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1 Abstract

This goal of the research is to solve the capacitated vehicle routing problem (CVRP) with multiple real-world constraints, such as on-duty time limits, delivery windows, and drive time limits and the model captures all the assumptions made in the problem without making any changes. We used a combined heuristic approach for a CVRP that is modified with the incorporation of delivery window constraints and Department of Transportation (DOT) regulations regarding driving and service duty time. The heuristic method uses the nearest neighbor algorithm to obtain an initial solution to the modified CVRP considering the additional constraints mentioned. Next, we use the 2-Opt algorithm to refine the solution, and we found that 7 drivers are needed weekly to travel 8940 miles, assuming one driver for each route.

2 Introduction

We propose a model to find an optimal and comprehensive design for the Northeastern Home Goods (NHG) and shipment planning for the outbound distribution network. NHG is considering outsourcing their transportation services but is uncertain what a reasonable proposal may be and require an internal estimate of annual freight transportation miles if the current delivery day schedule is maintained and all stores are restocked from a single DC in Wilmington. We assume that each day the routes begin and end at the depot and each route begins at 08:00 am and ends at 06:00 pm. Thus the routing decisions in each day are independent. For this reason, we modelled the delivery windows as time windows and split the problem into five instances, one for each weekday, and solved each instance individually [1]. We conducted a Sensitivity analysis on number of trucks and distance travelled by varying parameters vehicle velocity (vehicle drive speed), waiting time for unloading, and demand because the value of these problem parameters changes with time.

3 Methodology

This problem is a modified version of five different CVRP problems after we break it down into five different days. These problems are NP hard and a large instance of these problems will take significant computational expense to find a good enough feasible solution. This is why we move forward with a heuristic approach.

Constructive Heuristic (Nearest Neighbor Algorithm): We use a nearest neighbor algorithm to as a constructive heuristic to generate the initial feasible solution. Nearest neighbor algorithm selects the nearest possible location and adds it to the current route and then keeps adding locations until a certain condition is met. We used route terminating four conditions for our algorithm to check. These are:

1.route capacity + demand of next location <= vehicle capacity: we keep updating the route capacity at any location with the demand of next location to decide whether we should add the next location to our current route or not. This condition ensures that vehicle capacity is not exceeded during route execution.

2. route time + travel time from current location to next location + waiting time on next location <= 600 minutes: we keep updating the route time (calculated from the arrival time at the first location in the route) at any location with the travel time and waiting time of next location to decide whether we should add the next location to our current route or not. This Condition ensures that the delivery to each destination is made within 8 am to 6 pm delivery window.

3. driving time + travel time from current location to next location + travel time from the next location to the depot <= 660 minutes: we keep updating the driving time (calculated from the start time of the route at depot) at any location with the travel time to the next location and also the travel time to return back to the

Day	Routes	Capacity	Total Distances	Route time	Drive Time	Service time	Start time(am)	End Time
Mon	['1581', '1752', '2135', '2132', '2111', '2110', '2114', '2129', '1821']	3166	1721	399.9	191	484.9	6:47	2:51 pm
	['2210', '2466', '2493', '3906']	847		279.7	294	414	7:32	2:26 pm
	['5401']	325		0	600	630	3:00	1:30 pm
	['6032', '6156', '6103', '6102', '6108', '6040', '6043', '6095', '6096']	2752		365	432.8	717.2	4:59	4:56 pm
	['6183', '6457', '6415', '6320', '6340', '6269', '6241']	2523		408.5	488.1	698.1	5:14	4:52 pm
	['6517', '6524', '6825', '6897']	610		203.6	562.7	682.7	4:25	3:47 pm
Tue	['1730', '1821', '1887', '1845', '1984', '1910', '2110', '2114', '2116', '2115']	3179	1872	409	159.7	459.7	7:39	3:18 pm
	['2138', '2139', '2142', '2215', '2467', '2481', '2493', '3755']	2361		480.3	437.3	677.3	7:35	6:52 pm
	['3820', '4047', '4276']	620		285.5	529.9	619.9	6:35	4:54 pm
	['6032', '6106', '6156', '6115', '6105', '6183', '6033', '6040', '6082', '6091']	2337		432.8	509	809	4:59	6:28 pm
	['6320', '6340', '6349', '6457', '6524', '6484']	1823		326.3	565.7	745.7	4:55	5:20 pm
	['6830', '6927', '6902', '6854']	1217		161.8	592.5	712.5	3:18	3:10 pm
Wed	['1060', '1101', '1606', '1752', '1701', '1801', '1854']	1371	1826	429.4	419.4	629.4	5:11	3:40 pm
	['1876', '2110']	3128		149.8	70.2	184.1	7:51	10:55 am
	['2111', '2210', '2155', '2114', '2135', '2115', '2332']	1524		301	192.5	402.5	7:33	2:15 pm
	['2370', '2903', '2822', '2840']	2835		301.3	338.8	490.8	7:02	3:12 pm
	['2914', '2917', '6032', '3431']	2940		499.3	579.1	735.1	6:14	6:29 pm
	['6033', '6269', '6108', '6096', '6095', '6156', '6105', '6062']	1665		377.3	498.5	738.5	5:05	5:23 pm
	['6516', '6517', '6524', '6854', '6901', '6927', '6903']	1729		330.9	626.9	836.9	4:12	6:08 pm
Thu	['1701', '1752', '2108', '2111', '2110', '1890', '1821', '1867', '1886']	3006	1804	389	188.1	470.1	7:14	3:04 pm
	['2115', '2142', '2139', '2138', '2134', '2215', '2116', '2120', '2188']	3055		319	128.4	398.4	7:30	2:08 pm
	['2451', '2493']	3187		113	67.2	175.2	7:32	10:27 am
	['2747', '2766', '3054', '3103', '3109', '3101', '3755']	1648		536	613.4	823.4	6:05	07:48 pm
	['3766', '4101', '4092']	766		343	561.2	651.2	5:22	4:13 pm
	['6033', '6103', '6105', '6492', '6451', '6320', '6340']	1678		368	513.4	723.4	5:05	5:08 pm
	['6510', '6524', '6814', '6877', '6927', '6840', '6851', '6854']	1660		371	620.9	860.9	4:19	6:39 pm
Fri	['1420', '1510', '1570', '1581', '1772', '1701', '1801', '1821', '1843'],	3151	1717	483.4	298.5	568.5	6:51	4:19 pm
	['1867', '1970', '2129', '2114', '2111', '2199', '2115', '2120', '02138', '2453', '2451']	1767		422.5	129.9	459.9	7:51	3:30 pm
	['2493a']	3153		0	65.7	160.7	7:27	10:07 am
	['2493b', '4101']	305		234.6	355.2	415.2	7:27	2:22 pm
	['6032', '6050', '6051', '6156', '6103', '6108', '6084', '6035']	1973		360.9	488.1	728.1	4:59	5:07 pm
	['6320', '6340', '6524', '6615', '6810', '6814']	1694		365.1	625.4	805.4	4:55	6:20 pm
	['6824', '6877', '6901', '6902', '6870']	1425		217.1	600	750	3:52	4:22 pm

depot from there if we decide to go to the next location. This condition corresponds to the DOT regulation that all freight companies must abide by shift length regulations that specify a driver can drive for at most 11 hours.

4. service time + travel time from current location to next location + waiting time on next location <= 840 minutes: we keep updating the service time (calculated from the start time of the route at depot) at any location with the travel time to the next location, waiting time at the next location, and also the travel time to return back to the depot from there if we decide to go to the next location. This condition corresponds to the DOT regulation that a driver can be on duty for at most 14 hours, before taking a break.

We add a location to the existing route only if all the above-mentioned conditions are satisfied.

Improvement Heuristic (2-Opt Algorithm): Once we have a set of routes as our initial feasible solution, the task is to improve those routes. One way to do that is to solve the Travelling Salesperson Problem (TSP) for each route. We used 2-opt swapping algorithm to solve for the TSP problems within each route. This would eliminate the crossings inside of a route as shown in figure 1 and improve the routes by finding the shortest distance for each route.

4 Results and Discussion

Our solution using a heuristic method is divided into two phases. In the first phase, the nearest neighbour algorithm was used to quickly generate a feasible initial solution by assigning the closest customer to each vehicle's current location, thus reducing the computation time for finding an initial solution where constraints involve route time, service time, driving time and vehicle capacity. In the second phase, we used the 2-opt algorithm to refine the solution by swapping pairs of edges and eliminating crossing in routes to reduce the total distance travelled while still taking the vehicle capacity constraint into account. In each destination on any given weekday, multiple orders in any destination were consolidated as long as the consolidated order does not exceed a vehicle capacity. This process helped to streamline the process and ensure that a single delivery vehicle does not travel the same route repeatedly.

The heuristic method was implemented using the Python programming language. Table 1 summarizes the result from the heuristic method. The table shows utilized capacity (Cap.), total distance, route time, service time, start time and the end time of the vehicles on each route on each week day. The distance covered by each vehicle from the time it left the distribution centre in the morning until it returned completing the assigned route is included in the total distance. The route time is the interval of time between when a vehicle arrives at the first destination and when it departs from the last destination. Driving time and service time are explained in the context of the case.

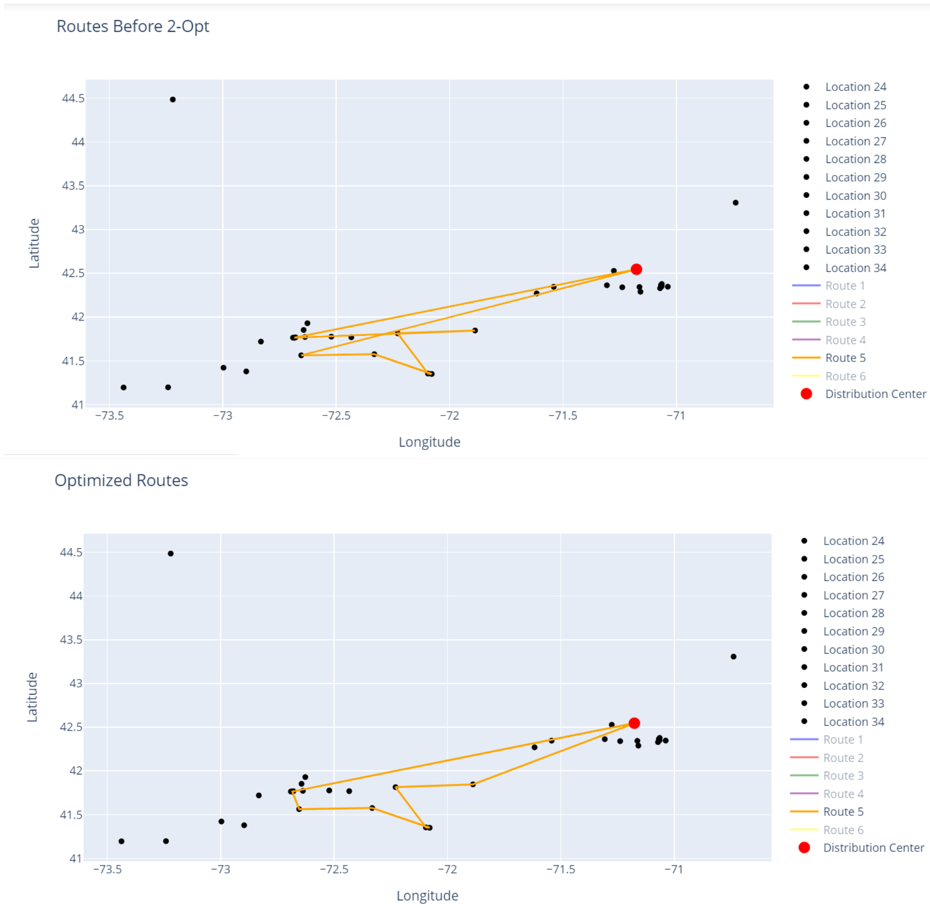

Figure 1: Before and after 2 opt

The solution set of routes for each day satisfies 8:00 am to 6:00 pm constraints, capacity constraints, driving time constraints for drivers, and service time constraints. Let us evaluate one route from this solution, the second route on Monday starts at 7:32 am from the depot and the truck reaches the first location on the route at ZIP ='2210' at exactly 8:00 am, Going through all other locations at that route respectively the truck reaches the last location '3906' after 279.7 minutes have gone past 8:00 am, So, this routes satisfies our 8:00 am to 6:00 pm constraint. Then, all the driving time on this route equals 294 minutes which is less than 660 minutes (11 hours). Similarly, the service time for the driver is 414 minutes which is less than the allowable limit of 14 hours. In all these routes we still have not considered the constraint of giving the drivers at least 10-hour breaks between two consecutive services. By looking at the start time and end time of the routes in previous days it is clear that our solution satisfies those conditions. When the earliest route on Tuesday starts at 3:18 am we have all the drivers available after they have had more than 10 hours of a break since their last trips from Monday. On Wednesday we get one conflict for a route start time of 4:12 am for just one route but by this time we have five different drivers available from the last day and a new one will be joining as the number of routes increases from 6 to 7. On Thursday we see a similar picture for one location with a route start time of 4:19 am. On Friday there are three route start times with such conflicts: at 3:52 am, 4:55 am, and 4:59 am. For these routes, we can still have respectively 5, 6, and 6 drivers available who can go on this route as their 10-hour break is already over.

In sensitivity analysis, we took three multipliers vm, wm, and dm, to vary the velocity, waiting time, and demand, respectively, in the interval of 0.4-2.0, 0.4-2.0, and 0.4-3.0. We can see the effect of change in the maximum number of vehicles required and total distance travelled from the box plot shown in figure-2. The impact of vm is the largest as when the velocity gets reduced to around some extreme situations such as 0.4vm - 0.6vm, the number of vehicles required jumps to around 16 trucks. Total distance is also impacted similarly.

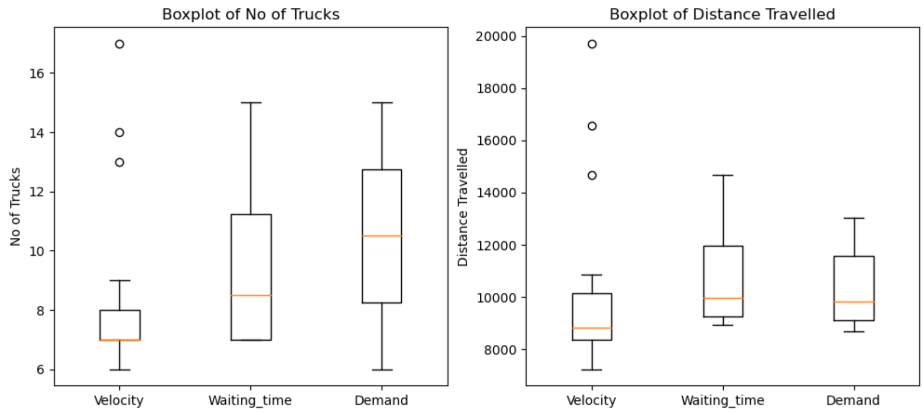

Figure 2: Sensitivity Analysis

5 Conclusion and Recommendations

This model aims to minimize the total distance travelled, resulting in fewer drivers and vehicles required to meet the defined service time and driving time regulations set by The United States Department of Transportation (DOT) and the obtained number of vehicles is 7 (3 out of 5 weekdays require seven vehicles and drivers and the rest two days require 6) to travel 8940 miles. We have used a Heuristic method (Nearest Neighbor) because it involves using practical or experiential knowledge to solve problems rather than relying solely on theoretical or analytical methods. These methods are often used when no established algorithm or formula for solving a problem and rely on trial and error or intuitive decision-making. Adding the 2-opt optimization step after the Nearest Neighbor algorithm helped to improve the solution by making minor adjustments to the route to remove any intersecting edges and reduce the distance by 412 miles. In addition, if we look at the table, we will notice some routes where the service time is lower than usual, and drivers might be idle. To avoid that, management can consolidate some routes. From sensitivity analysis, considering the velocity variation, we can conclude that we may have seven drivers as a backup as the highest number of routes is 7. As we don't have access to all information, the authority can decide the number of backup drivers by analysing their actual demand trend while remaining competitive in the market. The sensitivity analysis gives valuable insights to the decision makers to analyse and make decisions on the number of truck drivers and other critical choices if any disruption occurs that impacts the velocity of vehicles.

6 Reference

[1] Ashlea Bennett Milburn,Emre Kirac,Mina Hadianniasara (2017) Growing Pains: A Case Study for Large-Scale Vehicle Routing, INFORMS TRANSACTIONS ON EDUCATION,Vol. 17, No. 2, January 2017, pp(75-80)