B.Sc. in Computer Science and Engineering Thesis

Garbage Collection Routing Based on Traveling Salesman Problem

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CANDIDATES' DECLARATION

This is to certify that the work presented in this thesis, titled, "Garbage Collection Routing Based on Traveling Salesman Problem", is the outcome of the investigation and research carried out by me under the supervision of Dr. Sadia Sharmin.

It is also declared that neither this thesis nor any part thereof has been submitted anywhere else for the award of any degree, diploma or other qualifications.

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CERTIFICATION

This thesis titled, **"Garbage Collection Routing Based on Traveling Salesman Problem"**, submitted by the student as mentioned below has been accepted as satisfactory in partial fulfillment of the requirements for the degree B.Sc. in Computer Science and Engineering in September, 2017.

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Md. Mottakin Chowdhury

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ABSTRACT

Write your thesis abstract here.

Chapter 1

Introduction

As a regular citizen of Dhaka city, sitting in the middle of an 'infinite' amount of traffic jam at the busiest hours on a working day, can easily make anyone think about the very common question: *how many people are there in Bangladesh?*

The thing is, this question is very common and of course equally important. We have too many people. And that is even more significantly large comparing the world beyond our border.

When a country has too many people, it has too many things to do. From meeting the basic needs to advanced ones, there are always a very huge amount of things to be done. Since we have a large population, we have large production systems for anything. And this leads us to massive amount of wastes that are created by our people, *every single day.*

So when a country has these many people creating this much amount of wastes throughout the years, it is enormously important to build up a well organized waste management system to get rid of it. That does not necessarily mean that lower population does not need a quality waste management system. It is always important, regardless of the number of population a country may have, to build up a waste management so that the people living in the country can actually lead some comfortable life.

And consequently, one very important task in a waste management system is to collect the solid wastes from garbage bins located around the city and dispose them to a certain place for farther processing. In this regard, we need garbage collection vehicles to do the collection.

Throughout the years of algorithmic research based on real life applications, finding out an optimal *garbage vehicle collection route* has been a popular problem. In our thesis, we take a look at it from different perspectives.

1.1 Waste Collection: Some Basic Ideas

Before jumping into further discussion on our topic, it is in order that we build up some basic ideas regarding waste collection.

According to a report by World Bank [1],

"Waste collection is the collection of solid waste from point of production (residential, industrial commercial, institutional) to the point of treatment or disposal."

This definition points us to one very important direction: we are interested in solid wastes which are, of course, collectible. And these wastes are exclusively denoted as MSW (Municipal Solid Wastes).

1.1.1 Classification of MSW Collection

There are various ways to collect solid wastes in a municipal area. According to the report by World Bank [1], these are some major ways to collect MSW:

- **House-to-House**: Waste collectors visit each individual house to collect garbage. The user generally pays a fee for this service.
- **Community Bins:** Users bring their garbage to community bins that are placed at fixed points in a neighborhood or locality. MSW is picked up by the municipality, or its designate, according to a set schedule.
- **Curbside Pick-Up:** Users leave their garbage directly outside their homes according to a garbage pick-up schedule set with the local authorities (secondary house-to- house collectors not typical).
- **Self Delivered:** Generators deliver the waste directly to disposal sites or transfer stations, or hire third-party operators (or the municipality).
- **Contracted or Delegated Service:** Businesses hire firms (or municipality with municipal facilities) who arrange collection schedules and charges with customers. Municipalities often license private operators and may designate collection areas to encourage collection efficiency.

The above classification of garbage collection methods leads us to another very important direction: we are considering the method of **Community Bins** where municipal corporation sends garbage collection vehicles to collect the wastes disposed by the city-dwellers.

Figure 1.1: *Separate garbage bins in Singapore [1].*

1.1.2 MSW Collection in Developed Cities

Due to the technological advances along with rapid urbanization around the world, it has become incessantly important for the countries to build up an efficient waste management system. To meet this burning need, developed countries have been investing billions of dollars throughout the years. And consequently, the more a country is capable of managing its wastes in an optimal-environment-friendly way, the more it has the scope of providing a healthy life style to its citizens.

As a result, we have seen different developed cities to implement various methods to collect its wastes and dispose them. For example, countries which are more interested in garbage treatment and recycling systems, try to classify the garbage at the very beginning, like in Singapore shown in Figure 1.1.

The garbage collection vehicles follow particular schedules regarding when to come and collect garbage in these cities. There are disposal points where the collected wastes are taken care of by recycling or further processing. The whole system is massive and dynamic. Since the developed countries are investing more and more amount of money in this sector, further improvements in garbage collection is evident.

One of the very popular garbage collection ideas which has been already implemented in many smart cities, is using IoT (Internet of Things) to build up an automated garbage collection system. Many research papers and publications have popularized this IoT based idea over the years and consequently, this is getting much more attention. The idea is quite interesting and realistic. According to [6],

”The system consists of smart containers or smart bins, each bin or container installed with

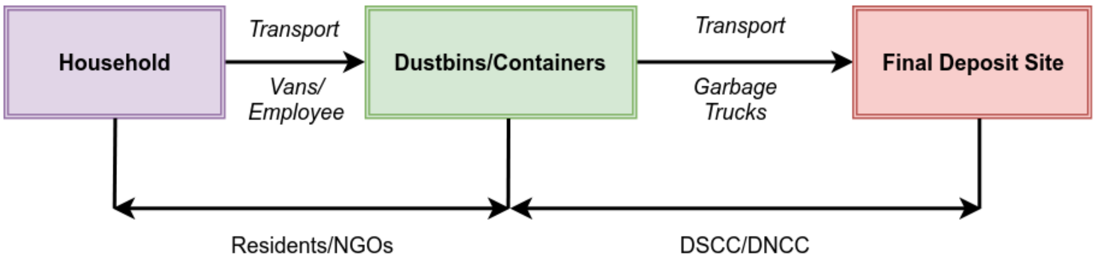

Figure 1.2: *Garbage collection in Dhaka city [2].*

Arduino Uno, ultrasonic sensor and Radio Frequency (RF) transmitter on the top of the container. When the container is full of waste, it sends signal to the control center which will have the level of waste in the containers and through GSM/GPRS , a message (SMS) will send to the mobile phone of the truck driver of which waste bin is full and need to be emptied."

So what is the motivation behind using a full-fledged IoT system in garbage bins? It is actually quite intuitive. When garbage bins get overflown, the environment around them starts to get affected. As a result, it is really important to collect the garbage from these bins as soon as they are full. This job is done by using IoT - the buzzword in today's world of technological wonders.

1.1.3 MSW Collection in Dhaka

Unfortunately, we have a very different and unexpected scenario in the capital city of Bangladesh. The MSW collection system is not very well organized in Dhaka which leads us to suffer from serious environmental crises regarding solid waste management. In spite of being the heart of the country, the waste management and collection system has not been developed as much as the other aspects of the city.

According to [7], Dhaka city is now producing 4600-5110 tons of waste per day. There are two administrative units, Dhaka North City Corporation (DNCC) and Dhaka South City Corporation (DSCC), who are in charge of collecting waste and its disposal in their particular ranges. But very unfortunately, only approximately 50 percent of the total wastes produced are collected and processed by these two administrative units.

In this paper [7], the methodology of MSW collection in Dhaka is categorized and then analyzed based on environmental perspective. Their study area was the 33 no. ward of DSCC.

The methods discussed in the paper are noted below:

- **Household Waste Collection by Vans:** In this method, several vans (like in Figure 1.3 are sent to the households of a locality to collect the garbage produced in each of the houses.

Figure 1.3: *Waste collecting vans [3].*

- **Household Waste Disposal by Employment:** In many regions, people appoint someone to collect the wastes from the households to dispose them to the nearest garbage disposal bins established by the authority.

- **Roadside Dumping Areas:** There are some roadside dumping areas around the city where dwellers dump their wastes. Unfortunately, these roadside dumping areas are extremely unhygienic and injurious to the environment.

- **Roadside Garbage Bins:** Authority of a locality establishes garbage bins in a suitable place where dwellers can easily dump their wastes.

- **Garbage Collection Vehicles:** Following different schedules, garbage collection vehicles visit all these dumping places to collect the MSW produced. They do not follow very definite schedule. And more surprisingly, it is very common that no garbage collection vehicles come to collect wastes for a long time.

So overall, the garbage collection procedure that we are interested in can be depicted in Figure 1.2 based on [2]. In this figure, we see two particular sections into which the whole collection system is divided into. One part is handled by the residents or some NGOs where the other part is the concern of two city corporations of Dhaka.

Our purpose is to find out optimal routes for the garbage trucks maintained by DNCC and DSCC. The next section briefly tries to describe the motivation behind our work. Further chapters approach to our problem gradually.

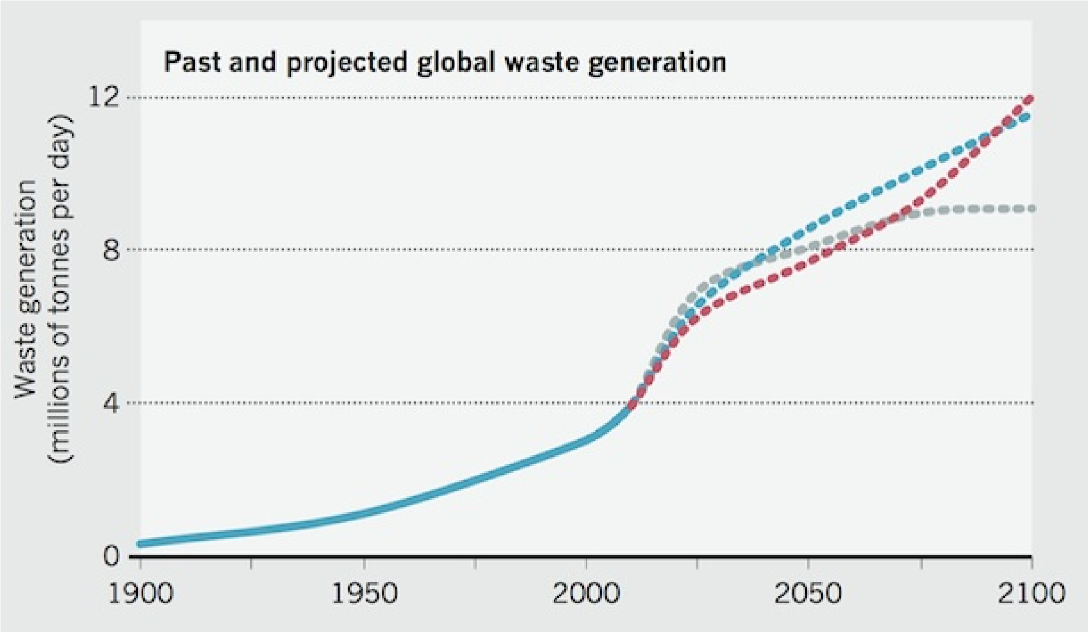

Figure 1.4: *Global waste generation*

1.2 Motivation

It is very evident that efficient waste management is a burning need. In this section, we try to build up the motivation regarding the necessity of optmizing the grabage collection routing.

1.2.1 Waste Generation: Where is the World Heading?

According to [1], current global MSW generation levels are approximately 1.3 billion tonnes per year, and are expected to increase to approximately 2.2 billion tonnes per year by 2025. This represents a significant increase in per capita waste generation rates, from 1.2 to 1.42 kg per person per day in the next fifteen years. However, global averages are broad estimates only as rates vary considerably by region, country, city, and even within cities.

There are practically two scenarios in current world regarding waste management. In one part of the world, some countries are showing concern in developing a full functioning waste management system. Still some of these countries like China or USA are having a hard time to achieve their purpose. On the other hand, there are some other countries which are less concerned regarding the waste management crisis they are facing or they will have to face in near future.

The only one word that can actually describe the scenario of the world is: *alarming*. This earth is a *pale blue dot* [8] of seven billion people. The amount of wastes that this amount of people are responsible for producing every day is simply staggering.

We need a way to manage the wastes we are responsible for. Not for the sake of the environment,

Figure 1.5: *Garbage bins creating public inconvenience [4].*

but for the sake of humanity.

And in this regard, a small improvement in MSW collection can contribute to the whole management system in a great deal. From the perspective of the whole world, this is surely evident.

1.2.2 A Brief Scenario of MSW Management in Dhaka

The idea which we tried to build up in the previous section is that the city of Dhaka has a huge population with even huger MSW production every day. Solid waste management, without any doubt, represents a very concerning issue due to the fact that it causes land contamination if transparently dumped, water contamination if dumped in the swamps and air contamination if smoldered or burnt openly. Dhaka city is confronting serious environmental imbalance because of the uncollected transfer of waste on avenues and other open territories, obstructed seepage by tainting of water assets close uncontrolled dumping locales. Almost all the area of this city does not experience adequate waste management [7].

On top of that, approximately about 40 percent waste is collected by the authority (DNSC and DSCC), but uncollected waste is dropped in open dustbins beside the roads which is of course, very disastrous to the environment. Considering the Dhaka city's fast development and lacking waste management, the requirement for enhanced strong waste management shows a key open door for concurrently tending to the environmental and health issue [9]. There is a variation of waste generation between Old Dhaka and New Dhaka. Dhaka creates roughly 1.65 million metric huge amounts of strong waste every year. Per person waste generation is somewhere around 0.29 and 0.60 kilograms dependent upon the people of various income levels [10].

Figure 1.6: *Trucks disposing of garbage in a location near Uttara, Dhaka.*

On the other hand, it is not very easy to expect that the authorized body is performing the duty of collection in a well-organized way. Apart from schedule failure and overflowing bins, there is the problem of inconsiderate allocation of garbage bins. As mentioned in the report [4], the authority is failing to introduce proper locations for the garbage bins to be established. This failure in management is responsible for public nuisance every day. Then again, people of some localities themselves can be responsible for the unhealthy environment they are living in. Specially it is very common to find out people throwing their garbage to some random corner which eventually turn into a garbage dumping area.

So it should be clear by now that to manage this tremendous amount of waste, we need a fairly efficient waste management as well as collection system. The more we can optimize the collection procedure, the more it will be easier for us to manage the wastes through further treatment and processing. There are garbage collecting trucks which are deployed by the central authority (DNSC and DSCC) to do the collection but there are scopes to improve the whole procedure. We are interested in optimizing the route for these vehicles in our thesis.

It should be noted that to solve all those problems mentioned till now is not very easy a task. There are lots of factors creating significant amount of embankments in the process of solving all these problems. Starting from the amount of population and huge waste production the authority needs to deal with to the unhelpful behaviour of city dwellers - lots of such scenarios are responsible for the mismanagement we face all the time.

1.2.3 The Last Words

So finally, what we want to establish is that waste management in an efficient way is a burning need in the perspective of current worlds environmental and infrastructural scenario. In developed cities around the world, this issue is regarded as the few of the most important issues and thousands of projects as well as researches are being conducted in a massive scale. As an emerging nation of the future world, we believe that Bangladesh should look for methodical ways to collect and manage its wastes. Not only because of the current needs we are dealing with, but also because of the futurist necessities we will encounter. As a part of meeting the upcoming challenges Bangladesh will have to deal with in near future, we are interested in improving garbage collection methods based on algorithmic approach.

In the next chapter we try to build up some technical ideas or backgrounds which are exclusively important for approaching towards a solution for the problem we are interested in. We will also have a look at various approaches done by other researchers as well as the algorithms developed by them in further chapters.

Chapter 2

Background

In the previous chapter, we lighted upon the garbage collection basic concepts along with the current situation of Dhaka city. To build up a better waste management system for our city, we need a lot of technological implementations in this sector.

It has already been noted several times that we are in quest of finding out an optimal route for the garbage collection trucks that are deployed in the city. In order to complete our quest for solution, it is in order to discuss the technical ideas. In this chapter, we aim at building the necessary technical background to further proceed towards the solution of our problem.

2.1 Notations

Some frequently used notations in this paper are noted below:

- V - a set of nodes/vertices.
- E - a set of edges built up using V.
- $G(V, E)$ - denotes a graph of V and E. If it is not mentioned explicitly, $G(V, E)$ is always an un-directed graph.
- $C(u, v)$ - denotes the cost between two vertices u and v. If not mentioned otherwise, $C(u, v) = C(v, u)$ which is intuitive in case of un-directed graphs.
- $MST(G)$ - the Minimum Spanning Tree of $G(V, E)$.

Less frequently used notations will be introduced in the respective sections.

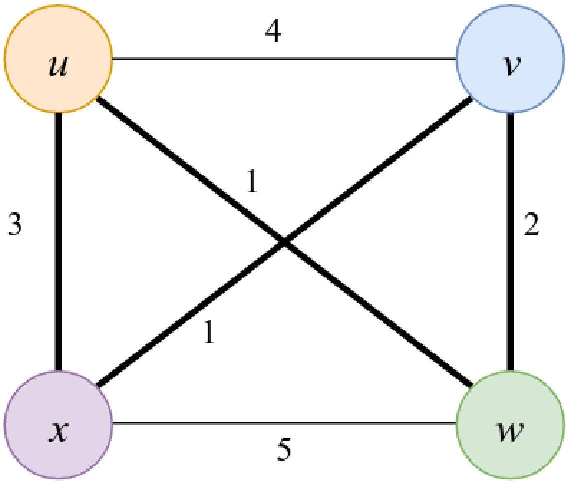

Figure 2.1: *An instance of TSP. The thick lines denote the minimum cost tour, with cost 7 [5].*

2.2 The Traveling Salesman Problem (TSP)

One of the very popular and universally studied problems of Computer Sciences would be Traveling Salesman Problem (TSP). This is the core foundation of our thesis work.

2.2.1 Definition

TSP has been defined in [5] as:

In the traveling-salesman problem, which is closely related to the Hamiltonian-cycle problem, a salesman must visit n cities. Modeling the problem as a complete graph with n vertices, we can say that the salesman wishes to make a tour, or Hamiltonian cycle, visiting each city exactly once and finishing at the city he starts from. The salesman incurs a non-negative integer cost $c(i, j)$ *to travel from city* i *to city* j*, and the salesman wishes to make the tour whose total cost is minimum, where the total cost is the sum of the individual costs along the edges of the tour.*

As an example, we can check out Figure 2.1. The minimum-cost tour in this example is (u, w, v, x, u) with cost 7.

In the definition noted above, the graph G is modeled as a complete graph. The cost function c is a function from $V \times V \to \mathbb{Z}$. And if the G has a traveling-salesman tour with cost at most $k \in \mathbb{Z}$, then

$TSP = (G, c, k)$.

2.2.2 NP-completeness of TSP

TSP is **NP-complete**. This is a kind of bad news as this class of problems are not easy to solve. We cannot solve this problem quickly. To be more formal, we have no polynomial time solution to solve this problem. As a result, over the years we have approached this problem using [11]:

- **Heuristics:** If we cannot quickly solve the problem with a good worst case time, we can at least try to use some heuristics to solve a reasonable fraction of the common cases.
- **Approximation:** A lot of the time it is possible to come up with a provably fast algorithm, that doesn't solve the problem exactly but comes up with a solution you can prove is close to right.
- **Exponential Time Solution:** Trying to solve the problem with an exponential time solution is also used in mostly small cases.

The proof for the NP-completeness of TSP can be found in [5] provided in **Theorem 34.14**. The proof is conducted by first showing that TSP is NP, then it is proved to be an NP-hard based on its connection with Hamiltonian cycle.

To be noted that the naive solution complexity of TSP is $\mathcal{O}(n!)$. In this naive approach, all different permutation of the nodes are considered and the tour cost following each permutation is calculated. Then we take the minimum one.

Not to mention that very rarely this naive approach is used. A better approach is using *Dynamic Programming* with *bitmasks*. This approach is further discussed later.

2.3 Classification of TSP

TSP can be divided into three classes based on the salesmen or nature of the graph. They are [12]:

- **sTSP:** Symmetric TSP. Let $V = v_1, v_2, ..., v_n$ be a set of cities, $E = \{(r, s) : r, s \in V\}$ be the edge set, and $d_{rs} = d_{sr}$ be a cost measure associated with $(r, s) \in A$. The $sTSP$ is the problem of finding a minimal length closed tour that visits each city once. If the cities $v_i \in V$ are given by their coordinates (x_i, y_i) and d_{rs} is the *Euclidean distance* between r and s, then we have something called *Euclidean* TSP.
- **aTSP:** Asymmetric TSP. This is same as $sTSP$ but only opposite in one criteria. At least for one edge (r, s), $d_{rs} \neq d_{rs}$.

- **mTSP:** Multiple TSP. In a given set of nodes, let there are m salesmen located at a single depot node. The remaining nodes (cities) that are to be visited are intermediate nodes. Then, the $mTSP$ consists of finding tours for all m salesmen, who all start and end at the depot, such that each intermediate node is visited exactly once and the total cost of visiting all nodes is minimized. The cost metric can be defined in terms of distance, time, etc.

  There are some variations of $mTSP$ which can be of some interest in our thesis:

  - *Single vs. Multiple Depots:* In the single depot, all salesmen finish their tours at a single point while in multiple depots the salesmen can either return to their initial depot or can return to any depot keeping the initial number of salesmen at each depot the same after the travel is finished.
  - *Number of Salesmen:* The number of salesman in the problem can be fixed or a bounded variable.
  - *Cost:* When the number of salesmen is not fixed, then each salesman usually has an associated fixed cost incurring whenever this salesman is used. In this case, the minimizing the requirements of salesman also becomes an objective.
  - *Timeframe:* Here, some nodes are needed to be visited in a particular time period that is called time window which is an extension of the $mTSP$, and referred as *Multiple Traveling Salesman Problem* with specified *timeframe* $(mTSPTW)$. We can easily relate the research on garbage collection within time-window with $mTSPTW$.

  Interestingly, different problems regarding vehicle routing are based on $mTSP$. We have seen approaches to the garbage collection routing problem based on $mTSP$ along with fixed time-windows.

2.4 Linkage of TSP with Real Life Applications:

It is obvious that TSP will have real-life applications. Below we discuss couple of them:

- **Drilling of Printed Circuit Boards:** A direct application of the TSP is in the drilling problem of printed circuit boards (PCBs). To connect a conductor on one layer with a conductor on another layer, or to position the pins of integrated circuits, holes have to be drilled through the board. The holes may be of different sizes. To drill two holes of different diameters consecutively, the head of the machine has to move to a tool box and change the drilling equipment. This is quite time consuming. Thus it is clear that one has to choose some diameter, drill all holes of the same diameter, change the drill, drill the holes of the next diameter, etc. Thus, this drilling problem can be viewed as a series of

Figure 2.2: *PCB drilling.*

TSPs, one for each hole diameter, where the *cities* are the initial positions and the set of all holes that can be drilled with one and the same drill. The *distance* between two cities is given by the time it takes to move the drilling head from one position to the other. The aim is to minimize the travel time for the machine head. [13].

- **Overhauling Gas Turbine Engines:** It occurs when gas turbine engines of aircraft have to be overhauled. To guarantee a uniform gas flow through the turbines there are nozzle-guide vane assemblies located at each turbine stage. Such an assembly basically consists of a number of nozzle guide vanes affixed about its circumference. All these vanes have individual characteristics and the correct placement of the vanes can result in substantial benefits (reducing vibration, increasing uniformity of flow, reducing fuel consumption). The problem of placing the vanes in the best possible way can be modeled as a TSP with a special objective function [14].

- **X-Ray Crystallography:** Analysis of the structure of crystals [15] is an important application of the TSP. Here an X-ray diffractometer is used to obtain information about the structure of crystalline material. To this end a detector measures the intensity of X- ray reflections of the crystal from various positions. Whereas the measurement itself can be accomplished quite fast, there is a considerable overhead in positioning time since up to hundreds of thousands positions have to be realized for some experiments. In the two examples that we refer to, the positioning involves moving four motors. The time needed to move from one position to the other can be computed very accurately. The result of the experiment does not depend on the sequence in which the measurements at the various positions are taken. However, the total time needed for the experiment depends on the sequence. Therefore, the problem consists of finding a sequence that minimizes the total positioning time. This leads to a TSP.

- **Computer Wiring:** [16] reported a special case of connecting components on a computer board. Modules are located on a computer board and a given subset of pins has to be connected. In contrast to the usual case where a Steiner tree connection is desired, here the requirement is that no more than two wires are attached to each pin. Hence we have the problem of finding a shortest Hamiltonian path with unspecified starting and terminating points. A similar situation occurs for the so-called testbus wiring. To test the manufactured board one has to realize a connection which enters the board at some specified point, runs through all the modules, and terminates at some specified point. For each module we also have a specified entering and leaving point for this test wiring. This problem also amounts to solving a Hamiltonian path problem with the difference that the distances are not symmetric and that starting and terminating point are specified.

- **The Order-picking Problem in Warehouses:** This problem is associated with material handling in a warehouse [17]. Assume that at a warehouse an order arrives for a certain subset of the items stored in the warehouse. Some vehicle has to collect all items of this order to ship them to the customer. The relation to the TSP is immediately seen. The storage locations of the items correspond to the nodes of the graph. The distance between two nodes is given by the time needed to move the vehicle from one location to the other. The problem of finding a shortest route for the vehicle with minimum pickup time can now be solved as a TSP.

- **Vehicle Routing:** Suppose that in a city n mail boxes have to be emptied every day within a certain period of time, say one hour. The problem is to find the minimum number of trucks to do this and the shortest time to do the collections using this number of trucks. As another example, suppose that n customers require certain amounts of some commodities and a supplier has to satisfy all demands with a fleet of trucks. The problem is to find an assignment of customers to the trucks and a delivery schedule for each truck so that the capacity of each truck is not exceeded and the total travel distance is minimized. Several variations of these two problems, where time and capacity constraints are combined, are common in many real- world applications. This problem is solvable as a TSP if there are no time and capacity constraints and if the number of trucks is fixed (say m). In this case we obtain an $mTSP$ [16].

The last application of TSP interests us the most. It has long been studied as a solution approach for various kinds of Vehicle Routing Problems (VRPs).

The sections written above were intended to building up concepts regarding TSP and its real-life applications. The next section gives us a *literature review* on our topic.

2.5 Literature Review

In this section, we intend to give a look back to the previous work related to our topic.

In [18], authors solve the waste collection routing problem from individual inhabitants. This type of waste collection routing problems is determined as kerbside collection. This problem was modified to the problem of the assignment of vehicles to tasks. The presented method in this paper designates the set of tasks which are assigned to each vehicle, so it designates the routes of vehicles. The method consists of two stages. In the first stage the tasks were designated, whereas in the second stage the assignment of vehicles to tasks was made.

In order to solve the assignment problem, the authors considered several variables like: *set of nodes, size of waste, waiting time in loading and unloading, distance between the points in the transportation network, number of drivers, number of trucks, expected unloading time etc.*

Then they tried to optimize the cost based on the following optimization function:

$F(X, Y) = KZZ(X) + KZP(X) + KPZ(Y) + KPP(Y)$

Where, $KZZ(X)$ - the costs related to the fuel consumption in the tasks, $KZP(X)$ - the costs related to the hourly rate of a driver, $KPZ(Y)$ - the costs related to the fuel consumption in the assignment route, $KPP(Y)$ - the costs related to the hourly rate of a driver in the assignment route.

Finally, to do the optimization phase, the authors used a *hybrid algorithm* as a heuristic.

On the other hand, the paper [19] proposed a waste collection system based on positions of waste bins, the road network and the population density in the area under study. In addition, waste collection schedules, truck capacities and their characteristics were also taken into consideration. The authors basically used MST to locate the shortest possible routes to collect waste from all dustbins in their study region. They took a small part of Kolhapur city as the case study area. The Corporation of Kolhapur has divided its area in about 11 sanitary wards solid waste collecting programs, where in general each one includes approximately 100 waste bins. Any garbage truck that is responsible for the collection of the solid waste in that given area must visit all the bins in order to complete its collection program.

After collecting data and building up a garbage bins map of the study region, the MST of the study region was built up. This paper proposed the route of MST to be an optimized route for their study area.

Genetic Algorithm was used in the paper [20]. In this paper, the proposed MSW management system is based on a geo-referenced spatial database supported by a geographic information system (GIS). The GIS takes into account all the required parameters for solid waste collection. These parameters include static and dynamic data, such as the positions of waste bins, the road

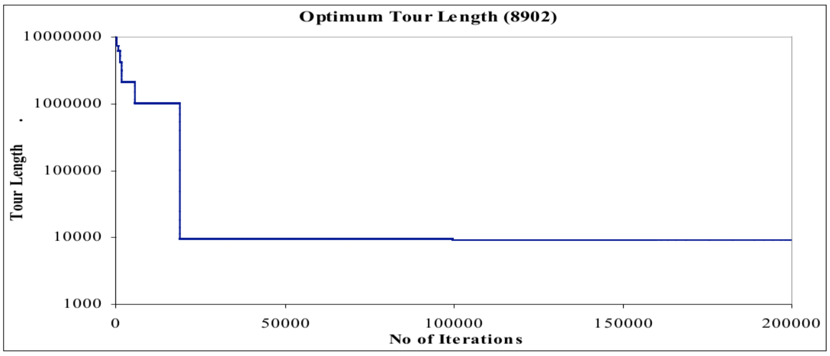

Figure 2.3: *The best result in GA Algorithm.*

network and its related traffic, as well as the population density in the area under study. In addition, waste collection schedules, truck capacities and their characteristics were also taken into consideration in their work. Spatio-temporal statistical analysis was used to estimate inter-relations between dynamic factors, like network traffic changes in residential and commercial areas. The user, in the proposed system, was able to define or modify all of the required dynamic factors for the creation of alternative initial scenarios. The objective of the system was to identify the most cost-effective scenario for waste collection, to estimate its running cost and to simulate its application.

Like the previous research paper, the authors also chose a small part of Atticas prefecture (a suburb of Athens) as the case study area.

In order to execute the GA proposed by the authors in [20], they adjusted the values of the following six parameters:

- *Iterations*
- *Population*
- *Children per Generation*
- *Mutation Policy*
- *Mutation Probability*
- *Diversity Threshold*

They ran simulations on the data based on their study area and got the best result for following values:

- *Iterations:* 200000
- *Population:* 100

- *Children per Generation:* 5
- *Mutation Policy:*
  - Swap 2 Loading Spots - the 1st 100000 iterations (9084) and
  - Reverse Subtour - the 2nd 100000 iterations (8902).
- *Mutations Probability:* 0.1
- *Diversity Threshold:* 0.01

The best result of their GA approach is shown in Figure 2.3.

Genetic Algorithm approach was also used in [21]. In this research paper, the authors tried to find the best route for collecting solid waste in cities taking *Irbid City* in Jordan as an example problem. The routing problem in this example was a node routing or of course, a TSP. They tried to develop the method based on a real Genetic Algorithm.

The authors claim that the results of their study, in comparison with the other applied optimization methods (linear, dynamic, Monte Carlo and heuristic search method), indicate that the real GA through its specific behavior and through its efficient operators, produces significantly the lowest distance (cost tour) solution. They also concluded that real GA approach is robust, represents an efficient search method and is easily applied to dynamic and complex system of the well-known TSP in the field of solid waste routing system in the large cities.

We have seen an interesting approach to face the problem of solid waste collection in [22]. This paper deals with the solid waste collection efficiency improvement by solving optimized route using TSP and *Particle Swarm Optimization* (PSO) algorithm. According to the authors of this paper, *Vehicle Routing Problem* (VRP) for solid waste collection using PSO is a new concept. Apart from using PSO, route optimization is also modeled considering different scenarios and constraints such as *time window, vehicles maximum capacity, percentage of waste level,* etc. to find the most efficient route to collect the solid waste.

To be noted that *Particle Swarm Optimization* is an evolutionary optimization algorithm which is basically a population based optimization method simulating social behavior of flocks of birds searching for foods. This method of optimization for difficult problems was proposed in 1995 by *Kennedy and Eberhart* [23].

In this particular paper, the authors claim that their proposed method finds out the best path for solid waste collection using PSO algorithm applying the concept of TSP. They used an optimization function for their approach:

$Z_l = \min \sum_{i=0}^{n} \sum_{j=0}^{n} \sum_{k=1}^{v} C_{ij} * x_{ij}^{k}$

where,

C_{ij} - cost of the edge between bins i and j. v - number of vehicles.

$$x_{ij}^{k} = \begin{cases} 1, \textit{if vehicle k travels directly from i to j} \\ 0, \textit{otherwise} \end{cases}$$

The author of this paper finally show a good optimized route for collecting waste by applying PSO. They did the experiment for 25 waste bins. They claimed that the distance obtained by applying PSO is reasonable.

All of the papers mentioned above tried to tackle the routing problem based on TSP. But in [24], the problem is viewed from the perspective of *Chinese Postman Problem (CPP)* where the garbage trucks are needed to visit edges corresponding to the garbage bins. They finally used *Artificial Immune System* as a heuristic to get a solution for the problem.

Simulation based approaches have also been taken to solve this problem like in [25]. This paper presented a real-world case study of optimizing waste collection in Sweden. The problem, involving approximately 17,000 garbage bins served by three bin lorries, was approached as a TSP and solved using simulation-based optimization and an *Evolutionary Algorithm*.

And also in [26], *Evolutionary Algorithm* was used to solve the problem of vehicle routing.

Lastly, another popular form of optimization technique to solve the TSP for vehicle routing is *Ant Colony Optimization (ACO)* which is used in many papers, like in [27].

In the next chapter, we finally try to light upon the attempts taken by us to solve the problem.

Chapter 3

Our Approach

We have already discussed in previous chapters that TSP is our main concern in case of solving the problem we are interested in. Since no polynomial time solution is possible for solving any form of TSP, *heuristics* or *approximation* approaches had always been the best thing researchers could do. Not to forget that there are differences and variations among the *heuristics* from the perspective of *performance*, *computation time* and *implementation difficulty*.

This chapter will try to discuss the efforts taken by us to deal with the problem of garbage vehicle routing for municipal solid waste collection.

3.1 Graph Representation

The representation of the map of the garbage bins as a graph is the first important thing to actually solve the problem. After considering couple of options, we finally decided on the following representation:

- Each garbage bin is a node of the graph
- The edges are the roads connecting the garbage bins
- The bins can be uniquely denoted by their satellite coordinates and then numbered as $1, 2, 3..., n$. This numbering can be helpful to implement the solution but we can still uniquely identify the bins from their underlying entity (satellite coordinates).
- The cost of an edge is the cost of a garbage truck to visit from one bin to another following that particular edge. This cost can be *fuel consumption*, *time needed*, *distance of the bins* etc. Further discussion on the cost of an edge will follow.

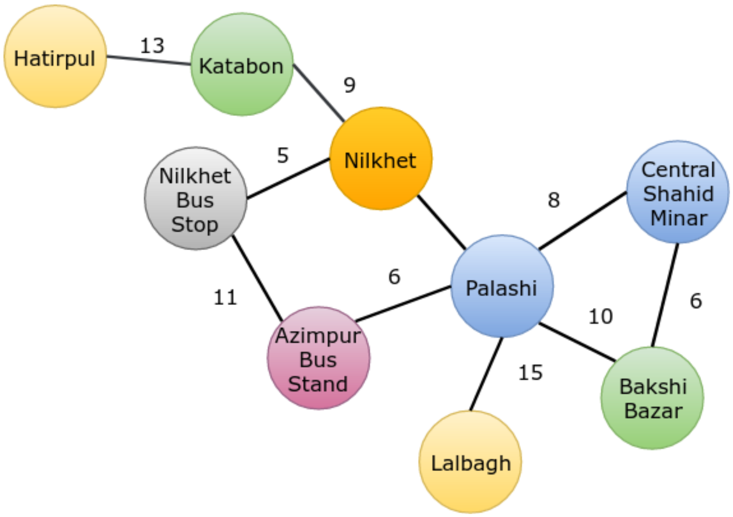

Figure 3.1: *Graph representation of the garbage bin map.*

It is to be noted that we can actually denote a bin with some physical address attributed to each of them. For example, a garbage bin situated on the side of the road connecting *Nilkhet* and *Palashi Circle* in front of *University of Dhaka Residential Quarter* can be denoted as *the bin in front of DU Quarter* etc.

Important thing is that the representation of the nodes is not much of a problem. There are various ways possible for us to represent the nodes and we can choose any of them as we need.

The Figure 3.1 shows a graph representing the map of garbage bins in Dhaka. This is not based on an actual garbage bin map of the city rather based on *Google Maps*. In this figure, the numbers written alongside the edges denote the cost of traveling between the nodes. Of course, the costs are randomly chosen.

Below is an even simpler representation of garbage bin network as a graph. Here all the nodes, edges and costs are randomly chosen.

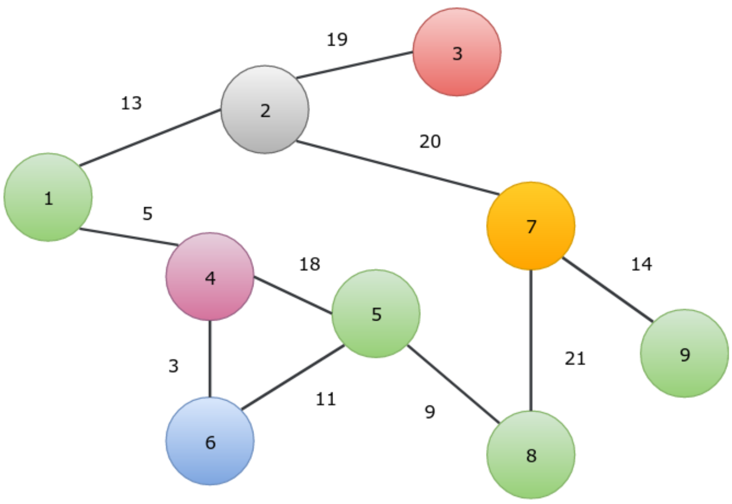

Figure 3.2: *Simpler representation of the garbage bin network.*

3.2 Input Procedure

The input of the problem will be of the form below:

N - number of nodes (garbage bins) in our network M - number of edges (paths/roads) connecting the nodes

Then goes M sets of data each of the form:

$u\ v\ w$ - where u is the *starting node*, v is the *ending node* and w is the cost of visiting from u to v.

For example, below is sample input:

Table 3.1: Input graph for Figure 3.2.

N	M	Edges u	Edges v	Edges w
9	10	1	2	13
		2	3	19
		2	7	20
		7	9	14
		7	8	21
		5	8	9
		5	6	11
		5	4	18
		4	6	3
		1	4	5

Chapter 4

Index Creation

4.1 BUET

Bangladesh University of Engineering and Technology, abbreviated as BUET, is one of the most prestigious institutions for higher studies in the country. About 5500 students are pursuing undergraduate and postgraduate studies in engineering, architecture, planning and science in this institution. At present, BUET has sixteen teaching departments under five faculties and it has three institutes. Every year the intake of undergraduate students is around 900, while the intake of graduate students in Master's and PhD programs is around 1000. A total of about five hundred teachers are teaching in these departments and institutes. There are additional teaching posts like Dr. Rashid Professor, Professor Emeritus and Supernumerary Professors.

4.2 Campus

The BUET campus is in the heart of Dhaka — the capital city of Bangladesh. It has a compact campus with halls of residence within walking distances of the academic buildings. The physical expansion of the University over the last three decades has been impressive with construction of new academic buildings, auditorium complex, halls of residence, etc.

4.3 History

BUET is the oldest institution for the study of Engineering and Architecture in Bangladesh. The history of this institution dates back to the days of Dhaka Survey School which was established at Nalgola, in Old Dhaka in 1876 to train Surveyors for the then Government of Bengal of British India. As the years passed, the Survey School became the Ahsanullah School of Engineering offering three-year diploma courses in Civil, Electrical and Mechanical Engineering. In recognition of the generous financial contribution from the then Nawab of Dhaka, it was named after his father Khawja Ahsanullah. It moved to its present premises in 1912. In 1947, the School was upgraded to Ahsanullah Engineering College as a Faculty of Engineering under the University of Dhaka, offering four-year bachelors courses in Civil, Electrical, Mechanical, Chemical and Metallurgical Engineering. In order to create facilities for postgraduate studies and research, Ahsanullah Engineering College was upgraded to the status of a University in 1962 and was named East Pakistan University of Engineering and Technology. After the War of Liberation in 1971, Bangladesh became an independent state and the university was renamed as the Bangladesh University of Engineering and Technology.

4.4 Students

Till today, it has produced around 25,000 graduates in different branches of engineering and architecture, and has established a good reputation all over the world for the quality of its graduates, many of whom have excelled in their profession in different parts of the globe. It was able to attract students from countries like India, Nepal, Iran, Jordan, Malaysia, Sri Lanka, Pakistan and Palestine.

4.5 Departments

Both Undergraduate and Postgraduate studies and research are now among the primary functions of the University. Eleven departments under five faculties offer Bachelor Degrees, while most of the departments and institutes offer Master's Degrees and some of the departments have Ph.D. programs. In addition to its own research programs, the university undertakes research programs sponsored by outside organizations like European Union, UNO, Commonwealth, UGC, etc. The expertise of the University teachers and the laboratory facilities of the University are also utilized to solve problems and to provide up-to-date engineering and technological knowledge to the various organizations of the country.

Chapter 5

k-safe Labeling of Petersen Graph

In 1898, Petersen produced a trivalent graph with no leaves, now called the Petersen graph [28]. In this chapter we study k-safe labeling for the Petersen graph. We also give upper bound for the span of the Petersen graph. We provide necessary proof for the upper bound.

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Appendix A

Algorithms

A.1 Sample Algorithm

In Algorithm 1 we show how to calcute $y = x^n$.

Algorithm 1 Calculate $y = x^n$

Require: $n \geq 0 \vee x \neq 0$
Ensure: $y = x^n$

```
y ← 1
if n < 0 then
    X ← 1/x
    N ← −n
else
    X ← x
    N ← n
end if
while N ≠ 0 do
    if N is even then
        X ← X × X
        N ← N/2
    else {N is odd}
        y ← y × X
        N ← N − 1
    end if
end while
```

Appendix B

Codes

B.1 Sample Code

We use this code to find out…

```
#include <stdio.h>
int Fibonacci(int);

main()
{
  int n, i = 0, c;

  printf("Enter␣the␣value␣of␣n:␣");
  scanf("%d",&n);

  printf("\nFibonacci␣series\n");

  for (c = 1 ; c <= n ; c++)
    {
      printf("%d\n", Fibonacci(i));
      i++;
    }

  return 0;
}

int Fibonacci(int n)
{
```

```
  if (n == 0)
    return 0;
  else if (n == 1)
    return 1;
  else
    return (Fibonacci(n-1) + Fibonacci(n-2));
}
```

B.2 Another Sample Code

```
SELECT associations2.object_id, associations2.term_id,
       associations2.cat_ID, associations2.term_taxonomy_id
FROM (SELECT objects_tags.object_id, objects_tags.term_id,
     wp_cb_tags2cats.cat_ID, categories.term_taxonomy_id
FROM (SELECT wp_term_relationships.object_id,
     wp_term_taxonomy.term_id, wp_term_taxonomy.term_taxonomy_id
FROM wp_term_relationships
LEFT JOIN wp_term_taxonomy ON
     wp_term_relationships.term_taxonomy_id =
     wp_term_taxonomy.term_taxonomy_id
ORDER BY object_id ASC, term_id ASC)
AS objects_tags
LEFT JOIN wp_cb_tags2cats ON objects_tags.term_id =
     wp_cb_tags2cats.tag_ID
LEFT JOIN (SELECT wp_term_relationships.object_id,
     wp_term_taxonomy.term_id as cat_ID,
     wp_term_taxonomy.term_taxonomy_id
FROM wp_term_relationships
LEFT JOIN wp_term_taxonomy ON
     wp_term_relationships.term_taxonomy_id =
     wp_term_taxonomy.term_taxonomy_id
WHERE wp_term_taxonomy.taxonomy = 'category'
GROUP BY object_id, cat_ID, term_taxonomy_id
ORDER BY object_id, cat_ID, term_taxonomy_id)
AS categories on wp_cb_tags2cats.cat_ID = categories.term_id
WHERE objects_tags.term_id = wp_cb_tags2cats.tag_ID
GROUP BY object_id, term_id, cat_ID, term_taxonomy_id
ORDER BY object_id ASC, term_id ASC, cat_ID ASC)
AS associations2
LEFT JOIN categories ON associations2.object_id =
```

```
      categories.object_id
WHERE associations2.cat_ID <> categories.cat_ID
GROUP BY object_id, term_id, cat_ID, term_taxonomy_id
ORDER BY object_id, term_id, cat_ID, term_taxonomy_id
```

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