Research Review of Green Vehicle Routing Optimization

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Abstract. Green vehicle routing problem (GVRP) has emerged as an important agenda in green logistics and received scientific attention from researchers. In this paper, a literature review on recent developments regarding the GVRP is presented. In order to further clarify the research status, a classification of GVRP that categorizes GVRP into pollution routing problem and new energy vehicle route problem. it is concluded with some significantly promising tends and future directions about the research on GVRP.

Keywords: Green vehicle routing problem, pollution routing problem, new energy vehicle.

1. Introduction
With the continuous expansion of economic scale, energy crisis and environmental problems become increasingly prominent, green and low-carbon economic growth mode has become a new trend of the world economy. As one of the main sources of carbon emissions, transportation plays an important role in energy conservation, emission reduction and environmental mitigation. According to a report by the International Energy Agency (IEA), transportation accounts for about 26% of global CO2 emissions in 2018, and the largest source of greenhouse gas emissions in the United States for three consecutive years comes from transportation. Therefore, it is of great significance to study the problem of green vehicle routing problem (GVRP) for sustainable economic development and coping with global warming.

With the fast growth of e-commerce, logistics has become a sunrise industry that promotes urban economic development and employment growth. The urban pollution caused by it has aroused people's close attention, and green logistics has gradually attracted extensive attention from the government and enterprises. Transportation occupies more than 80% of logistics, so the concern about GVRP has been constantly increasing in academic research. Therefore, besides the traditional economic cost, the protection of ecological environment has become an important factor that needs to be considered for vehicle routing optimization.

The traditional vehicle routing problem was first proposed by Dantzig and Ramser. It is mainly used to solve the problem of how to reasonably schedule vehicle routing, number of trips and travel time under the conditions of satisfying various constraints, so as to minimize the total cost. GVRP involves various issues, such as reducing exhaust emissions, promoting green fuels and new energy vehicles. Thanks to the support of relevant national policies and the development of technology, more and more enterprises have started to use new energy vehicles, such as Wal-Mart, Coca-Cola, China Post and Jing Dong.
Under the demand of low-carbon economy, this paper is to review the current research status of GVRP by systemically sorting out the relevant literature, and offer the possible future directions of GVRP.

2. Green Vehicle Routing Problem (GVRP)

The characteristic of GVRP is to harmonize environmental and economic costs by planning effective routes to maximize benefits and meet the environmental concerns. Chang and Morlok first studied GVRP in 2005, and they proposed the impact of vehicle speed on fuel consumption. Since then, GVRP has become a research hotspot among researchers all over the world. Through combing the relevant literature, it is found that the current research on GVRP is mainly divided into two categories: (1) Research on the pollution routing problem. The goal is to reduce carbon emissions and minimize pollution. (2) Research on the new energy vehicle routing problem (electric power, natural gas and ethanol, etc.). Especially, the route optimization of electric vehicles has attracted great attention.

2.1. The Pollution Routing Problem

The goal of standard VRP is generally to minimize the total cost, which is traditionally considered to be the total distance traveled by all vehicles. However, Bektas et al. [1] extended the goal of traditional VRP, taking into account vehicle emissions, and proposed the Pollution Routing Problem (PRP). Its optimization goal not only considers vehicle usage costs, but also vehicle fuel consumption, emissions and driver’s costs. Based on it, Demir et al. [2] proposed an adaptive large neighborhood search algorithm for PRP, and verified the effectiveness of the algorithm by using different instances generated from real geographic data, making the research on PRP more practical and realistic. Xiao et al. [3] considered the fuel consumption rate in the classic CVRP model, established an optimization model with the goal of minimizing fuel consumption, and introduced the simulated annealing algorithm to solve the problem. The results showed that the model can reduce fuel consumption by 5% compared with the classic CVRP. In addition to minimizing fuel consumption, PRP also needs to reduce the total driving time. However, Demir et al. [4] pointed out that the goals of minimizing fuel and time are contradictory and need to be solved by a multi-objective optimization method. Therefore, they introduced the weighting method, the weighting method with normalization, the $\varepsilon$-Constraint method and a hybrid method. Suzuki [5] proposed a hybrid algorithm to solve the dual-objective PRP. Firstly, simulated annealing was used to approximate the Pareto boundary, and then a modified tabu search was used to improve each element of the frontier.

For the time-dependent PRP, Franceschetti et al. [6] considered the traffic congestion and took the driver’s wage cost and greenhouse gas emission cost as the goal. He designed an adaptive large neighborhood search algorithm to determine the optimal route and optimize the speed of each route segment. Ge et al. [7] assigned a time window for customers before the start of distribution, and established a dual-objective optimization model of PRP to minimize the carbon emission cost, the travel cost and the delivery time as the targets. A hybrid genetic-tabu search algorithm was proposed.

It is well known that carbon dioxide emissions are directly proportional to the car fuel consumption rate, and Suzuki [5] shows that the fuel consumption rate is affected by factors such as speed, load, acceleration, road gradient and traffic congestion. Raeesi et al. [8] used the Chicago road network as an example to introduce a realistic urban freight distribution model, considering the flexible time window and departure time, crowded city road network, random vehicle number, as well as instantaneous acceleration and deceleration of trucks in fuel consumption estimation. Due to the complexity of PRP problem, most researches are based on (meta-) heuristic algorithms, while Dabia et al. [9] proposed a branch-and-price algorithm to find the exact solution for a variant of PRP.

2.2. New energy vehicle routing problem

With the continuous development and improvement of key technologies, new energy vehicles have become the future direction of transportation vehicles. Additional average annual sale of efficient and electric vehicles in the transport sector as a result of the sustainable recovery plan. According to the
statistics released by the Ministry of Industry and Information Technology, China’s total production and sales of new energy vehicles reached 1.242 million and 1.206 million respectively in 2019, ranking first in the world. At present, new energy vehicles mainly include hybrid electric vehicles, pure electric vehicles and fuel cell vehicles. Due to the limited fuel loading of fuel cells, researchers have focused more on the VRP of hybrid vehicles and pure electric vehicles.

Conrad et al. [10] introduced the charging vehicle routing problem, assuming that customers can provide charging services, and the vehicle is charged while providing the service. Erdogan et al. [11] conceptualized and formulated GVRP, and for the first time proposed a routing model considering charging stations. It was solved by the modified Clarke and Wright savings heuristic and the density-based clustering algorithm. Schneider et al. [12] extended their work by introducing the electric vehicle routing problem with time windows (E-VRPTW) and charging stations. They noticed the possibility of charging at any available charging station using an appropriate charging scheme, and a hybrid heuristic variable neighborhood search and tabu search algorithm are proposed. In the subsequent E-VRPTW research, Desaulniers et al. [13] studied four different charging strategies and used an exact algorithm to solve the GVRP. Hof et al. [14] designed an adaptive variable neighborhood search algorithm to solve the battery swap station location-routing problem with capacitated electric vehicles. Considering the more realistic nonlinear relationship between the time spent charging and the amount of energy charged, Froger et al. [15] designed a new model, a heuristic method and an exact marking algorithm to find the best charging decision for a given route. Wang et al. [16] aimed to minimize the total travel cost, including travel time, energy consumption and charging cost, and established a multi-objective optimization model. They introduced fuzzy planning methods and fuzzy preference relations, and designed genetic algorithms to a better driving route. Although electric vehicles have the advantages of zero pollution and low noise, they also have technical constraints such as short cruising range and long charging time, so researchers began to pay attention to plug-in hybrid vehicles with multiple drive systems. Murakami [17] established a mixed integer programming model considering the increase in charging level and time constraints. To solve the vehicle routing planning and scheduling problem, he designed an exact algorithm and an improved two-stage heuristic algorithm. For further research on GVRP, Gerhard et al. [18] tried a combination of traditional cars, plug-in hybrid electric vehicles and electric vehicles, and designed a hybrid genetic algorithm based on layered route evaluation procedures to solve the problem. They observed that careful use of hybrid fleets can significantly reduce operating costs.

3. Future research direction in GVRP

Based on the previous review of relevant literature, it can be seen that GVRP has developed rapidly in the past few years and has become a research hotspot under the requirement of sustainable development. The possible future research directions are as follows. Through our observation, most of the current GVRP research focus on statically determined systems, which deviate from the dynamic uncertainty of information in the actual distribution process. For example, random service time, stochastic travel time and random customer requirements has been largely ignored in the literature. It leads to lower feasibility of vehicle routing planning. Therefore, future research can target GVRP under dynamic environment to make the research more convincing. In addition, the experimental examples in the existing studies are mainly derived from previous studies or randomly generated. There is a lack of real experimental data and papers on real case studies. We can obtain data support from the government or other official organizations to get some more realistic meaningful conclusions. For new energy vehicles, the construction of charging stations is a prerequisite for solving GVRP. Therefore, future studies can consider combining the vehicle routing problem of new energy vehicles with the location of charging stations. A reasonable charging station location can bring higher efficiency for routing optimization. Finally, GVRP can be integrated into new technology, such as big data, Internet of Things technology and unmanned vehicles, to achieve more accurate and efficient delivery.
4. Conclusions
Whether in the field of enterprise or academic research, GVRP has received high attention from people, and it has become an important branch of the vehicle routing problem. Based on the review of existing relevant literature, in this paper, the current research status of different types of GVRP further research directions are discussed. GVRP plays an important role in optimizing vehicle routes, reducing energy consumption and alleviating environmental pressure, etc. It is an effective way to conform to the low-carbon economic development and promote new energy vehicles. It has broad application prospects in the field of green logistics. It is hoped that the future research on GVRP can connect with the development of e-commerce and the advancement of the technology, not limited to idealized models and theoretical results, but to find more realistic and dynamic solutions.

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