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Spreadsheet Solution for Small Vehicle Routing Problems for a Small Business

Olufemi Adetunji
University of Pretoria, South Africa
olufemi.adetunji@up.ac.za

Abstract

Route optimization is a problem that most companies face every day, and many small businesses do not have access to sophisticated solutions to their load consolidation and route planning due to the cost of acquiring and maintaining an Enterprise Resource Planning (ERP) system. However, spreadsheets are common desktop applications that are easily accessible to many small businesses and, hence, can be used for small-scale optimization of their Vehicle Routing Problem (VRP). This paper presents a case study of the spreadsheet solution for VRP in a previously disadvantaged South African community. The solution is shown to be capable of helping these small businesses with their load consolidation and route planning, and it performs well for many small problem sizes. The approach shows that many small businesses can make significant savings from route planning by adopting such simple solutions, even when they cannot afford the large capital investment required for deploying the more sophisticated ERP systems.

Keywords
Vehicle Routing Problem, route optimization, cost-effective, heuristics.

1. Introduction
In today's distribution logistics world, companies have a tremendous problem in optimizing routes for efficient and cost-effective product delivery. This problem is especially acute with company X which contends with factors such as customer demands, vehicle capacity utilization, and route selection. Due to Confidentiality purposes, the company will remain anonymous and will be referred to as Company X. Company X is a manufacturer that manufactures three types of plastic-based products: Linear Low-Density Polyethylene (LLDPE), High-Density Polyethylene (HDPE), and Low-Density Polyethylene (LDPE). The company distributes its own products to clients. This is known as the vehicle routing problem in which efficient routes are determined to deliver goods or services to customers while adhering to various limitations and constraints. The company has a poor route planning system as a result incorrect routes are taken leading to high delivery time, and vehicle capacity is not optimally used leading to high cost. The company has 5 delivery vehicles which must be utilized effectively. The company is small and does not have useful applications or capital to buy a solution that can address the problem. Acquiring an ERP system to address the problem is a taxing process for small businesses since ERP systems need huge capital investments for installation and integration. This paper provides a spreadsheet solution for this distribution problem.

Objectives
To address the problem cost-effectively.
To optimally use vehicle capacity.
To optimally determine delivery routes.
To use an effective open-source software package (Excel spreadsheet) that will address the problem.
The software package must be able to take input data and produce reliable solutions
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2. Literature Review
Vehicle Routing Problem (VRP) is a critical operational decision in the distribution network that plays a major role in cost savings and service enhancement by facilitating delivery routing and scheduling (Balaji et al. 2019). VRP is the process of determining the optimal routes for a fleet of vehicles to take to execute a sequence of

delivery or pickup duties (Toth and Vigo 2002). VRP can be represented as a directed weighted graph G (V, E), where $V = \{v_0, v_1, ..., v_n\}$ denotes the collection of nodes (customers) to be visited from the central depot v_0. Also, $E = [\{v_i, v_j\}, (i, j) = 0, 1, 2..., n, i\ j)]$ is the set of arcs connecting two points i, j (Goel and Maini 2017). Dantzig and Ramser (1959) were the first to suggest this problem in the literature. Following that, many alternatives were investigated (Montoya-Torres et al. 2015). Researchers realized the need to alter VRP throughout time to better reflect the complexities of real-world logistics and transportation settings. As a result of this understanding, numerous VRP variants have been developed, each addressing different issues and limits. The first wave of VRP variants concentrated on broadening the basic problem to include additional constraints such as time windows, multiple depots, or vehicle capacity constraints (Kumar and Panneerselvam 2012).

The Capacitated Vehicle Routing Problem (CVRP) entails calculating optimal routes for a fleet of homogeneous (fixed capacity) vehicles that service client demand from a central depot. Pick-up and mail delivery, food distribution, school bus routing, and various other real-world applications are available. The CVRP's major purpose is to reduce the total vehicle distance traveled or the number of vehicles used while serving all client requirements and ensuring that no vehicle exceeds its capacity (Augerat et al.1998). The Vehicle Routing Problem with Time Windows (VRPTW) is a variation of the standard Vehicle Routing Problem (VRP) in which a time window (delivery or pick up) restriction is added. VRPTW's purpose is to determine the most efficient way to distribute goods or provide services to a group of clients while staying within schedule limits (Desrochers et al. 1992). The Multi-Depot Vehicle Routing Problem (MDVRP) is a variant of the regular Vehicle Routing Problem (VRP) in which more than one depot or distribution hub is involved, where a set of clients with a known demand for goods or services, and a fleet of vehicles that start and finish their runs at different depots (Lim and Wang 2005).

The VRP is classified as a nondeterministic polynomial-time hard (NP-hard) problem because there is no obvious algorithmic solution for finding optimal solutions for large-sized problems. The term "NP-hard" refers to a certain sort of computing problem. An NP-hard problem is one in which finding a precise solution is expected to take a lengthy time as the problem size grows. They are common in a variety of disciplines, including optimization, scheduling, and decision-making, and it is widely known that they lack a simple, efficient technique for finding the ideal answer. As a result, for many NP-hard problems, the emphasis is on developing approximation algorithms or heuristics that can provide good, although not always optimal, answers in a reasonable amount of time (Izadkhah 2022).

Three techniques exist to solve VRPs, namely exact methods, heuristics, and metaheuristics. Exact algorithms are a form of computational approach used in optimization and operations research to select the best solution from a set of viable options. Given appropriate computational resources and time, these methods are distinguished by their mathematical rigor and the certainty that the best feasible answer will be found. Exact techniques are very useful when dealing with small to medium-sized combinatorial optimization problems. Exact methods include linear programming and integer linear programming (Laporte 2007).

Some industrial problems are so complicated that typical operational research approaches are ineffective. This arises occasionally because (1) the quantity of bits of information required to define the problem is huge; (2) the problem involves elements that are difficult to measure or involve a conflict of objectives; and (3) proper data collection may be challenging. In such instances, approximate methods that do not guarantee optimality are employed, these methods are called heuristics (Foulds 1983). A metaheuristic is a problem-independent, high-level algorithmic framework that provides a set of recommendations or techniques for developing heuristic optimization algorithms. Metaheuristics are designed primarily to discover a "good enough" solution in a "short enough" processing period (Sörensen and Glover 2013).

3. Model Presentation

Parameters

D_{ij} = distances travel to location i and j from the depot.
$C_k \triangleq$ maximum capacity for each vehicle k where k = {1, 2, …5}
$M_j \triangleq$ number of drivers where each driver j = {1, 2, ...5}
$V \triangleq$ number of vehicles
$N_i \triangleq$ number of deliveries loads i (kgs) that needs to be fulfilled where i = {1, 2, …8}
$L_i \triangleq$ amount of load I, where i = {1, 2, …5}
$T_i \triangleq$ working time period to deliver load, where i = {1, 2, …5}
$A_j \triangleq$ available time for each driver j, where j = {1, 2, ...5}

Binary variables

$X_{ijk} \triangleq \begin{cases} 1 \text{ if delivery load i is assigned to driver j and vehicle k} \\ 0 \text{ Otherwise} \end{cases}$

Objective Function

$$\text{Min } z = \sum_{i=1}^{N} \sum_{j=1}^{M} \sum_{k=1}^{V} D_{ij} * X_{ijk} \qquad (5.1)$$

Subject to:

$$\sum_{j=1}^{M} \sum_{k=1}^{V} X_{ijk} = 1 \qquad \forall\ i \in \{1,2, \dots 8\} \qquad (5.2)$$

$$\sum_{j=1}^{M} \sum_{k=1}^{V} X_{ijk} = 1 \qquad \forall\ j \in \{1,2, \dots 5\} \qquad (5.3)$$

$$\sum_{i=1}^{N} L_i * X_{ijk} \leq C_k \qquad \forall\ k \in \{1,2, \dots 5\} \qquad (5.4)$$

$$\sum_{i=1}^{N} \sum_{j=1}^{M} T_i * X_{ijk} \leq A_j \qquad \forall\ k \in \{1, 2, \dots 5\} \qquad (5.5)$$

$$X_{ijk} \in \{0,1\} \qquad (5.6)$$

(5.1) Is the objective function that minimizes the distance traveled by the fleet (driver and the vehicle) from the depot to the customers and back to the depot. It is important to note that each “i” is associated with specific geographical locations. (5.2) Ensures that each load is assigned to exactly one driver and one vehicle. (5.3) Ensures that each driver can only handle one load at a time. (5.4) Ensures that the total load assigned to each vehicle does not exceed its capacity. (5.5) Ensures that the total time required to complete all deliveries does not exceed the driver’s available time window.

4. Solution Procedure

This section describes the solution approach. The solution proposed uses a metaheuristics approach, Large Neighbourhood Search (LNS) to be exact. LNS is used because it supports diverse exploration of the solution space. This can assist the algorithm in avoiding local optima and finding better solutions. LNS is very adaptable and may be tailored to a wide range of problem variations, limitations, and objective functions. The solution involves 4 main steps; 1. Problem definition where objective(s), parameters, constraints, and variables are clearly defined. 2. Initial solution generation where a solution is generated by heuristics. 3 solution exploration and modification, here local search algorithm is used to search for an optimal solution. 4 Solution acceptance, this step compares the solution found in step 3 with the initial solution if better then it replaces the initial solution with the better solution through an iterative process.

5. Solution Application

One of the primary solution requirements is that the solution should be easily accessible and easy to operate and understand. For this reason, an Excel spreadsheet is provided since Excel is readily available. The spreadsheet solver by Erdoğan can be used to address the problem at hand since it caters to a wide variety of VRP variants due to the algorithm it uses (Erdoğan 2017). This section outlines how the spreadsheet is used and what type of data the spreadsheet requires. To understand and visualize the problem, interviews were conducted with the sales, general, and logistics managers. An Excel sheet was provided that contains sales data for the past 8 months. The following input data was extracted after the whole process. Since the costs per driver and vehicle vary for different delivery trips, average costs were used.

Input data

- Number of customers
- Number of vehicles and drivers
- Cost per driver and vehicle per delivery
- Profit per customer
- Demand per customer
- Capacity of vehicles

After the data collection process, the data is then inserted into the spreadsheet the spreadsheet generates the solution. The spreadsheet is comprised of 6 worksheets where the VRP solver console sheet is the main one which generates the subsequent sheets as depicted in Figure 1 below. Figure 2 below shows the worksheet that follows the VRP solver console sheet where input data is filled out. Details on how the spreadsheet is used can be found in the user manual (Erdoğan 2015).

Sequence	Parameter	Value	Remarks
0.Interface	Language	English	Please refer to the manual for modifying the interface.
	Optional - Bing Maps Key	AtOV8si_rtWxHqjUeIoA3jmtDN5Ak53rGo654czGf77-ZIHd-RaR5ARg3GxGnCph	You can get a free trial key at https://www.bingmapsp
1.Locations	Number of depots	1	[1, 20]
	Number of customers	20	[5, 200]
2.Distances	Distance computation method	Bing Maps driving distances (km)	Recommendation: Use 'postcode, country' format for a
	Duration computation method	Bing Maps driving durations	
	Bing Maps travel mode	Driving	
	Bing Maps route type	Fastest	Recommendation: Use 'Fastest'
	Bing Maps route detail level	10	[0, 10]
	Average vehicle speed	70	
3.Vehicles	Number of vehicle types	2	
4.Solution	Do the vehicles return to their depot(s)?	Yes - only once at the end	
	Time window type	Hard	
	Backhauls?	No	If activated, delivery locations must be visited before p
5.Optional - Visualization	Visualization background	Bing Maps	
	Location labels	Location IDs	

VRP Solver Console | 1.Locations | 2.Distances | 3.Vehicles | 3.1.Vehicle Compatibility | 4.Solution | 5.Visuali ...

Figure 1. VRP Solver Console worksheet

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	163 Lloy	-25,7665190	28,1348035	09:00	17:00	Starting location	0:00	0	0	0
1	Customer 1	62 Jurg A	-25,8690484	28,1636204	09:00	17:00	Must be visited	0:20	0	257	130
2	Customer 2	Raceway	-26,2316833	28,1435690	09:00	17:00	Must be visited	0:20	0	305	130
3	Customer 3	508 Tran	-25,7184791	28,1975774	09:00	17:00	Must be visited	0:20	0	108	130
4	Customer 4	2260 Bol	-25,6773130	28,1807863	09:00	17:00	Must be visited	0:20	0	136	130
5	Customer 5	485 More	-25,7279426	28,2957322	09:00	17:00	Must be visited	0:20	0	218	130
6	Customer 6	709 31st	-25,7065303	28,2376485	09:00	17:00	Must be visited	0:20	0	252	130
7	Customer 7	65 2nd S	-26,2320020	28,0116609	09:00	17:00	Must be visited	0:20	0	118	130
8	Customer 8	66 Jacob	-26,2551512	28,1354639	09:00	17:00	Must be visited	0:20	0	118	130
9	Customer 9	18 Eland	-25,7686659	28,2126948	09:00	17:00	Must be visited	0:20	0	700	130
10	Customer 10	13 Press	-26,1035116	28,1722336	09:00	17:00	Must be visited	0:20	0	605	130
11	Customer 11	420 Moo	-25,7142644	28,1612064	09:00	17:00	Must be visited	0:20	0	622	130
12	Customer 12	4 Berne	-26,1223971	28,2029775	09:00	17:00	Must be visited	0:20	0	516	130
13	Customer 13	467 Nico	-25,7721228	28,2510777	09:00	17:00	Must be visited	0:20	0	260	130
14	Customer 14	Amatole	-25,7500164	28,3615538	09:00	17:00	Must be visited	0:20	0	294	130
15	Customer 15	8 Frates	-25,7133133	28,2233522	09:00	17:00	Must be visited	0:20	0	214	130
16	Customer 16	Nietged	-26,0110167	27,9978706	09:00	17:00	Must be visited	0:20	0	218	130
17	Customer 17	44 Inver	-26,1928598	27,9849489	09:00	17:00	Must be visited	0:20	0	108	130
18	Customer 18	Doornkl	-25,8951759	28,2335472	09:00	17:00	Must be visited	0:20	0	204	130
19	Customer 19	Jet Park,	-26,1589222	28,2226486	09:00	17:00	Must be visited	0:20	0	233	130
20	Customer 20	224 Albe	-26,1543796	28,1787770	09:00	17:00	Must be visited	0:20	0	865	130

VRP Solver Console | 1.Locations | 2.Distances | 3.Vehicles | 3.1.Vehicle Compatibility | 4.Solution | 5.Visuali ...

Figure 2. Location worksheet

6. Results and Discussion

The spreadsheet caters to more than 64 VRP variants because of the metaheuristics algorithm (Adaptive Large Neighbourhood Search) implemented in the spreadsheet (Erdoğan 2017). Figures 3-6 show the results generated for each vehicle.

	A	B	D	E	F	G	H	I	N
1	Total net profit:	2191,98							
2									
3	Vehicle:	V1 (T1)	Stops:	8	Net profit:	727,17			
4	Stop count	Location Name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
5	0	Depot	0,00	0:00		08:00	0:00	0	1965
6	1	Customer 19	57,41	0:40	08:40	09:20	1:20	130	1732
7	2	Customer 20	67,59	0:53	09:33	09:53	1:53	260	867
8	3	Customer 8	84,60	1:10	10:10	10:30	2:30	390	749
9	4	Customer 2	89,34	1:17	10:37	10:57	2:57	520	444
10	5	Customer 7	110,09	1:36	11:16	11:36	3:36	650	326
11	6	Customer 17	117,97	1:52	11:52	12:12	4:12	780	218
12	7	Customer 16	147,07	2:20	12:40	13:00	5:00	910	0
13	8	Depot	182,83	2:57	13:37		5:37	910	0
14	9								
15	10								

Figure 3. Solution for Vehicle 1

The results show the customers each vehicle should visit orderly and the net profit collected from each customer.

Vehicle:	V2 (T2)	Stops:	5	Net profit:	401,98			
Stop count	Location Name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
0	Depot	0,00	0:00		08:00	0:00	0	1582
1	Customer 1	16,67	0:30	08:30	09:20	1:20	130	1325
2	Customer 12	51,34	1:04	09:54	10:14	2:14	260	809
3	Customer 10	57,74	1:14	10:24	10:44	2:44	390	204
4	Customer 18	96,87	1:46	11:16	11:36	3:36	520	0
5	Depot	118,02	2:10	12:00		4:00	520	0
6								
7								

Figure 4. Solution for Vehicle 2

Vehicle:	V3 (T2)	Stops:	6	Net profit:	606,05			
Stop count	Location Name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
0	Depot	0,00	0:00		08:00	0:00	0	1332
1	Customer 3	11,78	0:19	08:19	09:20	1:20	130	1224
2	Customer 6	16,71	0:31	09:32	09:52	1:52	260	972
3	Customer 15	18,61	0:35	09:56	10:16	2:16	390	758
4	Customer 4	27,97	0:51	10:32	10:52	2:52	520	622
5	Customer 11	34,99	1:00	11:01	11:21	3:21	650	0
6	Depot	43,95	1:14	11:35		3:35	650	0
7								
8								

Figure 5. Solution for Vehicle 3

Vehicle:	V4 (T2)	Stops:	5	Net profit:	456,78			
Stop count	Location Name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
0	Depot	0,00	0:00		08:00	0:00	0	1472
1	Customer 14	26,86	0:32	08:32	09:20	1:20	130	1178
2	Customer 5	35,08	0:44	09:32	09:52	1:52	260	960
3	Customer 13	46,57	0:59	10:07	10:27	2:27	390	700
4	Customer 9	52,27	1:09	10:37	10:57	2:57	520	0
5	Depot	63,22	1:24	11:12		3:12	520	0

Figure 6. Solution for Vehicle 4

7. Conclusion

Although there are numerous commercial software packages available to solve VRPs, any program must relate to the company's current software infrastructure and must be trained by the planning managers. Installing such packages can be very expensive for small businesses. Spreadsheet for VRP Solver has been used in the field by numerous companies from various industries and nations. Two US oil firms, an Argentine company in the agriculture industry, a Finnish company in the tourism sector, and two chilled food delivery networks in Taiwan and Turkey have all offered comments, all of which report considerable savings (Erdoğan, 2017).It is evident that the VRP spreadsheet can be a useful tool for small businesses for route optimization and planning.

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