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# A heuristic approach and a tabu search for the heterogeneous multi-type fleet vehicle routing problem with time windows and an incompatible loading constraint

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ABSTRACT

A generalization of the traditional vehicle routing problem – the heterogeneous multi-type fleet vehicle routing problem with time windows and an incompatible loading constraint (HVRPTW-ILC), is studied in this paper. Besides the common constraints of heterogeneous multi-type fleets and time windows, the incompatible loading constraint is also an important and unavoidable problem in a large number of deliveries to supermarket chains and department stores. This constraint originates from the fact that logistics companies often use heterogeneous multi-type fleets, like refrigerated and non-refrigerated vehicles, to transport various goods, some of which should be transported by a certain type of vehicles while others should not. To our knowledge, this is the first time that such constraint is addressed. To solve this problem, we develop a mathematical model, a ruin-recreate heuristic algorithm, and a threshold tabu search method. Furthermore, we conduct a series of experiments over a set of existing vehicle routing problem with time windows (VRPTW) instances, as well as analyze a real case in China to evaluate and demonstrate the effectiveness of the two proposed algorithms.



## 1. Introduction

The heterogeneous multi-type fleet vehicle routing problems with time windows and an incompatible loading constraint (HVRPTW-ILC) can be defined as an undirected network with single depot and a set of $n$ customers. There are two types of vehicles, refrigerated and non-refrigerated vehicles, and three types of goods stored in the depot. The first two types of goods must be transported by refrigerated vehicles and non-refrigerated vehicles, respectively while the third type of goods may be transported by either type of vehicles. We call the first two types of goods "refrigerated goods" and "non-refrigerated goods", respectively and the third type of goods "flexible goods". We name this constraint an incompatible loading constraint because there are two types of goods that cannot be simultaneously loaded into one vehicle. Each customer orders known amounts of one or more types of goods and must be serviced within a given time interval. Each type of goods required by a customer must be delivered by only one vehicle in order to minimize the number of customers' goods receipt. However, different types of goods ordered by a customer can be brought by different vehicles. The problem consists in determining a set of routes satisfying all customer orders at minimal routing and service cost.

It is surprising that the HVRPTW-ILC is seldom studied in the literature although it is widespread in real logistics. We found many genuine HVRPTW-ILCs in China. A typical example is given in the following description.

(1) A medium-sized supermarket chain with a main store and multiple branch stores usually sells a large number of goods, such as daily provisions, drinks, milk products, meat, eggs, fruits, vegetables, grains, etc. These goods have different storage requirements. Some goods, like meat, milk and tomatoes, can be kept long at the temperature of 2–4 °C and can only be transported by refrigerated vehicles. But rice, flour, etc. will get damp at this temperature and must be transported at non-refrigerated conditions. Eggs, drinks and most of daily provisions can be well stored as long as the temperature is not too high or too low, and therefore, these goods can be transported at both refrigerated and non-refrigerated conditions. Generally, such kind of

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supermarket in China does not sell frozen foods, which can only be found in large-sized department stores or supermarkets, so that the goods of the supermarket chain have only two temperature requirements – refrigerated and non-refrigerated requirements.

(2) Every morning, these goods are firstly collected at the main store (considered as the depot) and then delivered to the branches (considered as the customers). The deliveries from suppliers to the main store are made by the suppliers of each kind of goods and are not within the scope of the discussion of the paper. And the paper only focuses on the deliveries from the main store to its branches.

(3) Every day, each branch store opens at a fixed time. If a delivery vehicle arrives at a branch store before its open time, the vehicle must wait until the store opens. Furthermore, goods must be well prepared and put in place before buyers enter the stores to shop. And buyers always have their statistical law of shopping time, following which branch stores always require goods must be delivered before a certain fixed time. Any delivery later than that time means huge economic losses for branch stores. Therefore, a rigid time window constraint should be imposed to the problem.

(4) The problem aims at determining a set of routes satisfying all deliveries for branches at minimal routing and service cost.

(5) To solve such kind of problems, it is not economical if the multi-temperature joint distribution technologies are applied since each kind of the goods is in large scale and there are only two temperature requirements. Meanwhile, this scenario does not match the specific situations which the multi-temperature joint distribution approach is suitable for, as discussed in the references of (Kuo & Chen, 2010) and (Hsu & Liu, 2011). As a result, most practitioners choose the single-temperature distribution method instead of the multi-temperature one.

In the area of food distributions or B2B logistics, there are also other cases that are similar to the above example and can be generalized as the HVRPTW-ILC.

## 2. Literature review

To the best of our knowledge, this is the first time that the HVRPTW-ILC is addressed in the literature despite of its many substantial applications in practice. Relevant studies are concentrated on the following three aspects: (1) the vehicle routing problems with split deliveries (VRPSD), (2) the heterogeneous multi-type fleet vehicle routing problems with time windows (HVRPTW), and (3) the multi-temperature logistics (MTL). The researches of the three aspects and their differences with HVRPTW-ILC are explained respectively as follows.

(1) Relevant studies on VRP with split deliveries (VRPSD)

The VRPSD is a variation of the classical vehicle routing problem (VRP), in which each customer can be serviced by more than one vehicle. Thus, for the VRPSD, in addition to the delivery routes, the quantity to be delivered to each customer by each vehicle must also be determined. Archetti, Speranza, and Hertz (2006) developed a tabu search algorithm for solving the VRPSD. Chen, Golden, and Wasil (2007) combined an endpoint mixed integer program and a variable length record-to-record travel algorithm. The paper by Archetti, Savelsbergh, and Speranza (2008) is a good source for recent developments in modeling and solving the VRPSD. Recently, several variants of the traditional VRPSD have been explored in the literature including the vehicle routing problem with discrete split deliveries and time windows (Matteo & Ilaria, 2011), the heterogeneous fleet vehicle routing problem with time windows and split deliveries (Patrícia & Hugo, 2013), the multi-depot split delivery vehicle routing problem (Damon, Bruce, & Edward, 2011), and the crude oil transportation with split deliveries (Nishi & Izuno, 2014). In addition, two exact branch-and-cut algorithms for the VRPSD based on two relaxed formulations that provide lower bounds to the optimum were presented by Archetti, Bianchessi, and Speranza (2014).

There are mainly three differences between VRPSD and HVRPTW-ILC:

① VRPSD contains only one type of vehicles and any goods can be loaded into any vehicle. While in HVRPTW-ILC there are two types of vehicles and three types of goods. The refrigerated goods and non-refrigerated goods must be transported by refrigerated vehicles and non-refrigerated vehicles, respectively while the flexible goods can be transported by any type of vehicles.
② In VRPSD, all goods of a customer can be loaded into one vehicle. While in HVRPTW-ILC, refrigerated goods and non-refrigerated goods cannot because they have different temperature requirements.
③ Goods in the VRPSD can be split in any way, while goods in the HVRPTW-ILC can only be split into three types and each type of goods cannot be split anymore because of the fact that too many splits will lead to great inconvenience of goods receipts.

(2) Relevant studies on the heterogeneous fixed fleet VRP with time windows (HVRPTW)

The HVRPTW is one of the most concerned variations of the classical VRP, in which all the customers' demands can be delivered by any type of vehicles but a customer's demand cannot be split. The works on this problem include a tabu search algorithm by Gendreau, Laporte, Musaraganyi, and Taillard (1999), a new meta-heuristic known as BATA (back-tracking adaptive threshold accepting) by Tarantilis, Kiranoudis, and Vassiliadis (2004), another tabu search (Brandão, 2011), a multistart adaptive memory programming (MAMP) approach and a path re-linking approach (Li, Tian, & Aneja, 2010), a novel Adaptive Memory Programming (AMP) solution approach (Repoussis & Tarantilis, 2010), and a nonlinear mathematical model and two adaptive genetic algorithms (AGAs) (Low, Chang, Li, & Huang, 2014).

The differences between HVRPTW and HVRPTW-ILC can be depicted in a small example of Fig. 1. This example contains four customers {a,b,c,d}, three types of goods {refrigerated goods, non-refrigerated goods, flexible goods}, one depot, and two types of vehicles, {refrigerated vehicles, non-refrigerated vehicles}, with capacities of 7 and 8, respectively and the same fixed cost 10. The customers' time windows and their demands for each type of goods are indicated in square brackets and parentheses, respectively, and the traveling costs are given on each edge. And each customer has the same service cost 1. To obtain a HVRPTW, it is assumed that the three types of goods can be mixed and loaded in either type of vehicles. Therefore, the optimal HVRPTW solution consists of three routes (a,b), (c), (d), with a total cost of 45, while the optimal HVRPTW-ILC solution has two routes (a,b,c) and (a,d,b), transported by non-refrigerated and refrigerated vehicles, respectively, with a total cost of 41. The essential reasons that lead to the different optimal solutions are: (1) each customer's goods in the HVRPTW-ILC can be split into three types transported separately while goods in the HVRPTW cannot; (2) some goods in the