Survey of Green Vehicle Routing Problem: Past and future trends

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ABSTRACT

Green Logistics has emerged as the new agenda item in supply chain management. The traditional objective of distribution management has been upgraded to minimizing system-wide costs related to economic and environmental issues. Reflecting the environmental sensitivity of vehicle routing problems (VRP), an extensive literature review of *Green Vehicle Routing Problems* (GVRP) is presented. We provide a classification of GVRP that categorizes GVRP into *Green-VRP, Pollution Routing Problem, VRP in Reverse Logistics*, and suggest research gaps between its state and richer models describing the complexity in real-world cases. The purpose is to review the most up-to-date state-of-the-art of GVRP, discuss how the traditional VRP variants can interact with GVRP and offer an insight into the next wave of research into GVRP. It is hoped that OR/MS researchers together with logistics practitioners can be inspired and cooperate to contribute to a sustainable industry.

1. Introduction

Green Logistics has recently received increasing and close attention from governments and business organizations. The importance of Green Logistics is motivated by the fact that current production and distribution logistics strategies are not sustainable in the long term. Thus environmental, ecological and social effects are taken into consideration when designing logistics policies, in addition to the conventional economic costs. The environmentally sensitive logistic policy itself requires changing the transportation scheme and shifting it onto a sustainable distribution network with fewer negative impacts on the environment and the ecology, owing to the undeniable fact that transportation accounts for the major part of logistics. There is a wide variety of problems concerning Green Transportation, such as the promotion of alternative fuels, next-generation electronic vehicles, green intelligent transportation systems, and other eco-friendly infrastructures. A better utilization of vehicles and a cost effective vehicle routing solution would more directly achieve sustainable transportation schemes. In this context, designing a green distribution network by means of vehicle routing models is the major task. Bloemhof-Ruwaard, van Beek, Hordijk, and Van Wassenhove (1995) and Daniel, Diakoulaki, and Pappis (1997) specified the close interaction and the contributions of Operations Research methods to environmental

management and addressed some environmental issues related to routing, such as the reverse logistics in product recovery management and the routing of waste collection.

The studies of routing problems concern the fundeamental consideration in the distribution of goods from plant to warehouses to customers (Bodin, Golden, Assad, & Ball, 1983). In the traditional *Vehicle Routing Problem* (VRP), the focus is concentrated on the economic impact of vehicle routes on the organization that carries out the distribution service. Consideration of wider objectives and more operational constraints that are concerned with sustainable logistics issues pose new vehicle routing models and new application scenarios, which naturally lead to more complex combinatorial optimization problems. Green Logistics deals with the activities of measuring the environmental effects of different distribution strategies, reducing the energy consumption, recycling refuse and managing waste disposal (Sbihi & Eglese 2007a). Based on these dominating activities, we attempt to identify the VRP variants regarding these sustainable transportation issues in the literature from an operations research perspective and denote them as *Green Vehicle Routing Problems* (GVRP). GVRP are characterized by the objective of harmonizing the environmental and economic costs by implementing effective routes to meet the environmental concerns and financial indexes. As they have just arisen in the literature in recent years, there is a continuing need to enrich related studies either through theoretical contributions or by real applications. Sbihi and Eglese (2007a, 2007b) presented some research gaps that link the VRP with Green Logistics issues, such as employing the *Time-dependent VRP* as an approach to deal with the minimization of emissions during traveling. Salimifard, Shahbandarzaden, and Raeesi (2012) reported several recent articles

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published in 2010 and 2011 with direct consideration of environmental impact in the objective functions and stated that this topic is still at the beginning of being studied and is rather attractive. Despite their attempt of surveying relevant literature, they confined *VRP* with green transportation consideration to only those problems with explicit objectives of environmental costs. It seems that there is still room for investigation to explore *GVRP* in the area of energy consumption, emission control, and reverse logistics.

The contribution of this paper is to give an exhaustive literature review and clear classification of *GVRP*. More importantly, we have highlighted the lack of the existing studies and point out the future research directions for the *GVRP*. For academic purposes, a landscape of literature on *GVRP* is shown to shed light on this topic and help researchers find potential areas of further and deeper study. In particular, the classification of the traditional *VRP* variants is also summarized to inspire researchers to find out how these traditional variants can be related to the *GVRP*. For practical purposes, it is hoped that these idealized models can help governments, non-profit organizations, and companies to evaluate the possible economic and environmental significance of real-world transportation problems and to take action at different levels to contribute to Green Logistics.

The remaining part of this paper is organized as follows. Section 2 concerns the survey methodology of this paper. A review of the traditional *VRP* variants, with a brief introduction and sub-categories for each variant, is presented in Section 3 to show the evolution of *VRP* literature. Section 4 gives an overview of the most important *VRP* variant, *VRP with Time Windows*. A brief introduction to the algorithms and main benchmark test instances for *VRP* is presented in Section 5. In Section 6, we review the existing research on *GVRP* in depth, with a classification categorizing *GVRP* into *Green-VRP*, *Pollution Routing Problem*, and *VRP in Reverse Logistics*. The future research opportunities for each *GVRP* category are also suggested. Section 7 contains a summary of important trends and perspectives of the future development of the research into *GVRP*. Finally, a conclusion is drawn in Section 8.

2. Survey methodology

2.1. Source of the literature

The literature surveyed in this paper was majorly selected from three sources: (1) a wide set of academic databases such as *Science Direct*, *Springer Link*, *EBSCO*, etc., accessed from the university library by using keywords such as vehicle routing, time windows, green, reverse logistics, etc.; (2) bibliographies of survey papers and book chapters on *VRP*; (3) additional articles that are addressed in the initial articles in (1) and (2). The literature we searched is normally scattered at different times ranging from 1959 to 2012. As we intend to survey the studies on *GVRP*, we mainly confined our search to articles published from 2006 to 2012. The searching process was conducted in two dimensions: horizontal and vertical. In the horizontal dimension, attention was paid to the evolution of *VRP* on the timeline, especially when finding *VRPs* of sustainability issues (i.e. *GVRP*). In the vertical dimension, different classes of *VRP* are employed to distinguish each article. The majority of the literature falls into journal articles in terms of operations research, management science, and transportation, in such journals as the *European Journal of Operational Research*, *Computers & Operations Research*, *Transportation Science*, *Transportation Research (Part A, B, C, D, E)*, *Networks*, *Operations Research*, *Journal of the Operational Research Society*, etc. A small number of proceeding papers, working papers, technical reports and dissertations are also included in this overview as they were also taken as good references for some most up-to-date research directions or for the foundation of further study. In this study, about 280 papers were reviewed, which are shown in Fig. 1 and Table 1.

The fourth column of Table 1 summarizes the *VRP* variants that were studied in each year in our review work. It can be found that the research efforts before 2006 focused on the traditional *VRP*. Few studies on Green *VRP* had been conducted during this time period. After 2006, Green *VRP* covering energy consumption (*G-VRP*), pollution emissions (*PRP*), as well as recycling and reverse logistics (*VRPRL*) started to draw researchers' close attention and became a hot topic in the past several years. This trend can be re-
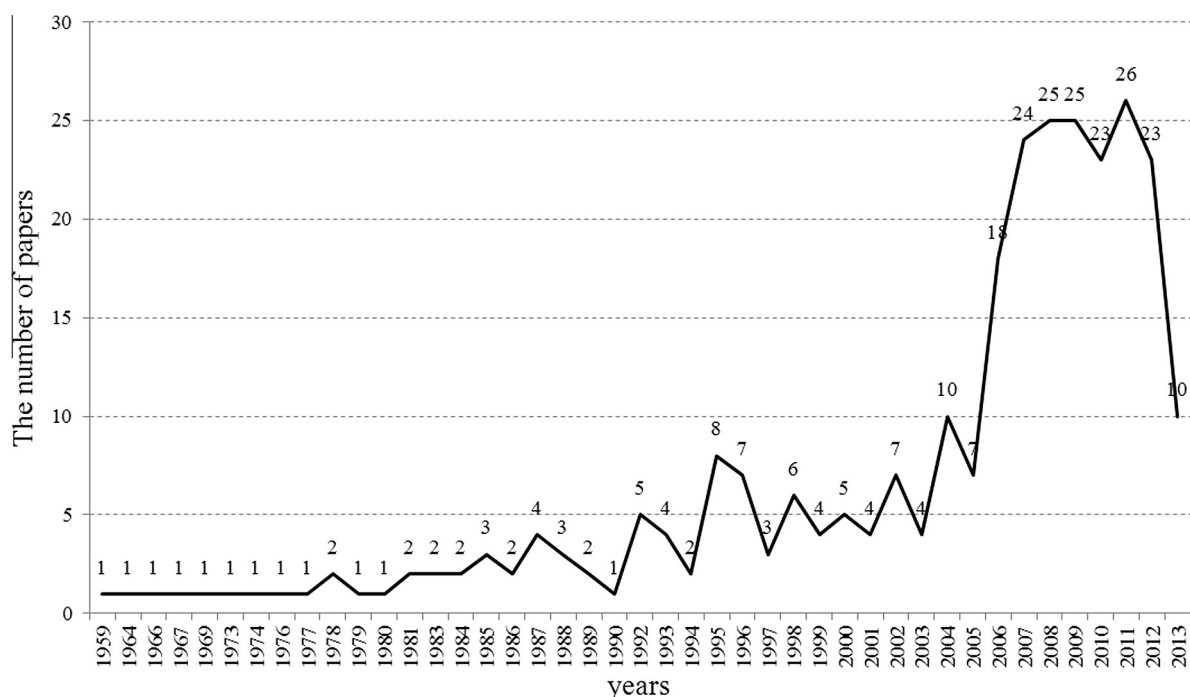

Fig. 1. The distribution of papers by year.