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An Adaptive Large Neighborhood Search for an E-grocery Delivery Routing Problem

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ABSTRACT

Online shopping has become ever more indispensable to many people with busy schedules who have a growing need for services ranging for a wide variety of goods, which include standard (or "staple") goods as well as "premium" goods, i.e. goods such as organic food, specialty gifts, etc. that offer higher value to consumers and higher profit margins to retailers. In this paper, we introduce a new mathematical programming formulation and present an efficient solution approach for planning the delivery services of online groceries to fulfill this diverse consumer demand without incurring additional inventory costs. We refer to our proposed model as the E-grocery Delivery Routing Problem (EDRP) as it generically represents a family of problems that an online grocery is likely to face. The EDRP is based on a distribution network where premium goods are acquired from a set of external vendors at multiple locations in the supply network and delivered to customers in a single visit. To solve this problem, we develop an improved Adaptive Large Neighborhood Search (ALNS) heuristic by introducing new removal, insertion, and vendor selection/allocation mechanisms. We validate the performance of the proposed ALNS heuristic through an extensive computational study using both the well-known Vehicle Routing Problem with Time Windows instances of Solomon and a set of new benchmark instances generated for the EDRP. The results suggest that the proposed solution methodology is effective in obtaining high quality solutions fast.

1. Introduction

The habits of consumers shopping online have rapidly changed in the last decade as a result of remarkable developments in e-commerce and the constant search of online retailers for new and more profitable business models offering more flexibility and alternative shopping experience for consumers. Many leading and visionary online retailers look for up-and-coming business strategies to diversify their in-stock or in-store "standard" (or "staple") product offerings with outsourced "premium" products, i.e. products such as organic or dietary food, specialty gifts, specialty wine, etc., that offer higher satisfaction value to consumers and higher profit margins to retailers. For instance, a popular online retailer AmazonFresh (fresh.amazon.com, 2014) offers a variety of grocery items like wine, pumpkin pie, vegetables, meat, seafood, etc. in addition to items from the main Amazon.com storefront. Another online retailer Peapod (www.peapod.com, 2014) provides groceries and vegetables via a centralized business model using warehouses and warerooms, where warerooms are the dedicated areas attached to a subsidiary international food provider. The main premise in all these new practices is to extend the traditional online offering to include additional high-value items for consumers' choice.

In this paper, we revisit this very idea introduced in two earlier studies by Bozkaya et al. [10] and Yanik et al. [47], and formally introduce the generalized problem as the E-grocery Delivery Routing Problem (EDRP). The problem is motivated by a large Turkish supermarket chain offering home delivery services to online shoppers. The company aims at gaining competitive advantage through a new business model that provides extended service to its customers. In this model, an online supermarket that normally uses its brick-and-mortar stores to fulfill online customer orders may now additionally collaborate with external vendors that offer an extended inventory of diverse consumer items. Hence, the shopping basket of an online customer is fulfilled either from the store or from an external vendor, depending on the items ordered. Within the same context, Campbell and Savelsbergh [11]

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give the more restricted partnership model of Staples that offers office supplies and a grocery delivery service in Canada.

In a similar setting, Instacart (www.instacart.com, 2014), an independent grocery delivery service operating in several major cities in the U.S. (e.g. Seattle, San Francisco, Los Angeles, Austin, Maryland, Philadelphia) allows its customers to combine items from multiple groceries in their area (such as Whole Foods Market, Costo, Kroger, Safeway and other retailers) into one order and have them all delivered in one order on the same day, even within an hour. AmazonFresh offers same-day delivery of fresh grocery and local products from bakery to ethnic foods to gourmet meals or organic food from the neighborhood shops, restaurants and bakeries in Northern California. In this new business paradigm, Amazon has recently expanded its delivery network and started operating its own truck fleet in San Francisco area [9].

Such online shopping and delivery service is obviously not limited to the groceries and may be extended to other retail sectors. Our main contribution in this paper includes an alternative mathematical model and an effective solution procedure for the underlying delivery problem with a set of additional business rules. We leave the topic of profit sharing amongst the e-grocery and the collaborating vendors to a future study, and focus on the logistics of the distribution operation, i.e. the cost minimization aspect.

The EDRP that we tackle is based on a distribution network, which consists of (1) a depot, i.e. a store of the online grocery that supplies "standard" products, (2) vendors, i.e. external stores that supply their own set of "premium" products not available at the depot, (3) "regular" customers, i.e. customers that only purchase standard products and (4) "premium" customers, i.e. customers that *additionally* purchase premium products. Routing regular customers only is a straightforward special case of the EDRP in the form of VRP (Vehicle Routing Problem) with or without time windows. On the other hand, routing premium customers present an additional challenge as two additional sets of decisions are to be made simultaneously: (i) allocation of vendor(s) to each premium customer so as to satisfy the customer's order of premium product(s), (ii) routing of regular and premium customers, and their respective vendor set while preserving feasibility concerns such as precedence, vehicle capacity, time windows. Under these circumstances, the delivery of goods to each premium customer takes place only after the entire set of premium products are collected and combined with the standard products already loaded at the depot. Transfers between vehicles are not allowed and the minimum total distance solution is sought in the presence of precedence, time windows, and capacity constraints.

The main contributions of this study can be summarized as follows:

- We propose an alternative generalized mathematical model, which focuses on the distribution aspect of the problem and attempts to minimize the total transportation costs subject to additional business rules.
- We propose an effective Adaptive Large Neighborhood Search (ALNS) heuristic to solve the EDRP. The proposed ALNS includes new selection/allocation mechanisms for EDRP to tackle a more complex problem structure due to inclusion of external vendors. It also improves some of the existing removal/insertion mechanisms.
- We validate the performance of the proposed ALNS using the Vehicle Routing Problem with Time Windows (VRPTW) instances of Solomon [43] and improve the best-known solutions for five real-numbered problems.
- We randomly generate a large set of EDRP instances based on Solomon's data and report benchmark results for future studies.

The remainder of this paper is organized as follows. In Section 2, we review the related literature. In Section 3, we describe the EDRP and formulate a 0–1 mixed-integer linear programming model. In Section 4, we provide the details of our proposed ALNS approach. In Section 5, we present an experimental design and present the computational results. Finally, we provide our concluding remarks in Section 6.

2. Literature Review

The essence of the EDRP, namely the concept of using multiple sourcing and consolidation points to fulfill premium orders of consumers in e-grocery settings is first identified and discussed by Bozkaya et al. [10]. In a succeeding study, Yanik et al. [47] investigate the role of premium product offerings in creating critical mass and profit, and propose a hybrid metaheuristic approach that employs a genetic algorithm for vendor selection-allocation phase followed by a modified savings algorithm for the vehicle routing phase. The proposed genetic algorithm guides the search for optimal vendor pick-up location assignments. The authors also show possible profit opportunities of the new business model on a case study using a real dataset.

VRP with intermediate facilities (VRP-IF) and VRP with satellite facilities (VRP-SF) are the two VRP variants that are closely related to EDRP. For instance, Angelelli and Speranza [3] study periodic VRP for a collection problem where the vehicles renew their capacity at certain intermediate facilities. Sevilla and Blas [41] take into account time windows in VRP-IF and propose an algorithm based on neural networks and an ant colony system to solve the problem. Tarantilis et al. [44] address the case where vehicles start their trips from a central depot with intermediate depots again acting as replenishment stations. They propose a three-step algorithmic approach where an initial solution is first obtained by a cost-saving construction heuristic, followed by a tabu search within a variable neighborhood search improvement framework. Finally, they apply a guided local search to eliminate low-quality features from the final solution produced. Polacek et al. [33] develop a simple and robust variable neighborhood search algorithm to solve the capacitated arc routing problem with intermediate facilities. Liu et al. [21] consider a waste collection problem in the presence of intermediate facilities where the vehicles are unloaded when they are full, and propose an improved ant colony system algorithm to solve it. Bard et al. [6,7] consider satellite facilities to replenish vehicles during a route. They present a branch-and-cut methodology for solving the VRP-SF subject to capacity and route time constraints.

The EDRP can also be viewed as a variant of VRP with pick-ups and deliveries (VRPPD) in which goods are transported from pickup points to delivery points where all pickups must be made before the deliveries. Recent studies offer a variety of approaches to solve the VRPPD, including tabu search [12,23,24,27,4,45], genetic algorithms [16,35], simulated annealing [17,20], ant colony optimization [15] and hybrid heuristics [8]. We refer the interested reader to the extensive reviews by Parragh et al. [28,29] of the problem classifications, formulations, exact and metaheuristic solution approaches.

In terms of effectiveness and flexibility, the approach introduced by Ropke and Pisinger [39] is one of the best methods at hand for solving the VRPPD as well as a large class of VRP variants [31,40]. Their proposed metaheuristic employs ALNS as an extension of the Large Neighborhood Search (LNS) framework put forward by Shaw [42]. This ALNS aims to improve an initial feasible solution progressively by means of multiple removal (destroy) and insertion (repair) mechanisms competing in an adaptive environment to diversify and intensify the search. ALNS has been successfully implemented for solving many VRP variants including pickup and delivery problems with transshipment [34] and with