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# On the Slot Optimization Problem in On-Line Vehicle Routing

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**Abstract**

The capacitated vehicle routing problem with time windows (cVRPTW) is concerned with finding optimal tours for vehicles that deliver goods to customers within a specific time slot (or time window), respecting the maximal capacity of each vehicle. The on-line variant of the cVRPTW arises for instance in online shopping services of supermarket chains: customers choose a delivery time slot for their order online, and the fleet's tours are updated accordingly in real time, where the vehicles' tours are incrementally filled with orders.

In this paper, we consider a challenge arising in the on-line cVRPTW that has not been considered in detail in the literature so far. When placing a new order, the customer receives a selection of available time slots that depends on the customer's address and the current (optimized) schedule. The customer chooses a preferred time slot, and the order is scheduled. The larger the selection, the more likely the customer finds a suitable time slot, leading to higher customer satisfaction and a higher overall number of orders placed. We denote the problem of determining the maximal number of feasible time slots for a new customer order as the Slot Optimization Problem (SOP).

We formally define the SOP and propose an adaptive neighbourhood search heuristic for determining feasible slots for inserting a new customer orders based on a given delivery schedule in real time. Our approach is tailored to the SOP and combines local search techniques with strategies to overcome local minima. In an experimental evaluation, we demonstrate the efficiency of our approach on a variety of benchmark sets.


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*Keywords:* Vehicle routing problem, time windows, online optimization, time slot management, adaptive neighborhood search.

## 1. Introduction

In this paper, we discuss a problem that arises in the context of delivering goods or performing services to customers at their home, where the customers need to be present. The arrival time of the service at the customer is typically not known in advance. In the past, the customer would have to reserve the whole (or large parts of the) day to await the service. Nowadays, to increase customer satisfaction, companies pre-arrange a *time slot* (or time window) with the customer, during which the service is guaranteed to arrive.

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Providing time slots bears a great advantage to the customers who can better manage their time by choosing an appropriate slot. However, to the service and delivery companies, this poses a challenge: their original problem, a capacitated Vehicle Routing Problem (cVRP), becomes a capacitated Vehicle Routing Problem with Time Windows (VRPTW). Furthermore, if customers are not offered a desirable time slot, approximately 25% of them refuse the service. Therefore, it is desirable for the service providers to schedule their fleet in such a way that maximizes slot availability for customers.

In this paper, we focus on the context of an online grocery shopping service, where customers place orders online: first, the system offers the customer a set of available time slots for delivery, then the customer chooses a time slot, and finally, the order is inserted into the fleet's schedule at the chosen time slot. The problem of stepwise (customer by customer) building an optimized schedule in real-time is referred to as the on-line capacitated Vehicle Routing Problem with structured Time Windows (cVRPsTW) (Hungerländer et al., 2016). An important feature of the cVRPsTW is that the time windows have a special *structure*: they are non-overlapping and can hold several customers.

We investigate the first step of the online cVRPsTW: maximizing the number of time slots offered to customers. Thus, we introduce a new combinatorial optimization problem, the so-called Slot Optimization Problem (SOP), that, given an existing, incomplete schedule and a customer order, is concerned with finding the maximal number of time slots into which the order can be inserted, without moving any of the existing orders into other time slots. Note that in this paper we assume that time slots are non-overlapping and can hold several customers, as with the cVRPsTW.

If we choose one slot for the new customer order, then the SOP is equivalent to the feasibility version of an appropriate cVRPTW instance. As the cVRPTW is strongly NP-hard, see e.g. Madsen and Kohl (1997), the SOP is also strongly NP-hard and consists of $q$ feasibility problems that are all strongly NP-complete.

This work stems from a collaboration with one of the world's largest supermarket chains, and in the corresponding real-world application, *time* is an important factor: time slots must be offered within milliseconds to satisfy the customers' satisfaction. This poses an additional challenge to solving this problem.

We discuss several heuristics for determining feasible slots for inserting a new customer based on a given delivery schedule in real time. These approaches combine local search techniques with strategies to overcome local minima and integer linear programs for selected sub-problems. In an experimental evaluation, we demonstrate the efficiency of our approaches on a variety of benchmark sets.

In summary the main contributions of this paper are:

1. We introduce a new NP-hard combinatorial optimization problem that is motivated by a real-world application.

2. We propose an adaptive neighbourhood search (ANS) heuristic that is tailored to the SOP and combines local search techniques with strategies to overcome local minima.

3. We compare various heuristic methods for solving the SOP. Additionally to our newly proposed ANS, we consider approaches suggested in our recent paper (Hungerländer et al., 2016) that can also be applied to the SOP. In particular all our approaches are able to exploit the special structure of the time windows that is motivated by an application emerging in the context of a large international supermarket chain.

4. We provide an extensive computational study, illustrating that our approaches perform very well in practice.

## 2. Related Work

The Vehicle Routing Problem (VRP) is extensively discussed in Toth and Vigo (2002) who give an overview of different VRP types including an extensive review of heuristics, integer programming approaches, and applications and case studies. El-Sherbeny (2010) provides a compact overview of exact and heuristic solving approaches for the Vehicle Routing Problem with Time Windows (VRPTW).

The home delivery problem (HDP), introduced by Campbell and Savelsbergh (2005), considers a very closely-related problem, where delivery requests arrive dynamically, and the system has to decide two things: first, if a new request is accepted or not, and second, in which time slot the new request should be scheduled. The HDP is based on a similar application as our use case, with an important distinction: in our application, the system offers a selection of available time slots, and the customers decide upon acceptance, while in the HDP, the system makes these decisions.