School of Science and Engineering

Capstone Report

Vehicle Routing Problem for Waste Collection

Submitted in:
Fall 2017

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Vehicle Routing Problem for Waste Collection

Capstone Report

Student Statement:
I, Sabrina El Mouhib, have applied ethics to the design process and in the selection of the final proposed design. And that, I have held the safety of the public to be paramount and has addressed this in the presented design wherever may be applicable.

_____________________________________________________
Sabrina El Mouhib

Approved by the Supervisor(s)

Dr. Abderrazak El Boukili

Dr. Ilham Kissani
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Acknowledgement

Throughout the semester, I put remarkable and considerable efforts to develop a project on Vehicle Routing Problem in Waste Collection. However, I wouldn’t achieve what I have done without the constant support and guidance of my two supervisors in Al Akhawayn University, Dr. Abderrezak El Boukili and Dr. Ilham Kissani. I would like to thank them for their remarkable supervision, assistance and advices concerning my capstone project.

Also, I want to thank to my Parents for their positive attitude and continuous encouragement that help me in completing my capstone.

Last but least, I want to thank Dr. Yassine Salih Alj for his contribution and successful coordination throughout the course of the semester.
Abstract

In this report, I will analyze the methodology and steps adopted to solve Vehicle Routing Problem (VRP) for waste collection. Capacitated Vehicle Routing Problem (CVRP) and Periodic Vehicle Routing Problem (PVRP) are the two variants of VRP that I will analyze in this project. My capstone aim to find the optimal routes for waste collection by designing a set of routes for a fleet of vehicles with the minimum costs possible and the shortest distance traveled. The first part of this report will cover a background and state of art of Vehicle Routing Problem, its variants and constraints. The second part of the capstone will cover a definition of CVRP and an optimization of the routes of waste collection within AUI using the web application LogVRP. The third part will cover PVRP model and a detailed explanation of its solution algorithm by solving manually a simple application using this algorithm. Last but not least, I will analysis the process to optimize waste collection of a real case study in Iran using TransCAD software and Tabu Search algorithm.
**Introduction**

Transportation is considered one of the major competitive advantage and force in any business. By optimizing the routes and distances traveled by vehicles, companies can save a huge amount of money. In fact transportation costs can reached 30% of the total expenses. Furthermore, transportation is playing an essential and crucial service in the logistical, environmental and economic function of businesses. In fact, Vehicle Routing Problem is considered one of the main issues faced in Logistics field. This problem mainly deals with designing the shortest route for multiple vehicles for various reasons: waste collection, products pickup and delivery, workers transportation … Also, it is considered a generalization of the Travelling Salesman Problem.

In the first part of the capstone, a literature review about VRP will be conducted followed by a deep analysis of the two mathematical models to optimize waste collection. In third part, I will explain the process to optimize waste collection process in AUI by comparing the current and suggested method. Last but not least, I will explain the steps to solve the PVRP by analyzing a real case study in Iran. In this capstone, I will also concentrate on the environmental effect of optimizing the routes for waste collection by calculating the emissions of CO2 saved in each case.
Chapter 1: Literature Review
Vehicle Routing Problem was first introduced by the two mathematicians Dantzig and Ramser in 1959. It is an extension and generalization of the Travelling Salesman Problem (TSP). “While the objective of the TSP is to find the shortest route for a single vehicle, the objective of the VRP is to find the optimal solution for a set of vehicles by finding the shortest route traveled and passing through all the stations with the least cost possible”[1].

In fact, VRP is directly connected to distribution and logistics management, which require massive expenses. Using the optimal set of routes, the company can generate savings that range from 5% to 30% of the total costs, since transportation expenses occupy a significant position in the chain of production of any firm [2] Therefore, many mathematicians attempted to solve it and minimize the cost of transportation, distribution of goods and waste collection.

The current VRP models are extremely different than the model introduced by Dantzig and Ramser or Clarke Wright. In fact, the recent ones incorporate real life complexities such as time window for pickup or delivery, demand information or traffic congestion…

**State of Art of Vehicle Routing Problem**

The Vehicle Routing Problem (VRP) is an NP hard problem that deals with the optimization of routes in order to deliver or pick up certain products from defined stations or costumers. Dantzig and Ramser were the first to introduce the problem in 1959 by optimizing the routes of a petrol delivery company. Later on, the two mathematicians Clarke and Wright developed the algorithm and introduced an improved version of the model in 1964. During the following years, multiple versions of VRP were developed in order to meet the demanding needs of the costumers. By the improvement of Central
Processing Unit of computers, many VRP models can now be solved based on heuristic and metaheuristic solution algorithms. The difference between the two methods will be discussed later on in this report. It is important to mention that vehicle routing problem is a generalization of Travelling Salesman Process (TSP) in the extent that VRP is dealing with a fleet of vehicles whereas TSP is about one vehicle. Therefore, the type of constraints differs from VRP to TSP.

**The importance of solving VRP**

Solving Vehicle Routing Problem is very important and essential for any business and industry. It can save up to 30% of the expenses of a company. The Application of vehicle routing problem is suitable and useful in many sectors such as:

- Product Delivery and Pickup
- Waste Collection
- Transportation
- Trip planning
- Freight distribution
- Food distribution
- Mail and Package delivery
- Oil, gas and fuel transportation

In my capstone, I will analysis one of the most used applications of VRP: **Waste Collection**.
Definition of Vehicle Routing Problem

Theoretical Definition

Vehicle Routing Problem can be defined by a $k$ number of vehicles that are supposed to deliver or pick up products from a set $m$ of customers in the most optimal way. All vehicles should start from the depot $D$ and finish in a defined station (can also be the depot). The solution of the algorithm implies finding the optimal set of routes to deliver or pick up the products (in our case, the waste). In other words, the objective of solving the problem is to minimize transportation costs by satisfying some constraints:

- The vehicles starts from the depot
- The stations or pick up points are visited only once.

The optimization of vehicle routing problem aim to reduce the time, distance and the number of vehicles used in the problem. Therefore, in my capstone I have decided to reduce the distance traveled by the costumers.

Mathematical definition

The vehicle routing problem can be represented as a graph $G$ composed by vertices $V$ and arcs $A$. Therefore, VRP can be defined as $G= (V, A)$. The depot is the vertex in which the vehicles start and may finish their trips, that is why it is situated in vertex 0. The arc is limited by indices $i$ and $j$. The cost in the problem is expressed as $C_{ij}$ that refer to the distance cost depending on the context of the problem.

In vehicle routing problem, the arcs can either be asymmetric in which cost between two vertices is different or symmetric in which traveled arcs generate in both directions the same cost.
Constraints of VRP

As mentioned earlier, many constraints in VRP must be satisfied.

- All vehicles should start and finish in the depot
- Each station must be traveled once
- VRP may include constraints related to capacity in order to make sure that the demands of stations fits the overall capacity of its assigned vehicle
- VRP may include constraints related to Time which is directly linked to the length of the arcs traveled and the speed of its vehicle
- VRP may include constraints related to time window by restricting the time in which vehicle can pass through the pick-up points or station.
- Last but not least, VRP can include constraints about precedence by stating that a certain station must be visited before another one.

Solution Methods

VRP is considered an NP hard problem in which exact solutions or algorithms are only applicable for small problems. By the increase of the capacity of our computers and the processing speed, the ability to solve more complicated VRP problems has become possible. In fact, we can differentiate between three methods of Vehicle Routing Problem solutions:

**Exact Algorithms**

Exact methods are generated to find the optimal solution of a given problem. The exact methods are mostly characterized by the following:

- Integer Linear Problem
• Dynamic Programming methods

The major inconvenient for exact algorithms is its inability to work in large scale problems.

**Heuristic Algorithms**

Heuristic algorithm is problem-based solution method.

In fact, heuristic methods are mostly efficient in solving real life problem because of their ability to handle high scale problems. The algorithm function as follow:

First, the algorithm needs to set and calculate some feasible solution.

Second, the algorithm tries to enhance them gradually until reaching an optimal solution.

Last but not least, the algorithm stops when no possible modification or improvement can be done to the solution.

Here are some famous heuristic algorithm:

• The Sweep Algorithm (1974)

• Clark and Wright Algorithm (1964)

**Metaheuristic Algorithms**

As oppose to heuristic methods, metaheuristic algorithms are not problem-based solution methods. It is a problem with an independent approach. In fact, they are more flexible and general than heuristics and not based on specifications of the problem. Metaheuristics are mostly applicable for complex optimization problems or problems with incomplete data.
Chapter 2: Variants of Vehicle Routing Problem
In this section, we will study two models used for waste collection, Capacitated Vehicle Routing Problem (CVRP) and Periodic Vehicle Routing Problem (PVRP).

**Capacitated Vehicle Routing Problem**

CVRP is considered one of the most used variant of VRP. In this type of vehicle routing problem, we consider that all stations have a deterministic demand. Furthermore, the vehicle are all located in a fixed starting point and must end their trip in a fixed station (in our case the depot, which is also the starting point). Similar to other VR problems, the main objective is to minimize the distance traveled by the vehicles to serve all the stations with their assigned demand.

It exists many heuristic and metaheuristic approaches to solve CVRP. The heuristic algorithms can solve large scale problems, up to 50 stations. However, the processing speed and the implementation of the program can take a long time.

The first solution of CVRP was an extension of Traveling Salesman Problem (TSP) by the two mathematicians Laporte and Nobert. They are also the first to generate a solution using an exact algorithm. It is also important to mention how to differentiate symmetric and asymmetric CVRP as mentioned previously in the report.

**The Mathematical Definition of CVRP for a waste collection application**

We assume \( N \) is the set of stations where the waste is collected. Every \( i \) is associated to a nonnegative waste quantity of the bins. \( V \{1,2,3 \ldots k\} \) are the number of
vehicles available at the depot with a maximum capacity $C$ for each. Also a nonnegative cost $D_{ij}$ is assigned with each arc $(i,j)$, where $i$ and $j$ represent the distances between bins. [1]

$$x_{ijk} = \begin{cases} 1, & \text{if vehicle } k \text{ traverses arc } (i,j) \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

$$\min \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{K} d_{ij} x_{ijk} \quad (3)$$

Subject to

$$\sum_{j=1}^{n} \sum_{k=1}^{K} x_{0jk} = 1 \quad (4)$$

$$\sum_{j=1}^{n} q_{0jk} = 0 \quad \forall k = 1, 2 \ldots K \quad (5)$$

$$\sum_{i=0}^{n} \sum_{k=1}^{K} x_{ijk} = 1 \quad \forall j = 1, 2, \ldots n \quad (6)$$

$$\sum_{i=1}^{n} x_{ijk} = \sum_{j=1}^{n} x_{ijk} \quad \forall i = 0, 1, 2 \ldots n; \quad k = 1, 2, \ldots K \quad (7)$$

$$\sum_{i=0}^{n} \sum_{k=1}^{K} q_{ijk} - \sum_{i=0}^{n} \sum_{k=1}^{K} q_{ijk} = c_j \quad \forall j = 1, 2, \ldots n \quad (8)$$
In the above model, it is specified that the vehicles should start from the depot with no load as shown in equations (4) and (5).

Each station or bin should be visited by only one vehicle. If the vehicle enters a node, it should empty the bins and leave the node. This is shown respectively in equation (6), (7) and (8). Equation (9) focuses on the allowable capacity carried in each vehicle. It should not exceed the capacity of the visited bins.

**Periodic Vehicle Routing Problem**

The periodic vehicle routing problem (PVRP) arise in many real-world applications. The first model was proposed by the two mathematicians Betrami and Bodin. The Periodic Vehicle Routing Problem is a variant of VRP characterize by the need to determinate an appropriate service time for each of the stations and simultaneously find an optimal route with the least cost possible.

In some cases of VRP, it is useful to visit the stations on different time according to product availability. In my case, the amount of waste collected from each collecting points is the factor that triggers the visits of the vehicles. Therefore, it is important to prepare a collection schedule that specifies the days in which station are available for waste collection.
The objective of the model in PVRP remains minimizing the distance traveled by the vehicles. Therefore, the solution is defining routes for each vehicle that starts from a depot, passes through the collection points. The station should be visited only once during the time they’re available (according to the collection schedule).

**The Mathematical Definition of PVRP for a waste collection application**

In this section, I will present a general model of PVRP than can be applied in waste collection.

First we need:

- T for number of days in which the vehicles can operate for each node
- D is the duration of the daily shifts of waste collection vehicles
- m is the number of vehicle with a capacity Q
- Every vertex i is given service time ti , the service time at the depot is 0
- n is the number of collection points
- k is the number of Change-Over Points (COP) (Disposal point or Warehouse, in which the vehicles must unload the collected waste)

The routes are designed in a graph G=(V,A) in which V\{ v0,v1… vn \} are the set of vehicles and A are the arcs that connect vertex i and vertex J. [3]

In the graph, not all vertices are connected, for example no vehicle goes from a depot to a COP since it should be empty before starting the shift. Also, there are no arcs connecting COPs, since the vehicle can unload the waste in only one disposal point. For
the same reason, there is no arc connecting a collecting point to the depot because vehicles should unload first in the COPs and then return to the depot.

In this model, collecting stations are given each a *feasible collection schedule*. It gives information on the amount of waste collected on each day. For instance, in a 4 days horizon, the following collection schedule \( \{12,0,10,0\} \) informs us that a visit is required for day 1 and 3 (this is the variant T that shows the time when the vehicle should operate for this node). However in day 2 and 4 the amount of waste collected is zero, so the demand is zero and there is no need for a visit.

The routes are defined as circuit in the graph that starts from the depot and pass through multiple collection points and end their trip in COP first and then go back to the starting point (depot) [3]

The solution in Periodic Vehicle Routing Problem is the set of optimal routes for each vehicle in a way that all the collecting points or station are visited only once according to its *collection schedule* with the least cost possible. Furthermore, it is important that the routes respect the capacity \( Q \) and the duration \( D \) assigned in the beginning of the model. Also, the demands (waste) in the visiting points shouldn’t exceed the capacity of the vehicle assigned for this collecting points.
Multiple Context for Periodic Vehicle Routing Problem

Another important factor that should be taken into consideration when modeling Periodic Vehicle Routing Problem is the type of collection system that is applied in the waste collection problem.

The collection system can be either differentiated (different types of waste are handled separately) or undifferentiated (the traditional, that handles all types of waste at once). In case of differentiated collection system, a modification of arcs is required because vehicles cannot mix different type of waste during the collection shift. Thus, we need to delete arcs that connect a container to an incompatible COP. Also, it is important to consider another issue that is applied to the differentiated system collections which is the strong relation and dependence of the capacity and the type of waste collected.
Chapter 3: Analysis
The analysis part of my capstone will describe different approaches and algorithms to solve two variants of vehicle routing problem, CVRP and PVRP in a waste collection context. The first part will include analysis of waste collection procedure within AUI that will be followed by a suggested optimal solution generated by LogVRP web application. In the second part, I will explain Tabu Search Algorithm as a way to solve PVRD by giving a manual solution of a simple application of the algorithm and apply it on a waste collection case in order to find the optimal routes for waste collection.

**Waste Collection:**

Waste Collection is considered a direct application of Vehicle Routing Problem. Managing waste collection has an important impact on the environment and the economy. In fact, rapid urbanization and everyday human activities produce a large amount of waste from residential and industrial areas [1] This activities has impacted the climate by increasing the emission of many greenhouse gases, among them CO₂. Today, CO₂ is reaching approximately 390 ppm, which lead to Global warning [1]

A good management of waste focuses mainly on finding an optimal route of garbage collection instead of relying on pre-defined path. The optimization method focuses essentially on reducing number of vehicles and reducing the distances traveled. In order to solve vehicle routing problem, there are many constraints to take into account. For the first case, I determined the capacity as an essential constraint (CVRP) in order to optimize the routes for waste collection. However, in the second case, waste availability (PVRP) was the main constraint.
Waste Collection Optimization

For the first waste collection optimization, the model I chose depend highly on the capacity of the vehicle C and the capacity of the bins available. In this project, we assume the maximum capacity of bins, 80 kg, as the actual capacity of all bins.

The constraints of the model are the following:

- Vehicles start at the same time from the depot
- All vehicles should return to the depot
- Each station should be visited once
- The cumulative waste capacity collection from all stations shouldn’t exceed the maximum capacity of the vehicles
- All bins are homogenous

Heuristic Approach to Optimize Waste Collection

Application of waste optimization in LogVRP

LogVRP is a web application, multiple stop, multiple destinations and multiple location route planner. It provides efficient routing optimization for transportation logistics. [2] After data entering, the software calculates the shortest and the optimum routes and then gives the results on map. Therefore, the results are not generated bases on Pythagorean distances; instead LogVRP takes into considerations real distance and any obstacles (ex: Buildings) that may occur while calculating the optimal route.
Solution algorithm in LogVRP

The solution algorithm used in the web application LogVRP is Adaptive Large Neighborhood Search (ALNS). It is a general heuristic algorithm for Vehicle Routing Problem. Its unified models allow solving the Capacitated Vehicle Routing Problem, the Vehicle Routing Problem with time window, the Multi-Depot Vehicle Routing Problem and the Open Vehicle Routing Problem.

ALNS is a framework in which a number of algorithms compete to modify the current solution. A set of iterations is conducted to find the best solution. An algorithm is chosen to destroy a solution and an algorithm is chosen to repair the solution in the hope of finding a better solution [5].

The destruction algorithm usually disconnects a number of nodes from their current route and places them into the unassigned node pool. One the other hand, the constructive algorithm inserts the node from the unassigned node pool to the route of solution.

The solution obtained after the destruction-construction procedure is accepted or rejected based on the comparison of the new and current solution. The algorithm stops running after a predetermined number of iterations. [6]
Figure 2: Adaptive Large Neighborhood Search Demonstration

The above schema is a simple application of The Adaptive Large Neighborhood Search, in which the starting solution goes through the destroy $D_k$ and repair $R_k$ process during multiple numbers of iterations till finding the optimal solutions.

**AUI waste collection**

The first case that I will be working on in this project is waste collection in Al Akhawayn University (AUI). I will apply the waste optimization model discussed below using the web application LogVRP. The first step was data collecting. After interviewing, the manager and responsible of waste collection in AUI, I was able to get all data needed. Actually AUI has only one vehicle assigned for waste and garbage collection. Its capacity is: 2700 KG. The bins available on campus have a maximum capacity of 80 kg. Station or
Stops of AUI vehicle for waste collection are divided in two groups as explained in the following tables:

Table 1: Route followed by AUI waste collecting vehicle in the Residential Area

<table>
<thead>
<tr>
<th>Order</th>
<th>Stop</th>
<th>Waste in Kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Gate</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Restaurant</td>
<td>720 kg</td>
</tr>
<tr>
<td>3</td>
<td>Residential bldgs. 1</td>
<td>480 kg</td>
</tr>
<tr>
<td>4</td>
<td>Residential Bldgs. 2</td>
<td>560 kg</td>
</tr>
<tr>
<td>5</td>
<td>Residential Bldgs. 3</td>
<td>480 kg</td>
</tr>
<tr>
<td>6</td>
<td>Building 38</td>
<td>160 kg</td>
</tr>
<tr>
<td>7</td>
<td>Building 39</td>
<td>240 kg</td>
</tr>
<tr>
<td>8</td>
<td>Main Gate</td>
<td>2640 kg</td>
</tr>
</tbody>
</table>
Table 2: Route followed by AUI waste collecting vehicle in the residential area

<table>
<thead>
<tr>
<th>Order</th>
<th>Stop</th>
<th>Waste Collected in KG</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Gate</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Ground and Maintenance</td>
<td>160 kg</td>
</tr>
<tr>
<td>3</td>
<td>Academic Area</td>
<td>560 kg</td>
</tr>
<tr>
<td>4</td>
<td>Gymnasium</td>
<td>160 kg</td>
</tr>
<tr>
<td>5</td>
<td>Main Gate</td>
<td>880 kg</td>
</tr>
</tbody>
</table>
In fact, AUI waste collecting vehicle operates everyday by making 2 rounds in the Residential Area and one round in the Academic Area every day. Therefore, the sum of garbage collected in the Residential Area is: \(2640 \times 2 = 5280 \text{ Kg}\) per day and \(880 \text{ Kg}\) in the Academic Area. Which make the estimated total waste collected every day is \(6160 \text{ kg}\).

*Figure 3: Map Representing the Actual Routes Traveled by AUI waste collecting vehicle*
Using LogVRP, I was able to calculate the sum of distances traveled by the AUI vehicle every day and its associated costs. The results are shown in the following table:

**Table 3: Costs for the current paths used by AUI vehicle to collect waste**

<table>
<thead>
<tr>
<th>Area</th>
<th>N. of Round</th>
<th>Capacity in Kg</th>
<th>Distance Traveled</th>
<th>Cost per Km</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Area</td>
<td>2</td>
<td>2620</td>
<td>2200 m *2 = 4400 m</td>
<td>1.2 Dh per Km</td>
<td>5.28 Dh</td>
</tr>
<tr>
<td>Academic Area</td>
<td>1</td>
<td>880</td>
<td>1000 m</td>
<td>1.2 Dh per Km</td>
<td>1.2 Dh</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
<td><strong>6160 kg</strong></td>
<td>5400 m</td>
<td>-</td>
<td><strong>6.48 Dh</strong></td>
</tr>
</tbody>
</table>

**Suggested Method**

After entering to needed data in LogVRP, an optimized route was calculated to find the shortest distance traveled by AUI vehicle to collect the waste. The solution proposed by LogVRP is having one vehicle with a capacity larger than the current one, almost double. The vehicle will collect waste once per day and can carry the waste of all bins in the university. The optimal route is the following:
### Table 4: Optimal route to collect waste in AUI

<table>
<thead>
<tr>
<th>Order</th>
<th>Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Gate</td>
</tr>
<tr>
<td>2</td>
<td>Ground and Maintenance</td>
</tr>
<tr>
<td>3</td>
<td>Restaurant</td>
</tr>
<tr>
<td>4</td>
<td>Residential Area 1</td>
</tr>
<tr>
<td>5</td>
<td>Residential Area 2</td>
</tr>
<tr>
<td>6</td>
<td>Residential Area 3</td>
</tr>
<tr>
<td>7</td>
<td>Building 38</td>
</tr>
<tr>
<td>8</td>
<td>Building 39</td>
</tr>
<tr>
<td>9</td>
<td>Academic Area and Gym</td>
</tr>
<tr>
<td>10</td>
<td>Main Gate</td>
</tr>
</tbody>
</table>
Figure 4: Optimal Route for waste collection in AUI suggested by LogVRP
Figure 5: Map showing the optimal route suggested by LogVRP for waste collection in AUI
The costs calculated below refer to fuel consumption of AUI vehicle during one trip. It takes into account, the distance, the fuel efficiency (12 L/Km) and the price of fuel. The calculated costs don’t include fixed costs such as: Driver Wage, Insurance, Registration and Maintenance.

Table 5: Costs of the optimal route

<table>
<thead>
<tr>
<th>Paths</th>
<th>Round</th>
<th>Capacity in Kg</th>
<th>Distance Traveled in Km</th>
<th>Cost per Km</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suggested Path</td>
<td>1</td>
<td>6160</td>
<td>3,4</td>
<td>1.2 Dh per Km</td>
<td>4.08 Dh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Total Cost</strong></td>
<td><strong>4.08 Dh</strong></td>
</tr>
</tbody>
</table>

Therefore, in case the waste collection manager of AUI chooses to operate with the suggested method, 2.4 Dh will be saved per day.

**CO₂ emission:**

High release of carbon dioxide affects negatively our environment. Climate Change and Global Warming are both strong consequences of high release of CO₂. Therefore, it is crucial to take into consideration our environment in each step we are taking. In average, the consumption of CO₂ for 12 l/100 km fuel consumption is 316 g/km [8]. Thus, by adopting the suggested method in which 2 km per day will be saved, 632 g per day of CO₂ will be saved as well.
The Suggested Vehicle

For waste collection, AUI is using a vehicle similar to the picture above with a capacity of 2700 kg. Since the suggested method by logVRP web application implies a vehicle with a capacity higher than 6500 kg, I suggest to buy a dropside trailer that will be attached to the small truck that AUI is using.

Figure 6: The vehicle used by AUI to collect Waste

Figure 7: Dropside Trailer that will be attached to AUI small truck
Therefore, there is no need to buy a new vehicle with a large capacity. It is perfectly sufficient to add a trailer of 4 tons at the back of the truck in order to collect AUI waste. The picture below illustrate the vehicle that can be used to optimize waste collection in AUI.

![Vehicle](image)

*Figure 8: The vehicle suggested to optimize the waste collection in AUI*

**Payback Period**

The added side drop trailer of 4 tons will cost 10,000 Dh. The cash saved from new equipment is 2.4 Dh per day, which is 74.4 Dh per Month. Since the vehicle will only operate during the fall, spring and summer, the estimated saved cash is 850Dh/Year.

The Payback period is **11 years**.
Metaheuristic Approach to Optimize Waste Collection

For the second part of the analysis, I decided to adopt the model of Periodic Vehicle Routing Problem in order to optimize the routes for waste collection. One of the major algorithms used to solve PVRD is the Tabu Search Algorithm.

The Tabu Search Algorithm (TSA)

The Tabu Search Algorithm was first introduced by Glover (1986). It is a metaheuristic approach to solve VRP. It starts from an incumbent solution and apply some moves or small changes to search for the most optimal solution.

Simple Application of TSA

In order to explain deeply the algorithm, I choose a problem with fictive data:

Cost Spanning Tree of 5 nodes along with constraints that allow or prohibit some edges to appear under certain conditions. Each edge is assigned a cost, therefore the objective is to find the minimum cost spanning tree.

<table>
<thead>
<tr>
<th>Edge</th>
<th>X1</th>
<th>X2</th>
<th>X3</th>
<th>X4</th>
<th>X5</th>
<th>X6</th>
<th>X7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>6</td>
<td>9</td>
<td>18</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>12</td>
</tr>
</tbody>
</table>

The two constraints are:

\[ X_1 + X_2 + X_5 \leq 1 \quad \rightarrow \quad \text{At most one of these edges is present in the tree} \]
\[ X_1 \leq X_3 \quad \rightarrow \quad \text{Edge } X_1 \text{ is present in the tree only } X_3 \text{ is in the tree} \]
Steps to solve the problem using TSA

Step 1: Initial Solution

The first step consists of building a starting tree with the minimum costs regardless of the constraints.

Step 2: Small Changes to the solution called “Moves”

After creating the initial solution, the algorithm starts repeatedly making some changes on it. Therefore it moves from one solution to another until the best feasible solution is found. The type of move that I am using in this case is edge swap (add and drop of edge). While solving the problem, a Tabu List records the edges that have been
moved to avoid doing the reverse later on. The Tabu List stores a limited number of moves $O(\ln(n))$, in which $n$ is the number of nodes [3].

In our case, the Tabu List length is 1.

The moves done to the initial solution are:

**Iteration 1:**

The best iteration would be dropping $X_1$ and Adding $X_3$ in order to get the best-cost change. No violation of constraints is recorded. Therefore $X_3$ is added to the Tabu List to prevent swapping the node in the upcoming iterations. Therefore, iteration 1 is the new best solution.

*Figure 10: Iteration 1 in TSA application*
Iteration 2:

To optimize further the costs, we can add $X_7$ and drop $X_8$. Then, $X_7$ is in the Tabu List. However, the first constraint is violated. So, the solution is not feasible.

*Figure 11: Iteration 2 in the TSA*
Iteration 3:

Now that the $X_3$ is no longer in the Tabu List, we can Add $X_2$ and drop $X_3$. No constraints are being violated and the new cost is less than the previous best solution.

Therefore, the current spanning tree is the optimal solution.

*Figure 12: Iteration 3 in TSA application*
Application of the Tabu Search Algorithm to the City of Marvdasht, Iran

Marvdasht City is located in Iran with 125 thousand inhabitants. The objective of the study is to optimize the routes of waste collection in a specific region in the city. The Area studied is 28689576 m²

Figure 13: Map of Marvdasht along with the area studied
Steps to solve the Marvasht Case using Tabu Search Algorithm and TransCAD software

**Step1: Initial Solution**

The first step in solving the case using TSA is building an initial solution by assigning routes to the fleet so that each collection points are visited according to its collection schedule. In this case, we have two ways in which bins are collected, either during even days (Tuesday- Thursday –Saturday) or odd days (Monday- Wednesday-Friday). No waste collection on Sunday.

**Step2: Changes and Moves on the initial Solution**

After creating the initial solution, the algorithm starts repeatedly making some changes on it. Therefore it moves from one solution to another until the best feasible solution is found. The moves or changes that the algorithms is considering are the following:

- A collection point can be removed from one route to another scheduled the same day.
- A change in the collection schedule of some stations
- Differently linked two routes that intersect. This move eliminate expensive intersections between routes
- Containers that exists on two routes are redistributed in order to solve difficult intersections routes [3]
While running the algorithm, number of collection points move from one route to other to find the optimal solution. The Tabu List records these movements in order to avoid doing the reverse later on. Therefore, a list of forbidden routes is updated after each iteration. When a set of possible route is generated, the last best solution that is not on the forbidden routes becomes the new current and most promising solution. If the number of iteration has stopped, then the new current solution is the optimal route. Otherwise, we continue iterations till finding the solution. [3]

**Step 3: Generate the solution using TransCAD Software**

Since the case proposed is very complicated, the use of optimization software is necessary. Therefore, the software used to solve the case is TransCad Transportation Planning.

One of the algorithms that the software work with is Tabu Search Algorithm [7]. The software is considered a Geographical Information System (GIS) designed for logistics purposes. It combines transportation modeling and GIS in a single platform. According to the software website, TransCad provides:
- A powerful engine with special extensions for transportation
- Visualization and Analysis for transportation applications
- Application of vehicle routing, public transit, site location, logistics and territory management [7]

**Methodology to solve the problem using TransCad**

Data Input in the Software

In order to solve the problem, two input files containing specific information on each vehicle and stop are required. The vehicle file has:

- Depot ID, Type (Code of vehicle), Capacity, Number of vehicle of each type and the cost of operation

The second file contains the coordination of the stations or stops for waste collection.
Result and Benchmark

Current situation of Waste collection in Marvasht, Iran

Figure 14: The current routes to collect waste in Marvasht, Iran

The figure above explains the current routes in which waste collection is proceeded. Three shifts are done weekly (on Daily, Odd and Even day basis explain earlier in the report) using two homogenous trucks with a 5000 kg capacity.

The table below summarized the distance traveled by the vehicles in the current method used to collect waste in Marvasht City
Table 6: Analysis of the current routes traveled by the two vehicles

<table>
<thead>
<tr>
<th>NO.</th>
<th>Truck Type</th>
<th>Length of collection (m)</th>
<th>Number of U-turn</th>
<th>Total time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Truck 1 - Odd Day</td>
<td>9031</td>
<td>5</td>
<td>5129</td>
</tr>
<tr>
<td>2</td>
<td>Truck - Even day</td>
<td>11945</td>
<td>15</td>
<td>8434</td>
</tr>
<tr>
<td>3</td>
<td>Truck 2 – Odd Day</td>
<td>9801</td>
<td>8</td>
<td>6070</td>
</tr>
<tr>
<td>4</td>
<td>Truck 2 – Even day</td>
<td>11218</td>
<td>1</td>
<td>5894</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>41995</td>
<td>29</td>
<td>25527</td>
</tr>
</tbody>
</table>
Suggested method for waste collection optimization in Marvasht, Iran

After data input, the software was able to generate optimal routes for waste collection for both even and odd days as shown below:

*Figure 15: Optimal Route for Truck 1 generated by TransCAD*
Figure 16: Optimal Route for truck 2 generated by TransCAD
Table 7: Analysis of the suggested routes by TransCAD for both trucks

<table>
<thead>
<tr>
<th>NO.</th>
<th>Truck Type</th>
<th>Length of collection (m)</th>
<th>Number of U-Turn</th>
<th>Total time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Truck 1 - Odd Day</td>
<td>8546</td>
<td>2</td>
<td>4237</td>
</tr>
<tr>
<td>2</td>
<td>Truck - Even day</td>
<td>10039</td>
<td>4</td>
<td>4761</td>
</tr>
<tr>
<td>3</td>
<td>Truck 2 – Odd Day</td>
<td>7312</td>
<td>3</td>
<td>3882</td>
</tr>
<tr>
<td>4</td>
<td>Truck 2 – Even day</td>
<td>9409</td>
<td>2</td>
<td>4672</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>35306</td>
<td>11</td>
<td>17552</td>
</tr>
</tbody>
</table>

**Comparison and Analysis**

The suggested routes by TransCAD are compared to the current routes. The results demonstrate that a reduction of **15.7%** of total distance traveled and **29.43%** in the total time was recorded. In numbers, the truck 1 and truck 2 reduced their traveled distance by 18585m and 16721 m respectively. The same way, the time of travel was reduced by 77min and 57min for the two truck. Furthermore, the U-turns were reduced which decreased remarkably the time traveled by the two vehicles.
Table 8: Reduction percent of the length of routes and total time

<table>
<thead>
<tr>
<th>NO.</th>
<th>Truck Type</th>
<th>Reduction percent in length of routes (m)</th>
<th>Reduction percent in Total Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Truck 1 - Odd Day</td>
<td>5.4</td>
<td>17.39</td>
</tr>
<tr>
<td>2</td>
<td>Truck - Even day</td>
<td>15.96</td>
<td>43.55</td>
</tr>
<tr>
<td>3</td>
<td>Truck 2 – Odd Day</td>
<td>25.4</td>
<td>36.05</td>
</tr>
<tr>
<td>4</td>
<td>Truck 2 – Even day</td>
<td>16.1</td>
<td>20.73</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>15.7</td>
<td>29.43</td>
</tr>
</tbody>
</table>

After the running the software TransCAD, a reduction of 15.7% of total distance traveled and 29.43% in the total time was recorded. Therefore, the algorithm is definitely applicable in this case.

**CO₂ Emission**

The emission of CO₂ for a waste collection vehicle and a fuel consumption of 12 l / 100 km is 316 g / km. Therefore, by adopting the method suggested by TranSCAD software, 7 km per day will be saved, which is 2212 g per day of CO₂ will be
saved as well. Therefore, the optimal route will definitely contribute to a better environment.

**Application in Morocco**

Since the software succeed in optimizing the waste collection routes in Marvdasht city in Iran, it is definitely possible to apply the same model (Periodic Vehicle Routing Problem) to any city in Morocco. By following the same methodology, the costs of waste collection will definitely be reduced along with the CO$_2$ emission. Therefore, an economical and environmental progress will be reached.
Steeple Analysis

- Solving Vehicle Routing Problem will have an impact on Green Logistics as it will reduce pollution. As a result, the society will benefit from a cleaner environment.

- The vehicle routing problem will be solved using models and algorithms implemented in softwares and web application

- Solving the vehicle routing problem is definitly ecofriendly as it will optimize the number of vehicles used along with the routes traveled. As a result, the quantity of gas or fuel consumed will decrease significantly. Furthermore, the CO2 emission will decrease

- This project main objective is to reduce the costs related to transportaion as it can represent up to 30% of expenses of a firm. Therefore if the results are being used in a large scale, important amount money will be saved.

- The implementation of this project will be in accordance with the government regulations and policies related to the legal quantity allowed to be shipped within vehicles

- Solving the VRP will results in a friendly and cleaner environment

*Figure 17: STEEPLE Analysis*
Recommendations and Future Developments

In this project, I was able to analyze deeply the Capacitated Vehicle Routing Problem along with the Periodic Vehicle Routing Problem using heuristic and metaheuristic algorithms. The solutions were generated using the web application logVRP and TranSCAD software.

Since there exist no standard format to solve and visualize VRP, all solutions found are not the most exact ones and can be subject of improvement because of the multiple limitations in software and its associated solution algorithm.

Therefore, for future work in this subject, I recommend:

1. Avoiding using the web application LogVRP because of the limited number of stations and vehicles that we can implement in its free version.
2. It is also important to mention that the larger the problem gets, the greater the processing time of software is. Therefore, it is recommended to operate with clustering method and use a combination of TSPs to solve the problem.
3. The solution generated by optimization software don’t take into account the traffic in the routes. Therefore, the shift duration of the vehicle remains approximate and not exact.
4. For further optimization of the traveled distance for waste collection vehicles, a new developed metaheuristic algorithm was recently introduced. In fact, the algorithm work along with smart bins that are equipped with sensors that detects if the bin are ready to be picked. Therefore, this method has decreased remarkably the costs and increase the waste collection efficiency.
Conclusion

In this project, I was able to analyze deeply the Capacitated Vehicle Routing Problem along with the Periodic Vehicle Routing Problem using heuristic and metaheuristic algorithms.

I choose to work in my capstone on Waste Collection as a direct application of the vehicle routing problem. The first part covers the optimization of waste collection in AUI in which I succeeded to reduce the distance traveled by 2 Km per day. Consequently, a decrease in costs and CO₂ emission was recorded.

In the second part, I demonstrate how we can solve a waste collection case in a large scale problem by taking the case of Iran as an example. Also, it included a detailed explanation of the Tabu Search Algorithm in a simple application solved manually to further understand the algorithm used to solve large scale vehicle routing problem.

Last but not least, I have encountered many challenges during the implementation of my capstone project. VRP is considered one of the hardest problems in logistics in which the solution is always subject to improvement. Since I wasn’t familiar with the subject, it took me some time to understand its models, variants and solution methods. However, the research I did was very enriching as I learned how to use multiple optimization software, web application logVRP, graph theory to solve Vehicle Routing Problem and apply it to waste collection.
References


http://shodhganga.inflibnet.ac.in/bitstream/10603/26322/7/07_chapter%202.pdf