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The time window assignment vehicle routing problem with product dependent deliveries

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ABSTRACT

This paper presents a new formulation for a time window assignment vehicle routing problem where time windows are defined for multiple product segments. This two-stage stochastic optimization problem is solved by means of a fix-and-optimize based matheuristic. The first stage assigns product dependent time windows while the second stage defines delivery schedules. Our approach outperforms a general-purpose solver and achieves an average cost decrease of 5.3% over expected value problem approaches. Furthermore, a sensitivity analysis on three operational models shows that it is possible to obtain significant savings compared to the solutions provided by a large European food retailer.

1. Introduction

Most distribution networks need to assign regular time windows to its delivery locations. Actually, in food retail, it is quite rare to find applications with complex unloading operations where no time windows are stipulated. This is due to the importance of the delivery process in managing physical space, product inventories, and personnel (Spliet and Gabor, 2015). Food retailers face several planning challenges related to warehouse, fleet, and retail site operations in order to provide good quality service to their final customer (Sternbeck and Kuhn, 2014). An example of a food retailer, including the involved stakeholders, is depicted in Fig. 1.

In the warehouse, products are received and prepared in shipping units (usually, products are palletized). Each supplier may have a different delivery lead time and time window. Therefore, different product segments are received by the warehouse in different periods of the day, influencing the preparation cycles. For instance, if fresh products are required to be in the retail site before its opening time, fresh product suppliers need to perform night deliveries so that the warehouse is able to prepare them in time.

The transportation activity also adds several constraints to be addressed. In multi-product operations, each product segment requires different logistics equipment and operations. Vehicles are often required to maintain product compatible temperatures. Retail sites may have accessibility constraints enforcing the fleet to comprise vehicles with different dimensions and heterogeneous trailers. Additionally, labour laws do not allow changes in the drivers' shifts for a given period of time. This means that the number of drivers available along day is not constant. When one driver ends his shift and another driver starts working using the same vehicle, the vehicle is idle at the depot for some time. These drivers will never perform routes that are incompatible with their shift switching period. Hence, shift switching periods limit the number of available drivers. For instance, in some European countries, new driver schedules need to be communicated seven days in advance.

Retail site constraints often demand certain products to be delivered during specified periods of the day. For illustration purposes,

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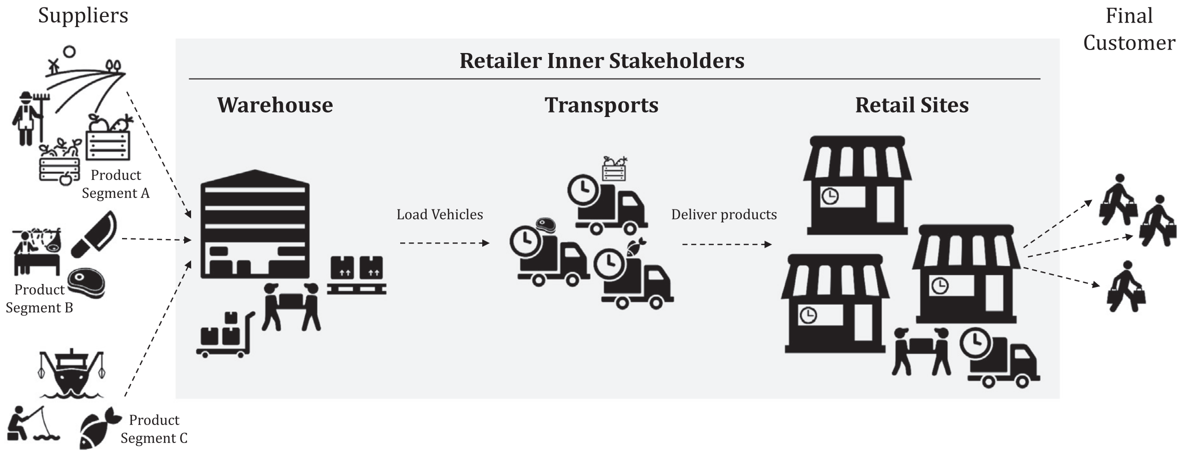

Fig. 1. An example of a food retailer including its stakeholders. Products are received from many suppliers and prepared in one warehouse. Afterwards, vehicles deliver products to each retail site, respecting product specific time windows.

it is quite common for some final customers to prefer buying fresh products (such as fruits or fish) early in the morning. This behaviour forces some products to be delivered to the retail site early enough so that the sales areas are ready at the opening hour. Likewise, laws to prevent noise near populated areas during the night time or traffic congestions at rush hours may demand specific delivery time windows at certain retail sites. Moreover, some products may only be received by expert collaborators that are a scarce resource only available during specific periods of the day. The aforementioned reasons demand the definition of product dependent time windows to ensure feasible unloading operations at the retail sites.

Assigning delivery time windows to each retail site is a tactical planning problem that needs to be tackled by retailers. These decisions largely impact the operational decisions taken in transportation planning, namely routing and fleet costs. Companies operating in similar environments to that described above are obviously interested in optimizing their integrated activities to pursue substantial cost savings. It is definitely worth a methodology to define the set of time windows capable of providing cost reduction opportunities.

The underlying problem is very complex as it involves assigning time windows based on transportation plans. The Time Window Assignment Vehicle Routing Problem (TWAVRP) can be defined as a two-stage stochastic optimization problem which integrates the tactical time window assignment decisions (first-stage) with the operational vehicle routing decisions (second-stage). Given a set of locations to be visited within a regular time period, the first stage decisions are to assign a set of time windows to each location, before demand is known. In the second stage, after the demand is revealed for each day, a delivery schedule respecting the assigned time windows is defined. Since the time windows remain unchanged for a reasonably long period of time, the goal is the way to perform this assignment while allowing for a daily efficient transportation planning across every demand scenario. Given their importance in many applications, time window assignment problems are now receiving an increasing level of attention.

In this paper, we build upon the aforementioned ideas and aim at extending the TWAVRP to deal with product dependent time windows, while complying with specific business constraints. Our approach is inspired by the case of a large European food retailer which owns two warehouses with a fleet for serving around 200 retail sites with time windows defined for different product segments. The state-of-the-art approaches in this field do not provide any solution for such challenge, as there is a significant complexity increment over the current formulations and approaches available in the literature. Note that the possibility for consolidating several product segments in a route invalidates formulations considering a single product.

Hence, the main contributions of this paper are the following. We propose an extended mathematical formulation for assigning time windows in real-world contexts, capable of dealing with (1) product dependent time windows; (2) multiple product deliveries; (3) split deliveries. A novel objective function, considering both the travelled distance and fleet requirements cost, is also proposed. We develop a matheuristic for dealing with real-world sized instances, with business-related decomposition strategies for accelerating the convergence of the algorithm. Extensive computational experiments are presented on a set of real-world instances. We test three operational models to assess the impact of different time window conditions on the solutions obtained by the proposed approach. A sensitivity analysis is performed over the number of retail sites where time windows changes are introduced. We provide interesting business-related insights as well as real-world considerations that have been revealed during the development and implementation of our solution approach.

The remainder of this is paper is organized as follows. In Section 2, we review the TWAVRP literature. In Section 3 we introduce a novel TWAVRP with product dependent deliveries and present the proposed formulation for the problem. Section 4 details our matheuristic solution approach. In Section 5, the computational experiments are analysed. In Section 6, the main conclusions of this work are presented as well as directions for future work.