

Applications of the Vehicle Routing Problem to Personnel Transport in Morocco

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Abstract

This project has been undertaken to define the Vehicle Routing Problem (VRP) and its applications to real transportation optimization. In this paper, the first part is dedicated to stating the Vehicle Routing Problem through a literature review. Then, the definition of the mathematical model used to evaluate Vehicle Routing Problems is provided. Different algorithms and software used to solve the Vehicle Routing Problem will be discovered through this project as well. At the end, the results obtained are interpreted from the optimization of a real case study of the Moroccan Company, VIR.

Keywords

Vehicle Routing Problem, transportation optimization, real life case study

1. Introduction

Mostly, supply chain operations chain back to customer satisfaction in terms of the quality of the service delivered (response time, product availability, price and quality...). Therefore the customer is perceived as a vital partner in the decision making process, making the company in a pressing and continuous need to optimize their operations and be able to pass on part of their profits to their customers for ultimately promoting a high level of customer satisfaction. Supply chain operations vary from sourcing, production, inventory and transport or distribution processes. Each of these involves expenses as time and costs that need to be optimized in order to ensure efficient and faster responses to customers that lead to an improved and a high level of quality service. In fact, the transport costs count for a high percentage of any company's total expenses. Transportation cost represents different expenses a company incurs to move its products, personnel, inventory from one location to another. That is why huge resources and funds have been allocated to optimize transportation costs (Caplice 2006, Applegate 2011). In this context comes the Vehicle Routing Problem, which is one of the main issues in the field of distribution management. The Vehicle Routing Problem deals with finding an optimal set of routes for one or more vehicles under a predefined set of constraints (Hansen 1992). Numerous old (Hansen 1992) and even recent attempts (Erdogan 2017, Gayev 2017, Yao 2017) were conducted by researchers to solve the Vehicle Routing Problem and minimize transportation costs for companies using advanced algorithms like the improved artificial bee colony algorithm proposed by Yao et al. in 2017, showing that this is a subject that matters much for companies.

In the first part, a literature review will be presented to define the Vehicle Routing Problem and realize where scholars have arrived trying to solve this problem. The Mathematical model, which is a linear programming one, will be defined as well to better understand the problem in terms of the objective function to minimize and different constraints to respect. The second part will be dealing with different algorithms to solve this optimization problem. There exists a variety of approaches to deal with the VRP. Therefore, I will be solving manually two algorithms which are most used to deal with optimization problems. At the end, the analysis of VIR Company will be presented incorporated with the results I was able to get. Recommendations, suggestions and future work will be the subject of the last part of this project.

2. Vehicle Routing Problem Setting

The Vehicle Routing Problem is one of the oldest problems in logistics management. This problem ranges in difficulty from being very simple to extremely difficult to solve depending on the size and constraints of each case. The basic situation is given by the existence of a certain starting point from which vehicles are supposed to visit $(n-1)$ other places so that every place is visited just once and each vehicle finishes its route back again at the starting point whereas the objective value (e.g. cost/distance function) is being minimized. The Vehicle Routing Problem belongs to the group of NP-difficulty problems with a time complexity of $O(n!)$ according to Kovarik (2008). These problems were first discovered by Euler in his attempts to know how a jumper on the chessboard would be able to visit 64 fields only once according to Guerraet al. (2007).

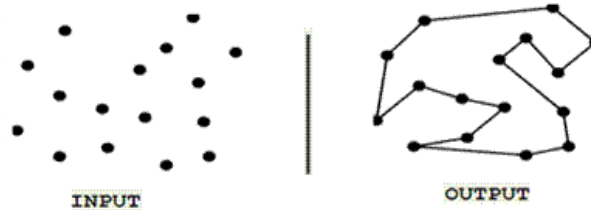


Figure 1: Vehicle Routing Problem Mechanism

After that, two mathematicians, Hamilton and Kirkman continued working on this problem which came down to be an exception of the Vehicle Routing Problem known as the existing Travelling Salesman Problem. The general form of this problem appeared in the 30's of the last century, and the term Salesman was used the first time in the early 30's. Applications of the Vehicle Routing Problem into logistics optimization are numerous Guerraet al. (2007).

They range from the distribution of products, the management of public transportation networks into the collect of personnel. In any distribution field, the efficiency should be based on the quality of transport construction and the optimal set of routes. That is why there is a huge need for the optimization of routes planning. Strategic planning of routes can be achieved by solving the Vehicle Routing Problem for a single or multiple vehicles moving from one location to another with the same departure and arrival locations. Therefore, a general formulation of the Travelling Salesman Problem, being the easiest case of the Vehicle Routing Problem, can be defined by the necessity of choosing a pathway optimal for one vehicle with respect to a given criterion such as distance, time, cost Caplice (2006). In any Vehicle Routing Problem, there exist numerous components by which we can define in which type of the Vehicle Routing Problem each case falls. However, the existence of these components is not vital to all cases. I am going to describe each component separately:

- **Starting Location:** The starting point of the problem can be fixed as a constraint, or it can be defined while generating the optimal solution. However, there may be one multiple starting points in one problem.
- **Locations:** as the objective of solving the VRP is to meet demands of locations. The existence of one or multiple locations is crucial.
- **Routes:** they are pathways that each vehicle is supposed to follow to meet demands of different locations. Routes are generally labeled by their distance or cost. The time needed to traverse each route may be also included in the description of routes.
- **Vehicles:** They are the mean of transportation between different locations. The number of vehicles depends on the demand of each problem. Generally parameters that characterize vehicles in each problem are the number of vehicles, cost and distance of travelling, capacity of each vehicle and the total maximum driving time.
- **Arrival:** It is the final point of the set of locations to visit. It may be the same as the starting point to close the circuit, e.g. the case of the Travelling Salesman Problem.

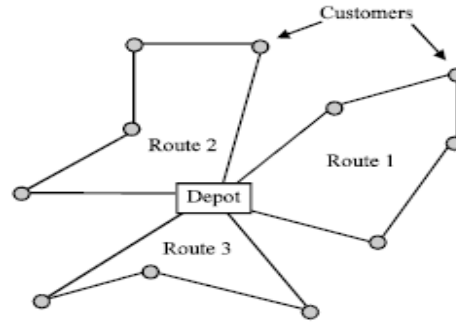


Figure 2: Vehicle Routing Problem Components

2.1. General Formulation of the Vehicle Routing Problem:

The Vehicle Routing Problem can be formulated using the graph theory. Let us suppose a graph $U = (N, S)$ such that N is the total number of vertices in the graph and S is the group of edges relating each two vertices. Weights of each edge are related to the main function to minimize such as the cost or distance function. Consequently, a matrix, directly related to the objective function, is generated from this graph. The graph can be symmetric if the direction of each edge is not specified. It may also be asymmetric where each edge is directed and have a weight e . The solution of the Vehicle Routing Problem depends on a number of constraints to be respected. These constraints define in which type of the Vehicle Routing Problem falls the problem exactly. There exist constraints related to the capacity of each vehicle. Other constraints may be related to the total time of the trip or to the time interval to pass in every station (Hansen 1992, Lahyani 2016).

The figure below presents the more general model used in the Vehicle Routing Problem (Kahligh 2016). While the variable x_{ij} represents the selection of the arc moving from station i to station j , and c_{ij} is the occurring cost to travel the distance ij .

$$\begin{aligned}
 &\text{minimize} && \sum_{i \neq j} c'_{ij} x_{ij} \\
 &\text{subject to} && \sum_{j=1}^{n'} x_{ij} = 1 \quad (i = 1, \dots, n') \\
 &&& \sum_{i=1}^{n'} x_{ij} = 1 \quad (j = 1, \dots, n'), \\
 &&& \sum_{i,j \in S} x_{ij} \leq |S| - v(S) \quad (S \subset V' \setminus \{1\}; |S| \geq 2), \\
 &&& x_{ij} \in \{0, 1\} \quad (i, j = 1, \dots, n'; i \neq j).
 \end{aligned}$$

Figure 3: The General Model of the Vehicle Routing Problem

2.2. Types of the VRP:

Based on the constraints used in every problem, the Vehicle Routing Problem can be separated to different types. The most used case is known as the classical VRP. It is the case where constraints involved are related to the depot being the starting and ending point and to the necessity to visit each station exactly one during the circuit (Erdogan 2017).

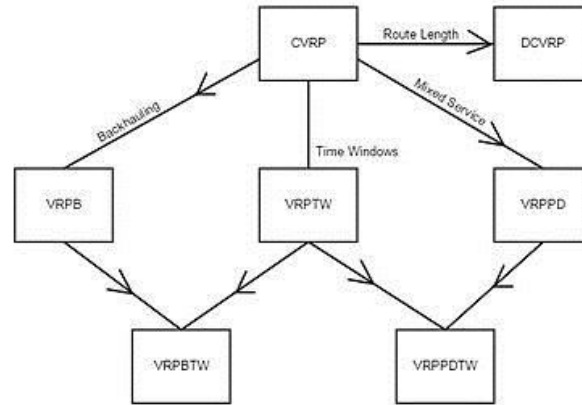


Figure 4: Types of the Vehicle Routing Problem

2.3. Solving the Travelling Salesman Problem

For simplicity, I will be dealing, in the remaining part of this literature review, with the Travelling Salesman Problem since it is the case when one vehicle is involved in the optimization. The transportation cost within any company constitutes up to 30% from its general expenses. That is why, there is a huge need to develop ways by which businesses can optimize routes to reduce costs and minimize risks. One of these ways is by solving the Vehicle Routing Problem. Literature provides numerous ways to solve this optimization problem. From some author's point of view, the Travelling Salesman Problem falls within direct applications of the theory of graphs and networks. Algorithms such as the efficient algorithm of Clarke and Wright, branches and bounds algorithm or the ant colony optimization algorithm can be used also to solve the Travelling Salesman Problem (Gath, 2016).

2.4. Formulating the Travelling Salesman Problem

Theoretical Definition:

The classical approach of defining the Travelling Salesman Problem asserts that for a specific number of locations n , one vehicle is supposed to deliver products starting from one depot D such that the vehicle visits each location exactly once and the departure and arrival locations should be the same. The objective of this whole operation is to deliver goods to various in different locations using the optimal set of routes. This will enable to minimize the objective function which can be cost, distance, time window or even the number of vehicles (Vikimoc, 2006).

Mathematical Definition:

$$\min \sum_{j \in S} \sum_{i \in S} c_{i,j} \cdot x_{i,j} \quad (2.2)$$

subject to

$$x_{i,j} = \{0,1\} \text{ for all } i, j \in S \quad (2.3)$$

$$\sum_{i \in S} x_{i,j} = 1 \text{ for all } j \in S \quad (2.4)$$

$$\sum_{j \in S} x_{i,j} = 1 \text{ for all } i \in S \quad (2.5)$$

$$\sum_{j \in S} \sum_{i \in S} x_{i,j} \leq |Y| - 1 \text{ for all } Y \subseteq S. \quad (2.6)$$

Figure 5: The Mathematical Model of the Traveling Salesman Problem

The objective function of this mathematical definition deals with minimizing the overall cost. The following two equations ensure that every customer is visited only once during the tour. The last equation is a sub tour elimination constraint guaranteeing that all locations are visited during single closed tour vehicles (Vikimoc 2006).

Methods to solve the Travelling Salesman Problem:

There exists a variety of algorithms to solve the Travelling Salesman Problem. These algorithms differ from exact methods into approximate algorithms. Let us cite the most used algorithms to solve this optimization problem:

Method of total Enumeration: This method consists of evaluating all possible routes to be able to identify the optimal one. The total number of sequences possible is $(n-1)!$. The advantage of this method is that it can always find the optimum route. However, if the number of locations increases significantly, the number of solutions grows exponentially (Guerra 2007).

Method of Branches and Bounds: This algorithm is one of the oldest and most used ones to solve the Travelling Salesman Problem. The method consists of decomposing possible sets into subsets as branches. This method will be explained in details in the analysis part of this work (Caplice2013).

Algorithm of Clarke and Wright: This method assumes that after each visit to a location a return to the departure point is a must. Then, the basic idea behind this method is the calculation of the optimal set of routes by integrating each time the depot in the circular route (Gath 2016).

Ant Colony Optimization Algorithm: it is one of the essential metaheuristics algorithms. The idea behind this algorithm is that the traveler is seen as a real ant, and upon finding food it must return to its colony which is the starting point. Every ant must leave a trail behind it. This trail will be used by other ants to find the optimal way to the food source and get back to their colony at the end (Gath 2016).

3. Application and findings interpretation

VIR is a company based in Tangier's free zone. The company was founded in 2004, and is specialized in the automotive industry. The company fabricates electrical beams, wiping systems, binnacle safety systems and many other parts. To better have a competitive advantage, VIR (S.A.R.L) is located in Tangier Export Airport Free Zone which facilitates the import and export flow of material. VIR (S.A.R.L) has a capital of 1000.000 and a workforce of 1100 highly qualified people (550 people with a mean age of 25 years) and operates on a surface of 7000m² area over 2 production units. Following these figures, the size of operations of the company is considerably high. That is why there is a huge need to optimize transportation costs.

3.1. Problem Statement:

VIR is based in Tangier' free zone which is 10 Km far from the city center. That is why the company is doing considerable efforts in order to guarantee transportation for all its personnel. The company is relying on services provided by a firm specialized in the transportation industry. However, the transportation expense accounts for a large portion of the company' total expenses. Therefore, VIR is in huge need to optimize the problem of transportation and minimize expenses.

3.2. Data Analysis:

The company works with different shifts starting 6 AM each having a demand and number of stations. Through my analysis, I will be working with the 6 AM shift since it is the one with the biggest number of stations (First one of the day). I was able to get data for all stations, but the most challenging part was to label data using Google Maps and transform addresses into latitude and longitude coordinates. The total number of stations is equal to 38 for the 6 AM shift, and the demand in each station is fixed.

Methodology:

3.3. Clustering:

Data clustering is one of the most used methods of data analysis. It aims to divide a set of data into different homogeneous "packets". Therefore the data of each subset share common characteristics (Gaye 2007). At the end, results obtained from each cluster are combined to get the best possible solution of the overall problem.

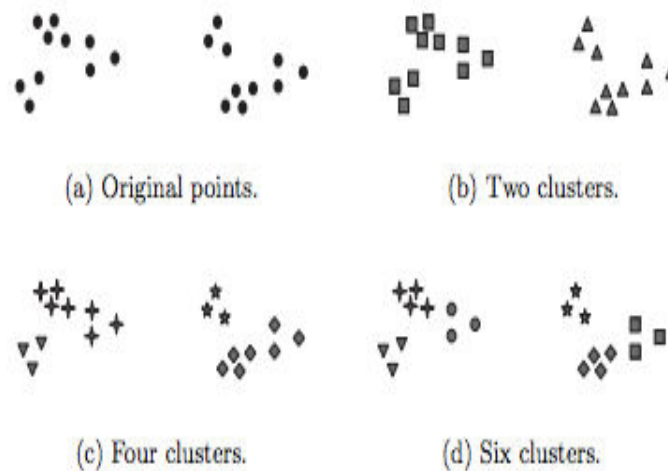


Figure 6: Clustering Technique

In the solution proposed, the first step was to cluster stations based on distances between stations as well as their positioning in the city of Tanger. The figure below shows the clustering performed by dividing the city into four main clusters (subclasses)



Figure 7: Clustering of Tanger

3.4. Final Data:

The clustering technique was done manually to better get familiar with stations and to label each station by the most accurate latitude and longitude coordinates.

Table 1: The Middle cluster: 14 stations

	Demand	Latitude (Y)	Longitude (x)
Mghogha	8	35,746529	-5,783889
El Mers	9	35,73904	-5,820796
Moujahidin	2	35,771359	-5,840167
Bir Chifa	13	35,743534	-5,82859
Branes	3	35,759076	-5,828633
Place de Toros	6	35,7645836	-5,7961658
Beni Makada	5	35,7503222	-5,81692499
Ben Diban	13	35,753372	-5,824176
Laazifat	1	35,755854	-5,801484
Sidi Driss	13	35,569783	-5,381509
Hopital Med 6	9	35,75111	-5,828489
Jirari	7	35,74882	-5,808681
Aouama	11	35,722792	-5,79417
Ain Ktiouet	2	35,773636	-5,816478
Achnad	15	35,738613	-5,831805

Table 2: The North Middle cluster: 11 stations

	Demand	Latitude (Y)	Longitude (x)
Lkharba	4	35,7533537	-5,84560439
Zemmouri	1	35,7760885	-5,8274791
Saada	3	35,7761257	-5,8081627
Lalla Chafia	3	35,7726658	-5,818902
La gare	1	35,7718281	-5,7863697
Idrissia	5	35,7619657	-5,801107
Mershan	1	35,7869738	-5,81824329
Souk Bara	3	35,786625	-5,813638
Dradeb	4	35,785496	-5,828242
Rue Sania	1	35,7878366	-5,81334
Iberia	4	35,7807602	-5,82022

Table 3: The North Geznaya cluster: 7 stations

	Demand	Latitude (Y)	Longitude (x)
Bariouyenne	15	35,7039701	-5,8749573

I9amat el Mostakbal	1	35,6972498	-5,9170305
Marjan	3	35,7462641	-5,8444332
Restaurant al achab	7	35,775663	-5,7984665
trek Rabat BMCE	2	35,7296062	-5,8802507
Geznaya Afriqia	2	35,469881	-6,00448059
Mojama3 Riad Al Salam	1	35,7361016	-5,8647316

Table 4: The Eastern cluster: 5 stations

	Demand	Latitude (Y)	Longitude (x)
Boukhalef	27	35,7358498	-5,890794
Ziaten	2	35,74336	-5,876277
Al Ifran	37	35,78517	-5,763888
Mesnana	23	35,753717	-5,8591246
Tanja Elbalya	5	35,77325759	-5,765419

3.5. Implementation:

In order to solve VIR? Vehicle Routing Problem, it was decided after many software trials, to work with the Large Neighborhood Search algorithm (LNS) implemented in Microsoft Excel.

Input:

To solve this optimization problem, certain data need to be entered:

- The number of stations is entered being the size of the problem.
- The average speed of the vehicle is assumed to be equal to 50km/h.
- The cost per unit distance is assumed to be 1.2 MAD/ km (Consumption of 12L/100km)
- The number of vehicle needed in each cluster is equal to the total demand of the cluster divided by the capacity of each vehicle (19).
- The limit driving time is entered so that each route does not exceed the limit.

Output:

The solution worksheet contains information regarding the optimal route found. The optimal distance, total driving time and total net profit are generated using the solver.

3.6. Results Obtained:

1st case: The Middle Cluster

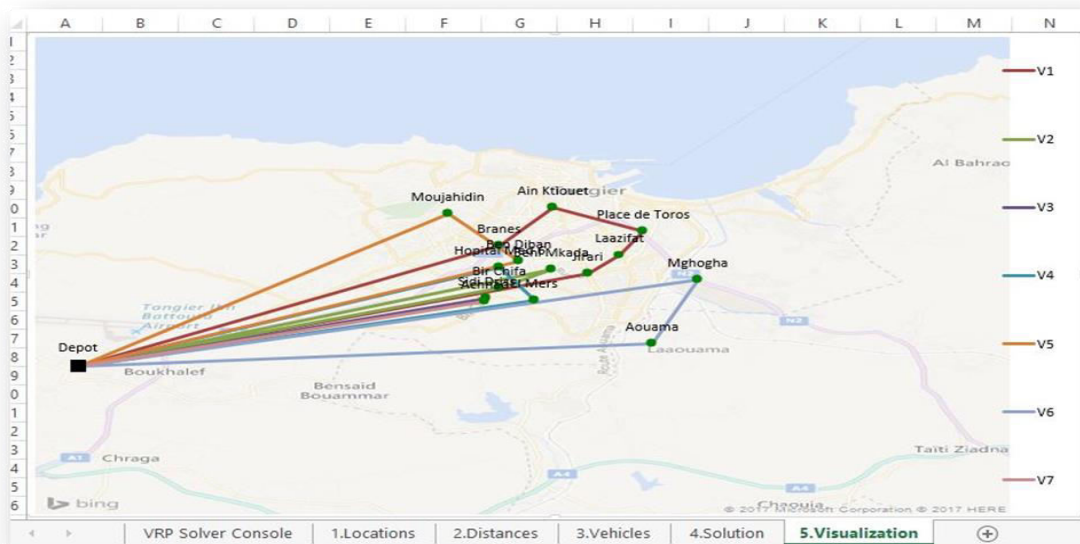
This cluster is the largest in terms of demand and vehicles needed. Therefore, the optimal route will be set using the order generated by the algorithm. The figure below shows the positioning of stations in the middle cluster.

Solution:

3	Vehicle:	V1	Stops:	6	Net profit:	-38,31			
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		06:00	0:00	0	0
6	1	Jirari	12,75	0:22	06:22	06:22	0:22	0	7
7	2	Laazifat	14,39	0:26	06:26	06:26	0:26	0	8
8	3	Place de Toros	15,81	0:31	06:31	06:31	0:31	0	14
9	4	Ain Ktiouet	18,15	0:35	06:35	06:35	0:35	0	16
10	5	Branes	20,94	0:40	06:40	06:40	0:40	0	19
11	6	Depot	31,92	0:58	06:58		0:58	0	19
12	7								
13	8								
14	9								
15	10								
16	11								
17	12								
18	13								
19	14								
20	15								
21	16								
22									

Figure 8: Cluster 1 Solution

Visualization:



As you can notice, the optimal set of routes is composed of seven routes that need to be served by seven vehicles. These vehicles are all of capacity 19, and they serve all the demand of the middle cluster. The order of stations is clearly displayed so that the itinerary followed by each vehicle is clear.

2nd case: The Northern Cluster

The same procedure is followed in each cluster afterwards. The locations are being changed to serve the new region. However, vehicle's capacity remains the same. The figure below shows different stations of the Northern cluster.

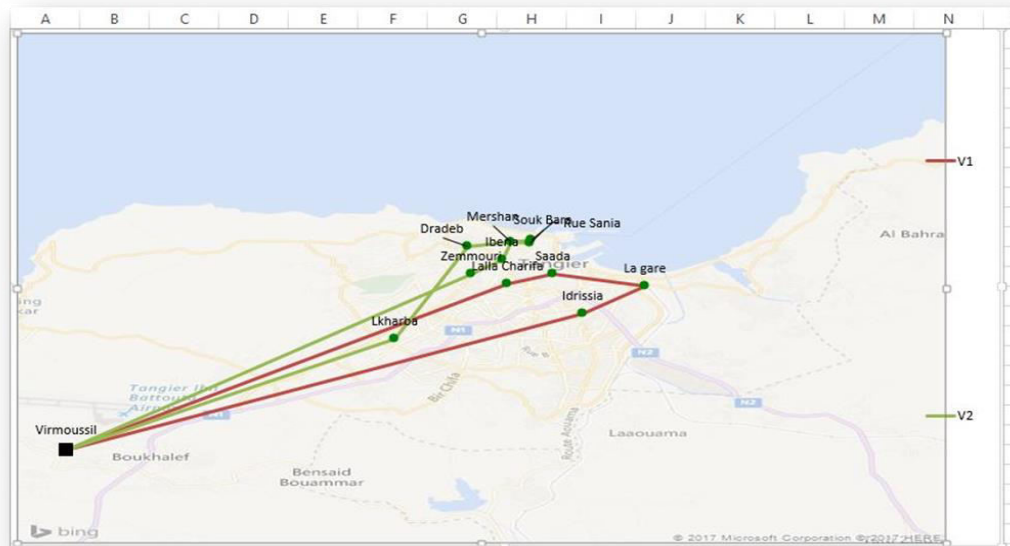
Solution:

After that, the optimal solution is generated after evaluating all possible iterations (3720 iterations).

Vehicle:	V1	Stops:	5	Net profit:	-41,16				
Stop count	Location name	Distance travelled	Driving time	Arrival time	Departure time	Working time	Profit collected	Load	
0	Virmoussil	0,00	0:00		06:00	0:00	0	0	
1	Idrissia	14,33	0:22	06:22	06:22	0:22	0	5	
2	La gare	17,34	0:29	06:29	06:29	0:29	0	6	
3	Saada	20,09	0:35	06:35	06:35	0:35	0	9	
4	Lalla Charifa	21,55	0:38	06:38	06:38	0:38	0	12	
5	Virmoussil	34,30	1:00	07:00		1:00	0	12	
6									
7									
8									
9									
10									
11									
12									

Figure 9: Cluster 2 Solution

The final step is to visualize the optimal set of routes following the optimal order of stations generated by the algorithm.



The same process is applied and the findings were interpreted evenly for the two other clusters.

Throughout this work, it was demonstrated how to solve a Vehicle Routing Problem under different constraints. The analysis was based on a metaheuristic algorithm known as the large neighbor search algorithm (LNS). It gives accurate results concerning distances since it uses features from Google Maps such that macro adds in Bing Maps. Still, it is not hundred per cent exact since the number of iterations increase with the number of stations. For future work, it would be recommended:

- The use of a software able to adapt to improve the accuracy of results.
- The use of a software to cluster data based on constraints entered by the user to avoid manual computations and save time.

As for the case of the Moroccan Company VIR, it was noticed that the demand in many clusters can be met easily if they use vehicles with bigger capacity. That is why, it is recommended:

- The use of vehicles with capacity of 30 or more. The payback period of this investment will remarkably be small since multiple shifts are being transported on a daily basis.
- The use of vehicles with bigger capacity will help the company gain considerable time every day. This may contribute to the increase of production for VIR. Also, this decision will help the company minimize both risks and costs.
- The use of optimal set of routes and vehicles with bigger capacity is directly linked to Green Logistics. The company should adopt this strategy to help reduce CO2 emissions and consequently decrease the risk of pollution and climate change.

Conclusion

This work summarizes the models of the Vehicle Routing Problem. This logistics problem consists of finding an optimal set of routes for one or more vehicles visiting different locations.

Working on this project, various obstacles were encountered mainly relatively to the technical aspect of the problem. Working with software like Matlab was limiting in terms of the lack of adaptability for inserting new constraints. OptiMap was limiting in terms of the number of stations allowed and also for inserting a variety of constraints. Therefore Excel was used to solve a large scope problem with using clustering and incorporating constraints relative to the capacity of the vehicles and also to time windows.

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Biographies

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