ISSN: 2414-1895 DOI: 10.6919/ICJE.202109_7(9).0076

A Survey of Electric Vehicle Routing Problem

Hao Sun[1,a]

[1]School of Management, Shanghai University, Shanghai 200444, China.

[a]sun_shiny@shu.edu.cn

Abstract

Logistics and transportation have penetrated into all walks of life. How to improve distribution efficiency, save operating costs and improve customer satisfaction in the logistics and distribution link has become a research problem. With the introduction of new energy, electric vehicles have gradually become the main means of transportation in the logistics, and the problem of electric vehicle routing has become a research hotspot. This article outlines the research background and origin of the electric vehicle routing problem, summarizes several major branch problems of electric vehicle routing optimization, such as multiple charging methods, heterogeneous electric vehicle, consideration of queuing theory, location selection of distribution and charging station, etc., and outlines common solving algorithms. The research prospects and practical applicability of this issue are emphasized. Finally, it summarizes the problems and challenges of the electric vehicle routing problem, and provides a certain reference for the research direction of future development.

Keywords

Logistics Transportation and Distribution; Electric Vehicle Routing Problem; Exact Algorithm; Heuristic Algorithm.

1. Introduction

With the advancement of science and technology and the development of e-commerce, online shopping has entered life and has gradually become one of the mainstream shopping methods. In addition, the requirements of retail transportation are gradually increasing, which poses huge challenges to logistics transportation and distribution. How to reduce costs and increase efficiency of logistics links and improve customer satisfaction has become a major problem. For inter-city transportation, intra-city transit, and remote terminal distribution, the entire process must use manual and transportation to transport the goods to the designated site. This is the main part of the entire logistics transportation process that incurs huge costs, especially the terminal distribution process is intra-city which is small-batch and multi-batch transportation, and the total cost, including the cost of express station, delivery staff, delivery vehicle, etc., accounts for more than 30% of the entire logistics transportation process [1]. The express parcel logistics transportation methods in various regions are mainly road, railway, air transport, and water transportation. Among them, road freight volume accounts for up to 77% of all transportation methods [2].

In this context, scholars have carried out a series of studies on the Vehicle Routing Problem (VRP). The vehicle routing problem was first proposed by Dantzig and Ramser [3] in 1959. It can be described as follows: under certain constraints, such as vehicle load limit, vehicle volume limit, customer demand, delivery time window, etc., oriented by certain optimization goals, such as the shortest total distance traveled by the vehicle, the least time or cost, etc., for the scattered customer points in the network, develop an appropriate vehicle path combination plan to make the vehicles start from the distribution center in an orderly manner After serving each customer, it will eventually return to the distribution center to complete the entire task.

After this groundbreaking question was raised, many scholars have paid attention to it. In the early research, most of the articles took the volume or load capacity of the vehicle as the constraint, and took the shortest total mileage of the vehicle as the optimization goal. Later, some scholars pointed out: The route with the shortest total mileage is not necessarily the route with the lowest cost, and the lowest cost is the real meaning of optimizing the vehicle route. In recent years, with the global warming and the worsening of automobile exhaust pollution, environmental issues have gradually received attention. Transportation companies must also take environmental protection into consideration while achieving sustainable development while pursuing profit maximization. The traditional vehicle routing problem considers fuel vehicles, ignoring the impact on environmental pollution. Nowadays, the concept of environmental protection, green and low-carbon is gradually recognized and valued by people, and it has become a new direction for scholars to research hot issues. VRP is gradually changing to the Green Vehicle Routing Problem (GVRP). The main consideration of GVRP is to minimize vehicle emissions. Demir et al. [4] combed GVRP related articles with the goal of reducing total energy consumption, and concluded that the five factors affecting energy consumption are vehicles, environment, traffic, drivers, and operations with external factors. The GVRPTW model of Erdoğan and Miller-Hooks [5] has important guiding significance for the subsequent electric vehicle routing problem (EVRP) problem.

With the advancement of technology, more energy-saving and environmentally-friendly battery electric vehicles (BEV) have emerged, which has accelerated the change of traditional fuel vehicle transportation methods. Its technology is simple, and it can participate in transportation tasks as long as the battery is sufficient. It has the advantages of stability, low noise, and almost zero emission, which can meet the requirements of vehicles in almost any road environment. However, due to the limitations of its battery capacity and the current number of charging stations on the road, battery electric vehicles cannot be transported over long distances like traditional fuel vehicles under current conditions. Transportation activities must be carried out within the mileage allowed by the power level. The battery must be replaced during the trip or it takes a certain amount of time to replenish at the charging station. As for the route optimization of electric vehicles, it is necessary to consider the charging time and the additional driving path, time and cost for charging. Scholars paid attention to this important issue and launched a series of researches on electric vehicle path planning (EVRP). In the solution method, heuristic algorithms such as Genetic Algorithm (GA), Simulated Annealing (SA), Tabu Search (TS), etc. are mostly used.

2. Research Review of Electric Vehicle Routing Problem

2.1 Common Research of EVRP

Sachenbacher et al. [6] formalized the EVRP problem of minimizing energy consumption into the shortest path problem in the context of graph theory. Conrad and Figliozzi [7] conducted a comparative sensitivity analysis of soft and hard time windows. When the vehicle travel distance is limited and the charging time is long, the impact of the customer time window will greatly limit the travel distance. Eisner et al. [8] believed that the optimal path structure would be very different when the vehicle is routed under the influence of the edge cost function caused by battery constraints and height. Afroditi et al. [9] pointed out that the related research of vehicle path optimization is shifting to a more energy-efficient direction, which requires a systematic analysis of the real environment to capture the dynamic nature of actual problems. Schneider et al. [10] constructed an EVRP (Electric Vehicle Routing Problem with Time Windows, EVRPTW) model that can be charged midway. This is the first electric vehicle routing problem that considers independent charging stations. It is based on the classic Solomon VRPTW. The example generates an example of a new EVRPTW problem, which is solved by a combination of Variable Neighbourhood Search (VNS) and Tabu Search (TS). Most of the subsequent studies use the results of the paper as a benchmark for comparison. It is

ISSN: 2414-1895 DOI: 10.6919/ICJE.202109_7(9).0076

proposed to improve the accuracy of the model by considering factors such as load rate and vehicle speed. The hard time window limit will greatly increase the number of vehicles required. It is necessary to explore the results of the soft time window. Liao et al. [11] extended the gas station to the fixed itinerant problem of switching stations, and proposed a dynamic programming algorithm that can best solve the problem of the shortest travel time of electric vehicles in polynomial time. Swed et al. [12] is the first research to consider the adaptive route selection and charging problems of distance-constrained vehicles, and realizes the two major functions of excess charging cost and the availability of uncertain charging stations. Barco et al. [13] pointed out that the two challenges of studying EVRP are path planning under power constraints and reasonable arrangement of charging time during peak and low periods. These two aspects also have a greater impact on battery life. Montoya et al. [14] believe that it is more practical to consider nonlinear charging, and ignoring nonlinear characteristics can easily generate infeasible or higher-cost solutions. The hybrid genetic algorithm (HGA) proposed by Shao et al. [15] has advantages in terms of effectiveness and scalability when solving EVRP problems. Zhang et al. [16] studied EVRP that minimizes energy consumption and found that the goal of minimizing energy consumption is more realistic than minimizing distance. Minimizing distance cannot guarantee the minimum energy consumption emissions. The Ant Colony Algorithm (Ant Colony , AC) can provide near-optimal solutions for small instances. Zhang et al. [17] constructed a fuzzy optimization model (FEVRPTW) for the vehicle routing problem of electric vehicles, and analyzed the three uncertain parameters of service time, battery energy consumption, and driving time, which greatly increased the complexity of the problem and improved The ALNS algorithm runs longer but can converge to a better solution in a smaller number of iterations.

2.2 EVRP with multiple charging methods

In the problem of electric vehicle path planning, the charging speed of electric vehicles includes fast charging, slow charging, battery replacement, etc. The charging times can be one or multiple times, and the charging rate can be divided into fixed time, linear charging, non-linear charging, and so on. Desaulniers et al. [18] compared four different charging methods, that is, each path allows only one charge and full charge (EVRPTW-SF), allows multiple full charges (EVRPTW-MF), and allows one partial charge (EVRPTW-SP).), multiple partial charging is allowed (EVRPTW-MP). It is found that allowing multiple charging and partial charging can help reduce the route selection cost and the number of vehicles used. The two-way marking B&P algorithm has more advantages in the solution effect and running speed. Verma [19] assumes that electric vehicles can choose to replenish power in fast charging, slow charging, battery replacement and other methods (EVRPTWBSS). Due to the shorter battery replacement time, it is easier to generate a better delivery route. Tomislav et al. [20] believe that a single charging strategy on one path is more in line with the reality than a multiple charging strategy.

2.3 EVRP with Partially Charged

When studying the charging state of electric vehicles, most scholars define full charge as the final state after each charge. Some scholars put forward the concept of partial charging and pointed out that this method is more suitable for practical applications. Felipe et al. [21] were the first to consider partial charging during driving, using local search (LS) and simulated annealing algorithm (SA) to solve the GVRP-MTPR problem of minimizing charging costs. Various charging modes can be To save operating costs, the location of the warehouse and the number of stations may have an impact on the demand for fast charging. Keskin and Çatay [22] studied the path planning problem of electric vehicle partial charging (EVRPTW-PR), and used the ALNS algorithm to verify that the partial charging scheme is effective, especially when the time window is stricter, the vehicle used is more Full charge is less. David et al. [23] studied the path planning problem of partially charged electric vehicles, and also considered the situation that the deliveryman can walk to a customer nearby during the charging time, with the goal of minimizing the total time spent at the charging station. , Using Iteration Local Search (ILS) meta-heuristic framework and Variable Neighbourhood Descent (VND) algorithm to solve, the average calculation time is less than the latest algorithm report time, it is found

ISSN: 2414-1895 DOI: 10.6919/ICJE.202109_7(9).0076

that this mode can reduce the total charge Time, avoid long idle time in charging activities, and get a new optimal solution.

2.4 Heterogeneous EVRP

The fleet in logistics and transportation activities is often composed of multiple vehicle types. Considering a single vehicle type is to simplify the problem and facilitate modeling and calculation to solve other important problems. There are also scholars who focus on the transportation and distribution of multiple vehicle types. Hiermann et al. [24] constructed an electric fleet size and hybrid vehicle routing problem (E-FSMFTW) model that minimizes the total fixed cost and driving cost of the vehicle, and used the ALNS algorithm to solve the problem. Optimality, but assumes that the energy consumption rate is constant and does not take into account the impact of load on electricity consumption. Macrina et al. [25] studied the VRPTW problem of a hybrid fleet of electric and fuel vehicles. The braking energy generated during the acceleration and deceleration phases of the vehicle was solved by using the Hybrid Version of Large Neighborhood Search (HLNS), considering the acceleration and deceleration of the vehicle. The model can estimate energy consumption more accurately.

2.5 EVRP Considering the Queuing Theory

The current distribution of charging stations is relatively scattered and the number is small, and the number of vehicles that can be charged at a time is very limited. The problem of queuing at charging stations has become one of the main issues that scholars have paid attention to. Qin and Zhang [26] proposed the Distributed Charging Scheduling (D-ECS) method to solve the problems of estimating the waiting time of each station and the exchange of waiting time information between stations under the dynamic change of charging reservation. Keskin et al. [27] used the queuing theory M/M/1 model to deal with the path problem of electric vehicles with a limited number of charging piles and a nonlinear segmented charging rate, and controlled the range of available power for electric vehicles from 10% to 90%. It is feasible to use ALNS to search. Space and determine feasible routes, CPLEX accurately solves optimized charging decisions, and finds that waiting time has a greater impact on routing decisions.

2.6 EVRP with Load-Dependent

The battery capacity of an electric vehicle limits its cruising range, and the power consumption rate is not only related to the length of the driving path, but also affected by factors such as load, speed, and slope. Preis et al. [28] considered the fixed effect of load on the power consumption rate, but did not relate it to the length of the travel path and the transportation time. Goeke and Schneider [29] proposed a hybrid fleet routing problem (E-VRPTWMF) for electric vehicles and traditional fuel vehicles with the goal of minimizing costs. Energy consumption is not only related to driving distance, but also to load, driving speed, slope, resistance, Acceleration and deceleration, etc., use the idea of punishment and ALNS to deal with infeasible solutions that violate constraints to obtain feasible solutions. Kancharla and Ramadurai [30,31] considered load-dependent electric vehicle path planning problems, proposed that energy consumption is related to vehicle load, speed, and level, and found that the goal of minimizing total energy consumption can reduce vehicles more than the common minimizing distance. Energy consumption, customer allocation method and time window range greatly affect the number of vehicles used and energy consumption, and then use the adaptive large-scale neighborhood search algorithm (ALNS) combined with the algorithm of simulated annealing (SA) criteria to solve the problem of minimizing The driving time and charging time are the goals, and the load-related electric vehicle path problem with nonlinear charging and the limited number of vehicles that can be charged at the charging station.

2.7 Electric location routing problem

In addition to the research on EVRP path planning, some scholars have also paid attention to the importance of the location of charging stations for path planning. Therefore, they have launched a study on the integration of charging station location and path planning to balance the entire electric

ISSN: 2414-1895 DOI: 10.6919/ICJE.202109_7(9).0076

vehicle operating system. Shao et al. [32] studied the electric vehicle routing problem (EVRP-CTVTT) in a dynamic traffic environment, and believed that the location of the charging station has a greater impact on the charging selection, and the location routing problem (LRP) is more worthy of in-depth exploration. Schiffer and Walther [33] considered charging stations to be built on customer sites with demand when studying the problem of electric vehicle location routing, and proposed that the research location problem (ELRP-TW) can expand potential charging facilities, and has more benefits than partial charging (WLRP-TWPR) to be high.

3. Conclusion

In the context of the current era, people have gradually realized the importance of environmental protection, and electric vehicles will gradually replace traditional fuel vehicles and become the main mode of transportation. Scholars have carried out in-depth research on the different branches of EVRP, and have achieved certain results in problem models and solutions, laying the foundation for subsequent research and providing guidance. Future research can start from the point of view of location and routing integrated planning, consider the location of distribution centers and charging stations, combine the characteristics of electric vehicles and actual traffic conditions, and provide the application of electric vehicle routing problems in practical and related problems greater reference significance.

References

[1] China e-Business Research Center. http://www.100ec.cn/detail--6134501.html. 2013-11-08.

[2] China industry information network. http://www.chyxx.com/industry/202005/864441.html. 2020-05-19.

[3] Dantzig G B, Ramser R H. The Truck Dispatching Problem[J]. Management ence, 1959, 6(1):80-91.

[4] Demir E , Bekta? T, Laporte G. A review of recent research on green road freight transportation[J]. European Journal of Operational Research, 2014, 237(3):775-793.

[5] Erdoğan S, Miller-Hooks E. A Green Vehicle Routing Problem[J]. Transportation Research Part E Logs &Transportation Review, 2012, 48(1):100-114.

[6] Sachenbacher M, Leucker M, Artmeier A, Haselmayr J. Efficient Energy-Optimal Routing for Electric Vehicles[C]// Proc Aaai Conference on Artificial Intelligence. 2011.

[7] Conrad R G, Figliozzi M A. The recharging vehicle routing problem[C]//Proceedings of the 2011 industrial engineering research conference. IISE Norcross, GA, 2011: 8.

[8] Eisner J, Funke S, Storandt S. Optimal route planning for electric vehicles in large networks [C]// Twenty-Fifth AAAI Conference on Artificial Intelligence. 2011.

[9] Afroditi A, Boile M, Theofanis S, et al. Electric Vehicle Routing Problem with Industry Constraints: Trends and Insights for Future Research[J]. Transportation Research Procedia, 2014, 3:452-459.

[10] Schneider M, Stenger A, Goeke D. The Electric Vehicle-Routing Problem with Time Windows and Recharging Stations[J]. Transportation Science, 2014, 48(4):500-520.

[11] Liao C S, Lu S H, Shen Z J M. The electric vehicle touring problem[J]. Transportation Research Part B: Methodological, 2016, 86: 163-180.

[12] Swed T M, Dolinskaya I S, Klabjan D. Adaptive Routing and Recharging Policies for Electric Vehicles[J]. Transportation ence, 2017, 51(2):457-479.

[13] Barco J, Guerra A, Munoz L, et al. Optimal routing and scheduling of charge for electric vehicles: A case study [J]. Mathematical Problems in Engineering, 2013, 2017.

[14] Montoya A, Guéret C, Mendoza J E , Villegas J G. The electric vehicle routing problem with nonlinear charging function[J]. Transportation Research Part B Methodological, 2017, 103:87-110.

[15] Shao S, Guan W, Bi J. Electric vehicle-routing problem with charging demands and energy consumption [J]. IET Intelligent Transport Systems, 2017, 12(3): 202-212.

[16] Zhang S, Gajpal Y, Appadoo S S, Abdulkader M M S. Electric vehicle routing problem with recharging stations for minimizing energy consumption[J]. International Journal of Production Economics, 2018, 203(9):404-413.

[17] Zhang S, Chen M, Zhang W, Zhuang X. Fuzzy optimization model for electric vehicle routing problem with time windows and recharging stations[J]. Expert Systems with Applications, 2020, 145: 113-123.

[18] Desaulniers G, Errico F, Irnich S, Schneider M. Exact algorithms for electric vehicle-routing problems with time windows[J]. Operations Research, 2016, 64(6): 1388-1405.

[19] Verma A. Electric vehicle routing problem with time windows, recharging stations and battery swapping stations[J]. EURO Journal on Transportation and Logistics, 2018, 7(4): 415-451.

[20] Tomislav Erdelić, Tonči Carić, Martina Erdelić, et al. Electric vehicle routing problem with single or multiple recharges[J]. Transportation Research Procedia, 2019, 40:217-224.

[21] Felipe A, Ortuo M, Righini G, Tirado G. A heuristic approach for the green vehicle routing problem with multiple technologies and partial recharges[J]. Transportation Research Part E, 2014, 71:111-128.

[22] Keskin M, Çatay B. Partial recharge strategies for the electric vehicle routing problem with time windows. Transportation Research Part C: Emerging Technologies, 2016, 65:111–127.

[23] David L.Cortés-Murcia, Prodhon C, Afsar H M. The electric vehicle routing problem with time windows, partial recharges and satellite customers[J]. Transportation Research Part E: Logs and Transportation Review, 2019, 130:184-206.

[24] Hiermann, Gerhard, Puchinger, Jakob, Ropke, Stefan et al. The Electric Fleet Size and Mix Vehicle Routing Problem with Time Windows and Recharging Stations[J]. European Journal of Operational Research, 2016, 252(3):995-1018.

[25] Macrina G, Laporte G, Guerriero F, Di Puglia Pugliese L. An energy-efficient green-vehicle routing problem with mixed vehicle fleet, partial battery recharging and time windows[J]. European Journal of Operational Research, 2019.

[26] Qin H, Zhang W. Charging scheduling with minimal waiting in a network of electric vehicles and charging stations[C]//Proceedings of the Eighth ACM international workshop on Vehicular inter-networking. 2011: 51-60.

[27] Keskin M, Laporte G, Catay B. Electric Vehicle Routing Problem with Time-Dependent Waiting Times at Recharging Stations[J]. Computers & Operations Research, 2019, 107(JUL.):77-94.

[28] Preis H, Frank S, Nachtigall K. Energy-Optimized Routing of Electric Vehicles in Urban Delivery Systems[M]// Operations Research Proceedings 2012. Springer International Publishing, 2014.

[29] Goeke D, Schneider M. Routing a mixed fleet of electric and conventional vehicles[J]. European Journal of Operational Research, 2015, 245(1):81-99.

[30] Reddy K S, Gitakrishnan R. An Adaptive Large Neighborhood Search Approach for Electric Vehicle Routing with Load-Dependent Energy Consumption[J]. Transportation in Developing Economies, 2018, 4(2):10-.

[31] Kancharla S R, Ramadurai G. Electric Vehicle Routing Problem with Non-Linear Charging and Load-Dependent Discharging[J]. Expert Systems with Applications, 2020, 160.

[32] Shao S, Guan W, Ran B, He Z, Bi J. Electric vehicle routing problem with charging time and variable travel time[J]. Mathematical Problems in Engineering, 2017.

[33] Schiffer M, Walther G. The electric location routing problem with time windows and partial recharging[J]. European Journal of Operational Research, 2017, 260(3): 995-1013.