School of Science and Engineering

Capstone Report

Applications of the Vehicle Routing Problem to Logistics Optimization

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Capstone Report

Student Statement:

"I, RIDA ELBOUSTANI, affirm that I have applied ethics to the design process and in the selection of the final proposed design. And that, I hold the safety of the public to be paramount and has addressed this in the presented design wherever may be applicable."

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Approved by the Supervisor

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List of Acronyms and Abbreviations

**VRP**: Vehicle Routing Problem.

**TSP**: Travelling Salesman Problem.

**B&B**: Branch and Bound Algorithm.

**NNS**: Nearest Neighbor Search Algorithm.

**LNS**: Large Neighbor Search Algorithm.

**NC**: North Cluster.

**MC**: Mid Cluster.

**EC**: East Cluster.
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I also thank my family, classmates and friends for their unconditional support and encouragement throughout this project.

I, also, seize this opportunity to express my deep gratitude to Al Akhawayn University School of Science and Engineering for the opportunity.
Abstract

This capstone project has been produced to define the Vehicle Routing Problem and its applications to logistics optimization. In this paper, I am going to start by stating the Vehicle Routing Problem through a literature review. Then, I will be defining the mathematical model used to evaluate Vehicle Routing Problems. Different algorithms and software used to solve the Vehicle Routing Problem will be discovered through this project as well. At the end, I will deliver results obtained while working on the optimization of the case study of the Moroccan Company, Virmousil.

In order to develop the theme of this work, the following structure was adopted:

- The definition of the Vehicle Routing Problem will be the subject of the first part of this work.
- The second part will deal with different algorithms used to solve the Vehicle Routing Problem.
- The third part will present results obtained while optimizing Virmousil’ Company Vehicle Routing Problem.
Introduction

Scope of the Project:

Transportation cost represents different expenses a company incurs to move its products, personnel, inventory… from one location to another. In fact, these costs count for a high percentage of any company’s total expenses. [3] That is why, huge resources and funds have been allocated to optimize transportation costs. In this context comes the Vehicle Routing Problem, which is one of the main issues in the field of distribution management. [7] The Vehicle Routing Problem deals with finding an optimal set of routes for one or more vehicles under different constrains. Numerous attempts were conducted by researchers to solve the Vehicle Routing Problem and minimize transportation costs 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 constrains 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 Virmousil 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.
STEEPLE Analysis:

**Social**
- Solving The Vehicle Routing Problem will reduce risks of accidents by choosing the optimal set of routes for a vehicle to visit.
- The optimization of routes will contribute in the reduction from CO2 emissions and will minimize pollution dangers.

**Technological**
- The implementation of the Vehicle Routing Problem requires the use of software such as Matlab, OptaPlanner, VRPlog, and Excel...

**Environmental**
- The environmental aspect of solving the Vehicle Routing Problem is very important since it is linked directly to Green Logistics. Green Logistics is the set of attempts aiming to protect the environment from transportation effects. The optimal set of routes will reduce considerably fuel consumption and will consequently protect the environment.

**Economical**
- Applying the Vehicle Routing Problem optimization into logistics will reduce transportation costs and by default lower total expenses for most companies.

**Political**
- From a political perspective, the field of transportation is regulated by the ministry of logistics and transportation. Therefore many constraints are applied to companies such as mechanical condition of vehicles and the maximum number of station.

**Legal**
- Legally speaking, the moroccan government is responsible for managing routes.

**Ethical**
- Solving the Vehicle Routing Problem will reduce pollution and consequently enhance efforts to achieve an eco friendly environment in all Moroccan cities.

*Figure 1: STEEPLE Analysis*
SWOT Analysis:

**STRENGTHS**
- Optimal Solution.
- Minimum Cost.
- Management of resources.
- Minimum time of delivery

**WEAKNESSES**
- Limited scale problems.
- Difficult to add constraints.

**OPPORTUNITIES**
- Development of software to solve the VRP.
- Adaptation to real life business problems

**Threats**
- Traffic and weather conditions.
- The Mechanical conditions of vehicles.

*Figure 2: SWOT Analysis*
Overview of the Vehicle Routing Problem

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. [1] The Vehicle Routing Problem belongs to the group of NP-difficulty problems with a time complexity of O (n!). 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. [2]

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. [2] Applications of the Vehicle Routing Problem into logistics optimization are numerous.
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. [3] 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… [3] 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 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 depend 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.

**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. [8] 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 depend on a number of constraints to be respected. These constraints define in which type of the Vehicle Routing Problem falls the problem exactly. There exists constraints related to the capacity of each vehicle. [7] Other constraints may be related to the total time of the trip or to the time interval to pass in every station. [8]
The figure below presents the more general model used in the Vehicle Routing Problem. [9]

\[
\begin{align*}
& \text{minimize} & \sum_{i \neq j} c_{ij} x_{ij} \\
& \text{subject to} & \sum_{j=1}^{n'} x_{ij} = 1 & (i = 1, \ldots, n') \\
& & \sum_{i=1}^{n'} x_{ij} = 1 & (j = 1, \ldots, n'), \\
& & \sum_{i,j \in S} x_{ij} \leq |S| - |v(S)| & (S \subset V \setminus \{1\}; |S| \geq 2), \\
& & x_{ij} \in \{0, 1\} & (i,j = 1, \ldots, n'; i \neq j).
\end{align*}
\]

*Figure 5: The General Model of the Vehicle Routing Problem*

**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. [11]
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. [5]

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. [4]
Mathematical Definition:

\[
\min \sum_{j \in S} \sum_{i \in S} c_{i,j} \cdot x_{i,j}
\]

subject to

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

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

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

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

Figure 7: 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 a single closed tour. [4]

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. [2]
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. [3]

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. [5]

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 trial 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. [5]

Analysis:
During this capstone project, I am going to describe different steps followed in order to solve a Vehicle Routing Problem. First, I am going to explore manually one of the most used algorithms to solve VRP, which is the Munkres Algorithm. Then, I will be working on the example of Al Akhawayn University Van’s routing problem as a mini case study for my analysis. At the end, I will deliver results obtained for the optimization of Personnel pick up for the Moroccan Company Virmousil.

Exact Methods: The Munkres Algorithm:
Solving any Vehicle Routing Problem manually requires tedious efforts and computations. To better understand the algorithm, the number of locations involved in the problem should be set to a minimum. I will be working in my example with 5 different customers A, B, C, D and E. The goal is to find the optimal route between these 5 locations in order to minimize the cost, time of delivery and distance travelled.
In order to implement the Munkres algorithm, it is important to formulate the linear programming problem. In our case, the vehicle delivering products is required to start from the origin A, visit all stations exactly once and return to the starting point at the end. [7]

From a Mathematical perspective, the goal is to minimize the distance function. Therefore our problem uses:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} x(i, j)d(i, j)$$

as the objective function to minimize for this optimization problem. Here the distance is denoted by $d_{ij}$ such that $i$ and $j$ are different vertices for different locations. The two constraints of this problem are related to the in degree and out degree of the graph. In the graph theory, the out degree refers to the number of edges leaving each node while the in degree refers to the number of edges entering each node. The two constraints:

$$\sum_{i=1}^{n} x(i, j) = 1, i = 1, 2, ... n \quad \text{And} \quad \sum_{j=1}^{n} x(i, j) = 1, i = 1, 2, ... n$$

mean that each location $i$ must be visited exactly once and that the vehicle must come from one location $j$. The decision variable of this linear programming model is binary which means that if the path between $i$ and $j$ is traversed $x_{ij}$ should be equal to 1. Otherwise, $x_{ij}$ would be equal to 0 if the path does not exist. [5]

$$x(i, j) = 0 \ \text{or} \ 1$$

Application:

The Munkres algorithm is a widely used optimization tool to solve assignment problems based on dynamic programming techniques. In fact, the latter is used by most software dedicated to solving the Vehicle Routing Problem. That is why, I am going to discover manually how this algorithm finds the shortest path possible between different locations. [6]
Data:

The figure bellow shows the graph illustrating the problem I will be solving using the Munkres algorithm. In this example, we are given a graph where different cities A, B, C and D must be visited by the vehicle. The measurements represent the cost generated by going from one city to another. We are asked to find the optimal TSP tour for this problem using the Munkres algorithm known also as the Hungarian method.

![Figure 8: Manual Problem Data](image)

Step 1:

In the first step, I am going to write the distance matrix from the weights given in the graph:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
<td>7</td>
<td>6</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
<td>-</td>
<td>8</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>6</td>
<td>8</td>
<td>-</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>5</td>
<td>9</td>
<td>-</td>
<td>8</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>-</td>
</tr>
</tbody>
</table>
Step 2:

In this step, we minimize rows by subtracting the minimum none zero value from each one respectively. The following matrix was obtained:

\[
\begin{array}{cccc}
A & B & C & D \\
\hline
A & - & 3 & 2 & 4 & 0 \\
B & 2 & - & 3 & 0 & 1 \\
C & 0 & 2 & - & 3 & 1 \\
D & 3 & 0 & 4 & - & 3 \\
E & 0 & 3 & 3 & 4 & - \\
\end{array}
\]

Step 3:

The third step has to do with column minimization. The same thing as done before with rows is performed this time with columns. After subtracting the minimum none zero value from each column, we got the following matrix.

\[
\begin{array}{cccc}
A & B & C & D \\
\hline
A & - & 3 & 0 & 4 & 0 \\
B & 2 & - & 1 & 0 & 1 \\
C & 0 & 2 & - & 3 & 1 \\
D & 3 & 0 & 2 & - & 3 \\
E & 0 & 2 & 1 & 4 & - \\
\end{array}
\]

Step 4:

After getting the minimized matrix, the penalties attributed with each zero need to be calculated. Penalties are the sum of minimum values in row and column corresponding to each zero. For
example, for the 0 in row 1, the penalty value is equal = 0+1= 1. Calculating penalties for all zeros
in the matrix, we got the following matrix.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-3</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>2</td>
<td>-</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

The 0 with the highest penalty refers to an assignment in our optimal route. Here our first
assignment is: \( B \rightarrow D \).

Step 5:

The next step consists of eliminating the row and column of the value with high penalty. In our
case we ended up by the following matrix.

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>2</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>-</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

What we need to do next is to reduce this matrix to its row reduced echelon form. (RREF)
Repeating step 4, we get the next assignment in our route: $A \Rightarrow E$

Step 6:

We repeat step 4 and 5 until we get our final 2 * 2 matrix.

\[
\begin{array}{ccc}
A & B & C \\
C & 0(0) & 0(0) & - \\
D & 1 & - & 0(1) \\
E & 0(0) & 0(0) & 1 \\
\end{array}
\]

Assignment: $D \Rightarrow C$

\[
\begin{array}{ccc}
A & A \\
C & 0(0) & 0(0) \\
E & - & 0(0) \\
\end{array}
\]

Assignments: $E \Rightarrow B$

$C \Rightarrow A$
Conclusion:

At the end, we ended up by the following assignment:

\[ B \rightarrow D \]
\[ A \rightarrow E \]
\[ D \rightarrow C \]
\[ E \rightarrow B \]
\[ C \rightarrow A \]

Therefore, our optimal route is:

\[ \text{Figure 9: Manual Problem Solution} \]

Metaheuristics Method: Nearest Neighbor Algorithm:

It is one of the first algorithms to deal with the Travelling Salesman Problem. This algorithm suggests that the vehicle should start from the origin and visit each time the closest location until all are being visited. [9]

The NNA uses the following rules:

1- From the origin, choose the edge with the smallest weight.

2- Repeat the first step choosing among edges connecting from the current vertex to vertices not yet visited.

3- Once every vertex in the graph is being visited, return the starting point to close the circuit.

With a total cost of:

\[ 4+6+5+9+6 = 30 \]
However, the nearest neighbor algorithm yields to a short circuit but never to the optimal. That is why, it is considered as an approximate method to solving integer linear programming problems. [9]

**Application:**

Let’s suppose we want to visit five cities: A, B, C, D and E. The following graph indicates distances between these cities:

![Graph showing distances between cities A, B, C, D, and E](image)

*Figure 10: NNA Application*

Applying the NNA we were able to get the following circuit starting from A.

![Circuit generated by NNA](image)

*Figure 11: NNA Output*

NB: The set of routes generated may or may not be the optimal solution for this problem.
**Solving the Vehicle Routing Problem:**

Solving manually the Vehicle Routing Problem requires computational efforts. Indeed, the time complexity of the solution increases with the size of the problem. That is why, there exists several algorithm implemented in software to give the best optimal approximate solution to the problem. In the following part, I will be presenting software to solve the problem as well as their limitations, if any.

**OptaPlanner:**

OptaPlanner is an open source software dedicated to solving optimization Problems. As every business faces planning issues, OptaPlanner is a very useful constraint satisfaction tool dedicated to solve business problems. Cases solved by OptaPlanner vary from employees shift scheduling, financial portfolio optimizing, event scheduling to Vehicle Routing Problem.

![OptaPlanner Applications](image)

*Figure 12: OptaPlanner Applications*

The software is 100% Java written and is compatible with the most known Java Integrated Development Environments (IDEs) such that NetBeans and Eclipse. [7]
After downloading the software and integrating it with the IDE Eclipse, I was able to run various examples concerning the Vehicle Routing Problem in general and the Travelling Salesman Problem in specific.

The figure illustrates the user interface of the OptaPlanner software. It is user friendly since different application are clearly separated. I executed different examples of the Vehicle Routing Problem. The first application concerns capitals of Europe. Here the vehicle is required to start from one capital, visits all capitals and return back to the starting point. The time complexity to solve the problem depends on the number of capitals involved. The best thing about OptaPlanner is that the solution is well visualized, so it is easy to find the optimal route. Also, the final distance travelled is clearly shown.
The second example is a bit complicated since it involves various vehicles delivering products to multiple customers with a fixed capacity constraint.
**Limitations:**

Although the software is very useful, it is very hard to adapt to specific cases since it is coded with advanced Java programming techniques. Indeed, the software uses classes as a way of coding, so changing the code requires changing all classes related to the main code, which remains a challenging task.

**Matlab:**

Matrix Laboratory is a widely used software dedicated to solve computational, graphical and optimization problems. In fact, the software is rich of functions already implemented. Also, it is possible to add personal functions in the library of Matlab. However, coding with Matlab requires a very deep mastering of the syntax especially while using the optimization tool.

**Limitations:**

Solving the Vehicle Routing Problem has been previously tested using Matlab. As it is one of the NP-hard problems, the time complexity increases exponentially while increasing the size of our problem. Also, Matlab does not take into consideration real life distances as it works with x and y coordinates generating straight lines instead of using the longitude and attitude of each station. For all these reasons, Matlab can be useful in small sized problems with x and y coordinates as input.

**Excel:**

Excel is a very powerful tool used widely by engineers and analysts. It is known for its accurate results and user friendly environment. [11] For this, I have done research to find a way to implement the Vehicle Routing Problem in Excel. Excel is considered as a programming language accessible to anyone with basic programming skills. It uses VBA as the programming language. Therefore, to access the editor embedded in Excel, visualizing options must be enabled from Microsoft Excel settings. The adaptation of the code is quite simple since basic functions are already implemented. Adding constrains to functions remains the only task to do. [11]
Why Excel for Vehicle Routing Problem?

Excel uses a metaheuristic algorithm known as the Large Neighborhood Search (LNS). This algorithm finds the nearest optimal set of routes based on generating the matrix distance and iterating multiple times to generate the best approximate distance. Also, Excel is very flexible in terms of adapting codes to execute real life cases. The best thing about using excel to solve Vehicle Routing Problems is that it generates real distances using the Bing Maps feature. In fact, this feature enables the solver to retrieve data from a Geographical Information System database (GIS) which is more realistic and accurate in the applications I will be working on. Bing Maps accept the latitude (y) and longitude (x) and generates distances and average driving time using google maps.

Gunes Erdogan is a developer from the University of Bath with main research interest in exact and approximate algorithms. He implemented the Nearest Neighbor Algorithm as a macro adds in Excel. After creating a Bing Maps free trial account, I was able to get the spread sheet and adapt input information with my cases. The following figure is the solver console interface where basic variables such as the number of locations, vehicles types and visualization options.

![Figure 16: EXCEL Solver User Interface](image-url)
Akhawayn Traveling Salesman Problem:

Problem Statement:

Al Akhawayn University provides transportation to students, faculty and staff on a daily basis. In this part I am going to explore deeply the way by which buses starting from Al Akhawayn University visit all stations and return back to AUI. The first thing was to gather data. For this purpose, I have contacted the ground and maintenance service at Al Akhawayn University to provide me with concrete data. Below is the itinerary for an AUI Shuttle Bus.

![Figure 17: Al Akhawayn University Van Schedule](image)

The first remark I was able to draw is that the itinerary followed by buses does not respect the travelling Salesman rules since the Market and Down Town stations are being visited twice.
Data Gathering:

The first challenge was to know exactly where the stops are locate. Using google earth, I was able to generate coordinates of the locations. The following table summarizes coordinates of the eight stations.

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Latitude (y)</th>
<th>Longitude (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al Akhawayn University</td>
<td>33.5393881</td>
<td>-5.1079893</td>
</tr>
<tr>
<td>Down Town Residence</td>
<td>33.530303</td>
<td>-5.108355</td>
</tr>
<tr>
<td>The market</td>
<td>33.526001</td>
<td>-5.115607</td>
</tr>
<tr>
<td>Pam/Slaoui</td>
<td>33.5258333</td>
<td>-5.1177443</td>
</tr>
<tr>
<td>Hay Atlas 1</td>
<td>33.536493</td>
<td>-5.1212247</td>
</tr>
<tr>
<td>Ifrane school residence</td>
<td>33.527736</td>
<td>-5.1355597</td>
</tr>
<tr>
<td>Annex Residence Ifrane School</td>
<td>33.5246802</td>
<td>-5.1355047</td>
</tr>
<tr>
<td>Hay Atlas 2</td>
<td>33.540424</td>
<td>-5.1209667</td>
</tr>
</tbody>
</table>

To make sure that my coordinates are right, I used Matlab’ draw feature to visualize the stations on Google Maps.
Implementation:

The next step was to enter details about each location (Longitude and Latitude) in the solver console. The pickup amount refers the demand, which is fictive in this case, of each station. The profit generated is equal to the fee for one trip (2DH per person as set by Al Akhawayn University) times the demand of each station.

<table>
<thead>
<tr>
<th>Location ID</th>
<th>Name</th>
<th>Address</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Time window start</th>
<th>Time window end</th>
<th>Must be visited</th>
<th>Service time</th>
<th>Pickup amount</th>
<th>Delivery amount</th>
<th>Profit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Alhaweyn University</td>
<td>33,5393881</td>
<td>-5,107906</td>
<td>0:00</td>
<td>23:59: Starting location</td>
<td>0:00</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Downtown Residence</td>
<td>33,5380380</td>
<td>-5,108255</td>
<td>0:00</td>
<td>23:59: Must be visited</td>
<td>0:00</td>
<td>6</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>The Marche</td>
<td>33,5260010</td>
<td>-5,115607</td>
<td>0:00</td>
<td>23:59: Must be visited</td>
<td>0:00</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Pam/Slaoui</td>
<td>33,5288333</td>
<td>-5,117744</td>
<td>0:00</td>
<td>23:59: Must be visited</td>
<td>0:00</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Hay Atlas</td>
<td>33,5264930</td>
<td>-5,121247</td>
<td>0:00</td>
<td>23:59: Must be visited</td>
<td>0:00</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Ifrane School</td>
<td>33,5277360</td>
<td>-5,135539</td>
<td>0:00</td>
<td>23:59: Must be visited</td>
<td>0:00</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Annex Residence Ifrane</td>
<td>33,5246802</td>
<td>-5,139504</td>
<td>0:00</td>
<td>23:59: Must be visited</td>
<td>0:00</td>
<td>2</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Timedikke</td>
<td>33,5404240</td>
<td>-5,120966</td>
<td>0:00</td>
<td>23:59: Must be visited</td>
<td>0:00</td>
<td>3</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

*Figure 20: Stations Spreadsheet*

In the visualization sheet locations are being set in the map with clear labels thanks to the Bing Maps feature. This is to make sure that all coordinates entered correspond exactly to the intended stations.

*Figure 21: Visualization Using Bing Maps*
After that, the feature of Bing Maps generates all possible distances between stations using Google Maps. The duration between each two stations is calculated based on the distance and the average speed.

Information about the vehicle such that capacity, consumption, driving limit time and cost per unit distance are being entered. The fixed cost refers to any cost incurred by the van during each trip. I decided to set the fixed cost to 0 since it won’t make a difference in the final solution.
The cost per unit distance was calculated using the assumption that the van consumes an average of 12L per 100 Km. Therefore, the price for 1 Km is approximately 1.2 MAD (Assuming that 1L of fuel costs 10MAD).

**Solution:**

After entering all data required into the solver, the solution is generated. The solution is generated using the Large Neighborhood Search (LNS) algorithm. The number of iterations is exponentially related to the number of stations.

In the solution spreadsheet, the total distance travelled as well as the time gap between each two stations is clearly stated. The net profit is being assumed as the expense incurred during the trip. This expense is simply the optimal distance found times the price per unit distance.
Figure 25: Solution

Visualization:

The final step is to visualize the solution using Bing Maps feature. The route traversed is clearly labeled in the map with the order of stations obtained.
Results:

Normally AL Akhawayn University shuttle follows the following order of stations.

<table>
<thead>
<tr>
<th>Station</th>
<th>Distance Travelled</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUI</td>
<td>0</td>
</tr>
<tr>
<td>Down Town</td>
<td>1.93</td>
</tr>
<tr>
<td>The Marché</td>
<td>1.88</td>
</tr>
<tr>
<td>Pam/Slaoui</td>
<td>0.68</td>
</tr>
<tr>
<td>Hay Atlas</td>
<td>2.95</td>
</tr>
<tr>
<td>Ifrane school</td>
<td>2.45</td>
</tr>
<tr>
<td>Timeddikine</td>
<td>2.58</td>
</tr>
<tr>
<td>The Marché</td>
<td>2.01</td>
</tr>
<tr>
<td>Down Town</td>
<td>1.88</td>
</tr>
<tr>
<td>AUI</td>
<td>1.93</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance</td>
<td>18.29</td>
</tr>
<tr>
<td>Cost</td>
<td>21.948</td>
</tr>
</tbody>
</table>

Figure 27: Old Distance Traveled

Therefore, the net profit following the new route is:

\[
Net\ Profit = (Old\ Distance - New\ Distance) \timesPrice\ per\ unit\ Distance = 4.8\ MAD\ /\ per\ trip
\]

Limitations:

- The new route can be used only to personnel pick up and not to pick up and drop off at the same time since the capacity is assumed to be fixed.
- The route linking the Down town station to Timeddikine is not always accessible. Therefore, the route cannot be adopted in case of bad weather conditions.
- The demand of each station should be fixed and known beforehand to avoid the overcapacity issue.
Virmousil Company Route Optimization:

Overview:

Virmousil 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, Virmousil (S.A.R.L) is located in Tangier Export Airport Free Zone which facilitates the import and export flow of material. Virmousil (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. [13]

Problem Statement:

Virmousil 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, Virmousil is in huge need to optimize the problem of transportation and minimize expenses.

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:**

**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. [12] At the end, results obtained from each cluster are combined to get the best possible solution of the overall problem.

![Clustered stations](image)

**Figure 28: Clustering Technique**

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

The Middle cluster: 14 stations

<table>
<thead>
<tr>
<th>Stations</th>
<th>Demand</th>
<th>Latitude (Y)</th>
<th>Longitude (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mghogha</td>
<td>8</td>
<td>35,746529</td>
<td>-5,783889</td>
</tr>
<tr>
<td>El Mers</td>
<td>9</td>
<td>35,73904</td>
<td>-5,820796</td>
</tr>
<tr>
<td>Moujahidin</td>
<td>2</td>
<td>35,771359</td>
<td>-5,840167</td>
</tr>
<tr>
<td>Bir Chifa</td>
<td>13</td>
<td>35,743534</td>
<td>-5,82859</td>
</tr>
<tr>
<td>Branes</td>
<td>3</td>
<td>35,759076</td>
<td>-5,828633</td>
</tr>
<tr>
<td>Place de Toros</td>
<td>6</td>
<td>35,7645836</td>
<td>-5,7961658</td>
</tr>
<tr>
<td>Beni Makada</td>
<td>5</td>
<td>35,7503222</td>
<td>-5,81692499</td>
</tr>
<tr>
<td>Ben Diban</td>
<td>13</td>
<td>35,753372</td>
<td>-5,824176</td>
</tr>
<tr>
<td>Laazifat</td>
<td>1</td>
<td>35,755854</td>
<td>-5,801484</td>
</tr>
<tr>
<td>Sidi Driss</td>
<td>13</td>
<td>35,569783</td>
<td>-5,381509</td>
</tr>
<tr>
<td>Hopital Med 6</td>
<td>9</td>
<td>35,75111</td>
<td>-5,828489</td>
</tr>
</tbody>
</table>
### The North Cluster: 11 stations

<table>
<thead>
<tr>
<th>Stations</th>
<th>Demand</th>
<th>Latitude (Y)</th>
<th>Longitude (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lkharba</td>
<td>4</td>
<td>35.7533537</td>
<td>-5.84560439</td>
</tr>
<tr>
<td>Zemmouri</td>
<td>1</td>
<td>35.7760885</td>
<td>-5.8274791</td>
</tr>
<tr>
<td>Saada</td>
<td>3</td>
<td>35.7761257</td>
<td>-5.8081627</td>
</tr>
<tr>
<td>Lalla Chafia</td>
<td>3</td>
<td>35.7726658</td>
<td>-5.818902</td>
</tr>
<tr>
<td>La gare</td>
<td>1</td>
<td>35.7718281</td>
<td>-5.7863697</td>
</tr>
<tr>
<td>Idrissia</td>
<td>5</td>
<td>35.7619657</td>
<td>-5.801107</td>
</tr>
<tr>
<td>Mershan</td>
<td>1</td>
<td>35.7869738</td>
<td>-5.81824329</td>
</tr>
<tr>
<td>Souk Bara</td>
<td>3</td>
<td>35.786625</td>
<td>-5.813638</td>
</tr>
<tr>
<td>Dradeb</td>
<td>4</td>
<td>35.785496</td>
<td>-5.828242</td>
</tr>
<tr>
<td>Rue Sania</td>
<td>1</td>
<td>35.7878366</td>
<td>-5.81334</td>
</tr>
<tr>
<td>Iberia</td>
<td>4</td>
<td>35.7807602</td>
<td>-5.82022</td>
</tr>
</tbody>
</table>

### The Geznaya Cluster: 7 Stations

<table>
<thead>
<tr>
<th>Stations</th>
<th>Demand</th>
<th>Latitude (Y)</th>
<th>Longitude (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bariouyenne</td>
<td>15</td>
<td>35.7039701</td>
<td>-5.8749573</td>
</tr>
<tr>
<td>I9amat el Mostakbal</td>
<td>1</td>
<td>35.6972498</td>
<td>-5.9170305</td>
</tr>
<tr>
<td>Marjan</td>
<td>3</td>
<td>35.7462641</td>
<td>-5.8444332</td>
</tr>
<tr>
<td>Restaurant al achab</td>
<td>7</td>
<td>35.775663</td>
<td>-5.7984665</td>
</tr>
<tr>
<td>trek Rabat BMCE</td>
<td>2</td>
<td>35.7296062</td>
<td>-5.8802507</td>
</tr>
<tr>
<td>Geznaya Afriqiu</td>
<td>2</td>
<td>35.469881</td>
<td>-6.00448059</td>
</tr>
<tr>
<td>Mojama3 Riad Al Salam</td>
<td>1</td>
<td>35.7361016</td>
<td>-5.8647316</td>
</tr>
</tbody>
</table>
The Eastern Cluster: 5 stations

<table>
<thead>
<tr>
<th>Stations</th>
<th>Demand</th>
<th>Latitude (Y)</th>
<th>Longitude (x)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boukhalef</td>
<td>27</td>
<td>35.7358498</td>
<td>-5.890794</td>
</tr>
<tr>
<td>Ziaten</td>
<td>2</td>
<td>35.74336</td>
<td>-5.876277</td>
</tr>
<tr>
<td>Al Ifran</td>
<td>37</td>
<td>35.78517</td>
<td>-5.763888</td>
</tr>
<tr>
<td>Mesnana</td>
<td>23</td>
<td>35.753717</td>
<td>-5.8591246</td>
</tr>
<tr>
<td>Tanja Elbalya</td>
<td>5</td>
<td>35.77325759</td>
<td>-5.765419</td>
</tr>
</tbody>
</table>

Implementation:

In order to solve Virmousil’ Vehicle Routing Problem, I have chosen 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.
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.

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:

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>V1</th>
<th>Location name</th>
<th>Distance travelled</th>
<th>Driving time</th>
<th>Arrival time</th>
<th>Departure time</th>
<th>Net profit</th>
<th>Profit collected</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Depot</td>
<td>0.00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>0:00</td>
<td>38.31</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Jirari</td>
<td>12.75</td>
<td>0:22</td>
<td>06:22</td>
<td>06:22</td>
<td>06:22</td>
<td>22</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Laazifat</td>
<td>14.39</td>
<td>0:26</td>
<td>06:26</td>
<td>06:26</td>
<td>06:26</td>
<td>26</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Place de Toros</td>
<td>15.81</td>
<td>0:31</td>
<td>06:31</td>
<td>06:31</td>
<td>06:31</td>
<td>31</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>4</td>
<td>Ain Khrouet</td>
<td>18.15</td>
<td>0:35</td>
<td>06:35</td>
<td>06:35</td>
<td>06:35</td>
<td>35</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>5</td>
<td>Branes</td>
<td>20.58</td>
<td>0:40</td>
<td>06:40</td>
<td>06:40</td>
<td>06:40</td>
<td>40</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>6</td>
<td>Depot</td>
<td>31.92</td>
<td>0:58</td>
<td>06:58</td>
<td>06:58</td>
<td>06:58</td>
<td>58</td>
<td>0</td>
<td>19</td>
</tr>
</tbody>
</table>

### 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 changer to serve the new region. However, vehicle' capacity remains the same. The figure below shows different stations of the Northern cluster.

After that, the optimal solution is generated after evaluating all possible iterations (3720 iterations).
The final step is to visualize the optimal set of routes following the optimal order of stations generated by the algorithm.
3rd case: The Geznaya Cluster

Stations:

Solution:

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>V1</th>
<th>Stops</th>
<th>Distance travelled</th>
<th>Net profit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0:00</td>
<td>0:00</td>
</tr>
<tr>
<td>0</td>
<td>Virmoussil</td>
<td>14.69</td>
<td>0:22</td>
<td>0:22</td>
</tr>
<tr>
<td>1</td>
<td>Restaurant Al Achab</td>
<td>20.75</td>
<td>0:33</td>
<td>0:33</td>
</tr>
<tr>
<td>2</td>
<td>Marjane</td>
<td>24.01</td>
<td>0:39</td>
<td>0:39</td>
</tr>
<tr>
<td>3</td>
<td>Riad Slam Complex</td>
<td>25.89</td>
<td>0:43</td>
<td>0:43</td>
</tr>
<tr>
<td>4</td>
<td>Route de Rabat</td>
<td>30.77</td>
<td>0:51</td>
<td>0:51</td>
</tr>
</tbody>
</table>

Visualization:
4\textsuperscript{th} case: The Eastern Cluster

Stations:
**Solution:**

<table>
<thead>
<tr>
<th>Stop count</th>
<th>Location name</th>
<th>Distance travelled</th>
<th>Driving time</th>
<th>Arrival time</th>
<th>Departure time</th>
<th>Working time</th>
<th>Profit collected</th>
<th>Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Virmoussil</td>
<td>0.00</td>
<td>0:00</td>
<td>06:00</td>
<td>06:00</td>
<td>0:00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Zieten</td>
<td>5.34</td>
<td>0:06</td>
<td>06:06</td>
<td>06:06</td>
<td>0:06</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Tanja El balya</td>
<td>15.88</td>
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<td>06:19</td>
<td>0:19</td>
<td>0</td>
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<tr>
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<td>06:38</td>
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<td>0:38</td>
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<td></td>
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</tr>
</tbody>
</table>

**Visualization:**

![Map showing routes and locations](image-url)
Suggestions and Future Work

Throughout this capstone, I learned how to solve a Vehicle Routing Problem under different constraints. My 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 ads 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, I would recommend:

- The use of a software easy 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 Virmousil, I noticed that the demand in many clusters can be met easily if they use vehicles with bigger capacity. That is why, I recommend:

- 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 Virmousil. 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 efforts made since the start of the semester to understand the Vehicle Routing Problem. This logistics Problem consists of finding an optimal set of routes for one or more vehicles visiting different locations. I have attributed considerable time and efforts to discover the topic from all its aspects. Unfortunately, this project period was not enough for me to identify all the complex aspects and scenarios of the Vehicle Routing Problem, but still the experience was a great enrichment for me in terms of acquiring knowledge and getting to apply learnings to a real case study.

I limited this study to the analysis of the classical Vehicle Routing Problem. This limitation can be justified by two reasons:

- The complexity of the topic as it is the first time I have heard about it.
- The limited time period of the capstone which was not enough for me to deepen my analysis.

Working on this capstone, I have encountered various obstacles mainly to the technological aspect of the problem. Working with software coded with C++ or Java was a challenge for me since I am not so familiar with advanced programming skills.

At the end of this journey, I can only appreciate its positive outcome. This experience was so enriching for me as I had to learn new concepts and apply them to real life.

Overall, it was a great, rewarding and informative experience bringing added value both for me and the company I have worked with. To conclude, I would like to re-extend a wide range of gratitude to everyone contributing to the success of this capstone project.
References


Appendix A: Project Specifications

Initial Project Specification
ELBOUSTANI Rida
EMS
VEHICLE ROUTING PROBLEM
ELBOUKILI Abderazzak
Fall 2017

The objective of this capstone is to apply the Traveling Salesman Problem into logistics optimization. Throughout this project, I am going to optimize mainly the cost of delivery function with respect to many variables such as time, distance and capacity. The cost of delivery reduces the manufacturer profit margin by approximately 30%. That is why, it is crucial to minimize this cost for all companies. The objective of my analysis will be to determine the optimum route for a single vehicle with multiple stops with respect to constraints such as time, cost and capacity. The methodology adopted throughout this project will consist of applying mathematics theories into a real life business problem. Linear programming, approximation theories and heuristic algorithms will be used as tools to minimize the cost function.

The first part of my analysis will consist of gathering information about the Vehicle Routing Problem and its implications. Through articles and papers from the literature, I am going to define the problem clearly and how linear programming optimization is applied into solving this problem. The next part will consist of finding existing algorithms that deals with the Travelling Salesman Problem.

Implementation and testing of the open source software will go hand in hand. Adjustments will be applied to the existing algorithm in order to optimize the required function. After that, data will be collected and a thorough application into a real life problem will be done to find the optimum solution in terms of time, distance and capacity constraints.

All procedures and steps followed will be clearly explained in the diaries witnessing the weekly progress.