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Invited Review

Rich vehicle routing problems: From a taxonomy to a definition

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Over the last years, several variants of multi-constrained Vehicle Routing Problems (VRPs) have been studied, forming a class of problems known as Rich Vehicle Routing Problems (RVRPs). The purpose of the paper is twofold: (i) to provide a comprehensive and relevant taxonomy for the RVRP literature and (ii) to propose an elaborate definition of RVRPs. To this end, selected papers addressing various cases are classified using the proposed taxonomy. Once the articles have been classified, a cluster analysis based on two discriminating criteria is performed and leads to the definition of RVRPs.

1. Introduction

The Vehicle Routing Problem (VRP), introduced by Dantzig and Ramser (1959), is a central problem in operations research applied to transportation sciences. Over the last three decades, the number of academic publications on the numerous variants of the VRP has increased extensively (see Eksioglu, Vural, & Reisman, 2009). These studies can be roughly divided into theoretical papers providing mathematical formulations and exact or approximate solution methods for academic problems and case-oriented papers. Several taxonomies and surveys devoted to the VRP have appeared, *e.g.*, Bodin (1975), Bodin and Golden (1981), Desrochers, Lenstra, and Savelsbergh (1990), and Laporte and Osman (1995) who provided a bibliography of 500 studies. More recently, Laporte (2009) reported on the last fifty years of academic vehicle routing from a historical perspective and Eksioglu et al. (2009) presented a taxonomy for the VRP literature. Many books or book chapters have been devoted to the VRP, its variants, and to exact and heuristic algorithms, see, *e.g.*, Toth and Vigo (2002a), Cordeau, Laporte, Savelsbergh, and Vigo (2007), and Golden, Raghavan, and Wasil (2008).

The most elementary VRP considered in the literature is the so-called *Capacitated* Vehicle Routing Problem (CVRP). Geographically scattered customers have demands for a homogeneous product. They have to be served by identical vehicles with a limited capacity based at one depot. The CVRP aims to determine a set of vehicles routes of minimum total cost over a single period such that: (i) each route starts and ends at the depot; (ii) each customer is served by only one vehicle; and (iii) the total demand on each route does not exceed the vehicle capacity. Most papers devoted to classical problems focus on idealized models and are motivated by unsolved theoretical problems. Nevertheless, in recent years methodological progress and the development of computer technologies has led to an increasing academic attention to new variants including more complex constraints and objectives. This trend is stimulated by the complex characteristics of real-life VRPs. The families of these extended problems are often called Rich Vehicle Routing Problems (RVRPs). Several works focusing on RVRPs have been published. In particular, two special issues were dedicated to works on rich combinatorial optimization problems (Hartl, Hasle, & Janssens, 2006; Hasle, Løkketangen, & Martello, 2006). Papers by Sörensen, Sevaux, and Schittekat (2008) and by Drexl (2012a) compare the VRPs in academic research versus the VRPs in the real-life and delineate the complexity of real-life VRPs. Based on identified gaps, they emphasize on the necessity of adapting commercial software systems to the evolution of customer needs, and of incorporating more intricate constraints. Doerner and Schmid (2010) present a survey devoted to hybrid math-heuristics for RVRPs and identify promising future avenues.

In most papers devoted to RVRPs, the authors claim that the problem addressed is rich, and then focus on the mathematical modeling and on the solution methods. Thus, the definitions of the RVRP are rather vague and not significantly different. For instance, Pellegrini (2005), Cruz Reyes et al. (2008), Rieck and Zimmermann (2010) and Drexl (2012a) suggest that the term rich vehicle routing is associated with problems that represent some or all aspects of a real-world application including optimization criteria, constraints, and preferences. Recently, some attempts have been made to propose unified models and algorithms tackling different classes of routing problems, see *e.g.* Røpke and Pisinger

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(2006), Subramanian, Uchoa, and Ochi (2011), Derigs and Vogel (2014) and Vidal, Crainic, Gendreau, and Prins (2013, 2014).

There is no precise definition either criterion which leads to determine whether or not a VRP is rich. Such definition has to rely on a relevant taxonomy which can help to distinguish among the numerous variants of the VRP. Therefore, the objective of this paper is twofold: (i) to provide a generic taxonomy for the RVRP literature with respect to relevant real-life issues and (ii) to propose a discriminating definition of the RVRP.

The remainder of this paper is organized as follows. Section 2 describes the taxonomy and introduces the key characteristics considered when it was built. Definitions of the hierarchical taxonomy attributes are provided. In Section 3, we survey several papers describing practical cases and addressing different issues related to RVRPs. They are classified on the basis of the taxonomy attributes. A cluster analysis of the selected papers is provided and discussed. Last, a RVRP definition is proposed. Section 4 concludes this paper by discussing some future research avenues.

2. RVRP taxonomy

Creating taxonomy is an efficient and effective way of consolidating knowledge (Reisman, 1992). It enables not only efficient and effective storage, sorting, and statistical analyses but also knowledge expansion and building (Eksioglu et al., 2009). Several surveys and classifications of the VRP have been used as guidelines for the RVRP taxonomy developed in this work. This taxonomy aims to build a relevant framework to classify any RVRP study without going into unnecessary details. It attempts also to highlight the different facets of richness encountered in the literature, and to distinguish RVRPs from standard VRPs.

To "validate" this taxonomy, we have selected papers devoted to RVRPs published since 2006. Real-life and academic works using as benchmarks randomly generated instances or real data have been considered. Surveys or theoretical articles without testbed have been omitted. Only papers devoted to node routing problems for road transportation have been retained. More than a half of them are based on real-life applications. We also have paid attention to take papers emanating from different countries. Indeed, each country has its geographical and political specificities and its own industrial practices. This may lead to introduce specific constraints on the routing plan. As a result, 41 papers published in different journals and conferences are examined attempting to be as exhaustive as possible. However, we apologize for any unintended omission of some relevant articles.

2.1. Taxonomy

In this section, we focus on the description of the taxonomy (see Table 1) and on the presentation of its main attributes. The taxonomy was iteratively built, due to the complexity of the distribution planning process. The taxonomy does not intend to highlight all differences between variants of the VRP in order to maintain its comprehensibility and its size. It is instead designed according to central concepts in routing that are often present in industrial applications. More precisely, the attributes mentioned are not necessarily the basic VRP features but are related to characteristics which alter the nature of the problem significantly. The purpose of the taxonomy is not to classify the papers according to all the details but rather to focus on relevant features. Indeed, we face the following dilemma. The omission of relevant variants of problems studied in the literature introduces some bias in the classification. Similarly, deepening the level of details may lead to an unmanageable taxonomy. Hence, we try to maintain a moderate level of granularity for the proposed RVRP taxonomy.

The taxonomy is constructed hierarchically with at most four subclasses. Problems are considered according to the Scenario Characteristics (SCs) and to the Problem Physical Characteristics (PPCs). Under each of these two classes, the most discriminating attributes are listed. They determine whether or not the problem under study can be classified as rich. The taxonomy is organized in an arborescent way with three levels associated with the *strategic* level, the *tactical* level and the *operational* level. Each of them is divided into sublevels. The difference between the three levels depends on the types of decision involved. The strategic and tactical levels are associated with the first branch of the taxonomy, *i.e.* the SCs. They correspond to the transportation strategy which describes the distribution system and designs its main components. At the strategic level, the company has to decide if the operational plan deals simultaneously with decisions related to different functions of the supply chain or if transportation planning issues are addressed. For instance, the strategic planning could include decisions related to the locations and the number of depots used. At the tactical level, the order type and the visit frequencies at customers over a given time horizon could be considered. The multi-use of vehicles or the data type leads to other extensions. Although these decisions are not related to daily transport activities, they affect the routing plan significantly.

The operational level is associated with the PPCs. It describes the distribution planning including the vehicle and the driver schedules. At this level, short-term and daily decisions are handled considering each vehicle route. These decisions relate to the routing of goods using the distribution system designed at the strategic and tactical levels. These decisions are based on the characteristics of vehicles, and on specific constraints faced daily. These constraints are specified for a customer, a vehicle, a driver or a road.

2.1.1. Scenario characteristics

In this section, we describe the sublevels of the strategic and tactical levels presented in Table 1. We briefly define the characteristics of each sublevel and provide some relevant references.

2.1.1.1. Input data. The uncertainty and the variability of the data over the planning period are key factors for a classification of VRPs. Data can be subdivided into four classes: *deterministic, stochastic, static and dynamic.*

The *deterministic* routing problem assumes that the problem parameters are known with certainty while the *stochastic* data assumes that probability distributions are associated with them. In the *Stochastic* Vehicle Routing Problem (SVRP), the routes may not be followed as planned. The three most common stochastic parameters studied in the literature are: customers demands, service times and travel times (Hasle & Kloster, 2007). We refer to Gendreau, Laporte, and Séguin (1996), Flatberg, Hasle, Kloster, Nilssen, and Riise (2005), Cordeau et al. (2007), Louveaux and Laporte (2009) and Ritzinger and Puchinger (2013) for focused surveys.

A seminal work on the *Dynamic* Vehicle Routing problem (DVRP) is due to Psaraftis (1988). In the DVRP, the scheduling plan established at the beginning of the planning period may be adjusted. It allows the possibility of receiving additional information and changing some problems parameters. Then, the problem is solved repeatedly. For example, new customer requests may occur during the planning period and must be considered while the vehicles routes are being executed. For recent literature reviews, we refer to Psaraftis (1995), Powell, Shapiro, and Simão (2001), Malca and Semet (2006), Powell, Bouzaiene, and Simão (2007), Larsen, Madsen, and Solomon (2008), Berbeglia, Cordeau, and Laporte (2010), and Pillac, Gendreau, Guéret, and Medaglia (2013).