Multi-commodity vs. Single-commodity Routing

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1 Introduction

In most of the literature on vehicle routing problems, a single numeric value expresses the demand of a customer. The typical constraint is that the total demand served by a vehicle cannot exceed the vehicle capacity. It is usually understood that all vehicles can serve all customers. If different commodities require different vehicles, it is assumed that, in a previous phase, it has been decided which vehicles will serve which set of customers. Then, a routing problem is solved, limited to the customers requesting a commodity and to the vehicles assigned to that commodity. In this paper, we study the cost implications from using vehicles dedicated to a single commodity compared with using flexible vehicles capable of carrying any set of commodities.

The problem we study has several important applications. A first natural category of applications is the one where different vehicles are available on the market, namely vehicles that are specific for a commodity and vehicles that are flexible and may be used for different commodities. Usually, the flexible vehicles are more expensive than the specific vehicles, and a decision has to be made about whether it is beneficial to invest in the flexible vehicles. A decision can be made only through the evaluation of the reduction of the operational costs due to the availability of the flexible vehicles with respect to the operational costs in case the specific vehicles are used. An example of this category of problems can be observed in waste management, where vehicles are available to collect one kind of waste only, and more expensive vehicles are also available that may collect two different kinds of waste at a time. These latter vehicles have the container divided in two sections. Similar problems are met, for example, when frozen and non-frozen food have to be delivered to the same customers. The question becomes whether it is more beneficial to
have vehicles dedicated to frozen and non-frozen food or flexible vehicles with dedicated sections.

A second category of applications concerns the evaluation of the opportunity for companies to collaborate and share vehicles and customers. In this case, the vehicles of the different companies serve the same kind of commodity, but each company uses its own vehicles for its own customers. Is it beneficial for the companies to invest in a collaboration project and share vehicles and customers? In supply chain management, there are several famous success stories of cost reduction due to the collaboration between companies that have shared their warehouses (capacity for stocking) or their vehicles (capacity for delivering). In general, it is believed that collaboration allows companies to better use their capacity and/or improve customer service by serving customers more frequently. However, to the best of our knowledge, only a few papers have attempted to quantify the cost reduction due to collaboration ((Ergun et al., 2007) and (Ergun et al., 2007b)).

In the problem we are analyzing, we are given a set of geographically scattered customers, a set of commodities and an unlimited fleet of capacitated vehicles. Each vehicle starts from a depot, visits a set of customers and returns to the depot at the end of the tour. Any customer may demand delivery of any of the commodities. We assume that the total demand of a customer, though, does not exceed vehicle capacity. We will consider different situations, depending on whether a vehicle is dedicated to a commodity or is flexible and also depending on whether the demand of a customer may be satisfied by one or several vehicles. If the demand may be satisfied by more than one vehicle, we will examine when deliveries of individual commodities can be split and when they cannot. Each situation gives rise to a different optimization problem. Whereas most of these problems are known, one is new to the best of our knowledge.

2 The problems

We consider a distribution network represented by a graph where vertex 0 is the depot and vertices 1, . . . , n the customers. We will indicate by C the set of customers. The graph is undirected and we denote by c_{ij} the distance or cost of the edge that connects vertices i and j. We assume the triangle inequality holds. An unlimited fleet of vehicles of capacity Q is available. A vehicle may carry a single commodity or all commodities, depending on the problem we consider. Commodities 1, . . . , m have to be distributed from the depot to the customers. We will indicate by M the set of commodities. Let us denote by d_{ij} the demand of commodity j to be delivered to customer i. Let t_j = \sum_i d_{ij} be the total demand of commodity j and d_i = \sum_j d_{ij} be the total demand of customer i. We assume that the total demand of each customer i is not greater than the vehicle capacity.

In the separate routing (SR) problem, a specific set of vehicles is dedicated to each com-
modity, and any commodity is delivered to any customer by one visit of a vehicle only. In this case, a classical Vehicle Routing Problem (VRP) has to be solved for each commodity. A customer will receive as many visits as the number of commodities requested.

The mixed routing (MR) problem is one where any vehicle can deliver any set of commodities. In the MR problem, no customer can be visited more than once, that is if a customer requests one or more commodities, all the requested commodities are carried to the customer by one vehicle in one visit. This problem corresponds to a single classical VRP.

We also consider the problem where any vehicle can deliver any set of commodities and split deliveries of a commodity are allowed, and the same problem where split deliveries of a commodity are not allowed. The split delivery mixed routing (SDMR) is the problem where any vehicle can deliver any set of commodities and split deliveries are allowed, that is the demand of a customer, requesting one or several commodities, can be served by one or several vehicles. The commodities can be split in any possible way. A customer may be visited several times if beneficial, even in the case one commodity only is requested. This problem corresponds to the Split Delivery Vehicle Routing Problem (SDVRP) (see (Archetti and Speranza, 2012) for a survey).

Finally, we consider the problem where the vehicles are flexible and can deliver any set of commodities, and multiple visits of a customer are allowed only if the customer requests multiple commodities. When a commodity is delivered by a vehicle to a customer, the entire amount requested by the customer is carried. If the customer is visited more than once, the different vehicles will deliver different sets of commodities. We call this problem the split commodities mixed routing (SCMR) problem. Splitting the demand of a customer for different commodities on different vehicles is more natural and likely more acceptable to customers than splitting the delivery of an individual commodity.

Solving the SR problem corresponds to solving a VRP for each commodity, whereas solving the MR problem implies solving a single VRP. Solving the SDMR problem corresponds to solving the SDVRP. The SCMR problem is a new problem for which we will present an optimization model and a heuristic.

3 Worst-case and computational analysis

We compare the problems from a worst-case perspective and show that, while it is intuitive that it may be highly beneficial to use flexible vehicles, there are situations where it is beneficial to use dedicated vehicles. We will show that allowing the delivery of different commodities with different vehicles and allowing the splitting of the delivery of a commodity are, from the worst-case point of view, equally beneficial, i.e., they lead to the same worst-case bound.
We will complement the worst-case analysis with a computational study to understand what problem characteristics yield different relative results for the different problems. We adopt an optimization-based framework (see (Archetti et al., 2008)) for the heuristic solution of each of the four studied problems, the SR, MR, SCMR and SDMR.

We generate 160 instances and compare the solutions obtained for the different problems. We identify what types of instances make flexible vehicles or split commodities yield particularly low cost solutions. This may be useful for managers in deciding when these types of delivery practices should be adopted.

References


