

# Finding the Optimal Route for a Garbage Collection System Using Graph Traversal Methods

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**Abstract**— Garbage collection is an essential activity in solid waste management. The increasing volume of garbage from businesses and homes is a pressing problem in any community. This study aims to find the optimal route for a garbage collection system for the Municipal Environment and Natural Resources Office in Estancia, Iloilo, Philippines. Actual observations on the route of the garbage collection truck were generated as a basis to determine the pickup point during the operation. Subsequently, computer-simulated routes were identified using the Depth-First Search (DFS) algorithm and the Breadth-First Search (BFS) algorithm. These algorithms were compared against the actual observed route to determine which of the two algorithms performed more efficiently in finding the optimal route based on the total distance covered and fuel consumption. Based on the results of the study, no significant differences were found when the two algorithms were compared against the actual observed route. However, the simulated routes produced by both the DFS algorithm and the BFS algorithm were 23.81% and 19.26% less, respectively, than the covered distance of the actual observed route. Moreover, the fuel consumption of both the DFS-simulated route and the BFS-simulated route resulted in savings of 13.50% and 6.32% respectively. The Depth First Search algorithm found the better optimal route for garbage collection. The findings of this study were also articulated to the Local Government Unit of Estancia, Iloilo, Philippines, for proper disposition.

**Index Terms**— graph traversal methods, Depth First Search algorithm, Breadth First Search algorithm, garbage collection

## I. INTRODUCTION

WASTE management, namely, collection, transport, sorting and processing, and disposal, is an issue of social concern owing to its environmental impact and effects on public health [1]. A voluminous amount of garbage thrown from households and business establishments not only presents harm to people, but at the same time, poses an eye-catching dilemma of the values and habits of people in the community. Thus, communities implement solid waste management efforts to provide a clean and livable environment to their inhabitants.

The Estancia Municipal Environment and Natural Resources Office (MENRO) is the office tasked with managing environmental concerns for the local government

unit. One of its responsibilities is garbage collection and disposal. The MENRO identified drop-off points where residential garbage, including that from businesses, can be dumped for collection by the garbage collectors. Garbage collection routes are also provided by the MENRO for the garbage trucks to follow. Unfortunately, the MENRO personnel observed that while the collection routes of the garbage trucks have been designed to visit all drop-off points, one of their problems was that the garbage truck collectors visit some of the streets twice or more in one collection schedule to arrive at a specific drop-off point. It is inefficient and costs more resources in time and fuel consumption. Under such conditions, we noted that a waste collection routing problem may have existed.

In garbage collection, the graph is usually an undirected grid with known distances between nodes, such as streets. We want to find a route that covers all required pickups as quickly as possible without missing any. Garbage collection is often modeled as a vehicle routing problem. The purpose of vehicle routing is to minimize time, cost, and distance [2][3]. “The waste collection routing problem (WCRP) can be defined as a problem of designing a route with the least total traveling time or distance, served by the least number of vehicles under specific constraints” [4]. There were studies conducted to improve WCRP by employing simulations and experiments with various algorithms. For instance, a genetic algorithm was used in [5] when they experimented to minimize travel distance using a hybrid genetic algorithm-tabu search. The results of their experiment showed that their hybrid algorithm was good for solving large problem sizes. In [6], they optimized the Vehicle Routing Problem with a Genetic Algorithm (GA) to determine the optimal route that minimized the total distance traveled by the trucks. In [7], they also employed the GA to minimize the total tour length of the waste truck through a set of loading points.

Another algorithm to find the shortest path is the Dijkstra algorithm. In the study conducted by [8], they used this algorithm to reduce the time taken to collect and dispose of solid waste among various nodes. The heuristic algorithm was adopted by [9] in developing a system called fastCARP for waste collection problems in Denmark. In [10], they applied a simheuristic to develop and describe the method to improve waste collection processes. Similarly, [11] argued that heuristic techniques have been proposed to solve one of the rising issues relating to garbage collection systems.

Some research focused on the implementation of the Internet of Things (IoT) in solving waste collection routing problems. In [12], a novel IoT-based system for garbage collection and disposal is proposed, integrating household bins and mobile garbage collectors for automatic waste

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collection and disposal. In the study of [13], they focused on the “development and application of a waste management system that segregates biodegradable and non-biodegradable wastes; measures the level of waste inside the container, and helps the waste collector to find the shortest path to the nearest waste container”. In [14], they developed an IoT framework that utilizes a sensor network for waste collection optimization, which they installed around a specific location in the city. They were able to employ an optimization algorithm that created routes that garbage trucks follow to collect the garbage.

In the study of [15], they modified the backtracking search algorithm to minimize the sum of the waste collection route distances. A study related to this study was proposed by [16] in the development of a vehicle routing model using the Clark and Wright algorithm to find the optimal route for garbage trucks with minimum cost. In [17], they introduced a memetic algorithm to perform routing enforced with time windows and conflict context. Their model incorporated a combination of flow and set partitioning formulation to accomplish multi-objective optimization. In the study of [3], he came up with a “novel hybrid method between Chaotic Particle Swarm Optimization and ArcGIS to generate optimal solutions for vehicle routing models.” His experiments showed that the proposed hybrid method was able to obtain a better total collected waste quantity than the manual waste collection procedures.

This motivated the researchers to develop a model that could provide an optimal route alternative for garbage truck drivers in the Municipal Environment and Natural Resources Office of Estancia, Iloilo. More so, the findings of this study were clearly articulated to the Estancia MENRO for their proper disposition.

## II. METHODS

### A. Path Finding Algorithms

Pathfinding algorithms are used to find the shortest path between two points in a graph or network. The task is to keep away from obstacles and minimize costs such as time, distance, risks, fuel, price, and others. The Breadth First Search and Depth First Search are two of the commonly used graph traversal methods and are often a required first step for many other types of analysis.

**Breadth-First Search Algorithm.** The Breadth-First Search (BFS) algorithm is a graph traversal technique in which a random starting node (source or root node) is chosen and the graph traversal is started layer by layer so that all nodes and their corresponding child nodes are traversed and explored [18]. Typically, for garbage collection, if we are looking for the shortest path from one node (depot or start) to all other nodes, BFS is a good candidate because the graph can be unweighted, meaning each street segment is traversed in fixed time, but it's more common that each node has an associated time, and then edges have weights. From an algorithm point of view, all child nodes are obtained by extending the vertices added to the FIFO (First-In-First-Out) queue [19]. The main idea behind the BFS is to explore all the nodes at a given depth level before moving on to the

nodes at the next depth level. This ensures that the shortest path between two nodes is found first. Algorithm 1 shows the Breadth-First Search algorithm pseudocode with time complexity of  $O(V+E)$ .

#### ALGORITHM 1: THE BREADTH-FIRST SEARCH ALGORITHM

```

1: Input: s as the source node
2: BFS (G, s)
3: Q.enqueue(s)
4: mark s as visited
5: while (Q is not empty)
6:   v = Q.dequeue()
7:   for all neighbors w of v in Graph G
8:     if w is not visited
9:       Q.enqueue(w)
10:    mark w as visited

```

**Depth-First Search Algorithm.** The Depth-First Search (DFS) algorithm is an algorithm that starts from the first node in the network and continues to explore until it finds the desired node or even a node without children. One of the key characteristics of the DFS algorithm is its ability to explore the depths of a graph or tree before backtracking. Backtracking is an algorithmic strategy for addressing issues in a loop by seeking to systematically create a solution. The DFS uses a stack data structure that involves a LIFO (Last in Last Out) and backtracking [20]. This means that DFS prioritizes exploring the deepest nodes of a graph before moving on to shallower nodes. The total time complexity for this algorithm is  $O(V+E)$  as shown in Algorithm 2.

#### ALGORITHM 2: THE DEPTH-FIRST SEARCH ALGORITHM

```

1: DFS(G,v)
2: Stack S:= {};
3: for each vertex u, set visited[u]:= false;
4:   push S, v;
5: while (S is not empty) do
6:   u:= pop S;
7:   if (not visited[u]) then
8:     visited[u]:= true;
9:     for each unvisited neighbor w of u
10:      push S, w;

```

Looking at the results of the time complexities in the preceding discussion, it can be concluded that both the time complexities of the BFS algorithm and the DFS algorithm are  $O(V+E)$ , or  $O(n)$ , which is the linear algorithm and has fair time complexity. Their difference is that the BFS algorithm uses the queue (first-in, first-out) method, while the DFS algorithm uses the stack (first-in, last-out) method.

### B. Data Collection Procedure

In the gathering of data needed for the conduct of this study, we first observed the actual route taken by the garbage truck collectors. We secured a vicinity map of the Municipality of Estancia through Google Maps and downloaded and printed it. We then followed the garbage truck collectors as they picked up the household wastes at certain pick-up points. We carefully marked each pickup point as a base for the simulation program. We then measured the approximate distances between each pick-up point using the measurement provided in Google Maps.

### III. RESULTS AND DISCUSSION

#### A. Total Distance Covered by the Garbage Truck Collectors based on the Actual Observed Route, and Simulated Routes using the Depth-First-Search Algorithm and Breadth-First-Search Algorithm

Within the town proper in the Municipality of Estancia, Iloilo, there are 12 garbage pick-up points. These pick-up points were strategically identified by the MENRO due to the volume of household waste being dumped and collected. The red lines indicate the route that the garbage trucks have to take from Point 0 (P0) as the starting point to Pick-up Point 12 (P12). We measured the distance between pickup points. The total distance covered by the garbage truck following its actual observed route was 2,855 meters. The garbage collection truck started from its starting Point (P0) to Pick-up point 1 (P1) at a distance of 250 meters; from P1, it went to Pick-up point 2 (P2), with a distance of 85 meters, and so on. However, we noted that some streets were being passed through more than once to reach the next pick-up point. For instance, the street covering P6 to P7 was traversed twice when the garbage collection truck took the route from P7 to P11. The same case happened with P12 to P9 and P9 to P8. Moreover, it was also observed that the route was not fixed. That is, the garbage collection truck also takes the route from P9 to P11 and went back following a similar route from P11 to P8 via P9. Thus, longer travel distances were carried by the garbage collection truck which also resulted in higher fuel consumption and prolonged operation time. Figure 1 shows the vicinity map with corresponding pick-up points duly marked during actual observation.

Figure 2 shows the pick-up points as simulated using the Depth-First-Search algorithm. In this routing pattern, the total distance covered was only 2,175 meters. As shown in the figure, no street was passed more than once just to reach the next pick-up point. Thus, making it an efficient route. The DFS requires extensive state tracking for all visited nodes. Using this pattern, it can be inferred that the garbage truck collectors can reach each pick-up point without the need to cover the area they have previously passed by. This would lead to faster collection of household garbage, allowing the garbage trucks to move to other routes within the Municipality and at the same time could save fuel consumption. A printed copy of this route was given to the MENRO, which was subsequently given to the garbage collection truck driver to follow. A three-day average of fuel consumption was recorded for analysis.

Similarly, a simulated route of the 12 pick-up points was produced using the Breadth-First-Search algorithm, as shown in Figure 3. In this pattern, the BFS algorithm was able to cover all the pick-up points in 2,305 meters. Standard BFS does not track which nodes have been visited. Notably, some streets needed to be passed through more than once to reach the next pick-up points. The street joining P6 to P11 had to be traversed again from P9 to P7. Similarly, a portion of the street was repeatedly covered when the garbage truck took P7 to P8 and then from P8 to P10. These resulted in a slight increase in the total distance covered. However, relative to the distance of the current route, the difference can still be noted. In the interest of this

experiment, a printed copy of this route was also given to the MENRO for the garbage collection truck to test. A three-day average of fuel consumption was also recorded to compare with the data from other routes.

From the total distance covered as shown in Table 1, there was a difference of 680 meters between the actual observed route and the DFS-simulated route, with the DFS-simulated route covering less distance than the actual observed route. This was due to the non-repetition of passing through the same streets to reach certain pickup points. The efficiency of the DFS-simulated route relative to the actual distance can be defined by the following equation:

$$\begin{aligned}\eta &= ((x - DFS_y)/x) * 100\% \\ &= ((2855 - 2175)/2855) * 100\% \\ &= 23.81\%\end{aligned}\quad (1)$$

where  $\eta$  is the efficiency;  $x$  is the actual observed distance;  $DFS_y$  is the DFS-simulated distance.

Thus, the DFS simulated route is 23.81% more efficient than the actual observed route. Similarly, the difference in the total distance covered by the BFS simulated route is 550 meters less than the actual observed route which is 19.26% more efficient as to the distance covered. The efficiency of the BFS-simulated route relative to the actual distance can be defined as:

$$\begin{aligned}\eta &= ((x - BFS_y)/x) * 100\% \\ &= ((2855 - 2305)/2855) * 100\% \\ &= 19.26\%\end{aligned}\quad (2)$$

where  $\eta$  is the efficiency;  $x$  is the actual observed distance;  $BFS_y$  is the BFS-simulated distance.

However, when compared directly against each other, DFS-simulated route was found to be slightly shorter by 130 meters, representing a 4.55% reduction in distance than the BFS-simulated route. By using route optimization algorithms, the total distance that garbage collection trucks can be effectively shortened. This can result in extended vehicle life as the wear-and-tear of the garbage collection truck may be reduced due to the shortened distance of travel. In fact, in a similar study by [21], they developed a system using the BFS and DFS algorithms in finding the shortest path for customers to track their orders and for the transportation company to assign vehicles for deliveries.

This finding was also supported by [22], who reported a 59.12% reduction in travel distance along the routine collection road network when route optimization techniques are applied to WCRP. However, the results contradicted the findings of [23], where they argued that the BFS algorithm provided a better routing pattern than the DFS algorithm in terms of mileage and processing times.

Subsequently, we also conducted comparative tests using both the actual observed route and the simulated routes to determine the fuel consumption of the three routes. We did the observations in three trials. With the current route, the average fuel used by the garbage collection truck was 11.85 liters. With the DFS simulated route, the fuel consumption was at an average of 10.25 liters while the BFS simulated route's fuel consumption was at an average of 11.10 liters.

As to fuel consumption, the DFS simulated route was able to save an average of 1.6 liters (13.50%). On the other



Fig. 1. Vicinity Map showing the pickup points based on the Actual Observed Route



Fig. 2. Depth First Search Algorithm Simulated Route



Fig. 3. Breath First Search Algorithm Simulated Route.

hand, the BFS simulated route saved an average of 0.75 liter (6.32%) of consumed fuel during the three-day observation. This is due to the shorter distance covered in both simulated routes as compared to the actual route. It can be noted, though, that there were other variables, such as volume of household garbage, waiting time, traffic conditions, and the number of personnel involved in the hauling of household garbage from the pickup point to the garbage collection truck, that made the travel time longer, and therefore might have contributed to fuel consumption.

These differences, when taken into account in actual operations twice per day and seven days per week, can bring big savings in fuel consumption and improve work efficiency.

Moreover, expeditious collection of household garbage can also lessen the environmental impact on the community. With the rise in the cost of fuel, a decrease in fuel consumption can save money for the government. More so, the environmental benefits, such as lower greenhouse gas emissions, can also contribute to a better quality of air.

These findings are supported by the study of [24], who argued that an optimized travel route in waste collection management resulted in savings on travel time and fuel consumption of around 14.21% and 10.81% respectively. Similarly, [25] concluded that when route optimization is applied to municipal solid waste collection schemes, a saving of 14.3% on fuel consumption can be achieved. As suggested by [26][27], performance indicators of solid waste collection include distances traveled by vehicles for haulage and scheduling and routing of vehicles [28]. These findings aligned with the results of the study conducted by [15] where their experiments showed that their system was able to provide the shortest route path with 13% efficiency as compared to the existing route. Similarly, the use of simulated patterns resulted in a reduced traveled distance of 66% [6].

TABLE 1  
DISTANCE COVERED BETWEEN PICK-UP POINTS OF THE  
ACTUAL OBSERVED ROUTE, DFS SIMULATED ROUTE  
AND BFS SIMULATED ROUTE

| Actual Observed<br>Route |     |       | DFS Simulated<br>Route |     |       | BFS Simulated<br>Route |     |       |
|--------------------------|-----|-------|------------------------|-----|-------|------------------------|-----|-------|
| From                     | To  | d     | From                   | To  | D     | From                   | To  | d     |
| P0                       | P1  | 250   | P0                     | P1  | 250   | P0                     | P1  | 250   |
| P1                       | P2  | 85    | P1                     | P2  | 85    | P1                     | P2  | 85    |
| P2                       | P3  | 110   | P2                     | P3  | 110   | P2                     | P3  | 110   |
| P3                       | P4  | 50    | P3                     | P4  | 50    | P3                     | P4  | 50    |
| P4                       | P5  | 110   | P4                     | P5  | 110   | P4                     | P5  | 110   |
| P5                       | P10 | 330   | P5                     | P10 | 330   | P5                     | P6  | 100   |
| P10                      | P6  | 220   | P10                    | P6  | 220   | P6                     | P11 | 230   |
| P6                       | P7  | 160   | P6                     | P7  | 160   | P11                    | P12 | 400   |
| P7                       | P11 | 550   | P7                     | P8  | 180   | P12                    | P9  | 230   |
| P11                      | P12 | 400   | P8                     | P9  | 150   | P9                     | P7  | 350   |
| P12                      | P9  | 240   | P9                     | P11 | 130   | P7                     | P8  | 180   |
| P9                       | P7  | 350   | P11                    | P12 | 400   | P8                     | P10 | 210   |
| Total                    |     | 2,855 | Total                  |     | 2,175 | Total                  |     | 2,305 |

d = distance in meters

#### B. Difference in the Total Distance Covered Between Actual Route and Simulated Routes based on the DFS Algorithm and BFS Algorithm

Using the Mann-Whitney U Test, we compared whether

significant differences in distance would exist. Comparing the actual observed route and the DFS simulated route, it was found that there was no significant difference ( $U=58.00$ ;  $z=-0.81$ ;  $p=0.417$ ) in the distance covered. Similarly, the comparison between the actual observed route and the BFS-simulated route did not produce a significant difference ( $U=0.60$ ;  $z=-0.70$ ;  $p=0.487$ ). Thus, our hypothesis was rejected since we presumed that significant differences would exist between the current route and the simulated routes. The DFS is useful when you want to explore as deeply as possible quickly, but it does not guarantee the shortest paths, while the BFS finds the shortest path by level, but requires that we don't revisit nodes without a mechanism. For one bin, it can work on an unweighted graph, but for multiple bins and no repetition, it becomes too heavy.

The findings contradicted the study of [24] when they found that significant differences existed between the existing and optimal routes with respect to the time of travel as well as fuel cost. This may be due to the fact that their study covered a wider area than the present study. Therefore, it can be inferred that while the simulated routes were arguably more efficient than the actual observed route, they would be statistically similar. Table 2 shows the data.

TABLE 2  
DIFFERENCE IN THE TOTAL DISTANCE COVERED BETWEEN  
ACTUAL ROUTE AND SIMULATED ROUTES BASED ON  
THE DEPTH-FIRST-SEARCH ALGORITHM AND  
BREADTH-FIRST-SEARCH ALGORITHM

| Category | Route  | N  | Mean<br>Rank | U     | Z     | p     |
|----------|--------|----|--------------|-------|-------|-------|
| Distance | Actual | 12 | 13.67        | 58.00 | -0.81 | 0.417 |
|          | DFS    | 12 | 11.33        |       |       |       |
| Distance | Actual | 12 | 13.50        | 60.00 | -0.70 | 0.487 |
|          | BFS    | 12 | 11.50        |       |       |       |

## IV. CONCLUSION

In this study, we conducted an actual observation of the waste management collection route and identified 12 pick-up points. Both the DFS and BFS would be applied in an initial static setup where we need to determine the optimal path based on a predefined map of streets and locations of pickup points.

We found out that the garbage collection trucks tend to pass through particular paths multiple times, which resulted in longer distances they covered. We came up with simulated routes using graph traversal methods, specifically, the Depth-First-Search algorithm and the Breadth-First-Search algorithm.

Applying these techniques, it was found that the simulated routes generated by the DFS are 23.81% shorter and the BFS is 19.26% shorter than the actual observed route. Moreover, observations were made to determine fuel consumption. The DFS simulated route was able to save an average of 13.50% while the BFS simulated route has a fuel consumption saving of 6.32%. Both simulated routes were found to be more efficient than the actual observed route.

However, no significant difference was found when comparing the two simulated routes against the actual observed route. Needless to say, we were able to recommend to the concerned agency to use the simulated

route generated by the DFS which will certainly cut the cost of fuel consumption and can consequently trim down the time of operations.

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