GIS-BASED ROUTE OPTIMIZATION OF MUNICIPAL SOLID WASTE COLLECTION AND MINIMUM FUEL CONSUMPTION IN KHULNA CITY

Masum M. Mohiuddin*[1], Islam M. Rafizul[2], Ankon Baral[3], Swadhin Das[4]

1 Undergraduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, e-mail: mdmohiuddin.ce.kuet@gmail.com

2 Professor, Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, e-mail: imrafizul@ce.kuet.ac.bd

3 Post-graduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology, Bangladesh, email: shuvanudevbaral@gmail.com

4 Post-graduate Student, Department of Urban & Regional Planning, Khulna University of Engineering & Technology, Bangladesh, email: swadhins9@gmail.com

***Corresponding Author**

ABSTRACT

Route optimization for solid waste collection is an important way to minimize the operating costs of municipalities. Khulna ranks third among Bangladesh's metropolitan cities. This city produces 1000 tons of waste every day, and 80% of the waste is collected. Khulna's existing system for collecting and transporting solid waste lacks route planning and relies only on the truck drivers' experience. Hence, this study aimed to optimize the existing travel routes and compare their feasibility with the existing ones. Secondary datasets like a list of vehicles, financial information, and a list of secondary disposal points (SDPs) have been collected from Khulna City Corporation (KCC). A field survey was conducted to verify the locations of SDPs. Multiple GPS devices have been installed for monitoring the routes, stops, and travel time of 25 waste collector trucks of Khulna City Corporation (KCC). Network analysis in ArcGIS Pro has been used for route optimization and reduced fuel consumption. This operation of ArcGIS Pro uses Dijkstra's algorithm, which is an algorithm for finding the shortest paths between nodes. The result reveals that the route and fuel were optimized at 11.11% and 0.71%, respectively. By implementing the findings of this study, KCC will be benefited financially.

Keywords: *Municipal solid waste (MSW), Waste collection, SDPs, Route optimization and Fuel consumption*

1. INTRODUCTION

Municipal solid waste (MSW) management is a key problem for increasingly urbanizing regions, and proper garbage collection and disposal are vital for sustaining urban populations' general health and well-being. Cities throughout the world are facing enormous problems controlling MSW as the world's population grows more metropolitan. Unskilled treatment of MSW in poor nations causes pollution of water, soil, and the atmosphere, which has a significant impact on public health (Batool & Ch, 2009; Sharholy et al., 2008)

Khulna, a large metropolitan hub in Bangladesh, is not an exception to this problem. Khulna is Bangladesh's third-biggest city, with a current population of around 950,000 people and a land area of 40.8 square kilometres (Ahmed, 2023). Khulna City produces 1000 tons of waste every day, and 80% of the waste is collected (AA News Desk, 2023). The existing MSW collection method in Khulna City, as in numerous other towns throughout the world, is beset by issues relating to transportation efficiency and fuel use. Traditional manual collection techniques can result in inefficient routes, resulting in higher fuel usage, increased operating expenses, and negative environmental implications. KCC employees collect MSW from SDP and carry it to the final disposal site in Raj bandh, which is 10 kilometres west of the city headquarters (Khair & Rafizul, 2018). One of the most promising systems for automating waste planning and management is the Integrated Geographical Information System (GIS) (Karadimas & Loumos, 2008). The GIS allows for the effective import, organization, and analysis of geographical data, which is the foundation of collecting system planning. It also offers fundamental services to the user, such as network-based analysis, and the use of ArcGIS allows the user to model realistic network conditions that may include factors such as the number of turns, road height restrictions, and other constraints such as speed limit variability and local traffic states (Malakahmad et al., 2014). Over the last few decades, GIS - Network Analysis - Vehicle Routing Problem (VRP) has been successfully used to improve waste collection while cutting system costs (Vu et al., 2018). GIS is thought to be the most practical tool for researchers since it enables them to display the findings in addition to storing, retrieving, analyzing, and applying vast volumes of data (Malakahmad et al., 2014). In the case of MSW, GIS can provide an MSW generation map of different locations, an existing MSW collection and disposal pattern from SDP to landfill site, employment distribution in different wards, and an existing MSW lifting route plan (M. R. Islam et al., 2012). With the use of GIS and spatial analysis, it can be really easy to map out the areas in detail. Spatial analysis is the process of calculating data that has been entered or saved to generate new information that can be used to improve MSW decisions.

This research project will use GIS with a multi-objective programming model for route optimization strategies to solve the critical issue of MSW collection and the lowest fuel use in Khulna City. This study seeks to analyze the existing waste collection routes and financial information of MSW management. Also, this research seeks to optimize existing routes through the analysis of ArcGIS, which will not only reduce the use of fuel but also operational costs and the environmental impact related to the handling of MSW by integrating geographic information, transportation systems, and waste production patterns. The research will look at how GIS may be used to construct efficient routes for MSW collection that take into consideration the geographic location of SDPs, trash generation rates, traffic circumstances, and additional important spatial parameters, all while favouring low fuel use. This research project adds to larger efforts to solve the difficulties of urbanization and environmental sustainability in Khulna by offering GIS-based optimization of routes for MSW collection with an emphasis on decreasing fuel use.

2. METHODOLOGY

2.1 Study Area Profile

The study area chosen for this research was Khulna city. Khulna ranks third among Bangladesh's metropolitan cities. Khulna is located in the southwest of the country and is situated below the tropic of Cancer, around the intersection of latitude 22.490 N and longitude 89.340 E (Islam et al., 2019). It is surrounded to the north by Dighalia Upazila and Khan Jahan Ali Thana, to the south by Batiaghata

Upazila, to the east by Rupsa and Dighalia Upazilas, and to the west by Dumuria Upazila (Palit, 2021). There are around 31 wards in the city, and the overall management of the city is managed by KCC. The selected area of Khulna city for the study of this research is shown in Figure 1.

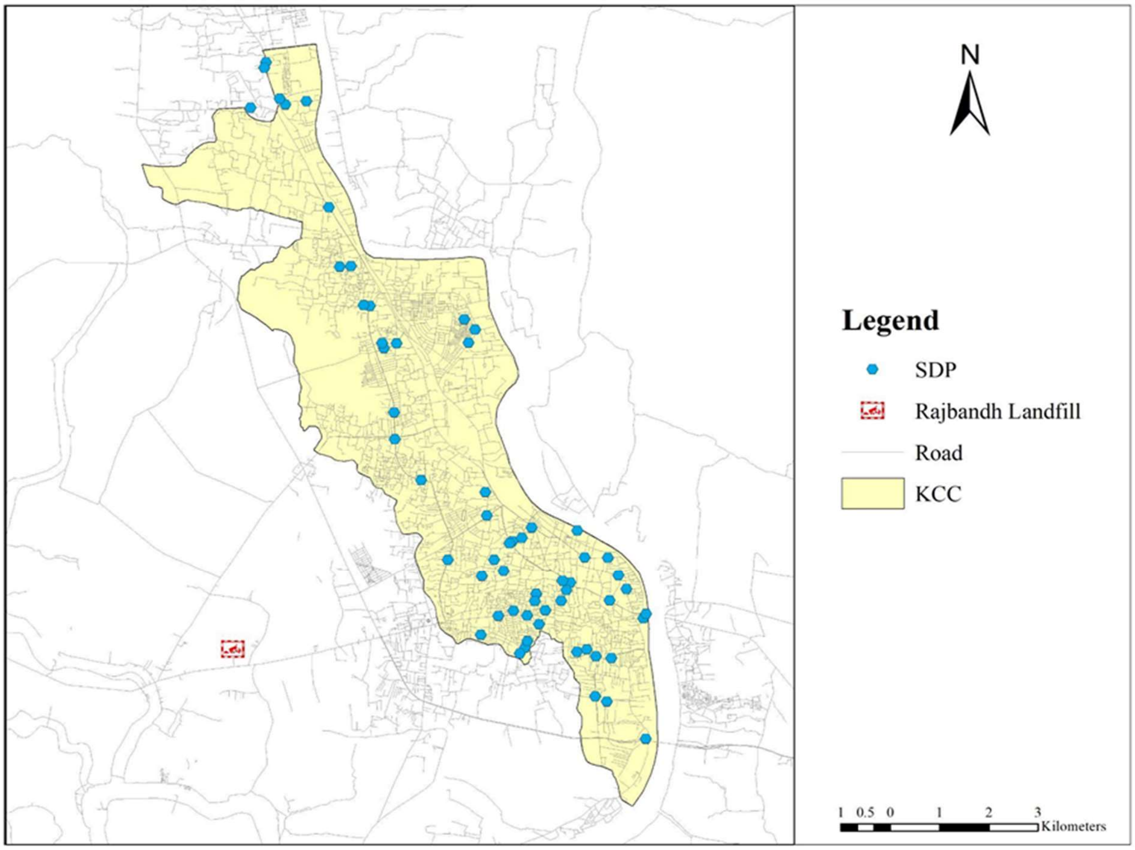


Figure 1: Secondary disposal points & landfill in KCC

2.2 Data Collection

The first part of achieving our target was to collect the primary data, which was acquired from the Khulna City Corporation (KCC) from garbage collection trucks and solid garbage disposal points (SDPs). This information comprised the number and kind of garbage collection trucks, as well as the locations of SDPs. The second part of the data collection was the secondary data which was collected from journals, articles, newspapers, books, and various other sources to make sure our objectives were met for the research.

2.3 GPS Tracker Installation

The second part of our methodology was to put GPS trackers on 25 garbage collector trucks operated by the Khulna City Corporation to capture real-time information regarding the waste collection process. These GPS trackers helped us monitor the garbage collection process's routes, pauses, speed of the vehicles, and number of trips the vehicles made.

2.4 Data Monitoring

The movement and activity of the garbage pickup vehicles were constantly tracked thanks to the GPS trackers. Information about the trucks' itineraries, the places where garbage was gathered (SDPs), the amount and length of the stops, and the overall journey time was collected. This real-time data was critical for further route analysis and optimization.

2.5 Analysis of the Data

Figure 2 illustrates the methodological framework of this research. The heart of our research was the use of ArcGIS Pro, a powerful GIS program, to handle and analyze data from GPS trackers. ArcGIS Pro allows users to save and interact with various elements in a single project, such as maps, layouts, tables, and charts (ESRI, 2023). The network analysis features of ArcGIS Pro were used to improve the existing garbage collection routes. Within this design, the network endpoints represent the several SDPs and other critical locations associated with the trash collecting process. The most effective garbage pickup routes were identified using ArcGIS Pro. These optimized routes sought to cut trip time and distance, resulting in lower fuel consumption. The recently improved routes were compared to the previous ones to assess the success of the route optimization. How well the optimized routes enhanced travel effectiveness, decreased fuel use, and lowered operating expenses was evaluated. The conclusions were drawn from this comparison analysis, and the results were quantified.

Figure 2: Methodological framework of this study

3. RESULT & DISCUSSION

3.1 Average speed of the vehicles

As shown in Figure 3, The DT-1 travelled approximately 50.91 miles at an average speed of 21.64 miles per hour. At an average speed of 25.35 miles per hour, the DT-2 covered approximately 131.33 miles. At an average speed of 17.86 miles per hour, the DT-3 covered around 50.45 miles. With an average speed of 24.22 and 18.23 miles per hour, respectively, the DT-4 and DT-5 covered 106.82 and 68.42miles.

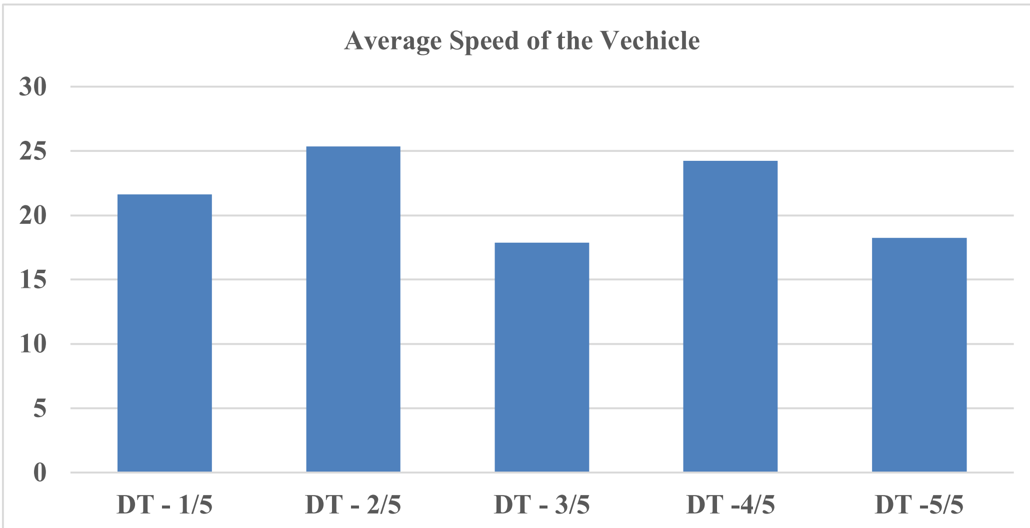


Figure 3: Average Speed of the vehicles

3.2 Daily Trip to Landfill

The DT-1 vehicle completed six trips in total, as shown in the above table, and the optimized route indicates that 1.89 miles would be saved (Figure 4). This means that the DT-1 can ensure that it makes one extra trip for every 26 trips. Similar to this, the table above shows that the DT-2 truck travelled 131.33 miles total over the course of 5 journeys.

The difference between the covered route and the optimized route is 26.12, meaning that the DT-2 may make one extra trip for every four. Additionally, the DT-3 made a total of 3 trips and can make around one extra trip for every twelve. In the same way, DT-4 and DT-5 made 4 trips each and with the optimized route they can make three and eight more trips, respectively.

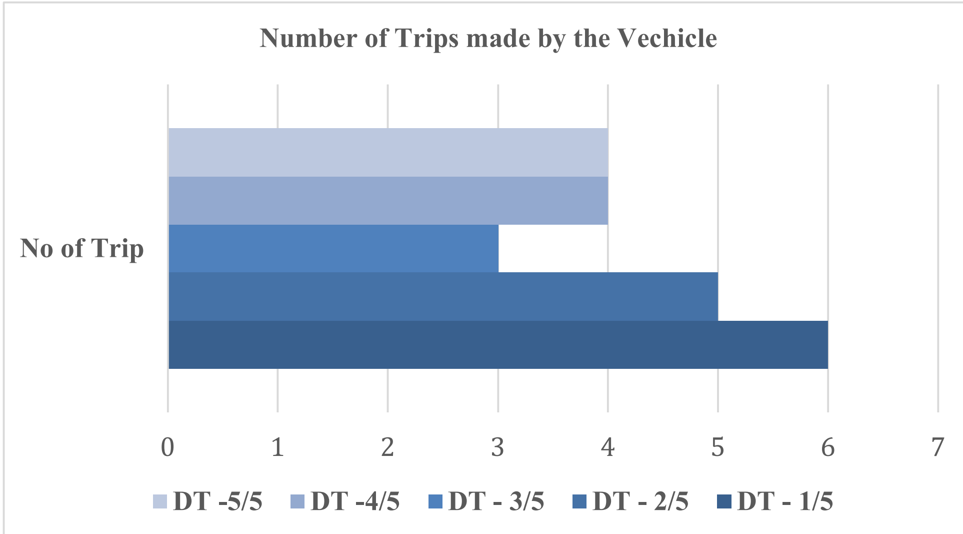
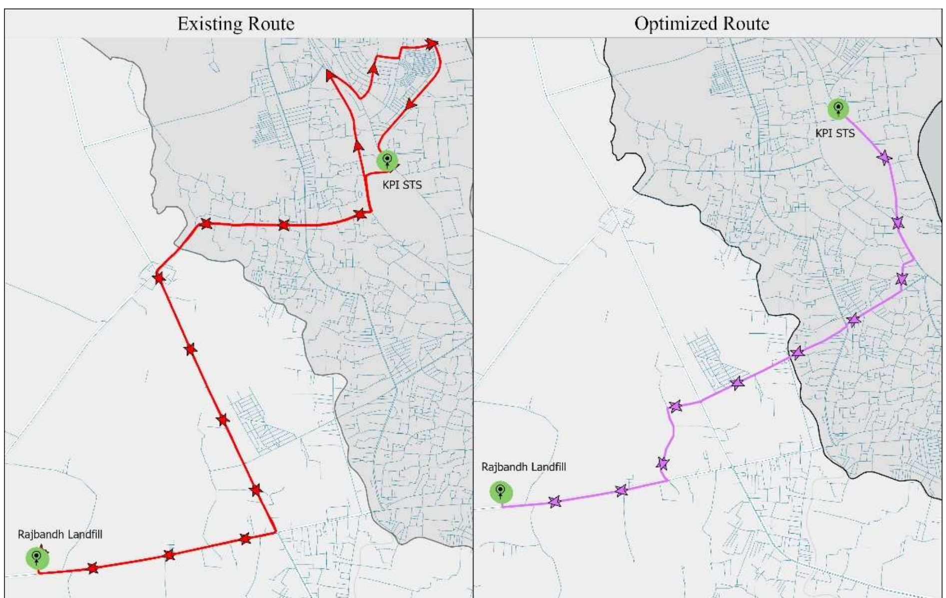


Figure 4: Number of trips made by the vehicle

3.3 Example of Route Optimization

The optimized route for each trip of 5 large trucks of KCC has been determined by ArcGIS Pro. Figure 5 illustrates the existing and optimized route of Trip No. 03 of DT-2/5. The optimized path is 7.28 kilometres shorter than the current route the driver is following.



DT-2/5 Trip - 03	Existing Route - 27.16 km, Optimized Route - 19.88 km, Distance Reduced - 7.28 km

Figure 5: Example of route optimization of DT-2/5

3.4 Comparison Between Existing & Optimized Scenarios

Table 1 shows the existing condition and optimized scenario. DT-4/5 and DT-2/5 travel more than others. They have more reduced distances than others. Following this, these 2 vehicles will save more fuel than others.

Table 1: Comparison Between Existing & Optimized Scenarios

Vehicle No	Distance Travelled (km)	Optimized Distance (km)	Distance Reduced (km)	Fuel Saved (ml)	Average Speed (kmph)	Time taken (hour)	Time for optimized Route (hour)
DT - 1/5	50.91	49.02	1.89	539.55	21.64	2.35	2.27
DT - 2/5	131.33	105.20	26.13	6903.67	25.35	5.18	4.15
DT - 3/5	50.45	46.52	3.93	1232.87	17.86	2.82	2.60
DT -4/5	106.82	76.70	30.12	8137.47	24.22	4.41	3.17
DT -5/5	68.40	60.80	7.60	2360.48	18.23	3.75	3.34

3.5 Benefits of Route Optimization

3.5.1 Distance Reduced

From our calculation, we found that the distance DT-1 will only need to make 49.02 miles using the optimized route where the distance it covers is 50.91 (Figure 7). The distance the DT-2 will need to make by using the optimized route is 105.60 miles where it covers 131.33 miles. The distance that will need to be covered by the DT-3 using the optimized route is 46.52 miles where it covers 50. 45 miles. Similarly, DT-4 and DT-5 will need to make 76.70 miles and 60.80 miles using the optimized route respectively where they covered 106.82 miles and 68.40 miles.

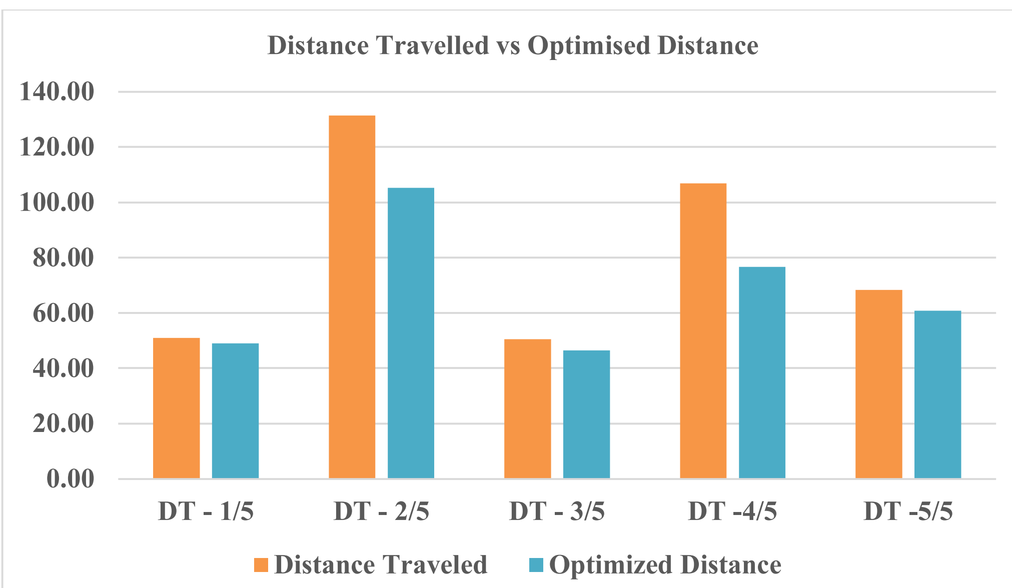


Figure 7: Distance Travelled vs Optimized Distance

3.5.2 Travel Time Reduced

As illustrated in Figure 8, The DT-1 needed 2.35 hours in total to go on the journey. The time can be lowered to 2.25 hours by taking the optimized route, saving 0.1 hours. In a similar vein, the DT-2 took

5.18 hours to travel the same distance, but with the optimized route, it only took 4.15 hours, saving 1.03 hours.

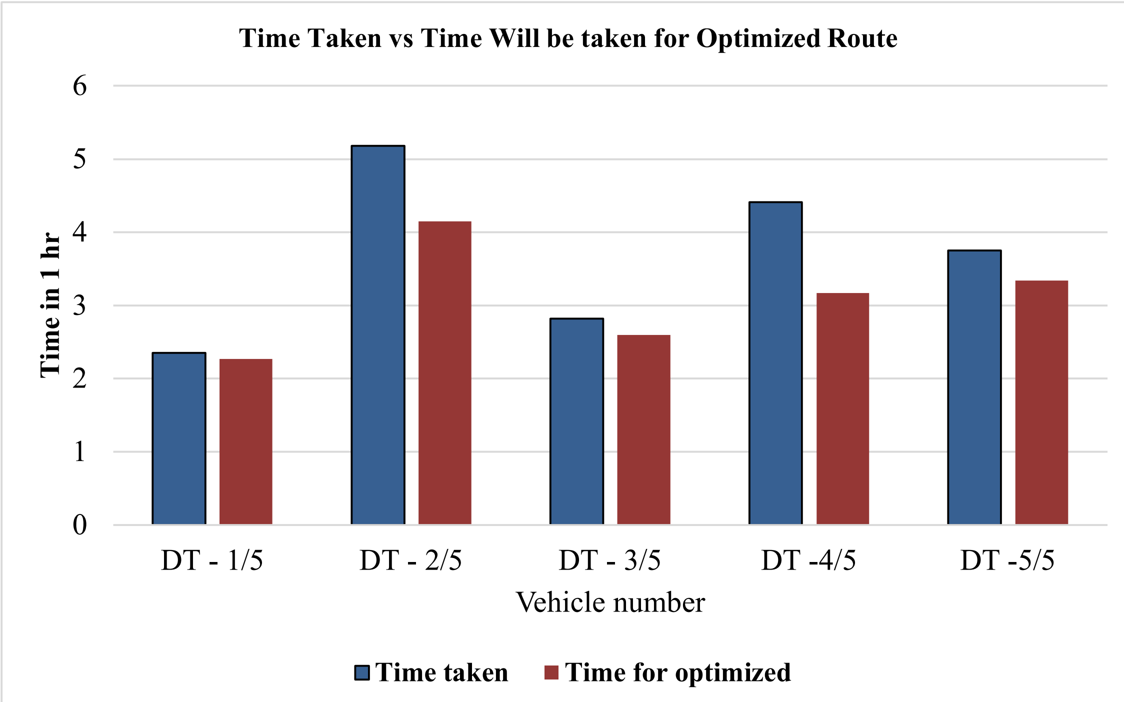


Figure 8: Time taken vs Time will be taken for optimized route

In addition, the DT-3's journey distance was 2.82 hours, but by taking the optimized route, that distance can be lowered to 2.60 hours, saving a total of 0.22 hours. The optimal path can save 1.24 and 0.05 hours of travel time for DT-4 and DT-5, whose respective trip times were 4.41 and 3.75 hours. Thus, almost three hours can be saved by taking the optimized route which is approximately 17% less time than the actual time.

3.5.3 Fuel Saved

Figure 9 shows the amount of fuel that can be saved by adopting an optimized route. It is evident from the above data that taking the optimal route will result in a fuel savings of 0.539 litters. The cost savings from the optimal route for the DT-1 is 59 Taka when considering the current diesel price of 109 Taka.

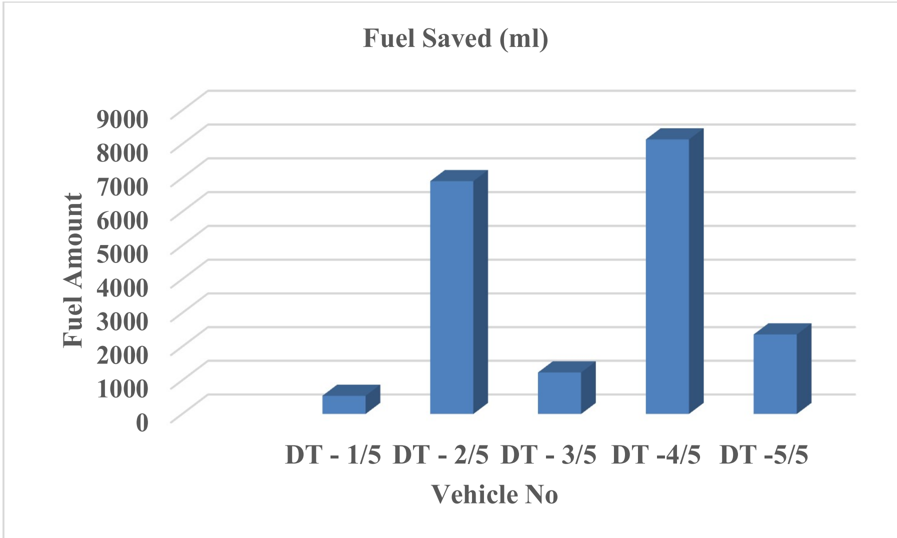


Figure 9: Fuel Saved

Similar to this, the DT-2 saves 6.903L of gasoline by taking the optimal route, which translates into a savings of roughly 753 Taka. Similar to this, the optimized route will save the DT-3 about 134.07 Taka and about 1.23L of fuel. Additionally, the DT-4 and DT-5 will save roughly 8.2 and 2.3 litters of fuel, or 894 and 251 Taka, respectively. Altogether, these five vehicles saved around 2092 taka by using the optimized route instead of the route they had been using. The KCC can ensure that the vehicles' fuel efficiency improves, more time is saved, the number of trips the vehicles make improves so that the vehicles can be used more effectively, and the cost of the KCC is reduced by using the optimized routes over the distance travelled and direction followed by the vehicles.

4. CONCLUSION

In conclusion, the main goal of this study was to minimize fuel consumption and operating expenses using the GIS-based route optimization of solid waste collection in Khulna City, Bangladesh. The inadequacies in the route planning of Khulna's current waste collection system resulted in higher fuel consumption and an adverse effect on the environment. By employing a thorough approach that included gathering data, installing GPS trackers, and utilizing ArcGIS Pro for analysis, the study sought to maximize current travel patterns and assess the viability of suggested modifications.

The study's findings showed that route optimization can lead to significant benefits in terms of travel distance and fuel consumption for trash collector vehicles, with an average reduction of 11.11%. The shortest paths between nodes were found by the use of Dijkstra's algorithm in ArcGIS Pro, which increased the overall effectiveness of garbage collection routes. Based on the results, it was found that the optimized routes saved time and fuel, which improved the efficiency of the waste-collecting vehicles. Almost 17% less time was taken to complete the trips and approximately 18L of fuel can be saved by using the optimized route. The results highlight the possibility of implementing comparable GIS-based strategies in other cities to tackle the worldwide problem of optimizing waste collection routes for improved operational and environmental results.

ACKNOWLEDGMENT

We would like to express our sincere appreciation to Prof. Dr. Eckhard Kraft and Senta Berner for their invaluable guidance and insightful feedback throughout this research. We would also like to express our gratitude to the "SCIP Plastics Project" on which this publication is based, which was funded by the German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety under grant no. 67MM0004.

REFERENCES

AA News Desk. (2023, April 17). *KCC lacks capacity to manage e-waste, resulting in health risks | The Asian Age Online, Bangladesh*. https://dailyasianage.com/news/304958/kcc-lacks-capacity-to-manage-e-waste-resulting-in-health-risks

Ahmed, N. (2023, January 6). *The non-mystery behind Khulna city's declining population | The Daily Star*. https://www.thedailystar.net/opinion/views/news/the-non-mystery-behind-khulna-citys-declining-population-3214026

Batool, S. A., & Ch, M. N. (2009). Municipal solid waste management in Lahore City District, Pakistan. *Waste Management*, *29*(6), 1971–1981. https://doi.org/10.1016/j.wasman.2008.12.016

ESRI. (2023). *Introducing ArcGIS Pro—ArcGIS Pro | Documentation*. https://pro.arcgis.com/en/pro-app/latest/get-started/introducing-arcgis-pro.htm

Islam, M. S., Moniruzzaman, S. M., & Mondal, S. (2019). MUNICIPAL SOLID WASTE QUANTIFICATION, TRANSPORTATION AND MANAGEMENT IN KHULNA CITY. In *Journal of Engineering Science* (Vol. 10, Issue 2). https://www2.kuet.ac.bd/JES/

Karadimas, N. V., & Loumos, V. G. (2008). GIS-based modelling for the estimation of municipal solid waste generation and collection. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *26*(4), 337–346. https://doi.org/10.1177/0734242X07081484

Khair, S., & Rafizul, I. M. (2018). Assessment on metal elements in soil of waste landfill at Khulna: a study based on multivariate statistics, GIS and BP-ANN. In *Journal of Engineering Science* (Vol. 09, Issue 1).

Malakahmad, A., Bakri, P. M., Mokhtar, M. R. M., & Khalil, N. (2014). Solid Waste Collection Routes Optimization via GIS Techniques in Ipoh City, Malaysia. *Procedia Engineering*, *77*, 20–27. https://doi.org/10.1016/j.proeng.2014.07.023

Palit, T. (2021, June 17). *Khulna City Corporation*. BANGLAPEDIA. https://en.banglapedia.org/index.php/Khulna_City_Corporation

Sharholy, M., Ahmad, K., Mahmood, G., & Trivedi, R. C. (2008). Municipal solid waste management in Indian cities – A review. *Waste Management*, *28*(2), 459–467. https://doi.org/10.1016/j.wasman.2007.02.008

Vu, H. L., Ng, K. T. W., & Bolingbroke, D. (2018). Parameter interrelationships in a dual phase GIS-based municipal solid waste collection model. *Waste Management*, *78*, 258–270. https://doi.org/10.1016/j.wasman.2018.05.050