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A CAPACITATED HETEROGENEOUS VEHICLE ROUTING PROBLEM WITH TIME WINDOWS: A CASE STUDY OF SANCHI GWALIOR

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Abstract

The milk delivery systems rely primarily on the routes planned by management to distribute the milk to numerous clients throughout the city within time constraints. This necessitates adequate route and vehicle planning such that the total cost of transportation is kept to a minimum and the organization's resources are efficiently utilized. To develop better routes in such scenarios, the Vehicle Routing Problem (VRP) has remained one of the most researched optimization problems in Operations Research. In this article, Madhya Pradesh State Co-operative Dairy Federation Limited (Sanchi, Gwalior) milk distribution case is examined to lower the cost of milk delivery to its 191 consumers while satisfying the constraints provided. VRP Spreadsheet Solver, a Microsoft Excel-based open-solver, is used for this purpose. Despite the software tool's limitations in data computation and optimization, encouraging results were reached. When compared to the prior routes, the entire distance traveled by milk delivery trucks in the new routes was reduced by 25% or 120 km, while the average capacity utilization of delivery trucks increased by 29%. As a consequence, the results effectively saved 1127.53 Indian Rupees in fuel and resources for a single shift of milk delivery.

Keywords: Vehicle Routing Problem, VRP spreadsheet solver, open-sourced solver, heuristics

INTRODUCTION

A robust supply chain in the current business scenario is the need of any company to stand out from its competitors. The timely delivery of the customer's requirement by keeping the transportation and service costs at the lowest calls for proper planning of all the available resources. The classical vehicle routing problem introduced by Dantzig and Ramser over 60 years ago has been one of the most researched topics in the area of logistics. [(Dantzig, et al.,1959)] VRP aims to minimize the cost of transportation of goods and services while serving different customers through a single or a fleet of vehicles where each vehicle has its own defined routes to be followed emerging from single or multiple depots. The problem is followed by a certain set of constraints such as vehicle capacities, time windows, types of vehicles, working limits of vehicles, and so on. The final optimal solution helps in improving the distribution network of the firm through cost reduction and service enhancement. [(Caccetta, et al.,2013)]

The VRP is considered an integral part of operations research rather than operations management because arriving at the optimal solution with the given constraints requires algorithms that have to be continuously altered to satisfy the problem and the practicality of implementing the solution in real-world cases.[(Erdoğan, 2017)] Many variants of VRP have developed with the combination of these constraints as capacitated vehicle routing problem CVRP where the demand of each customer is already known. Also, the capacity of vehicles in such a problem is fixed and the aim is to find a solution by varying travel time or number of vehicles. [(Pornsing, 2014)]

Another popular variant of VRP is the vehicle routing problem with time windows VRPTW where there is an added constraint of delivery at a specified time for the customer as well as starting and ending back at the depot. Other such variants are the vehicle routing problem with pick-up and delivery VRPPD, open vehicle routing problem OVRP, multi depot vehicle routing problem MDVRP, and vehicle routing problem with backhauls VRPB[(Baldacci et al., 2011)]

In real-world routing problems, distinctions between variants are often blurred, and a combination of constraints from both customers and companies comes into play. The paper's discussed problem involves a complex scenario: a single depot servicing multiple delivery points using a fleet of vehicles with different capacities, all operating within specified time windows. Specifically, it pertains to the milk delivery system employed by the Sanchi milk processing plant located on the outskirts of Gwalior. The challenge is to efficiently deliver milk packets to various city outlets, each with its unique demand, within designated time frames. In such cases, the company strives to determine optimal routes for its delivery vehicles, aiming to maximize vehicle capacities and minimize travel distances to reduce the overall transportation costs. Developing a solution algorithm for real-world problems often demands extensive coding knowledge and familiarity with integrated libraries for continuous data monitoring and adaptation to evolving constraints. While numerous open-source solution algorithms are available online, many are coded in C++, making them less accessible for users without prior coding expertise. One alternative is to utilize existing commercial software packages equipped to handle such scenarios, although their integration into a company's operations can be complex and costly. Training planning managers to use this software further adds to the expenses. To address these challenges, an open-source vehicle routing problem solver based on Microsoft Excel is employed. Developed using Visual Basic for Applications, it offers medium-level programmers an understandable and modifiable code. Leveraging the accessibility and familiarity of Microsoft Excel, this solution caters to medium and small-scale firms commonly using the software for their planning and financial tasks [(Erdoğan, 2017)].

LITERATURE REVIEW

Finding an optimal solution that satisfies the objective of the problem lowers the cost of vehicle transportation which constitutes a main portion of the logistics total cost incurred by the firm. [(Lin et al., 2014)] A key role in logistics and distribution management is played by the vehicle routing problem. After the inception of the first study on the vehicle routing problem by Ramser in 1959, numerous researches and studies have been conducted to solve the various variants of the problem.[(Clarke & Wright, 1964)] [(Christofides et al., 1981)] [(Vidal et al., 2014)][(Sakhala et al., 2017)] This analysis and explorations led to the development of many software that is either commercially available such as Opti Map, Routist or open-sourced such as VRP spreadsheet solver, Open door logistics solver.[(Schwartz et al., 2022)]

The vehicle routing problem is an important combinatorial optimization problem. Often savings ranging from 5% to 20% in the overall transportation costs using the computerized distribution process software and tools were reported by Toth and Vito.[(Maffioli, 2003)] Many such studies that showed substantial cost savings using the solution algorithms for vehicle routing problems were put out by Barker.[(Baker & Ayechew, 2003)] A common classification of methodologies for solving vehicle routing problems includes exact methods, heuristics approaches, meta-heuristic algorithms, and hybrid methods. Over time, the capacitated vehicle routing problem with time windows has become a prominent aspect of the challenges faced by major firms. This variant entails serving a set of customers with specific demands using one or multiple vehicles, each with limited capacities, all within defined time constraints from a single depot. The integration of global positioning systems for real-time traffic management, geographic information systems for precise customer location data, and the computational power of modern processors combined with programming languages has greatly facilitated the development of optimized solutions for such problems. [(Caccetta, et al.,2013)], [(Mittal et al., 2017)] The paper provides a comprehensive overview of various vehicle routing problem (VRP) variants and outlines different methods for solving VRPs. These methods are categorized into three main approaches. The first approach is the exact method, known for its high computational time but delivering the best possible solution. One of the specific techniques within this approach is the Branch and Bound method, which involves exhaustively exploring all potential VRP solutions, discarding non-optimal ones, and establishing upper and lower limits on constraints to ultimately identify the optimal solution..[(Lu et al., 2016)] Another method is to use this along with the cutting plane method to add linear inequalities in the problem known as the Branch and Cut method.[(Lysgaard et al., 2004)] The second approach is the heuristic method, which focuses on finding near-optimal solutions instead of exact ones, resulting in significant computational time savings. This method can be broadly categorized into tour construction and tour improvement heuristics, with further sub-classifications. The last method involves combining these heuristic approaches and their sub-methods to address any shortcomings in the solutions, ultimately yielding solutions that are almost near-optimal. This approach includes techniques like tabu search, genetic algorithms, and simulated annealing methods. [(Toth & Vigo, 2003)]

Clark and Wright's algorithm under the tour construction method of the heuristics approach is used to find the solution to the vehicle routing problem. This involves first the preparation of the distance matrix where the distance between each customer and between each depot and customer is separately computed and tabulated. [(Cordeau et al., n.d.)] A comparative study of the APSRTC that uses a fleet of buses to supply the various bus components from a single depot to its 26 customers is presented using the VRP spreadsheet open-solver and the Clark and Wright heuristic algorithm. The result showed that the VRP spreadsheet solver provides the best optimal solution of the two methods.[(Karthik & Dharma Reddy, 2019)] To solve the Green Vehicle Routing Problem, a Differential Evolution Algorithm Solution based on Clark and Wright's algorithm showed that an optimal solution for minimizing the consumption of oil is reached.[(Alinaghian et al., 2015)] Applying Clark and Wright algorithm in the vehicle routing problem results in savings of upto 30% of the initial transportation costs in a week and also decreases the number of vehicles used in the delivery.[(Baker & Ayechew, 2003)] An extensive study into the Vehicle Routing Problem spreadsheet open-solver to solve the two business case scenarios of tourism and the healthcare sector are presented in paper. The results show that without using high-end computational software requiring skill full employees, a near-optimal solution can be reached using this Microsoft Excel-based software. [(Erdoğan, 2017)]

[(Partyka et al., 2014)] conducted a survey using a questionnaire for the 15 software vendors of vehicle routing problems in the market in recent years. The study shows the various similar and distinct characteristics of each package that a vendor has to offer. A list of the different free and commercial software packages available in the market is provided by Wang in their survey where they tabulate the constraints that each software could handle.[(*THE ROUTLEDGE HANDBOOK OF TRANSPORTATION*, n.d.)] In the case of urban transportation, there is a growing need to solve the vehicle routing problem as presented for the bin collection along with routing the vehicle for solid waste management [(Hemmelmayr et al., 2014)], finding the optimal routes for the multiple points within the city that tourist buses need to visit [(Gavalas et al., 2014)] or for routing the school buses[(Bektaş & Elmastaş, 2007)]. In recent years, concerns have grown for the drastic climate change around the globe and an effort to solve the vehicle routing problem to minimize urban traffic to reduce carbon emissions, noise pollution, and traffic or to find the best of mix fleet of vehicles. Such studies to reduce the CO2 emissions using the Green Vehicle routing problem and to find the optimal size and mix of the electric vehicle fleet is presented in their respective papers. [(Tolga & Bekta¸s, n.d.)] [(Hiermann et al., 2016).

RESEARCH METHODOLOGY

For solving the vehicle routing problem discussed in this paper, the Vehicle Routing Problem spreadsheet open-source solver is used. To understand the problem and the solver, the methodology used is to first completely describe the current vehicle routing problem and then formulate the mathematical model showing the objective function, constraints, and various parameters. The next step is the description of the VRP spreadsheet solver followed by a guide to use the spreadsheet.

1. Description of the problem

In this research work it has a combination of capacitated vehicle routing problem (CVRP) and the vehicle routing problem with time windows (VRPTW). A capacitated vehicle routing problem involves multiple customers with fixed demands and a single fleet of vehicles with fixed capacities. The time windows type VRP consists of a time window with the starting time of the delivery for vehicles in use to the customers and the end time by which the delivery to the last customer in the route of the vehicle has to be finished. Constraints like the working limits of the driver, the travel distance of each vehicle, and the cost of running each vehicle can be customized. The Madhya Pradesh State Co-operative Dairy Federation Limited (MPCDFL) was set up in the year 1960 and today runs in a three-tier system. The first tier consists of nearly 7000 village milk cooperative societies, the second tier consists of 6 milk cooperative unions at Bhopal, Indore, Ujjain, Gwalior, Jabalpur, and Sagar and the third is the State-level Co-operative Dairy Federation known as MPCDF. [(MPCDF, Sanchi dairy, 2021)] The current problem discusses the milk processing plant situated at Banmore, Morena which is situated 26 km away from the Gwalior city. The processing plant currently serves 191 exclusive milk outlets and shops in the main Gwalior city. The demand for milk packets at each of these shops is known to the depot. A fleet of 6 vehicles of 1.5-ton, 2.5-ton, and 3-ton capacities are currently used to serve the customers. Each vehicle starts from the plant at 3:00 a.m. daily in the morning and has to finish the delivery to the last customer in their route by 6:15 a.m. on the same day. Only one among the 6 vehicles at present carries 80% of its capacities. Rest all have capacity utilization ranging between 40% to 60% of their capacities. This shows that there is a serious issue of underutilization of the vehicle capacity resulting in losses to the firm. Also, the distances travelled by each vehicle are very random ranging from a minimum of 40 kms to 90 kms showing that the routes are not well planned either.

2. Mathematical formulation of the problem

The problem statement of the vehicle routing problem discussed can be expressed in the following terms as given under.

Sets and Parameters:
Let C represent the set of customers, where C = {1, 2, ..., 191}.
Let V represent the set of vehicles, where V = {1, 2, ..., 6}.
Let d_i be the demand of customer i, ∀ i ∈ C.
Let Q_v be the capacity of vehicle v, ∀v ∈ V.
Let $c_{i,j}$ be the cost (distance or time) to travel from customer i to customer j, ∀i, j ∈C.
Let a_i be the earliest time a vehicle can start servicing customer i, ∀i ∈ C.
Let b_i be the latest time a vehicle can start servicing customer i, ∀i ∈ C.
Let D be the driving distance limit for each vehicle (576 km).
Let W be the working time limit for each vehicle (8 hours).
Decision Variables:
Let $x_{i,j,v}$ be a binary decision variable indicating whether customer i is visited by vehicle v in position j, ∀i ∈ C, j ∈ {1, 2, ..., |C|}, and v ∈ V.
Let $y_{i,j}$ be a binary decision variable indicating whether customer i is visited immediately before customer j in any vehicle's route, ∀i, j ∈ C.
Let s_v be the start time of the vehicle v's route.
Let f_v be the end time of the vehicle v's route.

the minimize $Z = \sum_{i=1}^{191} \sum_{j=1}^{191} \sum_{v=1}^{6} c_{ij}\, x_{ijv}$ (1)

subject to -

$\sum_{j=1}^{191} x_{ijv} = 1,\ \forall i \in C$ (2)

$\sum_{v=1}^{6} y_v = 1$ (3)

$\sum_{v=1}^{6} x_{ijv} = 1,\ \forall i \in C,\ \forall j \in \{1, 2, ..., |C|\}$ (4)

$\sum_{j=1}^{191} x_{depot,j,v} = 1,\ \forall v \in V$ (5)

$\sum_{j=1}^{191} x_{j,depot,v} = 1,\ \forall v \in V$ (6)

$\sum_{i=1}^{191} d_i\, x_{ijv} \geq 0.8\, Q_v,\ \forall v \in V$ (7)

$\sum_{i=1}^{191} d_i\, x_{ijv} \leq Q_v,\ \forall v \in V$ (8)

$\sum_{j=1}^{191} x_{depot,j,v}\ a_j = 1,\ \forall v \in V$ (9)

$\sum_{j=1}^{191} x_{j,depot,v}\ b_j = 1,\ \forall v \in V$ (10)

$\sum_{j=1}^{191} x_{ijv} = \sum_{k=1}^{191} x_{kiv},\ \forall i \in C,\ v \in V$ (11)

$x_{i,j,v} \in \{0, 1\},\ \forall i, \in C,\ j \in \{1, 2, ..., |C|\},\ v \in V$ (12)

$y_v \in \{0, 1\},\ \forall v \in V$ (13)

For each subset of customers S ⊆ C, where |S| ≥ 2;

$\sum_{i \in S, j \in S, i \neq j} x_{ijv} \leq |S| - 1,\ \forall v \in V$ (14)

$\sum_{i=1}^{191} \sum_{j=1}^{191} c_{ij}\, x_{ijv} \leq D,\ \forall v \in V$ (15)

$\sum_{i=1}^{191} \sum_{j=1}^{191} c_{ij}\, x_{ijv}$ / Vehicle speed $\leq T,\ \forall v \in V$ (16)

$\sum_{v=1}^{6} \sum_{j=1}^{191} x_{ijv}\ d_j = d_i,\ \forall i \in C$ (17)

In this mathematical formulation, the objective function stated in equation (1) states that problem aims to minimize the total cost of transportation for milk delivery system in use currently. Equation (2) states that each customer is visited exactly once while equation (3) states that each 6 vehicles can be used at most once. Equation (4) constraints the customer to be visited only by a single vehicle of the 6 available for use and equation (5) and (6) states that all of the 6 vehicles start their journey for milk distribution at the depot and end back at the depot. Equation (7) states the minimum level of vehicle utilization for the total vehicle capacity that it must begin with at the start of its journey from the depot. Equation (8) ensures that no vehicle is overloaded above its maximum capacity. The equation (9) and equation (10) correspond to the start time of the vehicle from the depot and the latest time by which the last customer in each route has to be served respectively. Equation (11) provides the flow conservation constraint and equation (12) and equation (13) are the non-negativity constraints. Constraint (14) eliminates any possibility of a sub-tour in the routes chosen by the vehicles. The final set of constraints in the equation (15), equation (16), and equation (17) limit the maximum driving distance of each vehicle, working time in a day and the demand of each customer is satisfied at the end of the solution respectively.

3. The VRP Spreadsheet Open-Solver

The Vehicle Routing Problem Spreadsheet Open-Solver used in this study was developed by Dr. Gunes Erdgan from the University of Bath in response to challenges faced by small and medium-scale firms lacking resources for problem-solving. It was created using Visual Basic for Applications (VBA), a widely understood programming language embedded in MS Excel. This solver can handle up to 200 customers or locations served by single or multiple depots. To pinpoint these locations, geographic information systems (GIS) were utilized, with Bing Maps being the chosen tool due to its free availability. The solver employs an incremental data entry process, creating new data sheets based on previous inputs. Users interact primarily with the VRP Solver Console worksheet, while other sheets (Locations, Distances, Vehicles, Solution, and Visualisation) are sequentially generated with relevant data. The spreadsheet's structure is hard-coded with VBA, so altering default worksheet names or modifying rows and columns is discouraged. Color coding is used throughout the spreadsheet to indicate specific cell functions, ensuring ease of use and data integrity [(University of Bath, 2013)].

3.1 VRP Solver Console: This central worksheet within the spreadsheet is integral, and it's essential to retain all cell values. It encompasses various parameters in a defined sequence. Firstly, the Bing Maps Key, acquired after signing up on the Microsoft Maps website, facilitates tasks such as populating latitudes, longitudes, distance calculations, and route visualization. The sheet considers the number of depots and customers, serving as starting points and destinations, respectively. Users can specify distance/duration computation methods, including options like manual entry, Euclidean distances, Hamming distances, and more. Notably, Bing Maps driving distances in kilometres are suitable for vehicles. Route types, such as Slowest, Fastest, and Fastest with Real-time traffic, can be selected. Average vehicle speed limits can also be set. The Number of vehicles parameter defines vehicle types, considering cost, capacity, and other factors. Options like vehicle return to depot, backhauls, and time window types are available. Users can customize visualizations based on latitude and longitude, with various location labels and CPU computation speed choices.

3.2 Locations: After configuring the parameters in the previous step, the next task involves setting up the location spreadsheet. In this spreadsheet, the first column automatically generates Location IDs. The subsequent column reflects the total number of depots and customers previously entered. To ensure accuracy, users must input customer addresses. For precise map visualization, the latitude and longitude columns should be populated with relevant data. Users can also specify the start and end times for customer deliveries in respective columns. Additionally, choices can be made regarding whether to visit a particular customer, along with options to define service time periods and input pick-up/delivery quantities, if available. Importantly, users have the flexibility to fill in only the columns relevant to their specific needs.

3.3 Distances: In this spreadsheet, parameters like "From" and "To" label the computed distances between different locations. When the user selects the "populate distance" option, it takes approximately 5 minutes to populate distances for 50 locations and about 45 minutes for 150 locations. The time required for this distance computation depends on the option chosen in the console sheet. If options other than Bing Maps are selected, the distances won't be in kilometres. Opting for the shortest path may lead vehicles through city centres, increasing travel time. The "Fastest" and "Fastest with real-time traffic" options, however, ensure the quickest deliveries.

3.4 Vehicles: Within this spreadsheet, users have the flexibility to adjust or maintain various parameters according to their preferences. The number of rows corresponds to the number of vehicles specified in the console sheet. Input columns include automatically generated Vehicle Type IDs, vehicle names for differentiation, and the capacity of each vehicle type. Users can set cost-related parameters such as the Fixed cost per trip and the Cost per unit distance traveled by each vehicle. Individual start times for vehicles can be configured, along with distance limits for each vehicle. Additional options encompass working limits, endpoints, and the quantity of vehicles for each vehicle type. This sheet holds significant importance, as the values entered here directly impact the cost and various constraints within the problem.

3.5 Solution: In this spreadsheet, you can visualize the route for each vehicle. Each vehicle has its own set of rows and columns outlining its specific route. Key parameters include the "Stop count," which indicates the number of stops the vehicle makes, including the return to the depot if applicable, and "Location names" which display the names of the visited locations. "Distance traveled" shows the total distance covered by the vehicle, while "Driving time" reflects the cumulative driving duration. "Arrival time" and "Departure time" detail the time of arrival and departure at each stop. Additionally, you can see "Working time," "Profit collected," and "Load," representing the total load (including pickups and deliveries) onboard at departure. These rows and columns are generated automatically when setting up the solution worksheet, and you can engage the VRP solver to find the optimal solution. The computation time for the final solution depends on the CPU limit set in the main console; a higher CPU limit leads to a more optimal solution.

3.6 Visualization: After the solution to the problem is generated, the user has the option to visualize the solution on a map. This spreadsheet when set up shows the locations of the depot and all the customers input by the user using the latitudes and longitudes from the GIS. The routes travelled by each vehicle through locations are highlighted separately using colours. Like any other chart, this map can also be formatted for various features using the available tools.

DATA COLLECTION AND ANALYSIS

To engage the VRP solver spreadsheet and get the optimal solution for the given problem, it is needed to populate the spreadsheet with the relevant information. A sequential process is described below indicating the different values that were input in the sheet. In the VRP Console Sheet, the free Bing Map Key was generated after signing in with Microsoft Account details. The number of depots in the given problem is 1 and there are 191 customers. Bing Maps driving distances in kms were chosen for the distance computation as the result was required in real kms and the Fastest mode was chosen for the Route type. Two types of vehicles were selected and the vehicles had to return to the depot after delivery. No backhauls were allowed and a Hard type Time Window was selected from the available options. In the end, Bing Maps were used for Visualisation and the CPU limit of 4200 seconds was set for the problem. In the Location sheet, all the latitudes and longitudes for 191 customers had to be input along with the location of the depot. Sanchi Gwalior was contacted for collection of all this information and the same was obtained. The officials at the dairy also provided information regarding the start time of the delivery from the depot at 3:00 AM and the last delivery at each customer by 6:15 AM on the same day after which the vehicles on each route would collect the distribution crate and return to the depot. Following this, the demand of each customer was recorded in the relevant column from the data available by the management. Though exact demand at each customer varies every day but remains the same on an average computed monthly. The Distances sheet is then populated to calculate the distance from one customer to another. Once done the next step is to input the data for the Vehicles. Of the two vehicles selected, the capacity of one was 1500 liters and the other 2500 litres. As the vehicles were hired through a third party, there is no fixed cost. The cost per unit distance for the vehicles is 15.22 Indian rupees 17.05 Indian rupees with a working and driving time limit of 8 hrs a day and a start time of 3:00 AM. In the number of vehicles column, 1 type one vehicle of 1500 tons was selected and 5 type 2 vehicles of 2500 tons were selected with the driving distance limit of 565 kms a day. Subsequently, the solution spreadsheet was generated and the VRP solver was engaged to generate the optimal results. Once the results were generated, a visualization sheet was also generated to visualize the routes each vehicle had travelled.

SOLUTION AND RESULTS

The solution to the problem is shown in the following screenshots of the VRP Spreadsheet solver.

Fig 1: VRP Solver Console and the input parameters of the problem

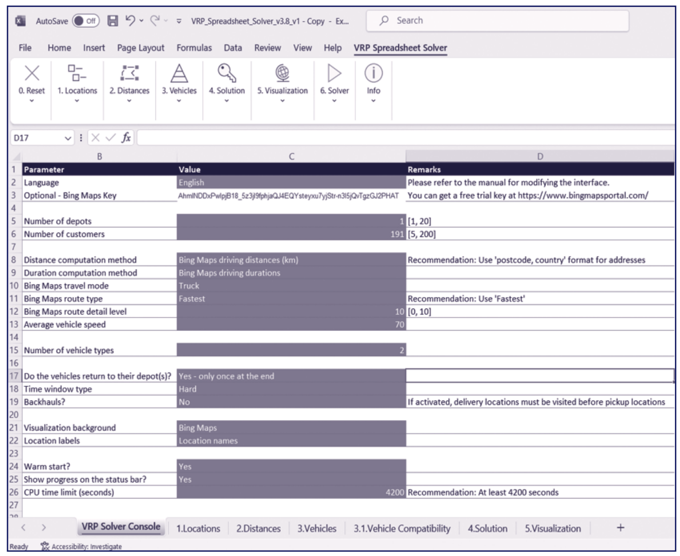


Fig 2: Location spreadsheet with 191 customers

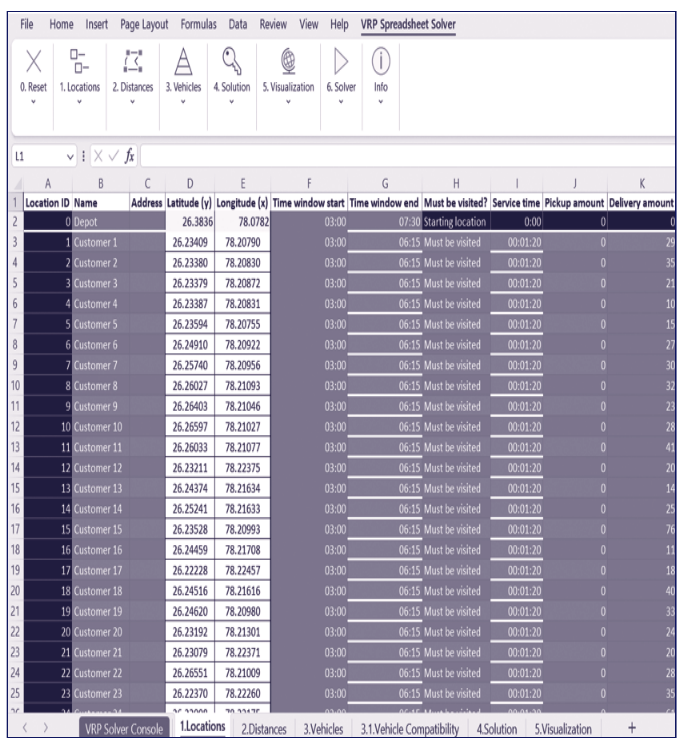
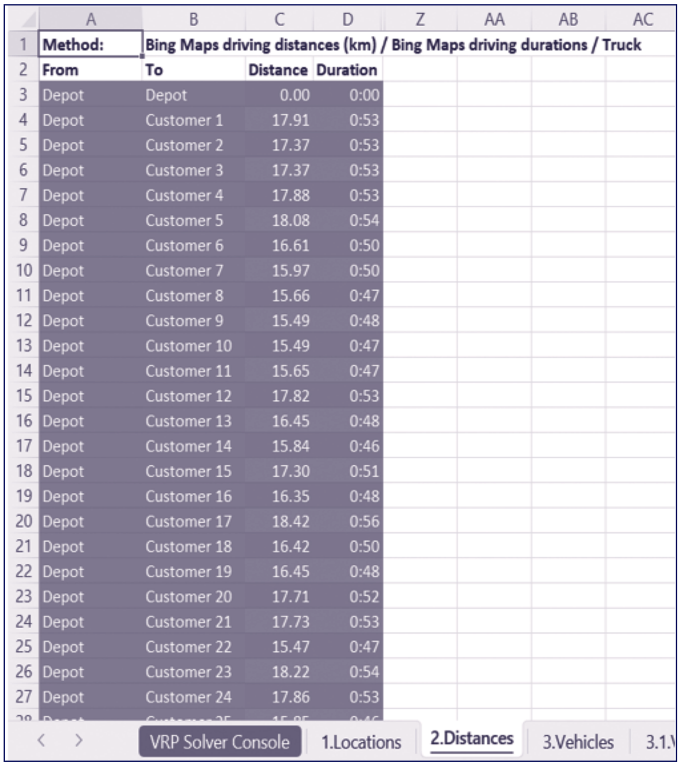


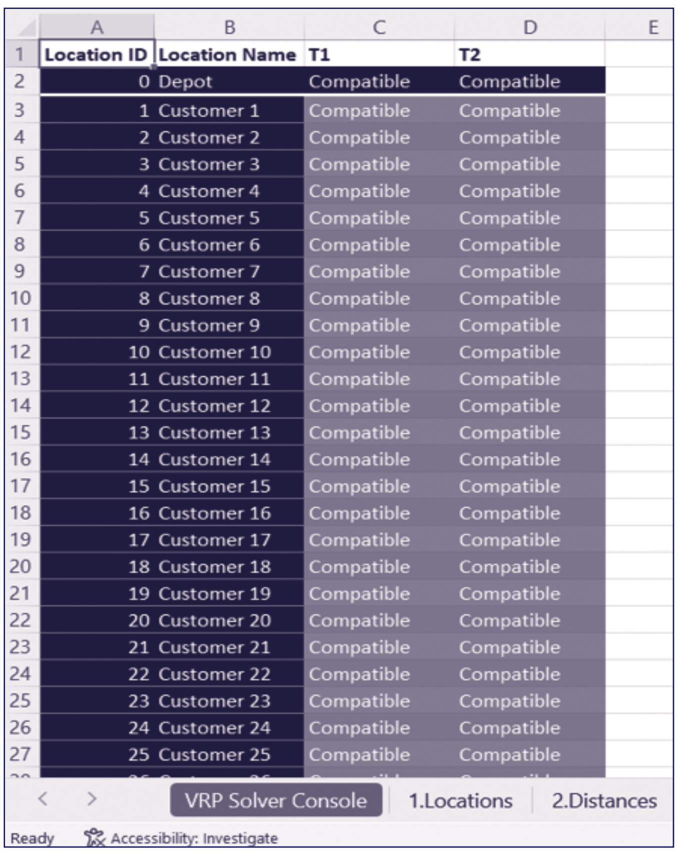
Fig 3: Distances spreadsheet



From	To	Distance	Duration
Depot	Depot	0.00	0:00
Depot	Customer 1	17.91	0:53
Depot	Customer 2	17.37	0:53
Depot	Customer 3	17.37	0:53
Depot	Customer 4	17.88	0:53
Depot	Customer 5	18.08	0:54
Depot	Customer 6	16.61	0:50
Depot	Customer 7	15.97	0:50
Depot	Customer 8	15.66	0:47
Depot	Customer 9	15.49	0:48
Depot	Customer 10	15.49	0:47
Depot	Customer 11	15.65	0:47
Depot	Customer 12	17.82	0:53
Depot	Customer 13	16.45	0:48
Depot	Customer 14	15.84	0:46
Depot	Customer 15	17.30	0:51
Depot	Customer 16	16.35	0:48
Depot	Customer 17	18.42	0:56
Depot	Customer 18	16.42	0:50
Depot	Customer 19	16.45	0:48
Depot	Customer 20	17.71	0:52
Depot	Customer 21	17.73	0:53
Depot	Customer 22	15.47	0:47
Depot	Customer 23	18.22	0:54
Depot	Customer 24	17.86	0:53

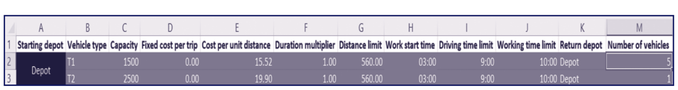
Method: Bing Maps driving distances (km) / Bing Maps driving durations / Truck

Fig 4: Vehicles compatibility spreadsheet



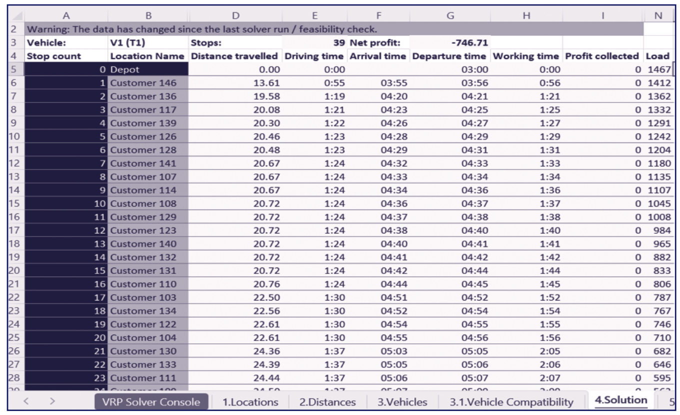
Location ID	Location Name	T1	T2
0	Depot	Compatible	Compatible
1	Customer 1	Compatible	Compatible
2	Customer 2	Compatible	Compatible
3	Customer 3	Compatible	Compatible
4	Customer 4	Compatible	Compatible
5	Customer 5	Compatible	Compatible
6	Customer 6	Compatible	Compatible
7	Customer 7	Compatible	Compatible
8	Customer 8	Compatible	Compatible
9	Customer 9	Compatible	Compatible
10	Customer 10	Compatible	Compatible
11	Customer 11	Compatible	Compatible
12	Customer 12	Compatible	Compatible
13	Customer 13	Compatible	Compatible
14	Customer 14	Compatible	Compatible
15	Customer 15	Compatible	Compatible
16	Customer 16	Compatible	Compatible
17	Customer 17	Compatible	Compatible
18	Customer 18	Compatible	Compatible
19	Customer 19	Compatible	Compatible
20	Customer 20	Compatible	Compatible
21	Customer 21	Compatible	Compatible
22	Customer 22	Compatible	Compatible
23	Customer 23	Compatible	Compatible
24	Customer 24	Compatible	Compatible
25	Customer 25	Compatible	Compatible

Fig 5: Vehicles spreadsheet



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	1500	0.00	15.52	1.00	560.00	03:00	9:00	10:00	Depot	5
	T2	2500	0.00	19.90	1.00	560.00	03:00	9:00	10:00	Depot	1

Fig 6: Solution spreadsheet with the computed optimal solution

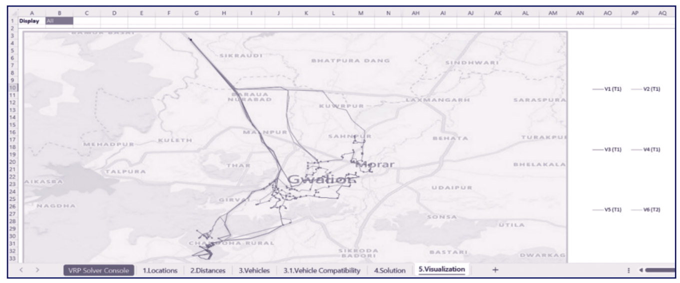


Warning: The data has changed since the last solver run / feasibility check.

Vehicle: V1 (T1) Stops: 39 Net profit: -746.71

Stop count	Location Name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load
0	Depot	0.00	0:00		03:00	0:00	0	1467
1	Customer 146	13.61	0:55	03:55	03:56	0:56	0	1412
2	Customer 136	19.58	1:19	04:20	04:21	1:21	0	1362
3	Customer 117	20.08	1:21	04:23	04:25	1:25	0	1332
4	Customer 139	20.30	1:22	04:26	04:27	1:27	0	1291
5	Customer 126	20.46	1:23	04:28	04:29	1:29	0	1242
6	Customer 128	20.48	1:23	04:29	04:31	1:31	0	1204
7	Customer 141	20.67	1:24	04:32	04:33	1:33	0	1180
8	Customer 107	20.67	1:24	04:33	04:34	1:34	0	1135
9	Customer 114	20.67	1:24	04:34	04:36	1:36	0	1107
10	Customer 108	20.72	1:24	04:36	04:37	1:37	0	1045
11	Customer 129	20.72	1:24	04:37	04:38	1:38	0	1008
12	Customer 123	20.72	1:24	04:38	04:40	1:40	0	984
13	Customer 140	20.72	1:24	04:40	04:41	1:41	0	965
14	Customer 132	20.72	1:24	04:41	04:42	1:42	0	882
15	Customer 131	20.72	1:24	04:42	04:44	1:44	0	833
16	Customer 110	20.76	1:24	04:44	04:45	1:45	0	806
17	Customer 103	22.50	1:30	04:51	04:52	1:52	0	787
18	Customer 134	22.56	1:30	04:52	04:54	1:54	0	767
19	Customer 122	22.61	1:30	04:54	04:55	1:55	0	746
20	Customer 104	22.61	1:30	04:55	04:56	1:56	0	710
21	Customer 130	24.36	1:37	05:03	05:05	2:05	0	682
22	Customer 133	24.39	1:37	05:05	05:06	2:06	0	646
23	Customer 111	24.44	1:37	05:06	05:07	2:07	0	595

Fig 7: Visualization spreadsheet with the 191 customers, depot, and the routes of 6 vehicles



The results obtained from the VRP Spreadsheet Solver are shown above. A comparison of these results with the previous data available from the management of Sanchi Gwalior is tabulated to calculate the increment in performance levels achieved.

Table 1: The existing scenario at Sanchi Gwalior

Routes	Distance travelled (in km.)	Total demand (in lts.)	Vehicle capacity (in lts.)	Vehicle cost per liter	Total vehicle cost	Load factor
1	80	1010	1500	1.23	1242.3	67%
2	75	1300	2500	1.05	1365	52%
3	90	2250	2500	1.45	3262.5	90%
4	80	1600	2500	1.08	1728	64%
5	85	1600	2500	1.45	2320	64%
6	72	1550	3000	1.88	2914	51%
Total	472	9310	14500		12831.8	64% (avg)

Table 2: Proposed scenario from the VRP spreadsheet solver

Routes	Distance travelled (in km.)	Total demand (in lts.)	Vehicle capacity (in lts.)	Vehicle cost per liter	Total vehicle cost	Load factor
1	67.86	1476	1500	1.23	1804.41	97%
2	45.08	1273	1500	1.23	1273	84%
3	56.66	1432	1500	1.23	1761.3	95%
4	56.86	1208	1500	1.23	1485.84	80%
5	65.32	1449	1500	1.23	1782.27	96%
6	59.72	2481	2500	1.45	3597.45	99%
Total	351.4	9310	10000		11704.27	93% (avg)

The above tabulated data shows that the vehicles in total travelled a distance of 472 kms in one shift for supplying milk packets while in the proposed model they travel only 351 kms. This is a significant 25% decrease in the distance travelled by vehicles. Also, the other aim that was to increase the vehicle capacity utilization in each route has been able to achieved and the average is increased from 64% to 93% with the least utilization at 80% of the vehicle capacity. Calculating all these values in terms of cost saving in transportation, it turns out at 1127.53 Indian Rupees for a single shift of milk delivery. The same figure when extrapolated for the yearly savings approximates for 8,11,440 Indian Rupees. Though this is achieved by changing the vehicle capacities for which new vehicles will have to be enquired from the third party and by finding new routes that will have to be discussed with the truck drivers, when viewed from management's side is worth an effort.

FUTURE SCOPE

While the results of the study show a significant increase in vehicle capacity utilization and a decrease in total distance travelled by vehicles which altogether decreases the total cost of transportation, the literature provides information that still efforts can be made to further lower the costs. Also, other limiting factors like time restriction of the project work, inadequate knowledge of high-level programming languages, and resource unavailability have restricted this project work to using open-sourced software with the limited computational capacity to find near to best optimal solution. Attempts can be made in the future to collect the data of this project and solve it using Data Science, Python, and Machine Learning. Data science will help in interpreting the data and converting it into a form that can be coded for objective functions and constraints in Python language. Machine Learning can be used to train the model and find new routes that the vehicle needs to travel. The new results will include solutions with lower total travel distances and no overlapping of routes between vehicles. Another finding would be that the vehicles of the required capacities would be chosen on their own rather than simply defining them as in the case of VRP Spreadsheet Solver.

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