UNC CHARLOTTE
The WILLIAM STATES LEE COLLEGE *of* ENGINEERING
Systems Engineering and Engineering Management
9201 University City Blvd, Charlotte, NC 28223-0001
t/ 704.687.3535 f/ 704.687.3616 www.coe.uncc.edu/mem

A Case Study for Large-Scale Vehicle Routing

Project Team Member(s):	TEAM 1 Aniket Amar Thopte | athopte@uncc.edu Brian Joseph | bjoseph6@uncc.edu Omkar Omprakash Jadhav | ojadhav@uncc.edu Shivraj Bhandigare | sbhandig@uncc.edu
Course:	EMGT 6926 080 Lean Supply Networks
Instructor:	Prof. Ertunga C. Ozelkan, ECOzelka@uncc.edu

Abstract:

Vehicle routing problem (VRP) is a generic name referring to optimization problems in transportation, distribution and logistics industry. . Route planning techniques is one of the main tasks of VRP which aims to find an optimal route from a starting point to a destination on a road map. Choosing an appropriate route planning algorithm among the existing algorithms in the literature to apply it in real road networks is an important task for any transportation application.

In this project, we first present two of the different route planning algorithms, and then explain how we compare and analyze their performance when they are applied in real

road networks. First one being the Integer Programming for optimizing the route and second technique includes usage of VRP spreadsheet solver in MS-Excel.

In this project, we initially segregated distance matrices and the delivery freight according to the day of the week. Further, single day wise optimization of the available road networks was implemented by the techniques mentioned above.

The open-source Excel workbook named VRP Spreadsheet Solver utilizes Bing Maps web service to retrieve coordinate and distance data and uses a Large Neighborhood Search algorithm to provide solutions. It can solve Vehicle Routing Problems with up to 200 customers.

Also, the open-source VRP Solver is a windows-based network optimizer that uses co-ordinates data for mapping locations, along with demand weights and distance matrix. It works on Clarke-Wright savings algorithm for vehicle routing problems.

Keywords:

Modeling techniques for transportation routing problem, optimization, logistic, Excel Spreadsheet Solver, VRP Solver.

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1. Introduction

Transportation routing is an important aspect for any supply chain system. Northeastern Home Goods (NHG) is a retail chain offering home furnished products operating over 123 stores and 6 states in the Northeast.

This project deals with developing an optimized distribution network for NHG and estimating the minimum freight distance over these stores. Various distribution networks and optimization techniques are mentioned which can help achieve the desired goal satisfying the operational constraints. This internal estimation will help to compare the proposed model with the MAD model.

Choosing a suitable route planning algorithm from the numerous algorithms proposed in the literature is a key issue in many transportation applications involving real road networks [1].

Project Charter

Project Description: The main aim of this project is to develop and optimize transportation model to transport maximum goods for the shortest path available using concepts like Integer Programming, Vehicle Routing Spreadsheet Solver and other optimizing tools and techniques.

Problem Statement: To prepare an internal estimate of annual freight transportation miles (Distance Optimization) to maintain the current delivery day schedule from a single point Distribution center to all the stores.

Goal Statement: The goal is:

1. To reduce the total freight distance.
2. To optimize the existing network considering the constraints.
3. To accommodate fixed, repeatable service schedules.

Scope: The scope of this project is to minimize the transportation cost by optimizing logistics networks

In Scope: In this project we will be using concepts such as Supply Network Strategy, Supply Planning, Transportation Scheduling from our course work.

Out of Scope: Concepts related to Integer Programming, Vehicle Routing Problem (VRP) Spreadsheet Solver are taken from courses such as Deterministic System Analysis and available sources from MS-Excel.

Assumptions:

Following are the assumptions based on the case study:

1. Vehicle must be dispatched at store during operational timings only.
2. The network cannot accumulate multiple days order on same route.
3. All stores are restocked from a single DC.
4. A vehicle will always be dispatched at the time required to arrive at the first store on the route at 8:00 a.m.
5. Store orders from different days cannot be grouped on to the same route.

Constraints:

1. According to the U.S. Department of Transportation, following constraints are mentioned:
2. The operational delivery timings for the stores are between 8.00 a.m. to 6.00 p.m.
3. All the stores receive order on the same day as mentioned.
4. A driver can drive for at most 11 hours or be on duty for at most 14 hours (whichever comes first), before taking a break. The required break length is 10 hours.
5. The on-duty driver time includes loading/unloading time, idle time as well as the driving time.

6. The vehicle speed is considered as 40 miles/hour because the vehicle will travel a mix of highway and non-highway routes.
7. The vehicle has a minimum unload time of 30 minutes per order if the unload rate multiplied by the order cube is less than 30 minutes. The unload rate is 0.030 minutes/cubic ft.
    1. Minimum unload time: 30 mins. or 0.030min./cubic ft. volume (max. value)
    2. The vehicle capacity is 3200 cubic ft. and should arrive at the store at 8.00 a.m.

2. Excel Spreadsheet Solver for Vehicle Routing

A VRP solver can be used to generate, optimize and visualize the routes of a vehicle routing problem. It cannot be used for medium and large-scale distribution network system as the maximum number of customers accepted as input variable is 200. It uses Geographical Information Systems (GIS) database to plot the customers on map and calculate the distance and driving time based on average speed of vehicle. It can use Bing maps google maps and android coordinates to plot the customers. It this case we have used Bing maps to track the location of each customer. It combines excel, public GIS and algorithms in C++ to solve the problem.

Step 1: Data Segregation, Unload Time Calculation & Distance Matrix.
In this step we segregated data based on individual days and calculated the unload time for each customer. The example shown below shows the unload time for first 10 customers on Monday with its respective details.

DayOfWeek	ORDERID	FROMZIP	TOZIP	CUBE	Unload Time	Y	X	CITY	STATE	ZIPID
Mon	20	01887	01581	111	30	42.2694444	-71.6158333	Westborough	MA	6
Mon	201	01887	01752	124	30	42.3461111	-71.5405556	Marlborough	MA	10
Mon	251	01887	01821	146	30	42.5277778	-71.2752778	Billerica	MA	13
Mon	28	01887	02110	285	30	42.3469444	-71.0375	Boston	MA	26
Mon	209	01887	02111	246	30	42.3505556	-71.0644444	Boston	MA	27
Mon	162	01887	02114	106	30	42.3644444	-71.0677778	Boston	MA	28
Mon	23	01887	02129	1,796	53.88	42.3775	-71.0638889	Charlestown	MA	32
Mon	90	01887	02132	187	30	42.2891667	-71.1580556	West Roxbury	MA	33
Mon	178	01887	02135	165	30	42.3436111	-71.1625	Brighton	MA	35
Mon	244	01887	02210	163	30	42.3294444	-71.0713889	Boston	MA	42

Distance matrix for Monday.

	Zip	id	01887	01581	01752	01821	02110	02111	02114	02129	02132	02135	02210
				6	10	13	26	27	28	32	33	35	42
	01887		0	49	43	8	17	18	17	16	30	23	19
1	01581	6	49	0	10	41	34	32	32	36	29	27	34
2	01752	10	43	10	0	36	31	30	30	33	27	24	31
3	01821	13	8	41	36	0	20	21	20	18	25	24	22
4	02110	26	17	34	31	20	0	1	1	2	9	8	2
5	02111	27	18	32	30	21	1	0	2	4	9	7	2
6	02114	28	17	32	30	20	1	2	0	2	9	6	2
7	02129	32	16	36	33	18	2	4	2	0	10	7	4
8	02132	33	30	29	27	25	9	9	9	10	0	6	10
9	02135	35	23	27	24	24	8	7	6	7	6	0	8
10	02210	42	19	34	31	22	2	2	2	4	10	8	0

Step 2: Bing map key.

In this step we created Bing map key for each day from bingmapsportal.com. Bing Maps helps to track multiple location. It is a web mapping service offered by Microsoft.

Step 3: Setting up the VRP solver and inputting the constraints based on locations, distances and vehicles details.

We have populated Locations and Distances are with the help of Bing maps. Alternate way to do is with the help of distance matrix. We have adjusted the Departure time manually for each vehicle and tried several different combinations by adjusting the number of vehicles to find the shortest path.

a. VRP Solver console:

Sequence	Parameter	Value
0.Optional - GIS License	Bing Maps Key	pwoRLNRLtXt4fZNhy3nS~vwMPnun8h27w8PynZV4cqA~AkyzY7H5X1AtUilReOccF0ArGfWrOG0TKkVE8wwilb5PzxT2QvlPA9JEzr6OVV_d
1.Locations	Number of depots	1
	Number of customers	34
2.Distances	Distance computation method	Bing Maps driving distances (miles)
	Duration computation method	Bing Maps driving durations
	Bing Maps route type	Shortest
	Average vehicle speed	40
3.Vehicles	Number of vehicle types	1
4.Solution	Do the vehicles return to their depot(s)?	Yes - only once at the end
	Time window type	Hard
	Backhauls?	No
5.Optional - Visualization	Visualization background	Bing Maps
	Location labels	Location IDs
6.Solver	Warm start?	Yes
	Show progress on the status bar?	Yes
	CPU time limit (seconds)	60

Fig-1: VRP Solver console

b. Locations:

Location ID	Name	Address	Latitude (y)	Longitude (x)	Time window start	Time window end	Must be visited?	Service time	Pickup amount	Delivery amount	Profit
0	Depot	Wilmington,	42.5639496	-71.18135834	06:00	19:00	Starting location	0:00	10223	0	0
1	Customer 1	Farmington, (	41.7489014	-72.86769867	08:00	18:00	Must be visited	0:44	0	1,479	1,479
2	Customer 2	Windsor, CT,	41.8512497	-72.64411163	08:00	18:00	Must be visited	0:30	0	157	157
3	Customer 3	Westboroug	42.2687988	-71.61386108	08:00	18:00	Must be visited	0:30	0	111	111
4	Customer 4	Charlestown,	42.3716888	-71.06243896	08:00	18:00	Must be visited	0:54	0	1,796	1,796
5	Customer 5	Boston, MA, (	42.3586617	-71.05673981	08:00	18:00	Must be visited	0:30	0	285	285
6	Customer 6	Weston, MA,	42.3692398	-71.29801941	08:00	18:00	Must be visited	0:30	0	279	279
7	Customer 7	Colchester, C	41.5748405	-72.32717133	08:00	18:00	Must be visited	0:30	0	213	213
8	Customer 8	East Hartford	41.7666283	-72.64539337	08:00	18:00	Must be visited	0:30	0	242	242
9	Customer 9	Hartford, CT,	41.7637482	-72.67394257	08:00	18:00	Must be visited	0:30	0	538	538
10	Customer 10	Dayville, CT, (	41.8507614	-71.84702301	08:00	18:00	Must be visited	0:30	0	102	102

Fig-2: Locations

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c. Distances

From	To	Distance	Duration
Depot	Depot	0.00	0:00
Depot	Customer 1	116	3:55
Depot	Customer 2	105	3:59
Depot	Customer 3	36	1:50
Depot	Customer 4	16	0:30
Depot	Customer 5	17	0:27
Depot	Customer 6	18	0:39
Depot	Customer 7	103	4:01
Depot	Customer 8	103	3:24
Depot	Customer 9	105	3:08
Depot	Customer 10	71	2:48
Depot	Customer 11	110	4:10
Depot	Customer 12	105	3:08
Depot	Customer 13	161	4:17
Depot	Customer 14	169	4:11

Fig-3: Distances

d. Vehicle

Starting depot	Vehicle type	Capacity	Fixed cost per trip	Cost per unit distance	Duration multiplier	Distance limit	Work start time	Driving time limit	Working time limit	Return depot	Number of vehicles
Depot	T1	3200	1.00	1.00	1.00	400.00	07:30	11:00	14:00	Depot	7

Fig-4: Vehicle

e. Results

Vehicle:	V1	Stops:	6	Net profit:	1402.60			
Stop count	Location name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
0	Depot	0.00	0:00		07:21	0:00	0	1642
1	Customer 6	18.33	0:39	08:00	08:30	1:09	279	1363
2	Customer 7	103.97	4:02	11:53	12:23	5:02	492	1150
3	Customer 11	124.32	4:38	12:59	13:29	6:08	1247	395
4	Customer 28	127.21	4:45	13:36	14:06	6:45	1540	102
5	Customer 10	168.06	5:55	15:16	15:46	8:25	1642	0
6	Depot	238.40	9:00	18:51		11:30	1642	0

Fig-5: Results

f. Visualization

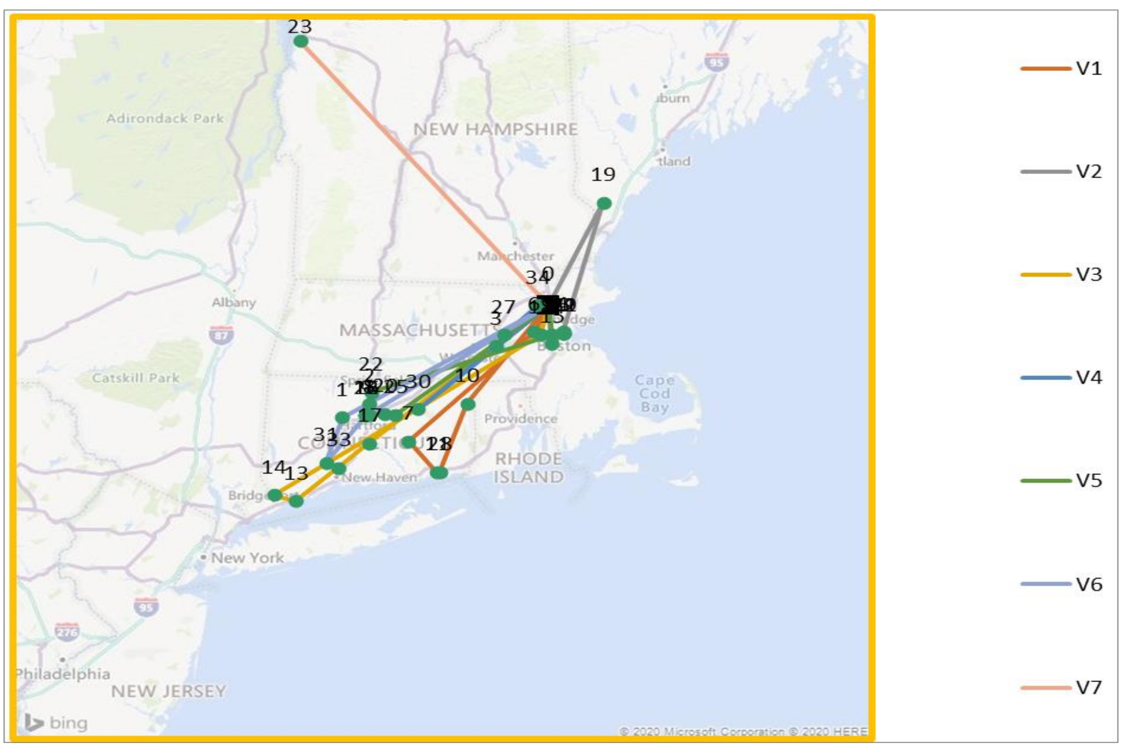

Fig-6: Visualization

3. LSVR using VRP Solver.

VRP solver is a Windows-based Solver used for vehicle routing problems. It builds vehicle routes that visit every customer point exactly once and that obey user-specified limits. It takes input from data containing listing of each customer's location (latitude and longitude), customer demands, vehicle capacity, node to node distance matrix, etc [2].

Working Method:

VRP Solver implements an adaptation of the Clarke-Wright savings algorithm for vehicle routing problems.

The Clarke-Wright savings algorithm is a well-known algorithm in vehicle routing and is described in various papers and texts [2]. The algorithm implemented by VRP Solver expands the Clarke-Wright algorithm in the following ways [2]:

- Randomization: Instead of choosing the best pairing of routes at each step, choose one of the k best pairings, chosen randomly.
- Repeat several times and choose the best overall solution.
- Improvement Heuristics: After an initial solution is built, various improvement heuristics are performed.
- These include the well-known 2-opt and Or-opt operations (the Or-opt uses group sizes of 1, 2, and 3), as well as a swap operation in which two customers on different routes may be removed from their routes and inserted into the opposite route.

Solution:

The data has been arranged in the following order as shown in the figure below. For our convenience we have assigned the term ‘Stop No.’ to the customers/ stores in the order taken.

For example, we have shown the ‘Friday Delivery Schedule’.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Stop No.	DayOfWeek	ORDERID	FROMZIP	TOZIP	CUBE	Unload Time	Y(Latitude)	X(Longitude)	CITY	STATE	ZIPID
2	1	Fri	0	01887	01887	0	0	42.54555556	-71.17555556	Wilmington	MA	20
3	2	Fri	2	01887	01821	556	30	42.52777778	-71.27527778	Billerica	MA	13
4	3	Fri	3	01887	01843	903	30	42.67055556	-71.18638889	Lawrence	MA	14
5	4	Fri	165	01887	02493	128	30	42.36305556	-71.30611111	Weston	MA	51
6	5	Fri	16	01887	06156	255	30	41.76444444	-72.68388889	Hartford	CT	92
7	6	Fri	17	01887	06320	507	30	41.35444444	-72.09527778	New London	CT	96
8	7	Fri	19	01887	06902	896	30	41.0525	-73.54111111	Stamford	CT	121
9	8	Fri	30	01887	06108	592	30	41.77222222	-72.63777778	East Hartford	CT	90
10	9	Fri	41	01887	06035	163	30	41.95388889	-72.78861111	Granby	CT	75
11	10	Fri	44	01887	06340	164	30	41.35	-72.07861111	Groton	CT	97
12	11	Fri	47	01887	02111	121	30	42.35055556	-71.06444444	Boston	MA	27
13	12	Fri	59	01887	02129	187	30	42.3775	-71.06388889	Charlestown	MA	32
14	13	Fri	64	01887	06824	143	30	41.17527778	-73.28111111	Fairfield	CT	111
15	14	Fri	82	01887	02199	161	30	42.34583333	-71.07722222	Boston	MA	41

Fig-7: Data Plan for VRP Solver

The location map of stores for Friday.

Fig-8: Friday Delivery Schedule Google Map

Final Answer we get has been given in the following format: The order of stores visited in single route/trip, the arrival and departure time, the cargo supplied to individual store and finally the distance travelled from store to store.

	A	B	C	D	E	F	G
2	Stop No	Location	Day	Arrival Time	Departure Time	Delivery Volume	Distance Travelled
3	1	Wilmington	Friday		6.51	0	46
4	33	Fitchburg	Friday	8.00	8.30	444	17
5	16	Clinton	Friday	8.56	9.26	390	18
6	32	Westborough	Friday	9.53	10.23	102	7
7	37	Southborough	Friday	10.34	11.04	119	15
8	4	Weston	Friday	11.27	11.57	128	4
9	30	Waltham	Friday	12.03	12.33	182	8
10	40	Cambridge	Friday	12.45	1.15	109	6
11	28	Boston	Friday	1.24	1.54	202	1
12	39	Boston	Friday	1.56	2.26	221	1
13	14	Boston	Friday	2.28	2.58	161	2
14	11	Boston	Friday	3.01	3.31	121	2
15	35	Boston	Friday	3.34	4.04	140	2
16	12	Charlestown	Friday	4.07	4.37	187	10
17	22	Woburn	Friday	4.52	5.22	195	9
18	1	Wilmington	Friday	5.36		0	-
19					Total	2701	148
20	Total On-Duty Time = 10 Hours 45 Minutes						

Fig-9: Friday Delivery Schedule Optimized Route-1

4. Summary and Conclusions

This project discusses about a case study for large-scale vehicle routing problems and their findings. The results will enable us to classify future findings in VRP. Furthermore, our outcomes allow us to analyze which variant is most recurrent and whose characteristics to follow. All constraints in this report are real-life constraints, moreover the variables applicable to this problem and its parameters are influenced in such a way to get better performance. The metaheuristic in this problem is applicable to the classical VRP, Closed VRP and the site dependent VRP. In conclusion, the advancement of such general approaches seems highly valuable.

The findings/results of our project.

DAYS	No. of Routes		Total Distance Traveled		Total Cargo Volume
	Method 1	Method 2	Method 1	Method 2	Both Methods
MONDAY	7	6	1823	1787	10223
TUESDAY	5	5	1518	1882	11537
WEDNESDAY	6	7	882	1434	15192
THURSDAY	7	7	1364	1990	15009
FRIDAY	5	6	1236	1380	13468

Table no. 1 Comparison Matrix

Here, we used two different methods to get the required solution the first method being Excel Spreadsheet solver and the second being LSVR using VRP Solver. Both the methods give a very different approach towards the solution, only second method implements adaptation of the Clarke-Wright savings algorithm for VRP, they also have different steps to follow while solving this heuristic VRP. The first method (M1) cannot be used for medium or large-scale distribution network system. M1 uses GIS database to plot the customers map and calculate distance matrix which in additionally calculates the driving time. After completing the first step, the second step is to segregate data and unload time calculations. While doing so we need to make sure that the data used for segregation is based on individual days i.e. Monday, Tuesday and so on. In third step of M1 it goes to bin map key to get each and every location. Based on the constraints the program determines the best possible routes in each scenario and gives an optimum solution for that particular day. Second Method (M2) as mentioned above it implements adaptation of the Clarke-Wright savings algorithm for VRP. It allows us to view the approach in a different way.

We can conclude on the following

• How to construct a solution to a VRP by successive insertion.
• How to improve solution using randomization and swapping for better results.
• Argument which method for solving vehicle routing problems.
• Real problems often have unique constraints.
• Easy to change the model to include new constraints without changing the core solve method.

In the comparison matrix above we conclude on factors such as No. of routes i.e. number of paths created by the software for the particular day meaning that many number of transports to conduct, total distance travelled and the total cargo volume. The total cargo requirement for the day will be same. The total distance travelled, and number of routes are inversely proportional to each other in most of this individual case. M1 has the higher number of routes for majority days and the distances travelled is comparatively less to that of M2. Similarly, we can conclude for M2 the routes calculated are less and distance travelled is higher in compare to M1. Wednesday has an exceptional case, as shown M1 is less than M2 for number of routes and in case of total distance travelled M2 is greater than M1. In M1 randomization is the first step so, n- number of routes can be formed and swapping of stores is also step followed by this method which allows it to get optimum answer for majority of cases. Considering all the constraints and the given data we can conclude the findings based on the above methods used. The number of routes and the total distance travelled found by NHG must be less than or equal to the number of routes and total distance travelled found and provided by MAD. If later case persist it means that the proposal submitted by the mad is a good one and better optimized model.

5. List of Supporting Files

No.	File Name	Description
1	Map of 123 Stores.xlsx	Contains all 123 stores co-ordinates and generated Google map.
2	Deliveries.xlsx	Contains Master data file having 2 sheets named ‘OrderTable’ & ‘locationTable’.
3	Distances.xlsx	Contains Master data file containing all the location co-ordinates.
	Method 1 Folder:-	
4	VRP_Spreadsheet_Solver_v3.33-Monday	Contains the Excel Spreadsheet solver workbook for Monday
5	VRP_Spreadsheet_Solver_v3.33-Tuesday	Contains the Excel Spreadsheet solver workbook for Tuesday
6	VRP_Spreadsheet_Solver_v3.33-Wednesday	Contains the Excel Spreadsheet solver workbook for Wednesday

7	VRP_Spreadsheet_Solver_v3.33-Thursday	Contains the Excel Spreadsheet solver workbook for Thursday
8	VRP_Spreadsheet_Solver_v3.33-Friday	Contains the Excel Spreadsheet solver workbook for Friday
9	Results.xlsx	Contains the final optimized routes for all days for method 1.
	Method 2 Folder:-	
10	Mondaydeliveries.xlsx	Contains the custom Data Plan in sheet-1 and the final optimized routes along with other information
11	Tuesdaydeliveries.xlsx	Contains the custom Data Plan in sheet-1 and the final optimized routes along with other information
12	Wednesdaydeliveries.xlsx	Contains the custom Data Plan in sheet-1 and the final optimized routes along with other information
13	Thursdaydeliveries.xlsx	Contains the custom Data Plan in sheet-1 and the final optimized routes along with other information
14	Fridaydeliveries.xlsx	Contains the custom Data Plan in sheet-1 and the final optimized routes along with other information
15	Mondaydistance.xlsx	Contains the Custom distance matrix
16	Tuesdaydistance.xlsx	Contains the Custom distance matrix
17	Wednesdaydistance.xlsx	Contains the Custom distance matrix
18	Thursdaydistance.xlsx	Contains the Custom distance matrix

19	Fridaydistance.xlsx	Contains the Custom distance matrix

6. List of Abbreviations

LSVR: Large Scale Vehicle Routing
VRP: Vehicle Routing Problem
NHG: Northeastern Home Goods
MAD: Massachusetts Area Distribution
M1: Method 1
M2: Method 2
GIS: Geographical Information Systems

7. References

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