Development of Time-efficient Waste Collection Routes for the UP Diliman Campus using GIS-based network analysis

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ABSTRACT:

Accumulation of waste poses significant environmental and public health concerns. Currently, the Campus Maintenance Office (CMO) of the University of the Philippines Diliman (UPD) facilitates all large-scale waste management procedures through contractual means with the Department of Sanitation and Cleanup Works of Quezon City (DSQC), being guided by CMO upon entry into UPD. The study aims to create time-efficient routes and maps for the current conditions of UPD and CMO through GIS-based network analyses. The datasets utilized in this study include the current UPD traffic scheme, the managed CMO waste collection points, impedance factors like speed bumps, and digitized and estimated traffic data obtained through combined sources from field measurements and online materials. The workflows for the network analysis in ArcGIS involve the preparation of the road network layer, calibration of the network considering the observed collection routes, and the generation of time-efficient routes with appropriately split collection points for the north and south sectors of UPD. The study's new routes found slightly different collection times than the observed collection routes but were able to accommodate more stops that were not observed during fieldwork in comparison.

1. INTRODUCTION

1.1 Solid waste management approaches

Waste is defined as any material byproduct of production or consumption activities that is discarded (Drackner, 2005). Accumulation of waste poses significant environmental and public health concerns when not properly disposed. Hult and Leader has mentioned a multitude of people that have complained about their garbage not being collected which caused them to experience headaches (Hult and Leader, 2015). The risks brought by waste accumulation elicit the need for proper waste collection and management. This study aims to help the cause towards the United Nations' 11th Sustainable Development Goal (SDG 11): Make cities and human settlements inclusive, safe, resilient and sustainable (United Nations, 2023).

In the University of the Philippines Diliman (UPD), the Campus Maintenance Office (CMO) is responsible for the waste collection for the academic and commercial buildings within the campus and follows two routes for collection, dividing the UPD campus into north and south sectors. These collection routes are a product of two checklists of buildings which they are contracted to collect from every Wednesdays and Thursdays. However, there is no predetermined route to reach each building in a timely manner and made the garbage collection inefficient.

The primary challenge researchers aim to address is the inefficiency of the CMO's current routing system. Fieldwork and interviews have revealed issues like frequent U-turns and unused roads in the truck route, leading to unnecessary delays in the collection process. This inefficiency affects both service providers and users. In line with this issue, researchers have identified the need to generate route maps for CMO. This study explores optimizing garbage collection in UPD Campus with the use of Geographic Information Systems (GIS). The current routes are spatially referenced and the times of travel in these routes are reduced using network modeling and analysis. The findings and results can be utilized by UPD CMO in their solid waste management practices by implementing a time-efficient garbage collection scheme considering the current topography in the campus.

1.2 GIS-based solutions in waste collection problems

In many different fields and applications, geospatial tools like Geographic Information Systems (GIS) are being used more and more to solve routing issues. Taking into consideration variables like traffic conditions, road closures, and vehicle capabilities, GIS can be used to model and analyze complicated transportation networks. It enables tasks such as finding optimal routes and paths to be solved with ease. It also allows for network connectivity analysis, flow assessment, with spatial considerations like terrain elevation and land use. GIS software essentially functions as an effective tool for optimizing logistics, resource allocation, and transportation networks across a variety of disciplines contributing to informed decision-making and network resilience.

In relation to waste collection, the study conducted by Sallem represents a notable application of geospatial tools to address routing problems (Sallem et al., 2021). The Network Analyst tool inside the ArcGIS framework was specifically used to increase the effectiveness of household waste collection in the El Bousten district using Geographic Information System (GIS) technology. The analysis took into account a number of important variables, including city population density, garbage generation rates, bin placements, road networks, traffic patterns, and collection truck capacity. Two different scenarios were looked at: *S1*, which concentrated on collection vehicle route optimization, and *S2*, which included bin reallocation as well as routing optimization. The results of this study demonstrated significant improvements in both scenarios when compared to the existing waste collection methods.

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In another related study conducted by Kus, researchers delved into another instance where geospatial tools were harnessed to address routing challenges (Kus et al., 2015). This study focused on route optimization for residential recycling collection, an important task in light of rising recycling rates and associated increases in transportation costs. This was achieved through the study's examination of potential routing advancements using ArcGIS and the Network Analyst extension. It was particularly remarkable because it was able to modify and expand the capability of GIS tools, which were originally created for larger applications, to the unique challenges of route optimization in the context of residential recyclables collection. The study's results demonstrated a successful method for addressing high-density routing jobs. More importantly, it offered recommendations for enhancements in future applications, emphasizing the enduring utility of geospatial tools in addressing evolving routing problems in multiple fields.

The offered examples highlight the practical uses and advantages of these geospatial technologies in resolving routing issues. Addressing routing issues across multiple sectors requires the use of geospatial tools like GIS. These solutions provide insightful information and optimization capabilities not found elsewhere.

2. METHODOLOGY

2.1 Data and materials

After a session of participatory mapping and interview regarding the waste collection process with the UPD CMO Sanitation head, field data needed to be obtained to understand the current practices and analyze the issue deeper for a solution. These data would be details such as potential obstacles to the road network, the present unmapped truck route, and other relevant on-ground variables. These data points are crucial for generating efficient route maps that can improve waste collection in UPD.

Lastly, the team also took note of the locations of each garbage pick-up point for each building that is covered in each partition, either North or South. It was observed that there were some collection points that had more than one building allocated for their collection. These points, much like the impedance factors, were plotted on a map considering the field observations. Other necessary elements for building the network and modeling the routes not found on-ground were obtained from openly available datasets such as OpenStreetMaps (OSM) and Google Traffic. These were preprocessed using GIS methods, specifically OSM being obtained from QuickOSM and Google Traffic being obtained from XYZ Tiles.

According to the interviews conducted with the CMO Sanitation Head and garbage truck drivers, once the truck enters the campus for collection, the collectors are given a short debriefing by a guide from CMO and led around the campus. They follow the designated checklist for the specific day and time. The checklists for both sectors would most likely be unfinished on the first day and then completed afterward on the second day. This case happens because the trucks are planned to collect only as much as they can within the checklist for that day and time. Once the truck's capacity is full, the garbage collection for that day and time is completed.

With permission from CMO, field datasets were collected over the course of three days: June 6, 14, and 15, 2023. June 6 focused on identifying potential obstacles to the network, such as closed gates, speed bumps, crosswalks, routing, and passable/non-passable routes. These obstacles were labeled as "Impedance Factors" and digitized from a physical map. June 14 and 15, divided into morning and afternoon sessions, captured details of the current truck route, including start and end times, route taken, time taken for trash collection, building coverage, and other on-ground barriers or obstacles. The Strava mobile app was used in recording the entire route drive time including each stop for collection, while another researcher used a separate timer to compare & verify the path being followed. The Strava mobile app also provided maximum and average speeds for each collection route during and after travel, which allowed the researchers to remodel and calibrate the network later on.

Moreover, one team member would initiate the Strava application as the truck begins its journey, while another member would record the duration it takes for the truck helper to complete the collection from the designated point and return to the truck. Throughout this process, any stops made by the truck are duly considered. Any buildings ignored from the checklist, or not included in the checklist but collected, are also noted down.

2.2 Data Processing in GIS

The garbage collection scheme is divided into North and South sectors shown in Figure 1. The division is done due to the amount of garbage to be collected in relation to the capacity of the trucks available. In relation to their pick-up point location, each half's area coverage was delineated using the Minimum bounding geometry tool in QGIS. The Base UPD Campus Road network was initially obtained through OpenStreetMap.

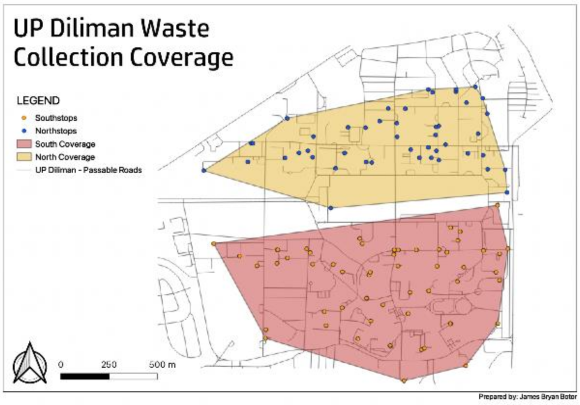

Figure 1. Garbage Collection Coverage in UPD Campus

Through a series of filters based on OSM attributes and information collected from fieldwork, the roads accessible by trucks, their respective travel directions (attributed as "oneways"), and their maximum speeds were processed further. The length of each road, drive time by average maximum truck speed *DT* (which is computed by the road length and speed), drive time per collection route average speed *DTIndAve*, and drive time per collection route maximum speed *DTIndMax* were computed using the field calculator tool. The planiarize and integrate tools in ArcGIS were also used in order to ensure the road network was traversable if new roads were digitized.

The collection points of the truck were manually digitized and supplied with the following information: stop code, building name, side or half coverage, day, stop order, and time spent for collection in minutes. The point factors which affected impedance like closed gates or crosswalks were manually digitized and supplied with their point barrier type.

Traffic data images from Google traffic obtained on the day of the fieldwork would be treated as polygon barriers as a pseudo-interpretation of traffic, affecting travel time. These polygons are treated as a day's typical traffic at a certain time for the rest of the study. The polygons were digitized and given a scaled cost value for their traffic level (i.e. 1.1 for *Orange/medium traffic*, and 1.2 for *Red/heavy traffic*). It is noted that low (Green) to no traffic was ignored since the delay caused by these were assumed negligible. When creating a new network analysis layer, these factors could be loaded in as barriers in order to model the current road network on a given day and time (i.e. Wednesday Morning).

Lastly, the collection points of the truck were also manually digitized and supplied with the following information: stop code (i.e. *S1-1* = Wednesday, Morning, 1st), name (i.e. Melchor Hall), side or half (N or S), day (1 being Wednesday, and 2 being Thursday), day order (i.e. 1 = 1st to be collected), and time spent for collection in minutes (i.e. 1 minute). Any point estimated but not noticeably taken during fieldwork would have their time spent for collection be the average time spent for collection of their expected collection route. If these points were unreachable or not located during network analysis, their points would be moved slightly towards a reachable edge on-the-fly in order to ensure a solution can be reached, since the cause for being unreachable was usually due to poor digitization or as observed in the field, collectors would just walk to the building rather than the move the truck.

There were 3 Network analysis problems that had to be solved to answer the time-efficiency problem of the research, in succession: (1) Is the road network dataset properly calibrated for the actual circumstances on the ground?, (2) Are the collection points best split for their halves geographically?, and (3) What is the best route, considering all parameters & factors, for collecting a certain half's garbage pick-up points in terms of time?

To solve the first problem of calibrating the network, the researchers opted to use the Route Analysis Tool. To be efficient, a garbage service must minimize distance traveled & reasonable service time (Farabakhsh and Forghani, 2019). In order to calibrate if the network is accurate to the experienced or observed data, route analysis layers were created in order to generate the routes taken during fieldwork, with distance being the impedance. It is noted that the polygon barrier for traffic was not included in calibration since the overall slow down of the truck was already incorporated due to the usage of average speed rather than maximum speed. A summary flowchart for the process of creating a calibrated route is illustrated in Figure 2.

The second network analysis problem was solved by using an Origin-Destination Cost Matrix (OD-Cost Matrix) in ArcGIS. Since the collection points per route could not be easily assumed as the best segregation of points for waste collection, the study opted to use the OD-Cost Matrix analysis tool to bisect the collection points into more geographically appropriate halves. The impedance of this analysis used distance or length and the only impedance factor included were restrictive point barriers or closed gates. In line with the preference of the CMO Sanitation head which was proximity, the collection points per side (North and south, as destinations) would be ranked by their combined distance from both the CMO building and CHK Exit Gate (as Origins) by shortest to longest. After sorting by combined distance, for both North and South sides, the collection points for the first half or closer points and the second half or farther points were exported separately. The specific steps are illustrated in Figure 3.

Finally, using the new points from the OD-Cost Matrix, new time-efficient routes can be modeled on the road network dataset since it is already calibrated. The time-efficient route

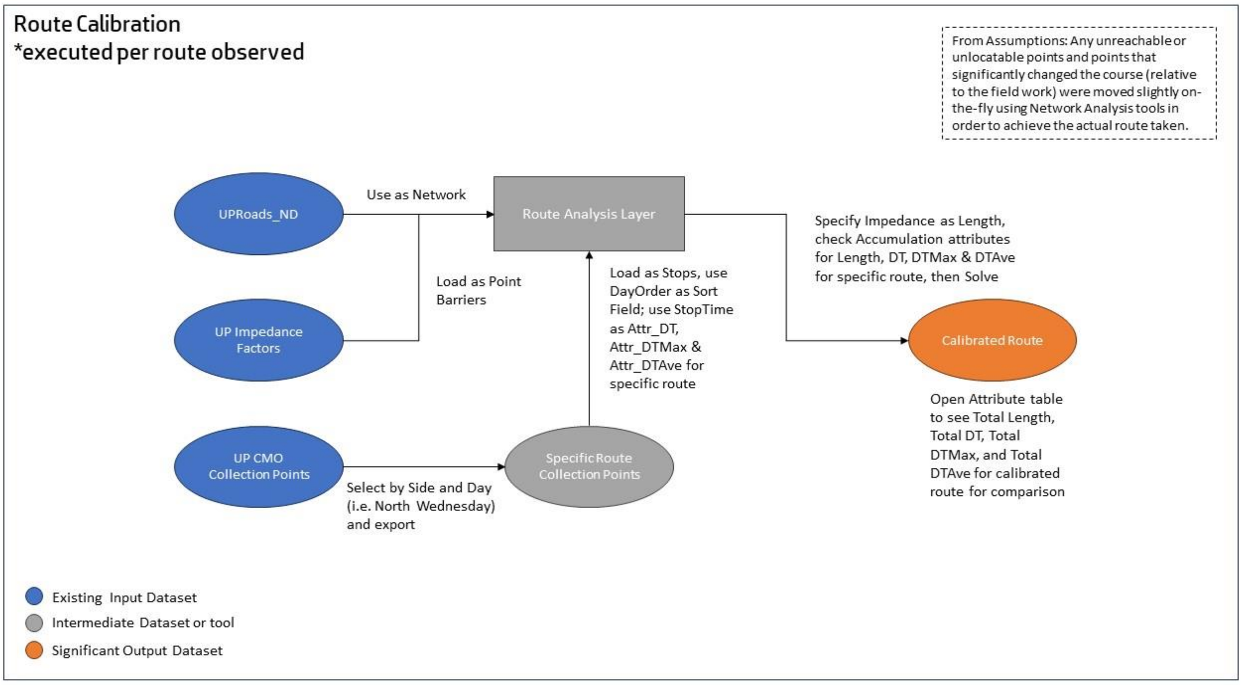

Figure 2. Route Calibration Flowchart

generation used route analysis layers with DT being the impedance. As mentioned before, U-turns were also restricted to only dead ends and intersections in order to minimize traffic delay caused by the truck. These routes utilized all point barriers (closed gates, crosswalks, and speed bumps) and polygon barriers per collection route (traffic data). A summary flowchart of creating a new time-efficient route is illustrated in Figure 4.

To remain consistent with actual site conditions, the researchers followed the assignment for each truck (north & south coverage) which was separated for each day and for each side, when generating new routes. The network dataset was divided into 3 major groups: the network, stops, and barriers. The network consisted of the road data, while the barriers were from impedance factors and traffic data (which were digitized with polygons). The stops consisted of the collection points (per side, per day) and the start & end point (which was assumed to be consistent per side, per day). Additional assumptions made in the study to narrow down inconsistencies include:

- When it comes to truck routes, the starting point is assumed to be at the location of CMO and endpoints is at the CHK gate based on interview
- Additionally, U-turns are only allowed at dead-ends and intersections as this would cause minimal traffic and is observed during field data acquisition. After each route, the trucks are full, which is necessary for the truck and crew to be paid fully.
- As some preprocessing assumptions: If a building was not noticeably observed to be collected, the collection point is assumed to be in front of the building. If there are multiple buildings sharing a collection point, the collection time is split by the number of combined points.
- Lastly, for the truck driving patterns assumptions, Speed Bumps and crosswalks in the network model add 10 and 5 seconds respectively to DT, for this is what was observed during fieldwork. Next, some one-way routing was not followed during data collection, hence in the road network, these were considered as two-way routing. Any unreachable points and points that significantly changed the course (relative to the fieldwork) were moved slightly on the fly using Network Analysis tools in order to achieve the actual route taken (field).

2.4 Assessment of time-efficient routes

There were two moments where time was compared: Route Calibration and New Route Generation. When it came to Route Calibration, these generated routes were cross-referenced with the paths taken, as seen in the field data collected using Strava. If these routes were significantly different from the observed paths, on-the-fly graphic picks and turning off oneway restrictions would be used to reorient the generated route's path.

After route generation, their total average drive time per collection route speed (*DTIndAve*) would be compared with the observed total time. If their elapsed times compared to the observed times were not significantly different for the study (>15%, subjective value), the network is said to be calibrated for further analysis.

On the other hand, for New Route Generation, the sequence of collection points per half would be reordered in order to find the most time-efficient route, while preserving the CMO Building start and CHK Gate end. After route generation, each route was inspected closely for any new findings or unexpected results. Since garbage collection only finishes once the truck is full, the observed route times & calibrated route times became the criteria for time-efficiency of the new generated routes. Alongside these comparisons, other factors, namely stop count and road length, per route, were included

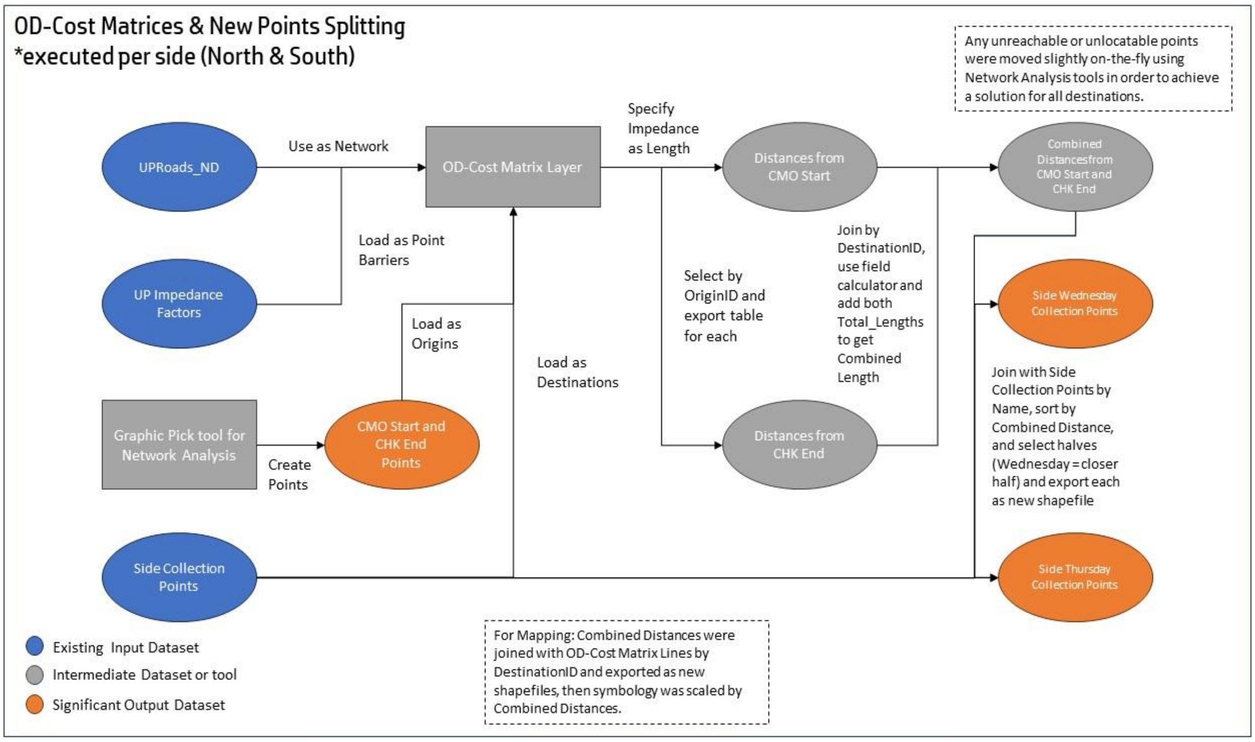

Figure 3. OD-Cost matrix & new point splitting flowchart

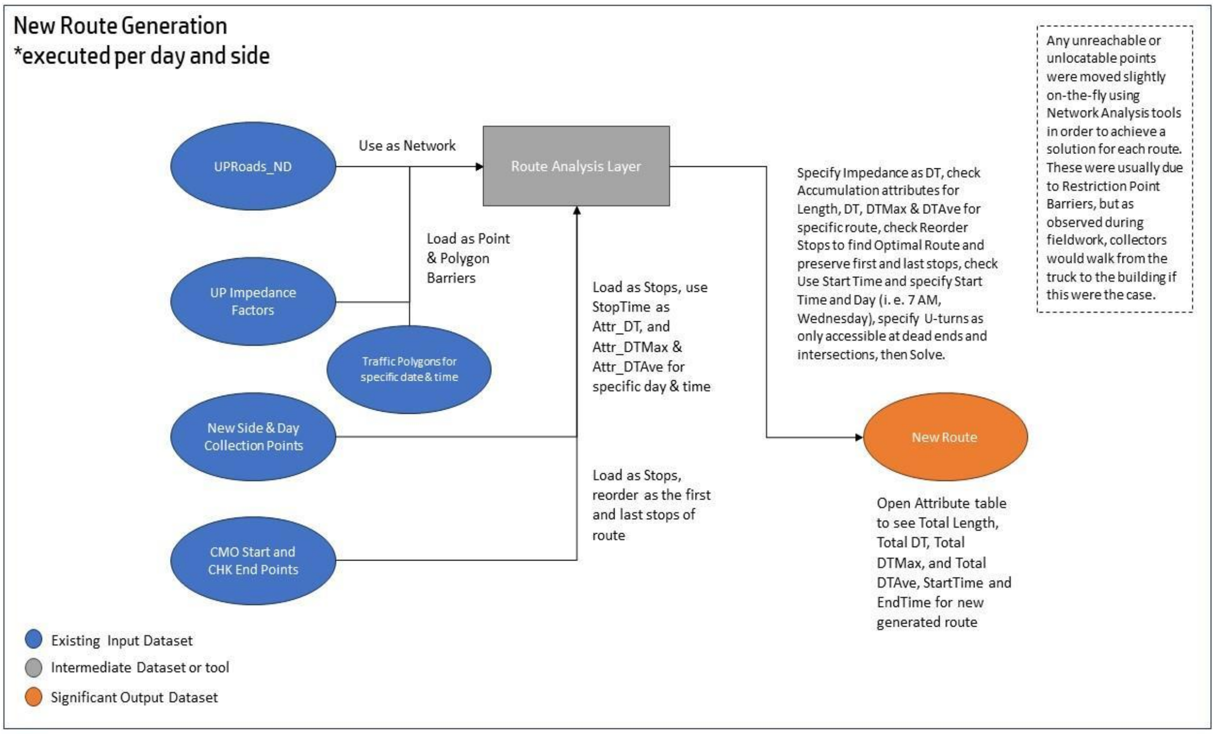

Figure 4. New Route Generation Flowchart

for a better context of the simulation. These comparisons were tabulated altogether.

3. RESULTS AND DISCUSSION

3.1 Route building coverage

The collection route of the trucks mainly focused on the academic buildings and the dormitories in UPD. However, it also includes a few administrative and commercial buildings. These include the Gyud Food Hub, SPMO, UP Press, Office of Campus Architect, UP Diliman Police, Office of the University Registrar, Executive House, Building, Quezon Hall Balay Chancellor, and Bahay ng Alumni. On the other hand, despite having a list of buildings to collect from, there are a number of academic, administrative, and commercial buildings that are not included in the route as compared to the total number of buildings in the checklist provided by CMO.

These routes include GT-Toyota Asian Cultural Center, Asian Institute of Tourism, Juguilon Hall, Bulwagang Rizal (Faculty Center, Dean's Office), Corredor, Enriquez Hall, Tolentino Hall, College of Home Economics or Alonso Hall, Child Development Center or Home Management House, Craft and Design Laboratory, Gusali 2, College of Human Kinetics / Ylanan Hall, Plaridel Hall, CMC Media Center and DZUP Station, Plaridel Hall Annex, Benton Hall, National Economic and Development Authority, Research & Extension for Development Office. Encarnacion Hall, School of Library and Information Studies, Gonzalez Hall, Bulwagan ng Dangal, and Lim Museum.

The area covered by each collected building with its respective sector can be viewed in Figure 5, with points symbolizing a building's collection or pick-up point.

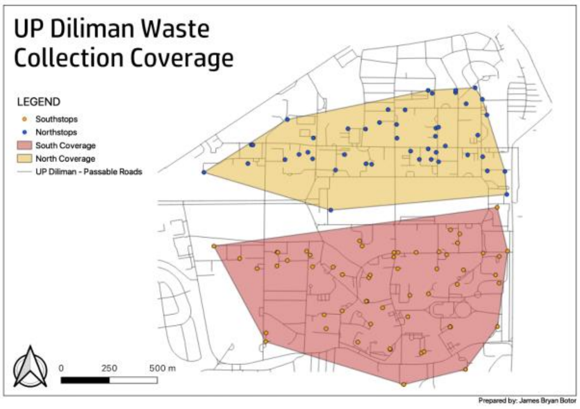

Figure 5. Building Point Coverage

In total, including the buildings that were not observed during fieldwork, 4 sets of points were created after OD-Cost Matrix Analysis: 23 North First Half points, 23 North Second Half points, 30 South First Half points, and 27 South Second Half points. It is noted that the south points took some geographic liberties splitting the points since some points belonged to one specific road, yet when split evenly by rank, their distances were separated exactly by the two halves. To avoid this scenario, those points that were separated were included in the first half. The OD-Cost Matrix analysis results is shown in Figure 6 and the new set of collection points are illustrated in Figure 7.

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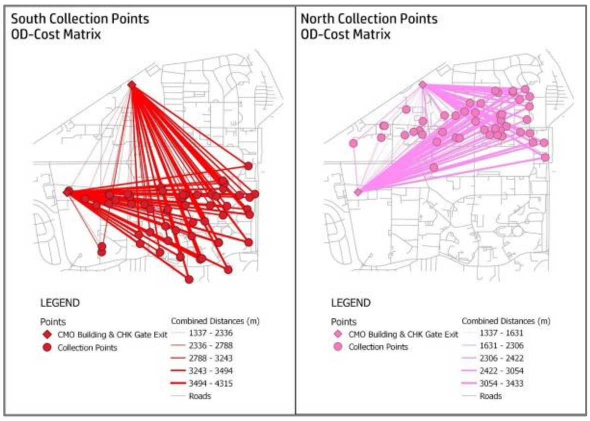

Figure 6. OD-Cost Matrix maps for North and South collection points

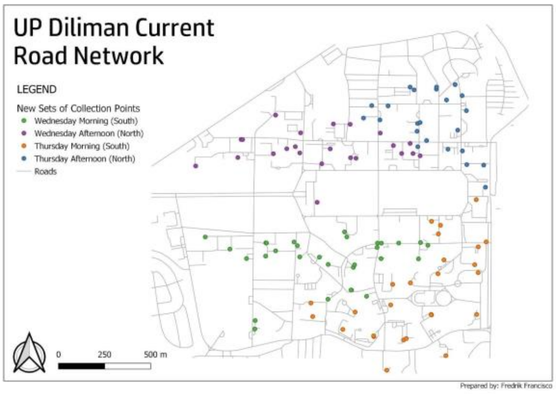

Figure 7. New sets of collection points

3.2 Calibrated routes

After digitization and calibrated route generation, they were mapped for better visualization. Furthermore, the assessment of calibration for time-efficiency was tabulated. As seen in the comparison of observed drive time (*Observed DT*) and appropriate simulated drive time (*DTIndAve*), since their elapsed times compared to the observed times were not significantly different for the study (>15%, subjective value), the network is said to be calibrated for other route analyses. The digitized STRAVA routes are provided in Figure 8. Calibrated routes are shown in Figure 9.

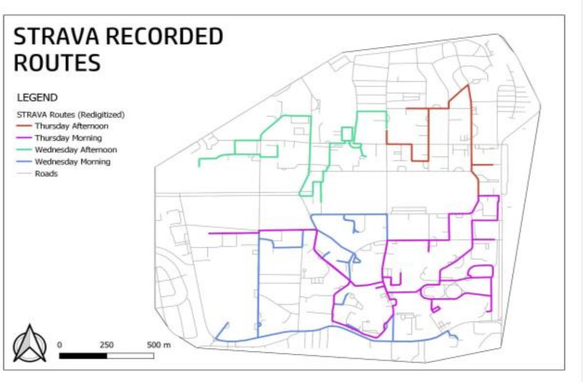

Figure 8. Digitized Routes from STRAVA

3.3 Waste collection routes

The simulated routes, despite generally being longer than the calibrated routes due to the initial and final stops being preserved, were able to accommodate more stops in roughly the same amount of time the calibrated would. After route generation, each route was closely inspected and found to ignore one-way restrictions at certain points. If one-way restrictions were to always be followed, no solution or route could be generated. The simulated routes or proposed new garbage collection routes are shown in Figure 10.

4. CONCLUSION

The study's findings have led to several key conclusions. Firstly, modeling the active road network of UPD Campus was deemed challenging but feasible, except for the difficulty of accessing live traffic data due to paywalls. This limitation may impact the accuracy of real-time routing analysis.

Secondly, the study identified that achieving time-efficient routing for waste collection is currently impeded by the strict adherence to one-way paths. To ensure a swift and efficient path, the garbage collection trucks are advised to follow a different set of rules for one-ways compared to other vehicles. This adaptation has the potential to enhance the overall efficiency of waste collection in terms of time and resource utilization.

Lastly, the study emphasizes the need for a comprehensive review and overhaul of the existing waste collection system. This involves considering the use of larger trucks, increasing manpower, and establishing clearer guidelines for the collection points of buildings. By implementing these improvements, consistency in collection time can be achieved, and future studies on waste collection can be conducted with greater accuracy.

Through this study’s findings, CMO can efficiently assess alternative routes for garbage collection. They may also apply these to a new framework or plan for efficient waste management. Furthermore, UPD can use these routes and data as additional references for different traffic schemes for the campus, should the truck obstruct other campus activities.

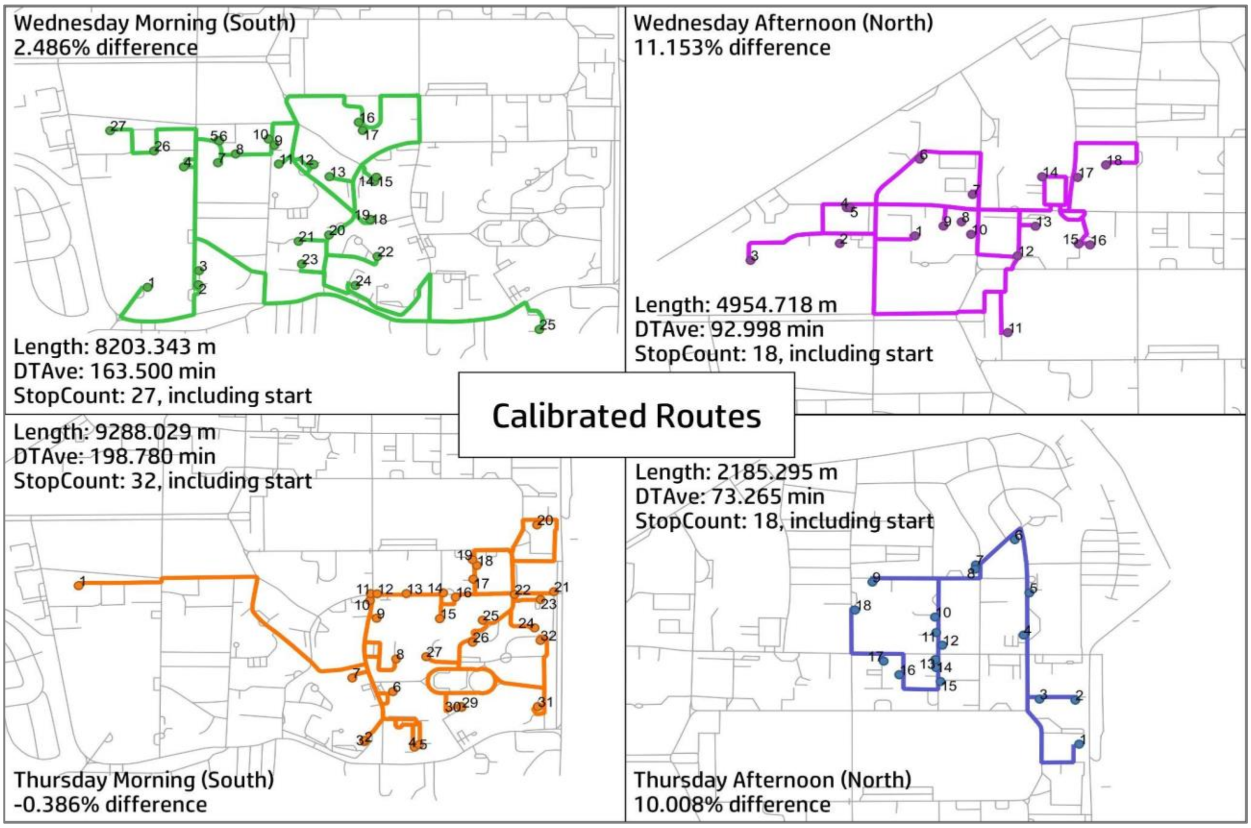

Figure 9. Calibrated Route Map in UPD Campus

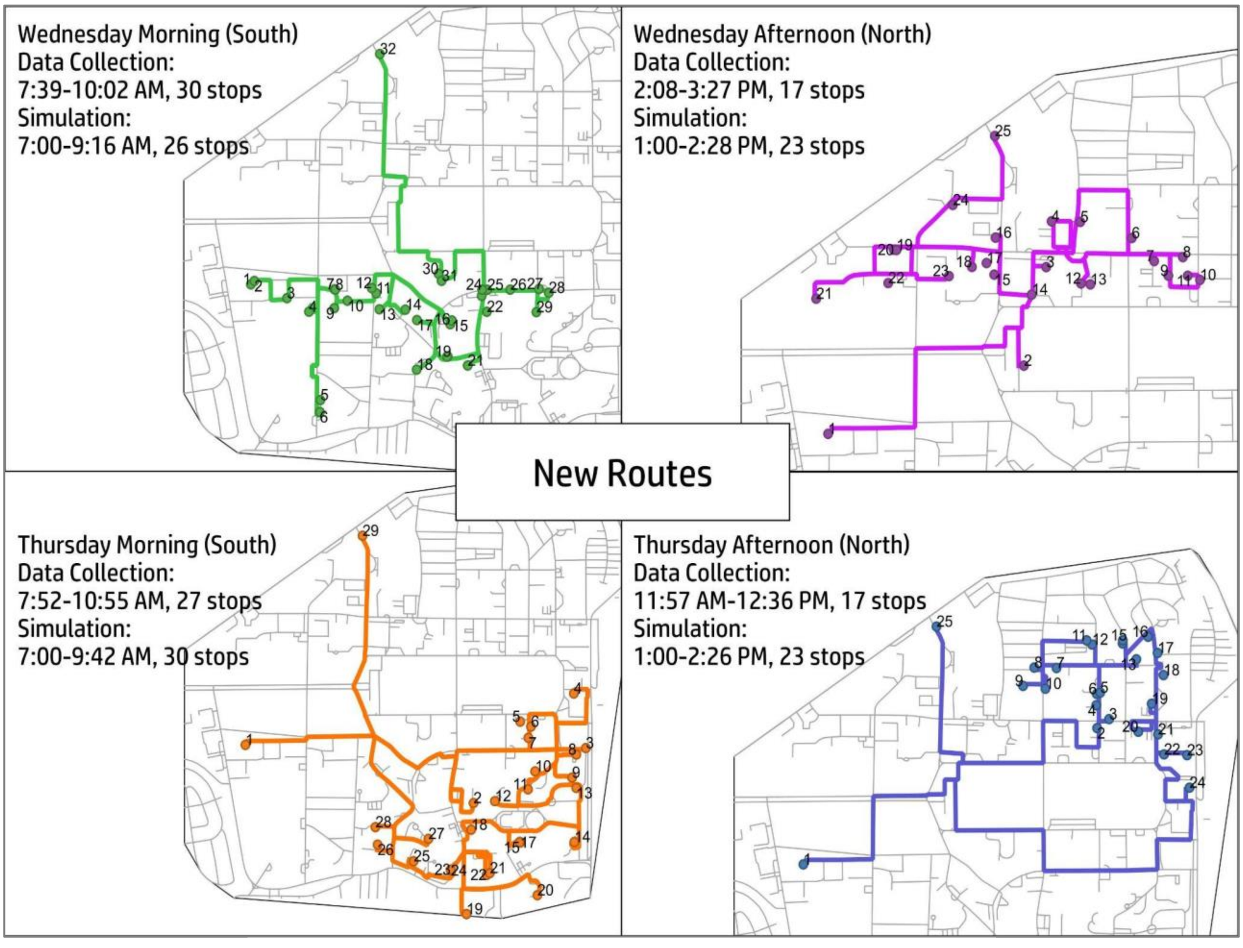

Figure 10. New or Proposed Garbage Collection Routes in UPD Campus

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REFERENCES

Clemente, C. C., & Geronimo, J. S., 2019, DEVELOPING THE CRITERIA FOR LOCATING THE MOST SUITABLE AREA FOR GARBAGE BINS IN UP DILIMAN CAMPUS USING GIS. Department of Geodetic Engineering, College of Engineering, UP Diliman.

Drackner, M., 2005, What is waste? to whom? - An anthropological perspective on garbage. journals.sagepub. https://journals.sagepub.com/doi/10.1177/0734242X05054325

Farahbakhsh, A., Forghani, M. A., 2018, *Sustainable location and route planning with GIS for waste sorting centers, case study: Kerman, Iran.* Waste Management & Research: The Journal for a Sustainable Circular Economy, 37(3), 287-300. https://doi.org/10.1177/0734242x18815950

Hult, J., Leader, A., 2015, Argus leader. Home. https://www.argusleader.com/story/news/2015/01/25/slow-garbage-pickup-causes-headaches/22321295/

K. Kůs, R. L. Cheu, T. Horák, 2016, "GIS approach in vehicle route optimization for residential recyclables collection," 2016 Smart Cities Symposium Prague (SCSP), Prague, Czech Republic, 1-6, https://doi.org/10.1109/SCSP.2016.7501024

Sallem, R., Serbaji, M.M., Alamri, A.M., Kallel, A., Trabelsi, I., 2021, Optimal routing of household waste collection using ArcGIS application: a case study of El Bousten district, Sfax city, Tunisia. Arab J Geosci 14, 1038. https://doi.org/10.1007/s12517-021-07265-2

United Nations, 2023, Goal 11: Make cities inclusive, safe, resilient and sustainable. United Nations Sustainable Development.
https://www.un.org/sustainabledevelopment/cities/