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Solving the multi-compartment capacitated location routing problem with pickup–delivery routes and stochastic demands ☆

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ABSTRACT

This paper considers an advanced capacitated location routing problem in a distribution network with multiple pickup and delivery routes, and each customer placing random multi-item demands on it. The pickup and delivery services need two fleets of vehicles and will form two different sets of routes. However, the unpredictability of variation in the multi-item demands makes the routing of multi-compartment vehicles to accommodate such demands complex. To solve this multifaceted problem, a new process employing the TABU search is proposed in this research study. This proposed approach includes three stages: location selection, customer assignment, and vehicle routing. The innovative concept is to divide all customers into assignment-determined and assignment-undetermined groups in order to narrow down the search area of a solution domain so the TABU search can be more efficient and effective. Two sets of benchmarks are then generated to verify the quality of the proposed method. According to the experiment results, the proposed solution process can both resolve the problems and yield good results in a reasonable amount of computing time. The analysis of the solution process parameters is also provided. In addition, the comparisons between stochastic demand and deterministic demand cases are calculated and discussed as well.

1. Introduction

The Location Routing Problem (LRP) is a complex problem that incorporates both the Facility Location Problem (FLP) and the Vehicle Routing Problem (VRP). Because the FLP is a strategical level problem and VRP is an operational level problem, these two levels of decision are most often tackled separately. However, each of the two problems constitute such a large portion of company expenses, comprehensive and simultaneous consideration could result in a better plan that significantly reduces the cost of researching them independently. Various researchers have devoted themselves to this problem and proposed several different solution processes. For instance, Tuzun and Burke (1999), Prins, Prodhon, Ruiz, Soriano, and Calvo (2007), and Caballero, Gonzalez, Guerrero, Molina, and Paralera (2007) employed the TABU Search (TS) algorithm to solve the LRP—a solution that has been proven to be an effective method. Duhamel, Lacomme, Prins, and Prodhon (2010) and Nguyen, Prins, and Prodhon (2012) use the Greedy Randomized Adaptive Search Procedure (GRASP) to solve the problem and obtain promising results. Yu, Lin, Lee, and Ting (2010) and Wu, Low, and Bai (2002) employed the Simulated Annealing (SA) heuristic to solve the LRP, while Ting and Chen (2013) applied the meta-heuristic Ant Colony Optimization (ACO) algorithm to resolve the problem. Other researchers, such as Belenguer, Benavent, and Prins (2011) and Karaoglan, Altiparmak, Kara, and Dengiz (2011), adopted the Branch-and-Cut method. Sets of benchmarks for solving the LRP have been established by Tuzun and Burke (1999) and Prins et al. (2007), among others. Subsequent researchers frequently base their solution processes on these benchmarks to verify the quality of their own work.

The conventional LRP is a deterministic node-routing problem. However, randomized cases are far more realistic for long-term planning; for example, when the same problem has to be repeatedly solved but the actual data varies from one instance to another. Only a few researchers, including Laporte, Louveaux, and Mercure (1989) and Chan, Carter, and Burnes (2001), have studied such complex cases. In addition, Albareda-Sambola, Diaz, and Fernandez (2010) studied a randomized location-routing problem and solved it using a two-stage model. In this study, an extended form of the LRP with uncertain demands that considers pickup/delivery routes and multi-item cargo is analyzed. For a parcel delivery service provider, for example, pickup and delivery routes both originate from depots and the cost of these two

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services is affected by the locations of these facilities. Moreover, the depots and routes may need to deal with more than one type of cargo because of incompatibility constraints in the real world, such as those presented by refrigerated food, frozen food, and room temperature food. The problem, in dealing with multiple products that must travel in independent compartments, is referred to as a multi-compartment vehicle routing problem, which is taken into account in this research as well. This kind of problem has been emerging in recent years. Fallahi, Prins, and Calvo (2008) apply two algorithms to solve the problem: the memetic algorithm with a post-optimization phase based on path relinking, and the TABU search method. Mendoza, Castanier, Gueret, Medaglia, and Velasco (2010) also employed the memetic algorithm to solve the multi-compartment vehicle routing problem with randomly determined demands. Mendoza, Castanier, Gueret, Medaglia, and Velasco (2011) further proposed three constructive heuristics to solve the multi-compartment vehicle routing problem with random demands. The three methods are the savings-based algorithm, novel look-ahead heuristic, and post-optimization procedure based on the classical 2-Opt heuristic. In addition, Muyldermans and Pang (2010) combined a localized search procedure with the Guided Local Search meta-heuristic to solve and improve the solution of the multi-compartment vehicle routing problem.

Ultimately, the objective of solving the Multi-Compartment Location Routing Problem with Pickup–Delivery Routes and Stochastic Demands (MLRPPDRSD) is to minimize the total cost, including depot opening costs, route costs, travel costs, recourse costs, and any penalties. This problem is categorized as a NP-hard problem since it is an extension of LRP. The MLRPPDRSD is divided into three parts and a solution process is proposed in this research study. In the pages that follow, Section 2 describes the problem, definitions and mathematics programming. Section 3 details the methodology used to solve this complex problem. The experiments and subsequent analyses are introduced in Section 4, with results and conclusions discussed in Section 5.

2. Problem definition and formulation

The MLRPPDRSD can be described as two sets of customers (the pickup set and the delivery set) with undetermined multi-item demands following a particular random distribution, along with one set of potential depot locations with known capacity scattered over a graph. In this study, a depot contains two compartments to accommodate pickups and deliveries, with each compartment able to store a variety of incompatible types of cargo. Each pickup and delivery vehicle contains multiple compartments for these cargoes and originates from one of the open depots to service a set of customers. Upon completing a pickup or delivery service, each vehicle returns to the same open depot. Each customer is served once, and only once, by one vehicle. The objective then is to determine potential locations for the opening of candidate depots, and *a priori* vehicle routes that minimize costs, including setup costs, travel costs and penalty costs.

The mathematics model for the problem is described as follows. Letting $G = (V, E)$ represent a complete, weighted, and undirected network G containing a set of vertices $V = (V_p, V_d, V_o)$ and a set of edges E. Three subsets, V_p, V_d, and V_o, constitute the set of vertices V where V_p represents the customers requiring pickup services, V_d represents the customers requiring delivery service, and V_o indicates all potential depot sites. Each customer $i \in V_p$ has a random pickup demand d_{iu} for product u that follows the Poisson distribution, and must be serviced by a single pickup vehicle; similarly, customer $i \in V_d$ has a random delivery demand d_{iu} for product u will be served by a single delivery vehicle. A depot site $m \in V_o$ with an opening cost O_m contains compartment capacities W^m_{pu} and W^m_{du} to accommodate pickup and delivery of cargo u, respectively. Set E is a collection of edges connecting each pair of nodes in V. The travel cost for each edge (i,j) is given by c_{ij}, which depends on the Euclidean distance between nodes $i \in V$ and $j \in V$. K would then represent the set of vehicles and two subsets K_p and K_d of identical vehicles of capacity Q^k_{pu} and Q^k_{du} for product u, respectively. A fixed cost, F_p or F_d, is incurred by a single pickup or delivery vehicle route, operating out of an open depot m. Total travel costs associated with a route include the fixed cost and costs of traversing edges (variable costs). Before constructing the mathematics formula, an introduction of the notations used immediately follows.

ρ_p	constant for deciding number of pickup vehicles
ρ_d	constant for deciding number of delivery vehicles
V	set of vertices, including customers and potential depot sites, wherein $V = (V_p, V_d, V_o)$
V_p	set of customers requiring pickup services, $V_p = \{1,2,\ldots,N\}$
V_d	set of customers requiring delivery services, $V_d = \{1,2,\ldots,R\}$
V_o	set of potential depot sites, $V_o = \{1,2,\ldots,M\}$
K	set of available vehicles where $K = (K_d, K_p)$
K_p	set of vehicles for pickup services
K_d	set of vehicles for delivery services
d_{iu}	random variable for customer demand i for product u following a known probability distribution with mean μ_{iu} and standard deviation σ_{iu}
O_m	opening cost of a depot $m \in V_o$
W^m_{pu}	pickup capacity for product u from a depot $m \in V_o$
W^m_{du}	delivery capacity for product u from a depot $m \in V_o$
c_{ij}	travel cost from node i to j where $i,j \in V$
F_p	fixed cost for one pickup route
F_d	fixed cost for one delivery route
ε_u	excess handling cost for one unit of product u exceeding the capacity of a compartment at a depot
Q^k_{pu}	capacity for product u of vehicle k and $k \in K_p$
Q^k_{du}	capacity for product u of vehicle k and $k \in K_d$
y_m	binary variable in which $y_m = 1$ if depot i is opened, otherwise $y_m = 0$
z_{jm}	binary variable in which $z_{jm} = 1$ if customer $j \in V_p \cup V_d$ is assigned to depot $m \in V_o$, otherwise $z_{jm} = 0$
x^k_{ij}	binary variable in which $x^k_{ij} = 1$ if edge (i,j) is traversed from i to j in the route driven by vehicle $k \in K$

The objective of this problem is to minimize total cost, including facility opening costs, route costs, travel costs, and any penalty costs.

2.1. Facility opening cost

A cost is incurred when a depot location is opened for business. It can be represented as

$$\sum_{m \in V_o} O_m y_m \tag{1}$$

In order to synchronize a facility's opening cost with travel costs, the facility opening cost is calibrated to the same time horizon with other costs.

2.2. Route cost

A route cost is incurred through the dispatching of a vehicle; technically, it includes the fixed costs of vehicle and labor. Since customer demands are uncertain in this problem, *a priori* route must be designed in advance so as to evaluate the route cost. In this study, vehicle capacity is the main consideration in deciding the number of routes to be constructed. Customer demand is