake in China. Ceselli et al. (2014) designed an exact algorithm based on column generation with three different types of columns and branch-price-cut algorithms. The algorithms were used for drug distribution problems to maximize the total satisfied demands. Rath and Gutjahr (2014) formulated the LRP with three objective functions: minimizing the costs of opening facilities, minimizing the costs of transportation and warehousing, and maximizing satisfied demands. The authors used a decomposition-based approach in which the location and routing problems were solved iteratively with a single objective in each step. A Variable Neighborhood heuristic was also proposed and compared with NSGA-II on a real problem in Manabi with 40 demand locations. Özdamar and Demir (2012) proposed a hierarchical clustering and routing (HOGCR) algorithm that obtains the delivery of supplies from warehouses to recipients and pickup of victims to hospitals considering the capacity of warehouses and hospitals. The algorithm first clusters demand nodes to form aggregate clusters and finally finds the optimal routings of the vehicles in each cluster. It applies divide and conquer to cluster nodes recursively until the optimal routing is found with the minimum total travel time. For a review on emergency logistics the reader is referred to Caunhye, Nie, and Pokharel (2012) and Luis, Dolinskaya, and Smilowitz (2012).

The LRP has also been studied in commercial distribution systems. Boujelben, Gicquel, and Minoux (2014) presented a clustering-based approach to deal with a three-level distribution network design problem in automotive industry to minimize primary, secondary, and transit costs. The authors also proposed different heuristics by relaxing the MIP formulation of the problem to solve large-sized problems with 500 customer nodes and 50 potential DCs. Averbakh and Berman (1994) presented a location-routing problem to minimize the total latency of customers on paths. The authors developed polynomial algorithms to solve the problem with one and multiple servers. Lin and Kwok (2006) presented a two-phased Tabu Search for costs minimizing and vehicles' workload balancing assuming homogeneous capacitated fleet with both time and load constraints. Chakrabarty and Swamy (2011) developed approximation algorithms for uncapacitated facility location and minimum latency with objective function sum of facility costs and customers' latency. Using linear approximation techniques, some improved constant factor approximations were proposed to solve special cases of the problem. Contardo, Cordeau, and Gendron (2013) proposed a three-stage exact algorithm to solve the capacitated location-routing problem. The first stage solves the two-indexed flow formulation by branching on location variables. In the second and third stages, the gap is improved by solving a column-and-cut generation of the linear relaxation of the set-partitioning formulation and branch and bound on the enumerated columns. Rahmani, Ramdane Cherif-Khettaf, and Oulamara (2016) formulated the two-echelon location-routing problem assuming pickup and delivery, multi-product, and intermediate facilities. Three heuristics based on nearest neighborhood, insertion, and clustering were applied to the problems with up to 200 customers and 10 DCs to minimize the total travel costs, facility opening costs, and vehicle fixed costs. Huang (2015) presented a three-stage solution approach to deal with the multi-compartment capacitated location routing problem with pickup-delivery and stochastic demands. The algorithm divides the problem to determine facility locations, assignment of customers to facilities, and routings by minimizing facility opening, vehicle, and travel costs, and violation of the vehicle and depot capacity constraints. Nadizadeh and Nasab (2014) formulated the capacitated-routing problem with fuzzy demands in a time horizon and developed a hybrid heuristic algorithm with four phases. The method also estimates route failures by stochastic simulation of each route.

Many metaheuristics have been recently applied to the location-routing problems. These approaches are popular since they are able to solve large scale problems with reasonable computation time. Karaoglan and Altiparmak (2015) proposed a Memetic Algorithm for the LRP with backhauls to minimize transportation costs, depot opening costs, and vehicle operating costs. Derbel, Jarboui, Hanafi, and Chabchoub (2012) developed a hybrid Genetic Algorithm with Iterated Local Search (ILS) to minimize costs in the LRP with capacitated depots and uncapacitated vehicles. Prodhon (2011) also proposed some hybrid evolutionary algorithms for the periodic location routing problem. The algorithms combine evolutionary local search with the randomized extended Clarke and Wright algorithm. Hemmelmayr (2015) developed a large neighborhood search (LNS) algorithm to solve the periodic location routing problem with minimum costs. The author also presented a general parallelization strategy to reduce the computation time. Escobar, Linfati, and Toth (2013) presented a two-phased hybrid algorithm for the LRP with minimum costs. The approach first constructs an initial solution and the solution is improved by granular Tabu search using different diversification strategies. More algorithms to tackle the LRP are: Genetic Algorithm (Ardjmand, Weckman, Park, Taherkhani, & Singh, 2015), Tabu Search (Martínez-Salazar, Molina, Ángel-Bello, Gómez, & Caballero, 2014), GRASP and path relinking (Prins, Prodhon, & Calvo, 2006), Particle Swarm