



FACULTY OF TECHNOLOGY AND ENGINEERING
DEPARTMENT OF WATER RESOURCES ENGINEERING

**OPTIMIZING SOLID WASTE COLLECTION ROUTES AND SCHEDULING IN
KAMPALA CITY**

By

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DECLARATION

I TENYWA EZERA hereby declare that this final report was written by me and it has not been utilized for academic award by any individual in any learning institution

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APPROVAL

The following supervisors have confidently approved this report submitted to the department of water resources engineering

SUPERVISOR;

Mr. KUSEMERERWA JOSEPH

Signature..........

Date.....12/05/2025.....

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ABBREVIATIONS

ABC: artificial bee colony

ACO: Ant colony optimization

BSA: Backtracking simulation annealing

CVRP: Capacitated Vehicle Routing Problem

CVRP: Capacitated vehicle routing problem

GA: Genetic Algorithm

GIS: Geographical Information System

GPS: Global Positioning System

KCCA: Kampala capital city authority

LU/LC: Land Use Land Cover

MILP: Mixed-integer linear programing

MSW: Municipal Solid Waste

MUINER: Makerere University Institute of Natural and Environmental Resources

NFA: National Forestry Authority

RL: Reverse Logistics

SA: simulation annealing

SDG: Sustainable Development Goal:

SSWM: Sustainable Solid Waste Management

VRP: Vehicle routing problem

VRPTW: Vehicle routing problem with time windows

ZW: Zero Waste

Community Engagement and Equity

Equitable service delivery requires targeted outreach. A *Clean Kampala* app could empower residents to report overflowing bins and track collection schedules, while school programs in partnership with UNICEF would instill waste management awareness in younger generations. Pro-poor pricing models should subsidize collection fees for low-income households in areas like Bwaise, and gender-inclusive hiring practices (30% female representation in driving roles) would enhance safety in isolated zones.

Monitoring, Evaluation, and Funding

Continuous improvement hinges on robust monitoring. Biannual audits by the Uganda National Bureau of Standards (UNBS) would assess route efficiency, while SMS-based feedback systems would capture resident satisfaction. Academic collaborations with Makerere University's AI Lab could explore reinforcement learning for dynamic routing, and open-data initiatives would crowdsource innovations. Financially, grants from the EU's Global Climate Change Alliance and the World Bank's Urban Resilience Fund should be pursued, alongside circular economy models such as plastic buy-back centers with Coca-Cola Beverages Africa to create youth employment.

Implementation Roadmap

The rollout should begin with a 6-month pilot in Kawempe, followed by IoT sensor deployment and cloud migration (Months 7–12). Policy reforms, including waste segregation laws and PPP frameworks, would follow in Months 13–18, culminating in citywide expansion and EV procurement by Month 24. This phased approach balances innovation with practicality, positioning Kampala as a leader in smart urban waste management in East Africa.

REFERENCES

- Abdallah, M., Adghim, M., Maraqa, M., & Aldahab, E. (2019). Simulation and optimization of dynamic waste collection routes. *Waste Management and Research*, 37(8), 793–802. https://doi.org/10.1177/0734242X19833152/ASSET/IMAGES/LARGE/10.1177_0734242X19833152-FIG9.JPEG
- Abdullah, N., Al-wesabi, O. A., Mohammed, B. A., Al-Mekhlafi, Z. G., Alazmi, M., Alsaffar, M., Baklizi, M., & Sumari, P. (2022). IoT-Based Waste Management System in Formal

- and Informal Public Areas in Mecca. *International Journal of Environmental Research and Public Health* 2022, Vol. 19, Page 13066, 19(20), 13066. <https://doi.org/10.3390/IJERPH192013066>
- Akhtar, M., Hannan, M. A., Begum, R. A., Basri, H., & Scavino, E. (2017). Backtracking search algorithm in CVRP models for efficient solid waste collection and route optimization. *Waste Management*, 61, 117–128. <https://doi.org/10.1016/j.wasman.2017.01.022>
- Aryampa, S., Maheshwari, B., Sabiiti, E., Bateganya, N. L., & Bukenya, B. (2019). Status of waste management in the East African cities: Understanding the drivers of waste generation, collection and disposal and their impacts on Kampala City's sustainability. *Sustainability (Switzerland)*, 11(19). <https://doi.org/10.3390/SU11195523>
- Aryampa, S., Maheshwari, B., Sabiiti, E. N., Bukenya, B., & Namuddu, S. (2023). The Impact of Waste Disposal Sites on the Local Water Resources: A Case Study of the Kiteezi landfill, Uganda. *Ecohydrology & Hydrobiology*, 23(2), 280–289. <https://doi.org/10.1016/J.ECOHYD.2022.12.002>
- Balikuddembe, J. K., Ardalan, A., Khorasani-Zavareh, D., Nejati, A., & Munanura, K. S. (2017). Road traffic incidents in Uganda: a systematic review of a five-year trend. *Journal of Injury and Violence Research*, 9(1), 17. <https://doi.org/10.5249/JIVR.V9I1.796>
- Bortas, I., Brnjac, N., & Dundović, Č. (2018). Transport Routes Optimization Model Through Application of Fuzzy Logic. *Promet - Traffic&Transportation*, 30(1), 121–129. <https://doi.org/10.7307/PTT.V30I1.2326>
- Bueno-Delgado, M. V., Romero-Gázquez, J. L., Jiménez, P., & Pavón-Mariño, P. (2019). Optimal Path Planning for Selective Waste Collection in Smart Cities. *Sensors* 2019, Vol. 19, Page 1973, 19(9), 1973. <https://doi.org/10.3390/S19091973>
- Cheng, C., Zhang, L., & Thompson, R. G. (2019). Reliability analysis of road networks in disaster waste management. *Waste Management*, 84, 383–393. <https://doi.org/10.1016/J.WASMAN.2018.11.027>
- Chong, L., & Osorio, C. (2017). A Simulation-Based Optimization Algorithm for Dynamic Large-Scale Urban Transportation Problems. <https://doi.org/10.1287/Trsc.2016.0717>, 52(3), 637–656. <https://doi.org/10.1287/TRSC.2016.0717>

- Costa, A., & Fichera, A. (2014). A mixed-integer linear programming (MILP) model for the evaluation of CHP system in the context of hospital structures. *Applied Thermal Engineering*, 71(2), 921–929. <https://doi.org/10.1016/J.APPLTHERMALENG.2014.02.051>
- Das, S., Lee, S. H., Kumar, P., Kim, K. H., Lee, S. S., & Bhattacharya, S. S. (2019). Solid waste management: Scope and the challenge of sustainability. *Journal of Cleaner Production*, 228, 658–678. <https://doi.org/10.1016/J.JCLEPRO.2019.04.323>
- Delahaye, D., Chaimatanan, S., & Mongeau, M. (2019). Simulated Annealing: From Basics to Applications. *International Series in Operations Research and Management Science*, 272, 1–35. https://doi.org/10.1007/978-3-319-91086-4_1
- Dorigo, M., & Stützle, T. (2019). Ant Colony Optimization: Overview and Recent Advances. *International Series in Operations Research and Management Science*, 272, 311–351. https://doi.org/10.1007/978-3-319-91086-4_10
- Fernandes, H., Teixeira, R., Daniel, B., Alves, C., Reis, A., Paredes, H., Filipe, V., & Barroso, J. (2017). Design of geographic information systems to promote accessibility and universal access. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 10279 LNCS, 291–299. https://doi.org/10.1007/978-3-319-58700-4_24/FIGURES/7
- Ferrer, A. L. C., Thomé, A. M. T., & Scavarda, A. J. (2018). Sustainable urban infrastructure: A review. *Resources, Conservation and Recycling*, 128, 360–372. <https://doi.org/10.1016/J.RESCONREC.2016.07.017>
- Ferronato, N., & Torretta, V. (2019). Waste mismanagement in developing countries: A review of global issues. *International Journal of Environmental Research and Public Health*, 16(6). <https://doi.org/10.3390/IJERPH16061060>
- Gaur, A., Gurjar, S. K., & Chaudhary, S. (2022). Circular system of resource recovery and reverse logistics approach: key to zero waste and zero landfill. *Advanced Organic Waste Management: Sustainable Practices and Approaches*, 365–381. <https://doi.org/10.1016/B978-0-323-85792-5.00008-3>
- Hulgaard, T., & Søndergaard, I. (2018). Integrating waste-to-energy in Copenhagen, Denmark. *Proceedings of the Institution of Civil Engineers: Civil Engineering*, 171(5), 3–10. <https://doi.org/10.1680/JCIEN.17.00042>

- Ilasz, D., Abramczyk, I., & Gdowska, K. (2023). Optimizing Segregated Waste Collection Routes as a Decision-Making Problem in the Municipal Solid Waste Management System in Small Town. *Journal of Vasyl Stefanyk Precarpathian National University*, 10(4), 6–16. <https://doi.org/10.15330/jpnu.10.4.6-16>
- Ishaq, S., & Andersen, J. (2023). *Development of a Floating Car Data (FCD) model to evaluate traffic congestion : a case of Kampala, Uganda*. <http://hdl.handle.net/10019.1/127253>
- Jamaluddin, S. H., Zulkefli, A., Mahmud, N., Syuhada, N., & Pazil, M. (2023). Optimising Routes Scheduling of Garbage Truck for Waste Collection using Artificial Bee Colony Algorithm. In *Applied Mathematics and Computational Intelligence* (Vol. 12, Issue 3).
- Javaid, M. A. (2013). Understanding Dijkstra's Algorithm. *SSRN Electronic Journal*. <https://doi.org/10.2139/SSRN.2340905>
- Kinobe, J. R. (2015). *Assessment of Urban Solid Waste Logistics Systems: The Case of Kampala, Uganda*.
- Kinobe, J. R., Bosona, T., Gebresenbet, G., Niwagaba, C. B., & Vinnerås, B. (2015). Optimization of waste collection and disposal in Kampala city. *Habitat International*, 49, 126–137. <https://doi.org/10.1016/j.habitatint.2015.05.025>
- Kinobe, J. R., Niwagaba, C. B., Gebresenbet, G., Komakech, A. J., & Vinnerås, B. (2015). Mapping out the solid waste generation and collection models: The case of Kampala City. *Journal of the Air & Waste Management Association*, 65(2), 197–205. <https://doi.org/10.1080/10962247.2014.984818>
- Liu, L., Sun, L., Chen, Y., & Ma, X. (2019). Optimizing fleet size and scheduling of feeder transit services considering the influence of bike-sharing systems. *Journal of Cleaner Production*, 236, 117550. <https://doi.org/10.1016/J.JCLEPRO.2019.07.025>
- Luwedde & Naayo - Dept. of Water Resources Engineering, 2022. (n.d.).
- Mareli, M., & Twala, B. (2018). An adaptive Cuckoo search algorithm for optimisation. *Applied Computing and Informatics*, 14(2), 107–115. <https://doi.org/10.1016/J.ACI.2017.09.001>
- Mohammed, A., & Elias, E. (n.d.). *Domestic solid waste management and its environmental impacts in Addis Ababa city JEWM Domestic solid waste management and its environmental impacts in Addis Ababa city*. www.premierpublishers.org,

- Mor, S., Negi, P., & Khaiwal, R. (2018). Assessment of ground water pollution by landfills in India using leachate pollution index and estimation of error. *Environmental Nanotechnology, Monitoring & Management*, 10, 467–476.
<https://doi.org/10.1016/J.ENMM.2018.09.002>
- Muvawala, J., Sebukeera, H., & Ssebulime, K. (2021). Socio-economic impacts of transport infrastructure investment in Uganda: Insight from frontloading expenditure on Uganda's urban roads and highways. *Research in Transportation Economics*, 88, 100971.
<https://doi.org/10.1016/J.RETREC.2020.100971>
- Nkechinyere Gift Nwagwu, Jasini Ali Alwadood, Nnaemeka Michael Ihenacho, Chikodili Evans Ezurike, Epsar Philip Kopteer, James Adah John, Kamila Abba Tukur, Augustine Abah Odeh, Sumaiyat Abdullahi Kpanja, Halimat Ifedolapo Oriola, & Philip Okoh Amodu. (2024). Spatial analysis of solid waste collection sites in Abakaliki metropolis. *World Journal of Advanced Research and Reviews*, 21(1), 2382–2387. <https://doi.org/10.30574/wjarr.2024.21.1.0276>
- Ogwuche, J. A. (2013). SPATIAL LOCATION OF SOLID WASTE DUMPSITES AND COLLECTION SCHEDULING USING THE GEOGRAPHIC INFORMATION SYSTEMS IN BAUCHI METROPOLIS, NIGERIA. In *European Scientific Journal* (Vol. 9, Issue 11).
- Okot, P., & Abandu, J. (2024). *Shortest Route Identification Model for Urban Solid Waste Disposal Management Using GIS: A Case of Gulu City, Northern Uganda*. 15.
<https://doi.org/10.37591/JoRSG>
- Patel, T., Brian, H. W., Guo, Y. Z., Isya, M., Rani, H. A., & Utama, F. P. (2019). Effect of Green Road Concept on Waste Management on Road Construction in The Banda Aceh City. *IOP Conference Series: Materials Science and Engineering*, 469(1), 012061.
<https://doi.org/10.1088/1757-899X/469/1/012061>
- Peña-Montoya, C. C., Bouzon, M., Torres-Lozada, P., & Vidal-Holguin, C. J. (2020). Assessment of maturity of reverse logistics as a strategy to sustainable solid waste management. *Waste Management and Research*, 38(1_suppl), 65–76.
<https://doi.org/10.1177/0734242X19897131>
- P. Singh, Y. P., A.K., S., & R.P., S. (2016). Web-GIS based Framework for Solid Waste Complaint Management for Sustainable and Smart City. *International Journal of*

- Advanced Remote Sensing and GIS*, 5(1), 1930–1936.
<https://doi.org/10.23953/cloud.ijarsg.71>
- Purwani, A., Hisjam, M., & Sutopo, W. (2020). Municipal solid waste logistics management: A study on reverse logistics. *AIP Conference Proceedings*, 2217. <https://doi.org/10.1063/5.0000676>
- Raven, J., Leone, M. F., Mills, G., Katzschner, L., Gaborit, P., Georgescu, M., Hariri, M., & Stone, B. (2019). Urban planning and urban design. *Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network*, 139–172. <https://www.iris.unina.it/handle/11588/729398>
- Roche, S. (2014). Geographic Information Science I: Why does a smart city need to be spatially enabled? *Progress in Human Geography*, 38(5), 703–711. <https://doi.org/10.1177/0309132513517365>
- Schneider, W., Miller, T. M., Holik, W. A., & Akron, U. of. (2016). *Route optimization*. <https://doi.org/10.21949/1503647>
- Shuen, H. N., & Johar, F. (2023). *Optimization of Capacitated Vehicle Routing Problem for Municipal Solid Waste Collection Using Simulated Annealing Algorithm* (Vol. 16).
- Sumathi, V. R., Natesan, U., & Sarkar, C. (2008). GIS-based approach for optimized siting of municipal solid waste landfill. In *Waste Management* (Vol. 28, Issue 11, pp. 2146–2160). <https://doi.org/10.1016/j.wasman.2007.09.032>
- Vidal, T., Laporte, G., & Matl, P. (2020). A concise guide to existing and emerging vehicle routing problem variants. *European Journal of Operational Research*, 286(2), 401–416. <https://doi.org/10.1016/J.EJOR.2019.10.010>
- Vivian, K. (N.D.). *FACULTY OF ENGINEERING DEPARTMENT OF WATER RESOURCES ENGINEERING A SMART MUNICIPAL WASTE MANAGEMENT SYSTEM FOR ROUTE OPTIMIZATION AND IMPROVED REVENUE COLLECTION*.
- Xie, X. F., & Wang, Z. J. (2019). Combined traffic control and route choice optimization for traffic networks with disruptive changes. *Transportmetrica B: Transport Dynamics*, 7(1), 814–833. <https://doi.org/10.1080/21680566.2018.1517059>
- Xue, W., Cao, K., & Li, W. (2015). Municipal solid waste collection optimization in Singapore. *Applied Geography*, 62, 182–190. <https://doi.org/10.1016/J.APGEOG.2015.04.002>

Vidal, T., Laporte, G., & Matl, P. (2020). A concise guide to existing and emerging vehicle routing problem variants. *European Journal of Operational Research*, 286(2), 401–416.

<https://doi.org/10.1016/j.ejor.2019.10.010>

World Bank Institute. (2017). *Financial Aspects of Solid Waste Management*. May, 1–20.

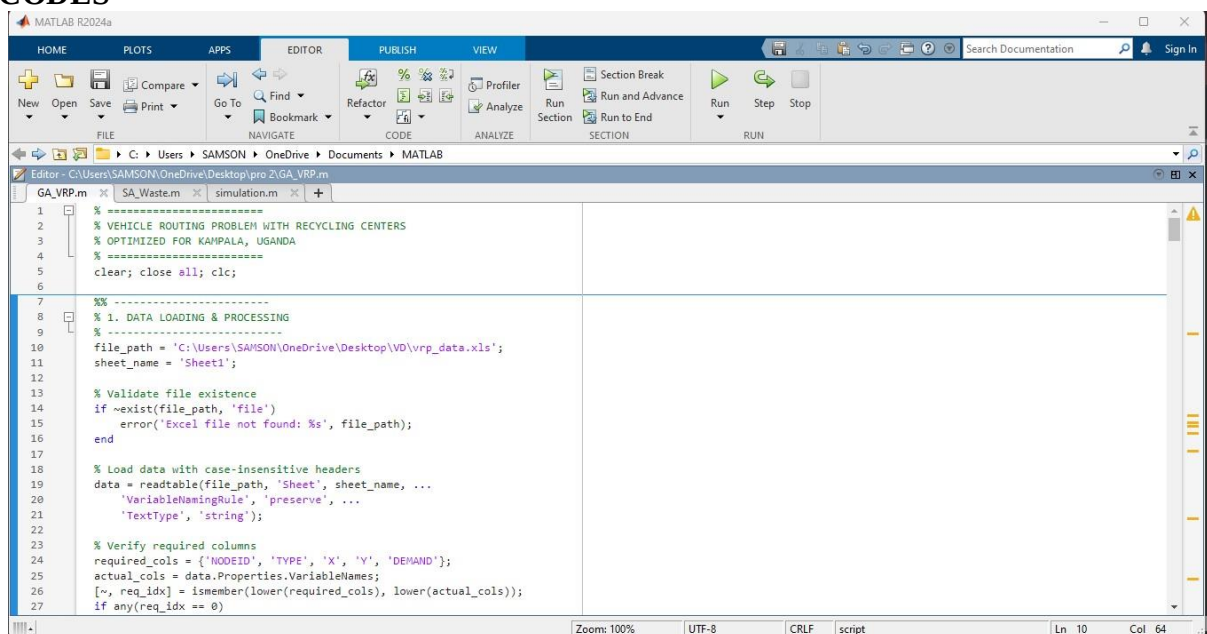
<http://web.worldbank.org/archive/website01007/WEB/IMAGES/FINANCIA.PDF>

Ssemugabo, C., Wafula, S. T., Lubega, G. B., Ndejjo, R., Osuret, J., Halage, A. A., & Musoke, D. (2020). Status of Household Solid Waste Management and Associated Factors in a Slum Community in Kampala, Uganda. *Journal of Environmental and Public Health*, 2020.

<https://doi.org/10.1155/2020/6807630>

APPENDICES

CODES



```
1 % =====  
2 % VEHICLE ROUTING PROBLEM WITH RECYCLING CENTERS  
3 % OPTIMIZED FOR KAMPALA, UGANDA  
4 % =====  
5 clear; close all; clc;  
6  
7 % =====  
8 % 1. DATA LOADING & PROCESSING  
9 % =====  
10 file_path = 'C:\Users\SAMSON\OneDrive\Desktop\vrp_data.xls';  
11 sheet_name = 'Sheet1';  
12  
13 % Validate file existence  
14 if ~exist(file_path, 'file')  
15     error('Excel file not found: %s', file_path);  
16 end  
17  
18 % Load data with case-insensitive headers  
19 data = readtable(file_path, 'Sheet', sheet_name, ...  
20     'VariableNamingRule', 'preserve', ...  
21     'TextType', 'string');  
22  
23 % Verify required columns  
24 required_cols = {'NODEID', 'TYPE', 'X', 'Y', 'DEMAND'};  
25 actual_cols = data.Properties.VariableNames;  
26 [~, req_idx] = ismember(lower(required_cols), lower(actual_cols));  
27 if any(req_idx == 0)
```

WORK SPACE