Route Optimization of Alternative Fuel Vehicles in Logistics Operations

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Abstract

The research that has been conducted for the past weeks was to come up with a solution to an alternative fuel vehicle routing problem. The problem at hand has 3 different kind of locations: depot, stations and customers. We are to satisfy the demand of each customer in one visit. Vehicles that are at hand are using alternative fuel and fuel of each vehicle is limited. Moreover, there is a time limitation for each driver. Throughout the research the nearest neighbourhood algorithm was chosen as the constructive algorithm to create an initial feasible solution. This algorithm is used on different datasets in order to come up with different results. Furthermore, an improvement algorithm is used as well to reduce the total distance that has been travelled to fulfill the demands. The improvement algorithm that has been used was swap.

1 Introduction

In the modern day of consumption economy, it is now more than ever important that to get something delivered. This item can be a cargo, can be food delivery or any other commodity that is available for public usage. With this demand, firstly travelling salesman problem(TSP) was born. "A TSP aims at finding the shortest tour that visits each node exactly once and return to the starting node." (*Metaheuristic Algorithms for the Vehicle Routing Problem with Time Window and Skill Set Constraints*,2016.)A further extension of this problem is the vehicle routing problem(VRP) which is the problem that is studied in this article. "In the well-known Vehicle Routing Problem (VRP) a set of identical vehicles, based at a central depot, is to be optimally routed to supply customers with known demands subject to vehicle capacity constraints." (Golden, B. L., Raghavan, S., & Wasil, E. A. ,2011). The vehicles that are considered were alternative fueled vehicles. Eventhough VRP was one of the most studied problems in the field of industrial engineering, every case offers a new challenge as a case consists special constraints and goals of its own. The case at hand offered a few constraints that was worth mentioning.

The agenda of the project were straightforward. The initial step was to understand the problem clearly. In this sense, I went through several articles that was quite eloborative. From these articles I decided on a constuctive algorithm amongst many of them. After working on the constructive algorithm , I applied an improvement algorithm to commend further iterations on the result that I currently have.

The data that is used in this article was originated from the article of Sevgi Erdoğan and Elise Miller-Hooks. My main goal was to state an algorithmic approach to an already solved problem. However this solution was created via an optimization software. My objective was to come as close as possible to that result without any optimization software usage. The obtained result of this project was worse than an optimization software based result as expected.

2 Dataset and the Given Case

There are multiple datasets with similar components that has been used in this project. In each dataset there are 3 kinds of locations:

- Depot: The beginning point of a vehicle in any tour. Any vehicle can go back to it for refueling and should return to it when shift hours end.
- Station: A refueling point in between a tour. Refuels the vehicle however does not resets the time count.
- Customers: The ones that should be visited an creates a demand to satisfy.

Another component of the problem is the limitations that are present. A vehicle can hold a maximum of 60 litres of alternative fuel. Vehicles have 0.2 fuel consumption rate as in they can go 300 km with one tank of fuel. When refuelling, the assumption is that we fuel up to the maximum of the fuel tank. A vehicle has to end its tour in 11 hours and should go back to the depot. For the sake of simplicity we are given a 40 miles of average velocity which corresponds to 64.35 km.

Given these factors, we are expected to meet the demands of 20 customers in most datasets. We have the exact lantitudes and longtitudes of the customers,depot and stations. There is a formula that is used to calculate the distances between each place. We take the radius of earth as 6371 km.

3 Mathematical Model

Before introducing the algorithmic view on the case, there is a vital information that has to be given. As previously mentioned, the owners of the article have already has an optimal solution via a mathematical model and an optimization software. In order to fully understand what this solution is the mathematical model will be furtherly discussed.

3.1 Sets and Parameters

d_{ij}: The distance between location i and location j.

T_{max}: Maximum time limit that a vehicle has (11 hours in this dataset.)

t_{ij}: A non-negative travel time between location i and j.

I_0: Set of customer vertices and depot.

F_0: Set of AFS vertices and depot.

p_i: Service time at location i

r: Vehicle fuel consumption rate (For this case 0.2)

Q: Vehicle fuel tank capacity (For this case 60 lt.)

3.2 Decision Variables

x_{ij}: Binary variable which is equal to 1 if a vehicle travels from location i to location j and 0 otherwise

y_j: Fuel level variable specifying the remaining tank fuel level upon arrival to location j. It is reset to Q at each refueling station location i and the depot

s_j: Time variable specifying the time of arrival of a vehicle at location j, initialized to zero upon departure from the depot.

3.3 Objective Function

$\sum_{\substack{i,j \in V' \\ i \neq j}} d_{ij} x_{ij}$ Minimizes the distance travelled considering if that route should be part of any tour or not.

3.4 Constraints

$$\sum_{\substack{j \in V' \\ j \neq i}} x_{ij} = 1, \quad \forall i \in I \tag{2}$$

$$\sum_{\substack{j \in V' \\ j \neq i}} x_{ij} \leqslant 1, \quad \forall i \in F_0 \tag{3}$$

$$\sum_{\substack{i \in V' \\ j \neq i}} x_{ji} - \sum_{\substack{i \in V' \\ j \neq i}} x_{ij} = 0, \quad \forall j \in V' \tag{4}$$

$$\sum_{j \in V' \setminus \{0\}} x_{0j} \leqslant m \tag{5}$$

$$\sum_{j \in V' \setminus \{0\}} x_{j0} \leqslant m \tag{6}$$

$$\tau_j \geqslant \tau_i + (t_{ij} - p_j)x_{ij} - T_{\max}(1 - x_{ij}), \quad i \in V', \forall j \in V' \setminus \{0\} \text{ and } i \neq j \tag{7}$$

$$0 \leqslant \tau_0 \leqslant T_{\max} \tag{8}$$

$$t_{0j} \leqslant \tau_j \leqslant T_{\max} - (t_{j0} + p_j), \quad \forall j \in V' \setminus \{0\} \tag{9}$$

$$y_j \leqslant y_i - r \cdot d_{ij} x_{ij} + Q(1 - x_{ij}), \quad \forall j \in I \text{ and } i \in V', i \neq j \tag{10}$$

$$y_j = Q, \quad \forall j \in F_0 \tag{11}$$

$$y_j \geqslant \min\{r \cdot d_{j0}, r \cdot (d_{jl} + d_{l0})\}, \quad \forall j \in I, \forall l \in F' \tag{12}$$

$$x_{i,j} \in \{0, 1\}, \quad \forall i, j \tag{13}$$

Second constraint makes sure that every customer location has exactly one successor while third makes sure that every station location may have one successor. Fourth constraint ensures that if a location is arrived that location is left. Fifth constraint ensures that at most m vehicles are used. (In the algorithmic approach this comes as a relaxation.) Sixth constraint nakes every vehicle used to return to the depot at the end of the shift. Next three constraints are used to keep track of the time used and if the time limit is met, the vehicle returns to the depot. Constraint 10 keeps track of the vehicle's current fuel level. Constraint 11 refuels the vehicle when needed.Constraint 12 guarantee that vehicle heads to any refueling location if it cant make it after stopping by a customer. The last constraint is a binary constraint .

4 Constructive Algorithm

A constructive algorithm is a method which is supposed to create an initial feasible solution. This initial feasible solution may or may not be optimal. A very important aspect of algorithmic thinking is that it depends on the case and the situation as in an algorithm which may be suitable and near optimal for a case may become useless for another. Considering this throughout the literature review for this project, I came across with many algorithms that are used in VRP. Some highlights from my options were sweep algorithm and savings algorithm. Sweep algorithm works as a literal sweeping line. A line starts and creates a connection between each location that is covered by that line. Eventhough this algorithm proved to be feasible, it also can be highly inefficient in many cases. Savings algorithm workes as it calculates gains and losses from changing an arc in a tour.

The algorithm that is the subject of this case is nearest neighbourhood algorithm. Nearest neighbour, was the first greedy algorithm which gave a solution for the travelling salesmen problem. The algorithm starts with a location of the depot as all of our vehicles should depart from there. Then, the algorithm continues with the nearest unvisited location to this location. The algorithm works with this trend until every customer location is visited. In every iteration the algorithm checks the nearest location and calculates the amount of fuel and time required to go there. If fuel is not enough, the algortihm checks the neares refueling point (depot or station) and goes there. A tricky part of the algorithm is that even if time and fuel checks out now, they may be insufficient for leaving the destination location. In this situation the fact that the algorithm that is applied iterative comes in handy. In every iteration algorithm checks if the vehicle also can leave the destination as discussed and if not erases the last iteration and goes on to refuel and reset the time.

There are several considerations to be made while choosing which algorithm to work with. The reason that nearest neighbourhood algorithm is chosen is that it is iterative, easy to apply , fast to come to a solution. However, the algorithm is a little bit 'blind' so to speak as in it only considers the iteration on hand. This may cause deficiencies in the result as the algorithm fails to see the 'bigger picture'.

```
for every location
if that location haven't been visited and distance from i to j<minimum
        minimum distance equals distance for i to j
if fuel is not enough
        go to refueling locations
if time is not enough
        go to depot
if time and fuel is enough and minimum=distance from i to j
        change the location from i to j
        add spent time to time
        reduce spent fuel from fuel
```

The upward pseudocode is the simplist summary of the constructive algorithm at hand.

5 Improvement Algorithm

As previously discussed, the algorithmic approach that has been the subject of this project requires further iterations in order to obtain better results. The nearest neighbourhood algorithm is indeed not considerate about any variations in the result. Thus, it has a unwanted difference between the calculated optimal solution.

In order to get a little bit closer to the optimal solution, there is an option to apply a improvement algorithm to the constructive algorithm. Since the constructive algorithm actually creates an initial feasible solution, we have the option to work from there.

There are many improvement algorithms in the literature, however due to time manners this project only includes one improvement algorithm. Between 2-opt,relocation and swap algorithms the solution is improved by swap algorithm.

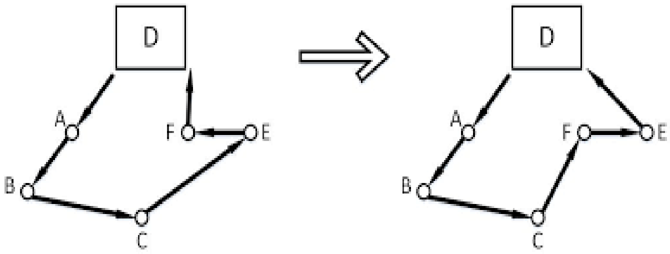

Figure 1: Relocation

Relocation algorithm was something that has been my next step in this project. If time would allow, I would implement relocation algorithm as well. There is a very simplistic idea behind it . The algorithm takes a location in this case and changes its place iteratively. While doing so, it checks if there has been any improvement in the final result. In an exhaustive manner, it checks every possibility and changes the routes accordingly.

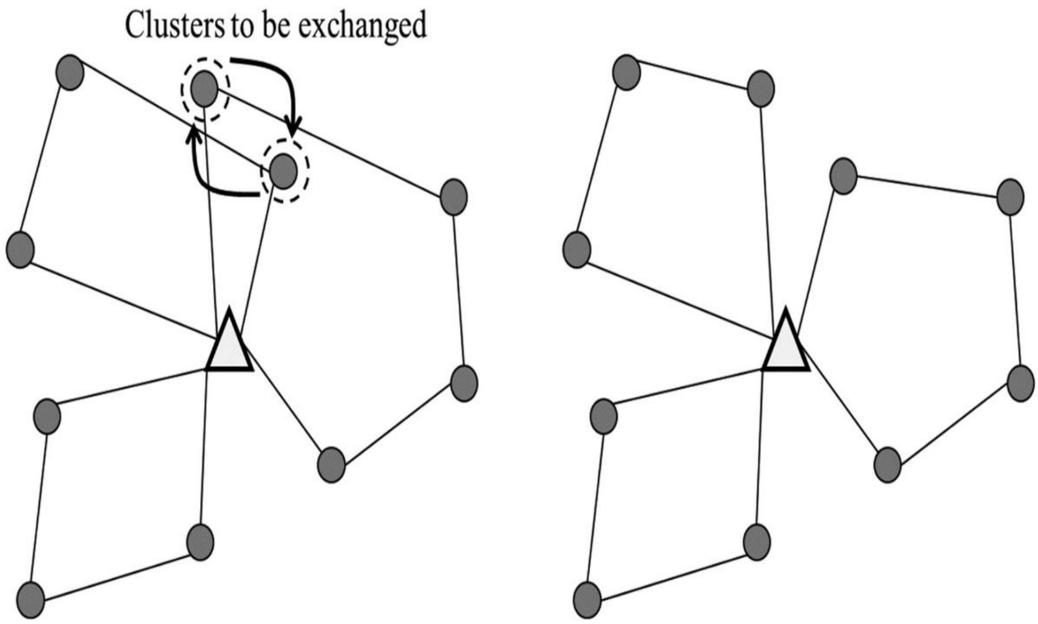

Figure 2: Swap

The improvement algorithm that I implemented was swap algorithm. They are very alike with relocation algorithm, the only difference is that when relocating, algorithm puts one location to a certain place and then slides the rest to the next spot. In swap, 2 location switch places. Exhaustively, the algorithm tries every possible scenerio available regarding the constraints and seeks an improvement.

In my case, I do this swap operation between each location that is in a vehicle's route. The most important part during this swapping operation is to make sure of that depot is in the end as it should be any vehicle's final destination.

6 Discussion,Findings and Conclusion

Data Sample	Article Solution	NNA Solution	Swap Solution
20c3sU2	1614.15	3026.3	2710.16
20c3sU4	1513.45	2517.7	2297.3
20c3sU8	1766.36	4006.6	3078.3
20c3sU10	2583.42	2862.1	2814.95

Table 1: Results

As seen above table, even with further iterations my algorithm failed to reach the numbers that were given in the ariticle. However, this result is highly expected regarding the fact that the constructive algortihm that is on hand and the limited time that this project had.

Also another important point that I would like to make is that as seen above, with different datasets, efficiency of both algorithm changes drastically. In 20c3Su10 swap algorithm barely made a difference but in 20c3sU8 the change is 25% which is really promising.

If I had more time with this project, I would have plenty of things to do. First thing would be to implement relocation algorithm to further observe the difference that an improvement algortihm makes. Secondly, I would like to use another constructive algorithm which would take higher coding skill that I currently developped. However, I am certain that savings algorithm with 2-opt as improvement would create better results than I had. During this limited time, I learned a lot about VRP,TSP and most importantly algorithmic thinking. My coding skills really improved as I learned a new coding language.

References

- Erdoğan, S., & Miller-Hooks, E. (2012). A Green Vehicle Routing Problem. *Transportation Research Part E: Logistics and Transportation Review, 48*(1), 100-114. doi:10.1016/j.tre.2011.08.001
- Golden, B. L., Raghavan, S., & Wasil, E. A. (2011). *The vehicle routing problem: Latest advances and new challenges*. New York: Springer.
- *Metaheuristic Algorithms for the Vehicle Routing Problem with Time Window and Skill Set Constraints* (Unpublished master's thesis). Thesis / Dissertation ETD. (2016).

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