



## Quantity discount with freight consolidation



H.N. Nguyen<sup>a,\*</sup>, C.E. Rainwater<sup>a</sup>, S.J. Mason<sup>b</sup>, E.A. Pohl<sup>a</sup>

<sup>a</sup> Department of Industrial Engineering, University of Arkansas, 4207 Bell Engineering Center, Fayetteville, AR 72701, USA

<sup>b</sup> Department of Industrial Engineering, Clemson University, 124 Freeman Hall, Clemson, SC 29634, USA

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### ABSTRACT

We study an integrated quantity discount and vehicle routing problem where truck utilization is increased by building multi-stop routes and increasing order sizes through a purchase incentive. We model the problem and prove it to be NP-hard. Our experiments show that commercial solvers do not effectively solve instances with more than ten buyers. We propose the use of non-compromising route elimination rules and other improvement techniques for a route-based formulation. Our experimentation suggests that a cost savings of 18% can be realized by utilizing our model.

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## 1. Introduction

In this paper, we study the integrated problem of an inventory-vehicle-routing problem and a quantity discount problem. The problem is encountered in practice by a manufacturer which wants to maximize truckload shipments and make savings by consolidating delivery orders into multi-stop truck routes and by offering discounts to increase customers' order size. The problem consists of a manufacturer and multiple customers (or a seller and multiple buyers in general).

The seller pays transportation cost on a shipment basis. The seller does not own or operate a truck fleet. It buys hauling services from common carriers. Each truckload shipment's cost is calculated by a rate per mile and the shipping distance. A rate per mile is defined by the combination of the origin and the destination of a shipment.

A half-full truckload shipment costs as much as a full truckload (FTL) shipment does because a whole truck is dedicated for the service in both cases. FTL shippers do not pay shipping cost based on their load metrics such as weight, volume, and pallet count. [Table 1](#) shows the typical maximum freight weight by mode. Parcel carriers usually do not accept shipments of 100 lbs or more. Less-than-truckload (LTL) carriers generally do not accept shipments of 20,000 lbs or more. From a shipper's perspective, an LTL shipment that weighs more than 13,000 lbs usually costs less when shipped as an FTL shipment. This paper considers full and partial truckload orders, each of which is economically shipped as an FTL shipment. This paper does not consider LTL and parcel modes. When an order is qualified for an LTL or parcel shipment, its shipping cost is calculated based on its weight and volume. Therefore, there is likely no motivation for increasing shipment size associated with these modes. On the other hand, splitting an order into multiple LTL shipments is not a viable option. Customers strongly discourage the option because it complicates their warehouse management.

Multiple partial truckload orders can be economically shipped in the same truck to customers in a market area. This is called a multi-stop truckload shipment. The shipping cost is calculated based on the number of delivery stops and the rate-per-mile charge. [Fig. 1](#) illustrates the stop-off charges of a typical multi-stop truckload shipment. In a standard stop-

\* Corresponding author.

E-mail address: [hxn002@uark.edu](mailto:hxn002@uark.edu) (H.N. Nguyen).

**Table 1**  
Typical maximum freight weight by mode.

Transportation mode	Maximum weight (pounds)
Parcel	100–150
LTL	13,000–20,000
FTL	53,000

off charge schedule, the first delivery stop is free and each subsequent stop is charged more than its previous one. The primary reason for an increasing stop-off charge schedule is that it takes significant effort for a truck driver to arrive on time at all stops. A late arrival at a stop will jeopardize all subsequent appointments.

In this problem, buyers are assumed to use a  $(Q, r)$  inventory policy. They will place replenishment orders of size  $Q$  to the seller when their inventory levels drop to  $r$ . The seller can deliver the size- $Q$  orders by direct truckload shipments or consolidate them into multi-stop truckload shipments. Some shipments are full or almost full truckloads. Other shipments are much smaller than FTLs but cost as much as FTLs do. In order to better utilize the truck capacity, the seller offers these buyers discounts for additional order quantities beyond their original replenishment quantities  $Q$ . The cost saved is the marginal transportation cost less the discount amount.

The problem studied in this work is encountered in many industries such as building material, office products, and canned food. These types of products have low value per unit weight (e.g. pound). Transportation cost is usually a high percentage of total sales revenue. In other industries, such as toys and electronics, the products have high value. When transportation cost savings is compared to the total revenue, it is only a small percentage which makes our problem less relevant.

In order to illustrate the problem, an example is discussed below (see Fig. 2). There is one seller and three buyers. Each buyer places a half FTL order, 25,000 lbs, every week. In scenario 1, the seller delivers the orders separately. It costs the seller six direct truckload shipments to deliver the orders to three buyers in two weeks. Each shipment is a truckload shipment. In scenario 2, the seller offers discounts to all three buyers and increases their orders to FTLs, 50,000 lbs each. The seller uses only three direct truckload shipments to supply three buyers with sufficient inventory for two weeks. It saves three direct truckload shipments while its sales revenue reduces because of the discounts it offers for the additional three half FTL order quantities. Scenario 2 presents a suboptimal solution. Scenario 3 presents the optimal solution. The seller utilizes direct and multi-stop truckload shipments to determine which discounts need to offer. Buyer 1 is offered a discount and receives its FTL replenishment stock every other week. Buyers 2 and 3 receive their half FTL orders every week by a multi-stop truckload shipment. Scenario 3 represents the balance of using discounts and multi-stop truckloads to maximize the total profit.

The quantity-discount-with-freight-consolidation (QDFC) problem can be summarized as below:

- There is one seller and multiple buyers. Buyers have constant demand and are supplied by the seller.
- Each buyer uses a  $(Q, r)$  inventory policy, in which  $Q$  must be less than a truck's capacity. Each buyer is replenished by only one truck in a time period.
- The seller can deliver more than  $Q$  to a buyer for a replenishment. The amount beyond  $Q$  will have a discount.
- There is no limit on the number of routes. Each route starts at the seller and ends at its last buyer.
- The problem's objective function is the seller's profit. The profit is the sales revenue less discounts and transportation cost.

The remainder of the paper is organized as follows. Section 2 reviews the current literature. Section 3 discusses the research motivation and contribution. Section 4 introduces the model and formulations of the problem. Section 5 presents the results from experiments. Section 6 concludes the paper.

## 2. Literature review

The problem studied in this paper seeks replenishment quantity and routing decisions taking into account inventory levels and locations. Therefore, this section will review vehicle-routing problems, inventory-routing problems, and quantity-discount problems.

### 2.1. Vehicle-routing problems

Vehicle-routing problems (VRP) have attracted a lot of research attention (see Toth and Vigo, 2002). A special case of the VRP is the Open Vehicle Routing Problem (OVRP). The unique feature of an OVRP is that trucks do not return to a depot or

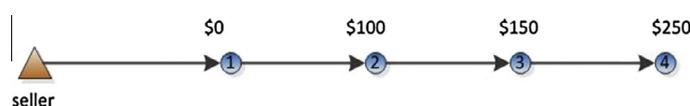


Fig. 1. Example stop-off charges in a multi-stop shipment.

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