ROUTE OPTIMIZATION OF ELECTRIC VEHICLES IN LOGISTICS OPERATIONS PROJECT

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Abstract

The aim of this project is to construct feasible routes for a vehicle routing problem. The difference from a classical route optimization problem is the vehicles used in this problem are electric vehicles fueled with electricity in stations. The problem contains distributions of goods to a set of customers according to customers demands with electric vehicles which have limited capacities in terms of battery and need refueling in stations. Usage of these electric vehicles in logistics are getting popular because of the contribution of reducing greenhouse gas emissions. Thus, leading companies started to convert their logistic fleet into electric vehicles. In this project, feasible routes are constructed by using two construction algorithms, nearest neighbor and insertion. While constructing tours, the privilege was minimizing the distance and to transport goods in appropriate time windows of customers. As a result, feasible routes were constructed and numerical results have been shown in this report.

Keywords: route, optimization, electric vehicles, time windows, refueling

1 Introduction

Petroleum is one of the main sources of wealth and gives the power to lead the world to people who have had it for more than a century because petroleum is the easiest way to satisfy the energy needs of the growing population of the earth. However, petroleum is not just an innocent energy source. It emits one of the main components of greenhouse gases, carbon dioxide. According to the study, the carbon dioxide concentration at south-eastern Australia has been measured %23 more than non-industrialized times and if the petroleum usage continues with this rate, the carbon dioxide level in the atmosphere will double itself by 2030.[1] The emission of carbon dioxide and greenhouse gases play a considerable role in climate change. The damage which petroleum has been caused, have already reached critical limits and it will become fatal for the lives on the earth if the governments do not take a step to reduce petroleum usage.

Most of the developed countries have started to take action about taking care of the earth and reducing their carbon dioxide emissions. According to Erdoğan and Miller-Hooks (2011), the transportation sector contributes 28% of national greenhouse gas emissions and petroleum-based fuels are formed nearly all of the sector.[2] Thus, the governments and the leading companies have started to search for new alternative fuels. In such a case, transforming logistic fleets into electric vehicles or alternative fueled vehicles from petroleum-based ones would be a significant change for the companies and the world.

In this project, a company's logistics fleet is studied to construct routes which serve to a set of customers with nature-saving electric vehicles. Typically, a single-vehicle route problem is defined as a traveling salesman problem (TSP) and multi-vehicle route problem as a vehicle routing problem (VRP). In a TSP, there is the only vehicle to consider and that vehicle should visit all of the customers in one tour. On the other hand, there are multiple vehicles which can visit different customer clusters on different tours in VRP. The difference of the studied route problem in this project from a classical VRP is the vehicles are electric fueled which need to refuel their batteries in some fuel stations in considerable time periods. The tours which are aimed to be constructed in this study should satisfy some requirements such as visiting all the customers, delivering the goods of each customer at once, considering the loading-unloading time and shift time of the drivers, visiting customers in their available time windows and refuel vehicle's battery in a feasible fuel station when it is needed. While satisfying those requirements, the main aim is to construct

[1] Hessami, 1998.
[2] Erdoğan and Miller-Hook, 2011.

feasible routes which minimize the total cost and the time of the company. Therefore, the total distance traveled by the vehicles should be minimum and tours should be completed in the most convenient way.

To solve a VRP problem, there are plenty of algorithms such as construction algorithms and improvement algorithms. In construction algorithms, the tours are constructed from nothing and afterward, in improvement algorithms the constructed tour is improved by some techniques. In this study, two construction algorithms were used, nearest neighbor and insertion. In both approaches, different aspects of the problem considered deeply. As one can see in the results, the findings of the study demonstrate that the problem is solved with feasible routes. If these routes will be improved with future improvements, companies can embrace these solutions in their electric vehicle fleets and as a result of it, they can create a considerable difference in carbon dioxide emission.

2 Approaches

2.1 Insertion

The first approach that is used to solve the vehicle routing problem is the insertion method by using alternative fuel. Some issues must have been controlled in every inserting step to finding a feasible solution. One of them is keeping the length as possible as short. For this reason, nodes are inserted in order to extend the route with a minimum length. In this algorithm, vehicles must start from the depot with the full battery and return the depot before the end of shift time. Firstly, the farthest node from the depot is found and added to the tour. Secondly, every node is attempted to be inserted into each interval in the route to find a feasible result. The node which gives the least extension when it is inserted to the tour is determined and checked its feasibility. The second issue is time. The vehicle must return the depot without exceeding shift time. According to our heuristic decision, we separate two hours of shift time to be spent on the charging issue. All customers are tried to insert until the end of the shift time except the separated two hours. Time is calculated by adding roading time and service time which lasts thirty minutes according to Erdoğan's data(2011)[3]. If the day is over, another route with a new vehicle is created.

Another issue is the fuel of vehicles. If the vehicles need the fuel in their tour, the fuel station must be inserted into the tour. During the insertion of the fuel station(s), the separated two hours were used. Fuel station(s) is located according to the least extension when it is inserted for every interval. Then the station

[3] Erdoğan and Miller-Hook, 2012

is inserted to the tour and this process lasts until the tour is satisfied in terms of energy. Therefore, all issues are checked and a feasible solution is obtained.

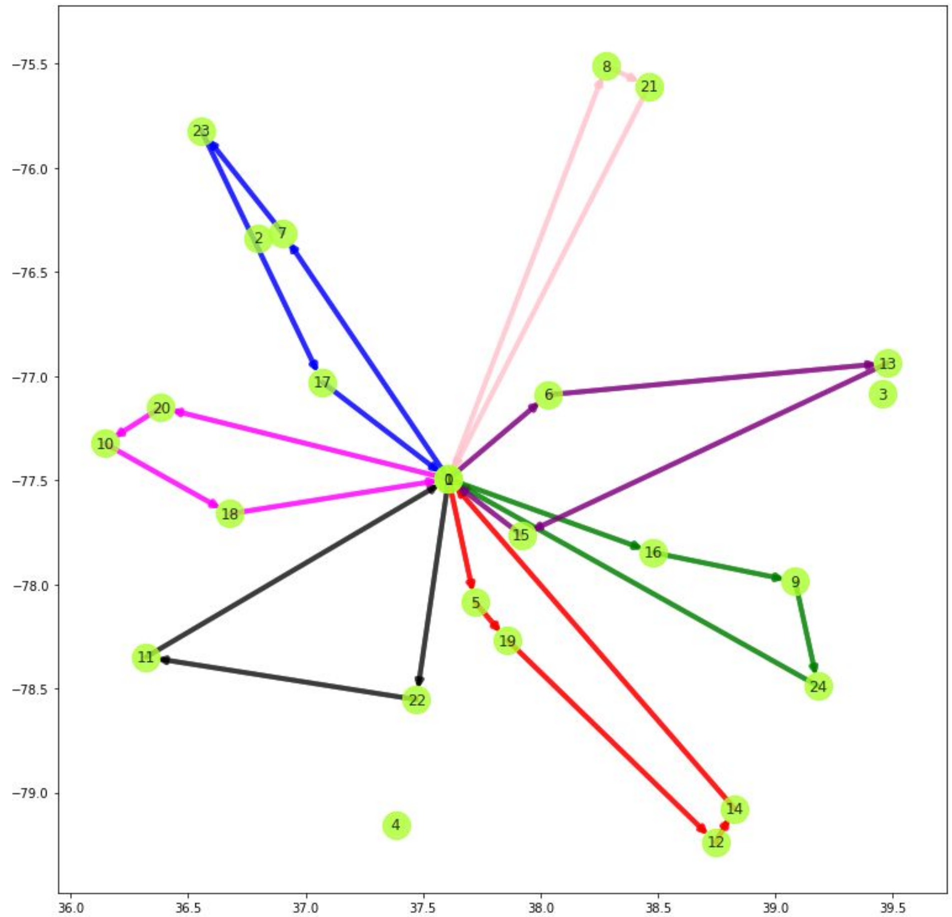

Figure 1. Routes of Insertion

2.2 Nearest Neighbor

The second approach that is used to solve the vehicle routing problem is the nearest neighbor method by using electric fuel. In this case, to obtain a feasible solution, some issues must be controlled. The vehicle has to start from the depot with fully charged and return the depot until shifting time in a tour. Then, all nodes are added in terms of their distance. Firstly, the nearest node to the depot is added to the tour, then the other nearest node to the previous tour. All customers are added until the other issues checked truly. The second issue is the demands of the customers. There is a capacity of the vehicle. For this reason, the tour is created according to which the customer's request does not exceed the capacity. If the demands of the nearest customer much more the remaining capacity, another nearest customer will find and added to the tour. Then, the third issue that is shift time is controlled. For check the time, calculated the time at spent on the way, then service time is added to the tour time. New customers are added until shifting time or capacity is over. The last issue is charging the vehicle. During the added station, the remaining charge of the vehicle is checked whether it is enough to go to the next node and the nearest charging station. If it is not, a battery station is added before the next node and fully charged the battery. Also, spending time in charge station is important because the electric vehicles are used in the problem and charging fully takes a long time in those vehicles. When shift time or capacity is over, the new vehicle is created and the remaining customers are served.

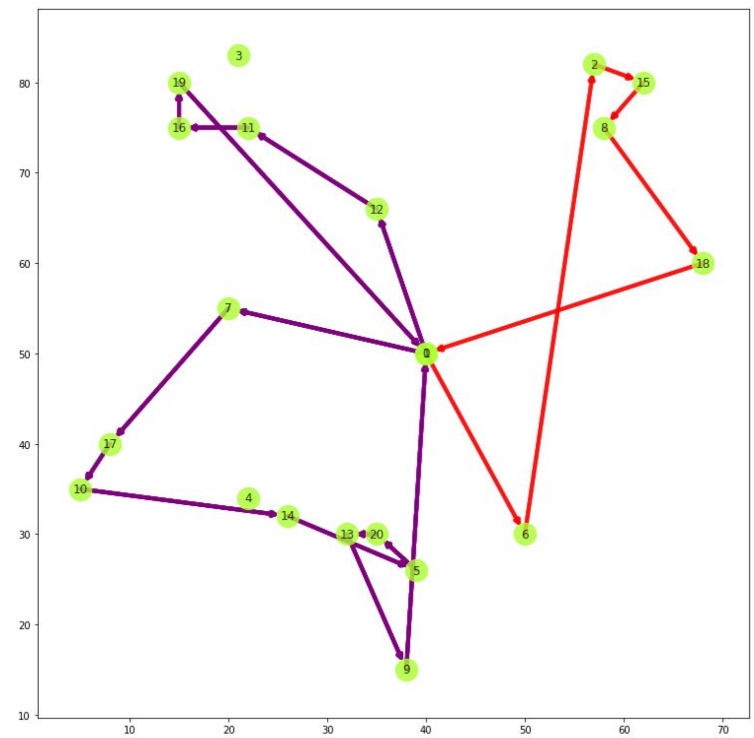

Figure 2. Routes of data c103-C15 with 'Nearest Neighbor'

2.3 Insertion with Time Windows

In this approach, the insertion method is combined with time windows of customers, which shows their available times, by using electric vehicles. As it was mentioned, all vehicles must start from the depot with fully charged and loaded and should return back without exceeding shift time. While creating a new route, the furthest customer from the depot is determined. There are some parameters for checking whether the determined node breaks the tour's feasibility. Initially, checks if the current commodity capacity of the vehicle can supply the node's demand. The second parameter controls that the vehicle has to arrive at the determined node before its due time to be able to serve. If the vehicle arrived earlier, it must wait until the starting time of the node for unloading. Another check decides that if the start and due times of the node are later than the follow-up node or if the start and due times of the node is earlier than the previous node, the node is becoming suitable. Also, the current battery of the vehicle and shift time always been computed. After checking all parameters, if the determined node is defined as appropriate, the tour extended with that node. Otherwise, the node is defined as inappropriate and the farthest node from the depot except inappropriate nodes is chosen and applied the same checking process. When a first proper node, seed node, is found, the second node adding method that detects which remained node will give the minimum extension. It calculates the change in terms of distance when the nodes are inserted for every interval between nodes in the tour and locates the minimum one. In order to ensure that this node does not impede the tour, it must be controlled by both discussed and some different parameters. One of these unmentioned parameters deals with time issues. When the node is inserted to the tour, the arrival time of the vehicle to the following nodes will be delayed because of traveling extended distance and the node's service time. This delay must not cause exceeding the due time of the following nodes. In every node adding steps, the current battery of vehicle must be reflected. The tour's interval where the battery is discharged completely is located and also the most efficient charging station in terms of giving the least extension of distance for the appointed interval is detected and it is controlled whether the vehicle can even achieve to the station. If the station does not lead to any infeasibility, it is added to the specified interval of the tour. On the other hand, if the station is not suitable, a new station is computed for the previous interval. This searching for appropriate station lasts until the battery problem of the vehicle is satisfied. Due to our heuristic decision, the battery is charged fully when a station is visited. Since visiting a station will cause passing a significant time because of traveling the extra distance and waiting for refueling of the battery according to refuel rate, the arrival time of the vehicle to the rest of the tour's nodes must be checked again for not exceeding their due time. After trying to find all proper station(s) and make the tour feasible in terms of proving energy, this parameter remarks whether the process was successful. If all checked parameters claim that the node makes the tour feasible, it is inserted to the tour and a new customer is searched to serve by implementing the same checking progress. If even one of these parameters signs that the node causes infeasibility, a group which is named inappropriate nodes is appended by the node in order to not to be checked until a new tour with another car is created. This group becomes empty for every new tour. The second node adding method is implemented until there is no such a customer which does not bring infeasibility. In that case, the tour is completed, therefore a new tour with another car is created by applying the same methods among unvisited customers.

When all customers are served, the progress is finished and the results which are routes of tours, total distances, total times and instant properties of vehicles are shown. We used Schneider et al. (2014)[4] 15 customer benchmark data set to evaluate our heuristic algorithm. There is a table which demonstrates some numerical outcomes of the algorithm. In the table, 'C' represents the number of customers.

Name of Data	Total Length	Total Time	# of Vehicles
c103-C15	1497.36	15446.31	6
c106-C15	1010.92	15215.30	6
c202-C15	2088.08	32966.74	6
c208-C15	1681.15	34266.65	6
r102-C15	1436.50	3972.84	7
r105-C15	1243.74	3682.37	8
r202-C15	2536.47	8518.81	4
r209-C15	2203.13	10157.85	4
rc108-C15	1621.33	2826.21	4
rc202-C15	2471.93	13100.91	6
rc204-C15	2541.94	5989.26	2

[4] Schneider et al., 2014

The graph is a visual presentation of routes calculated by the algorithm for c103-C15 data. Each color represents a vehicle and vehicles travel as indicated by arrows. '0' which seems to be in the middle of the picture represents the depot. 1 to 5 symbolize charging stations and other nodes symbolize the customers.

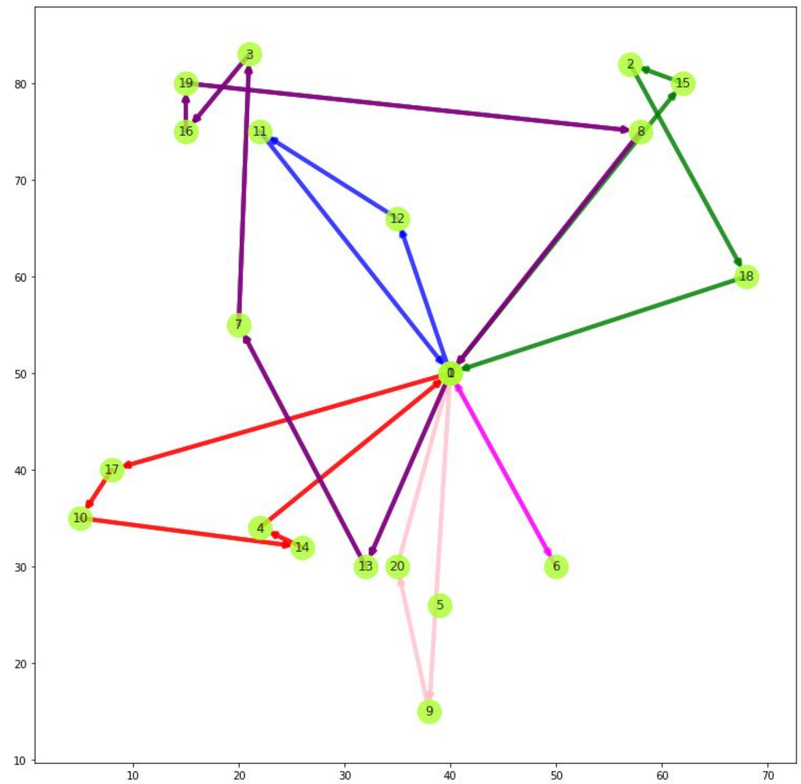

Figure 3. Routes of data c103-C15 with 'Insertion with Time Windows'

3 Discussion and Conclusion

In this project, a route optimization problem with electric fueled vehicles is studied to be solved and findings and results have been shown in this paper. As a first step, a background research had been done about TSP, VRP and their algorithms. Generally, heuristics approaches have been considered during the project. Three approaches and solving algorithms have been embraced which are insertion algorithm, nearest neighbor algorithm and insertion algorithm with time window of customers included. As one can understand from the findings and sample route visuals in approaches part, multiple feasible routes have been constructed with those different algorithms.

Since the vehicles are fueled with electricity, there are some main differences in the algorithms in terms of fueling and timing criteria. In the first insertion algorithm, the charging time of the battery is stable with a determined time. But in the other two algorithms, each time a vehicle visits a fuel station, charging time changes according to the battery's unoccupied capacity. Thus, if the vehicle has come to the station with a lower capacity of fuel, it would take more time to fully charge the battery. But this approach seems more reliable in terms of real life experiences.

There can be some further improvements and studies about this route optimization problem. The routes can become better in terms of distance and energy costs with some improvement algorithms like 2-opt or replacement. Another improvement to reduce the expenses can be saving more time. For this purpose, charging fully in each station would be unnecessary. If the vehicle charges its battery just what it is needed at that moment, there would be no need to wait until a full charging time. In further steps, this time saving method can lead to visit new customers which it could not visit in the tour before.

In conclusion, the project mostly completed the aims with constructing feasible routes to a electric vehicle, visiting and distributing the goods of customers and working during the shift time and considering the availability of customer times.

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