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A practical time slot management and routing problem for attended home services[☆]

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ABSTRACT

This paper describes the solution methodology developed to address an attended home delivery problem faced by an Italian provider of gas, electricity, and water services. This company operates in several regions and must dispatch technicians to customer locations where they carry out installation or maintenance activities within time intervals chosen by the customers. The problem consists of creating time slot tables specifying the amount of resources allocated to each region in each time slot, and of routing technicians in a cost-effective way. We propose a large neighborhood search (LNS) heuristic to create time slot tables by relying on various simulation strategies to represent the behavior of customers and on an integer linear program to optimize the routing of technicians. In addition, we also use a second integer program as a repair mechanism inside the LNS heuristic. Computational experiments carried out on data provided by the company confirm the efficiency of the proposed methodology.

1. Introduction

Attended home delivery (AHD) is a last-mile service that requires the attendance of customers and it is an important distribution policy adopted in many industries, especially in e-grocery, where profit margins are typically low. The design of efficient and reliable delivery plans is a critical aspect for the success in this market. In addition, in order to meet customer needs in the best possible way, a certain quality of service (QoS) level must be provided while balancing delivery costs. There are many examples of companies, such as Webvan (Agatz et al. [2]), that became popular and then went bankrupt because they were unable to design a sustainable distribution model.

Obviously, AHD is not limited to e-grocers and appears in several other industries. As mentioned by Campbell and Savelsbergh [7], this type of distribution is becoming common in drug companies that offer delivery services and companies that deliver office supplies to business customers. It is common in the telecommunications sector, where companies such as AT&T allow customers to book appointments for cable and phone installation through their online channel. It also arises in the context of home health care services (Liu et al. [15]).

In this paper, we focus on the market for commodities such as gas, electricity, and water. In Europe, this market is generally structured in such a way that several trading companies compete against each other to sell the commodities to the customers, while a local distributor is responsible for operating the delivery network. The distributor has to perform several AHD services related to the meters installed at the customer locations. These services involve installing new meters, re-initializing the meter when a customer changes from one trading company to another, closing the meter in case the customer does not pay, performing general maintenance operations, etc.

In particular, we study the activity of a large Italian corporate group called *Iren*, which provides gas, electricity, and water services throughout the country. We address the practical problem faced by *IRETI*, a subsidiary of this group that operates the distribution of gas and water in the region of Emilia Romagna, providing services for approximately 1,300,000 residents. We concentrate on the province of Reggio Emilia, where IRETI performs AHD services by using a dozen of hired technicians that depart from three different depots, as well as a third-party logistics provider.

Following a series of laws from the European Union, starting in 1998 and culminating in the directive 2009/73/CE (European Parliament [12]), the market for natural gas has been regulated and common rules have been established. As a consequence, all

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distribution companies operating in this market were forced by their national authorities to implement online applications in which customers are able to make requests for services by booking time slots. These time slots are subject to national regulation constraints and are made available in certain days and time intervals.

Designing an automated approach that is capable of proposing cost-efficient time slot tables is a very complex task, because it involves solving a two-stage stochastic decision problem. The first stage consists in choosing a time slot table for each region, while the second stage consists in routing the technicians after the customers' demand becomes known. To solve the problem we use a three-step algorithm. In the first step, we are interested in producing a time slot table for each region such that the amount of unserved demand is minimized. A key aspect of this step is that the expected demand has to be taken into account so that the offer of slots is neither underestimated nor overestimated. In Step 2, we simulate the fact that customers request services by booking time slots in the time slot table associated with their region, thus revealing the actual demand. Finally, having the assignments of services to time slots, in Step 3 we design the routing plan for each technician such that the total distance traveled is minimized. Notice that a solution for the problem is the actual set of time slot tables generated in Step 1, but it is only possible to evaluate the quality of a given solution by first simulating Step 2, and then evaluating the actual routing costs in the last step. Furthermore, as a consequence of the stochastic nature of the second step, the design of exact algorithms as well as the evaluation of meaningful lower bounds are not straightforward, and heuristic approaches are preferable.Another important aspect of the problem is that service requests cannot be rejected and, eventually, all services have to be performed. This feature is not exclusive to our problem and can be found in other AHD applications, such as in e-groceries, where customers must always receive their purchases.

To address this problem, we propose an optimization method based on the concept of *large neighborhood search* (LNS) that is capable of producing feasible and cost efficient solutions. A key component of our approach is an *integer linear programming* (ILP) model that is able to solve the Step 1 problem by taking into account the expected demand of each region and the popularity of each time slot. The model also considers that an even distribution of consecutive opened time slots is usually beneficial, as it increases the probability of having services assigned to neighbor time slots. These services can be performed consecutively by the same technician, possibly resulting in routing cost savings. The quality of the solutions generated at each LNS iteration is evaluated by a procedure that first reveals customers demands in Step 2 with an algorithm that simulates customer choices in the online application. To this end, we propose four different simulation strategies and the decision of which one to use is an input of the LNS. Two of them assume that all time slots are equally popular and perform an even distribution of the services among the available slots, whereas the other two are based on past data from the online application. Once all customer requests are assigned to time slots, in Step 3 we must design the routing plan for the technicians. This routing problem involves multiple depots, multiple vehicles and strict time windows, and is solved by means of a second ILP model, which evaluates the optimal routing plan that minimizes the total distance travelled.

The remainder of this paper is organized as follows. A brief review of the related literature is presented in Section 2 and the problem definition is provided in Section 3. The algorithm that we use to simulate customer choices and evaluate the expected solution costs is discussed in Section 4. Our complete solution method is presented in Section 5 and computationally evaluated in Section 6. Finally, in Section 7 some conclusions are drawn and future research directions are proposed.

2. Literature review

There are many challenges and opportunities relevant to operations researchers in the context of AHD. Agatz et al. [1] use as an illustrative example one of the largest internet grocery stores in the U.S. at the time, named Peapod, to identify combinatorial problems arising in AHD and suggest potential ways to address them.

According to Campbell and Savelsbergh [7], the fulfillment process of requests for most AHD service models can be divided into three phases: 1. order capture and promise; 2. order sourcing and assembling; and 3. order delivery. There seem to be two main streams of research in the literature on AHD. While some studies concern the management of service time windows, others emphasize the routing and scheduling of delivery tours. Regarding the former, the literature focuses either on the tactical or operational level.

The tactical level is concerned with the design of the time windows themselves, i.e., the number of time slots to offer, their length, and whether or not they overlap. Punakivi and Saranen [17] assess the impact of variations on the length of time windows in both attended and unattended home deliveries. They show that significant cost reductions can be achieved in a scenario with completely flexible unattended services, compared to attended deliveries with two-hour time windows. Campbell and Savelsbergh [7] report that an increase in time window length from one hour to two hours can result in a 6% increase in profits. This benefit is even greater when considering an expansion to three-hour time windows, reaching up to 11%. Of course there is an associated trade-off, that is, the longer the time windows the lower the QoS level that is provided.

The operational level refers to the selection of time slots by customers and decisions such as when to open and when to close certain time slots. In this spirit, Campbell and Savelsbergh [7] propose several mechanisms to determine when to accept or reject requests. In a later work (Campbell and Savelsbergh [8]), the same authors show that the use of incentive polices to influence customer behavior can result in significant reductions in delivery costs.

In the second stream of research, the basic problem is the *vehicle routing problem with time windows* (VRPTW), which has been extensively studied in the last two decades. For detailed reviews of the literature on this problem, we refer the interested reader to the surveys of Bräysy and Gendreau [5,6] and of Baldacci et al. [3].

Spliet and Gabor [20] have introduced the *time window assignment vehicle routing problem* (TWAVRP), where time windows have to be assigned to a fixed set of customers before the demand is known. Once the demand is revealed, a routing plan is constructed with the objective of minimizing the travelling costs. They propose a branch-and-price algorithm with two types of route relaxation, and use capacity inequalities to strengthen their lower bound. Computational results indicate that their approach is able to solve instances with up to 25 customers and 3 demand realization scenarios. Our problem is different because the set of customers may vary consistently from one week to another, and because the time windows are not assigned by the company but chosen by the customers.

In the TWAVRP each customer requires a service in each scenario, while in the *consistent vehicle routing problem* (ConVRP), proposed by Groër et al. [13], this constraint is relaxed. In addition, customers must always be visited by the same driver in each scenario and there is a limit on the total driving time. Recently, Spliet and Desaulniers [19] proposed the *discrete time window assignment vehicle routing problem* (DTWAVRP). This problem differs from the TWAVRP by considering, for each customer, a finite number of candidate time windows from which a single one must be selected. The authors indicate that this problem is common in retail chains