Geographic Information System (GIS) - Based Network Analysis as a Decision Support for Relief Goods Distribution in Selected Barangays in Marikina City, Philippines

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Geographic Information System (GIS) – Based Network Analysis as a Decision Support for Relief Goods Distribution in Selected Barangays in Marikina City, Philippines

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Abstract: *The increasing frequency and severity of natural disasters necessitate the development of efficient and effective systems for the distribution of relief goods. The study aimed to determine the optimal route of the delivery vehicles focuses on the three barangays near the Marikina River specifically Barangays Nangka, Concepcion 1, and Malanday. Through a comprehensive evaluation of various alternatives, the results revealed differing outcomes. Route analysis produced a total length of 9.8 km and a driving time of 20 minutes, while Closest Facility analysis resulted in a total length of 13.9 km with a driving time of 27 minutes. OD Cost analysis showed a total length of 13.86 km with no specified driving time. However, the Vehicle Routing Problem (VRP) Analysis emerged as the most effective solution, with a total length of 19.3 km and a driving time of 3 hours and 39 minutes.*

Keywords: Geographic Information System, Network Analysis, Relief Goods Distribution, Vehicle Routing Problem

1. INTRODUCTION

Flooding, primarily from heavy rainfall and typhoons, is a major and frequent disaster in the Philippines, posing serious risks to lives and property and affecting 74% of the population [1]. Floods brought about by typhoons and thunderstorms are a perennial problem in Metro Manila, especially in low-lying areas like Marikina City [2]. Urbanization increases impervious surfaces that alter water flow, making effective flood management increasingly critical [3]. Over the years, residents living near the Marikina River were forced to evacuate to schools, and even churches as their temporary shelter which they called camps. Meanwhile, the City Disaster Risk Reduction and Management Office (CDRRMO) is tasked to spearhead distribution of relief goods to all the camps. With the limited trucks available, an efficient routing system is a need to deliver the necessities of the victim.

The primary goal of emergency rescue is to increase the effectiveness of the distribution of relief goods, such as life essentials. The delivery workers of emergency resources, who are searching for possible ideal distribution routes, need to be more aware of these distribution challenges. The CDRRM office can meet the needs for emergency rescue before the crisis worsens by sending emergency supplies to the rescue site promptly and with an acceptable schedule. Hence, the study aimed to determine the optimal route of the delivery vehicles focuses on the three barangays near the Marikina River specifically Barangays Nangka, Concepcion 1, and Malanday. Consequently, the goal of this research is to apply network analysis based on Geographical Information Systems (GIS) modeling to identify the optimal route for emergency resource scheduling as soon as possible following the flood.

2. METHODOLOGY

2.1 Study Area

Marikina, officially known as the City of Marikina (Filipino: Lungsod ng Marikina), is a 1st class highly urbanized city situated in the National Capital Region of the Philippines. With a population of 456,159 people according to the 2020 census conducted by the Philippine Statistics Authority [4]. Located at approximately 14.6349° N latitude and 121.1220° E longitude. For the purpose of this study, the Disaster Risk Reduction Management (DRRM) of Marikina has recommended focusing on three barangays: Concepcion Uno, Nangka, and Malanday. These barangays are identified as the most vulnerable areas within Marikina City. In Figure 1, the study area's boundary, evacuation camps, and distribution centers are illustrated.

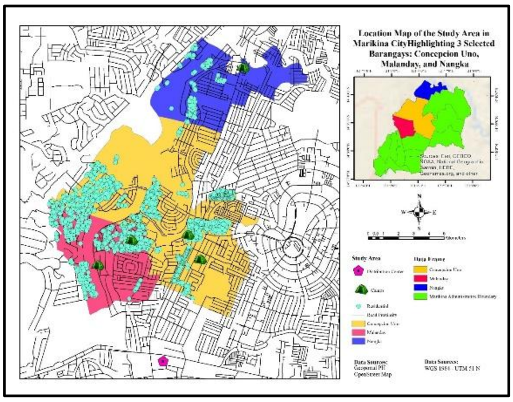

Fig. 1. Location Map of the Study Area in Marikina City

2.2 Data Collection and Sources

In this study, data collection involved gathering information from diverse sources. Official records regarding the demands of trucks were utilized from Marikina City's DRRM. Geographic data, including building footprints and road networks, were obtained from OpenStreetMap. The volume of trucks and the number of relief packs were cited from Nazareno *et al* [5]. Lastly, supplementary data, such as elevation models and geohazards, were gathered from USGS Earth Explorer and Project NOAH. Refer to Table 1 below for a summary of the data collection used in this study.

Table 1. Data Collection and Sources for Network Analysis

No.	Data Type	File	Source
1	Administrative Boundary of Marikina	Shapefile	Marikina City Planning
2	Philippine Road Network • Total Length • Driving Time • Maximum Speed	Shapefile and CSV	Open Street Map
3	Philippine Building Footprint • Residential • Evacuation Camps • Distribution Center	Shapefile	Open Street Map
4	Truck Demand and Travel Time	CSV	DRRM Marikina
5	Volume of truck and No. of Relief Packs per Camps	CSV	Nazareno *et al.*, 2016
6	Elevation Model	Raster	USGS Earth Explorer
7	Geohazard	Shapefile	Project NOAH

2.3 Methodological Flowchart

This study employs a systematic approach to address its objectives. It starts by defining the study area: Marikina City's vulnerable barangays—Concepcion Uno, Nangka, and Malanday. Data from various sources, including government records, census data, satellite imagery, are collected for analysis. After data collection, pre-processing steps, such as boundary clipping and road network filtering, are conducted. Network analysis techniques, like routing algorithms, are then applied to evaluate transportation routes and evacuation strategies. Results are evaluated based on factors like travel time and population density. Validation and sensitivity analysis ensure the robustness of findings. Figure 2 illustrates the methodological framework aims to provide insights and recommendations for disaster risk management in Marikina City, enhancing community resilience to natural hazards.

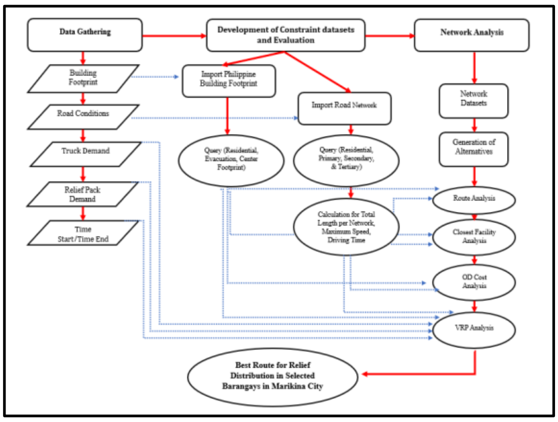

Fig. 2. Methodological Flowchart for Relief Distribution Route Analysis

2.4 Preparation of the Study Area

The initial step involves delineating the specific geographic scope of the study by defining its boundaries. The comparison in Figure 3 depicts the administrative boundary of Marikina City before and after the implementation of the clipping process. On the left side of the figures, the original administrative boundary of Marikina City is shown, encompassing a broader area. On the right side, the result of employing the clipping process is displayed, where the administrative boundary has been refined to include only the selected barangays: Concepcion Uno, Malanday, and Nangka. By doing so, the study ensures that subsequent data processing and analysis are concentrated solely within these delineated areas.

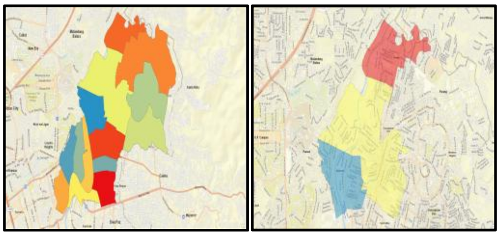

Fig. 3. (Left) Administrative Boundary of Marikina City, (Right) Administrative Boundary of the Study Area

2.5 Building Footprint (Residential/House)

In Figure 4, the building footprint data undergoes a refining process to exclusively include residential structures, filtering out other types of buildings. This refined dataset becomes pivotal in understanding the distribution of the population across the study area with greater precision. This step ensures that transportation routes, evacuation strategies, and distribution networks are effectively planned to meet the needs of the residential population within the study area.

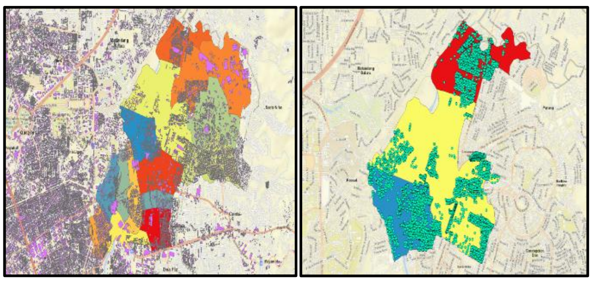

Fig. 4. (Left) Philippine Building Footprint, (Right) Building Footprint of the Study Area

2.6 Building Footprint (Evacuation Camps)

In Figure 5, the building footprint data is filtered similarly to the residential houses process, isolating evacuation camps and distribution centers.

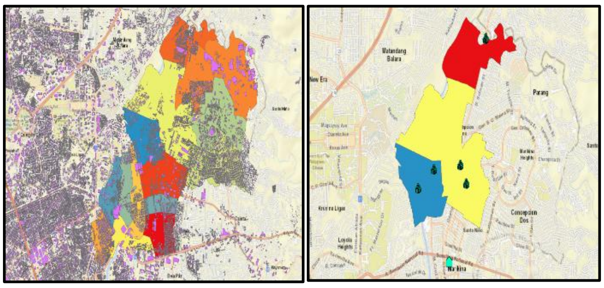

Fig. 5. (Left) Philippine Building Footprint, (Right) Building Footprint of the Evacuation Camps

2.7 Road Network

In Figure 6, the road network data undergoes a refining process similar to the approach used for filtering residential houses. This involves carefully selecting primary, secondary, tertiary, and residential roads while excluding pathways, pedestrian paths, trunks, bridges, and expressways. By doing so, the analysis focuses on roads that are usable for transportation while excluding routes that are impassable or unsuitable for travel. This refining process ensures that the subsequent network analysis is based on a realistic representation of the road network, providing a solid foundation for route planning and transportation logistics. By prioritizing usable roads, the analysis can accurately assess travel routes and transportation options, leading to more effective disaster response strategies.

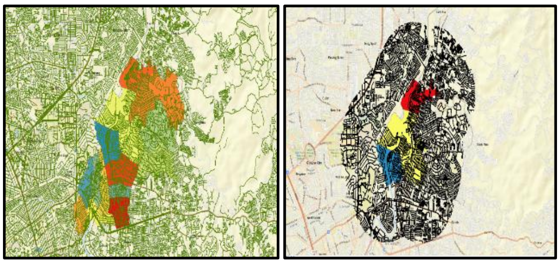

Fig. 6. (Left) Philippine Road Network, (Right) Proximity Road of the Study Area

2.8 Calculation for the Road Length, Maximum Speed and Driving Time

The final step in the pre-processing stage involves calculating key metrics for the road network. This includes measuring the total length of the roads, determining the maximum allowable speed on each road segment, and estimating the driving time. These metrics are essential for subsequent network analysis, forming the foundation for evaluating route efficiency and travel times.

The geometrical length of the road was calculated in the attribute table using "field calculator" to determine the length. The recommended maximum speed is in km/hr, however, due to its significant figures deemed small, conversion of units was done. To find the maximum speed in km/min, refer Equation 1, divide the speed in km/hr by 60 since there are 60 minutes in an hour.

$$Max\ Speed\ (km/\min) = \frac{30\ km/hr}{60\ min/hr} \qquad \text{Equation 1}$$

$$Driving\ time\ (i,j) = \frac{Road\ Length\ (km)}{Max\ Speed\ (km/min)} \qquad \text{Equation 2}$$

$$where\ i,j = 1,2,\ldots N\ or\ the\ number\ of\ barangays$$

Equation 2 is the Driving Time. The distance between node i and node j was obtained using the calculated length of the Road Network data while the speed of the delivery truck considered for this is 30 km/hr. The number of campers (evacuees) was assumed 1,000 per camp. The carrying capacity of the truck is 2,500 packs of relief goods [5].

2.9 Network Analysis Routing in ArcGIS

The Network Analyst toolbox in GIS software, such as ArcGIS, provides tools for performing network analysis and maintaining network datasets. These tools facilitate modeling transportation networks and conducting various network analyses, including route optimization, closest facility determination, service area analysis, origin-destination cost matrix calculations, vehicle routing problem solutions, and location-allocation analysis [6]. Additional constraints are the following:

1. Traffic Management: Vehicles heading to Loyola Memorial Park from Barangka Fly-over to A. Bonifacio Avenue should use the left lane to enter through Gate 2 of Loyola Memorial Park.
2. City Proper Access: Vehicles going to the city proper should use the right side of the road.
3. Route Restrictions for Specific Roads: Vehicles from C-5 By-Pass Road or Marcos Highway using Riverbanks Avenue should exit at Riverbanks Avenue and Bonifacio Avenue to access the city proper or Loyola.
4. Exit Protocol from Loyola: Vehicles exiting through Gate 1 of Loyola may turn right onto Don Gonzalo Puyat Street, Paspasan Street, and Chorillo Street, then right onto A. Bonifacio Avenue towards Quezon City.
5. Quezon City Access: Vehicles going to Quezon City from the city proper may use J.P. Rizal Street towards Marcos Highway.
6. Rerouting from specific streets: Vehicles from Olive Street, Katipunan Avenue, Aquamarine Street, and Tangerine Street are required to reroute to nearby roads.

The assumptions of the study are as follows:

1. Uniform Road Speed: All roads are assumed to have a speed limit of 30 kph, based on the study by Nazareno *et al*. [5].
2. Vehicle Capacity: All delivery vehicles have an equal carrying capacity, able to transport 2500 relief packs each.
3. Evacuation Camp Capacity: Each evacuation camp can accommodate up to 1000 campers.
4. Priority of Service: All barangays and evacuation camps are given equal priority in the delivery and service process.

2.10 Route Analysis

Route Analysis is a type of network analysis that determines the best route from one network location to one or more other locations. It can also calculate the quickest or shortest route depending on the impedance chosen. The order of the stops may be determined by the user. Calculation of travel distances and times in ArcGIS can be automated through the software's built-in functionalities. For example, once routes are generated, the software can automatically calculate the total distance traveled along each route and estimate travel times based on predefined average speeds or travel time estimates for different road segments. For this study, the driving time is the impendence to generate the shortest path. Figure 7 illustrates the generated Route Analysis in GIS.

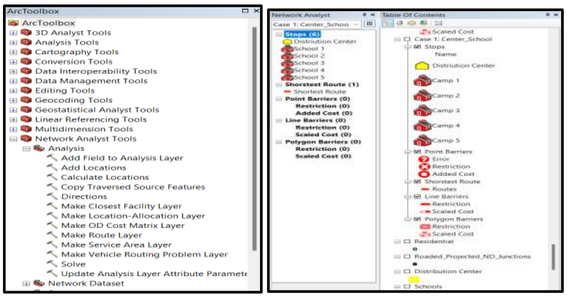

Fig. 7. (Left) ArcTool box for Network Analysis, (Right) Route Analysis

2.11 Closest Facility Analysis

The process of finding the closest locations (facilities) from sites (incidents), based on the impedance chosen—for example, finding hospitals near a car accident. When finding the closest facilities, users can specify how many to find and whether the direction of travel is toward or away from the site (incident) [6].

In this study, conducting closest facility analysis involves determining the nearest evacuation camps from distribution centers. This process begins by defining distribution centers as origin points and evacuation camps as target facilities. The proximity algorithms are applied to calculate the closest evacuation camps to each distribution center based on distance or travel time. This analysis is crucial for optimizing emergency response planning and resource allocation ensuring efficient distribution of relief supplies and services to affected areas within the study area. Refer to Figure 8 for the implementation of the analysis.

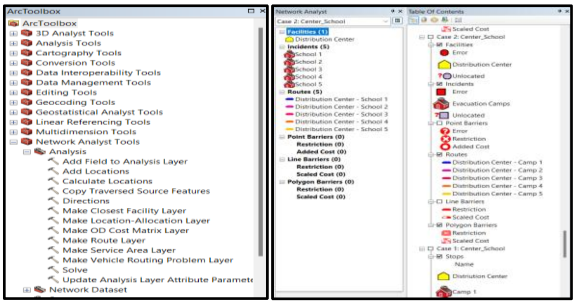

Fig. 8. (Left) ArcTool box for Network Analysis, (Right) Closest Facility Analysis

2.12 OD Cost Matrix Analysis

A type of network analysis that computes a table containing the total impedance from each origin to each destination. Additionally, it ranks the destinations that each origin connects to in ascending order of the time it takes to travel from that origin to each destination [6]. The process begins by specifying origin points (distribution centers) and destination points (evacuation camps), refer Figure 11. The total impedance for each route is calculated and compiled into an OD cost matrix, a table displaying travel costs for all origin-destination pairs. For each origin, destinations are ranked by travel time or distance, identifying the closest options. In this study, OD cost matrix analysis determines travel times from distribution centers to evacuation camps, optimizing emergency response by finding the fastest routes for supply delivery and prioritizing resource distribution based on proximity.

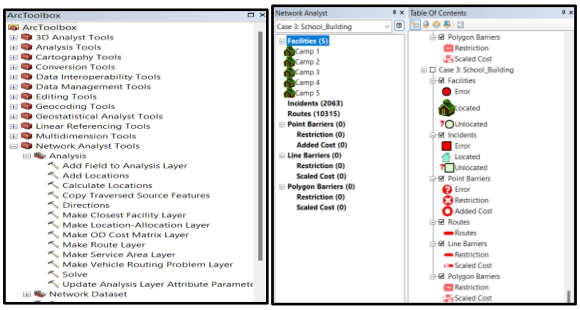

Fig. 9. (Left) ArcTool box for Network Analysis, (Right) OD Cost Matrix Analysis

2.13 Vehicle Routing Problem Analysis

Vehicle Routing Problem (VRP) analysis is a type of network analysis that involves routing a fleet of vehicles to achieve specific goals while satisfying various constraints [6]. The primary objective could be to lower operating costs or improve delivery efficiency. This analysis ensures that vehicles follow optimal routes to meet delivery schedules, accommodate vehicle capacities, and adhere to travel duration limits, (see Figure 10).

For instance, in emergency response planning, VRP can optimize the delivery of supplies from distribution centers to evacuation camps. The analysis determines the best routes to minimize travel time and costs while considering constraints like vehicle capacity and required delivery windows. This method enhances resource allocation and logistical efficiency, ensuring timely support to affected areas.

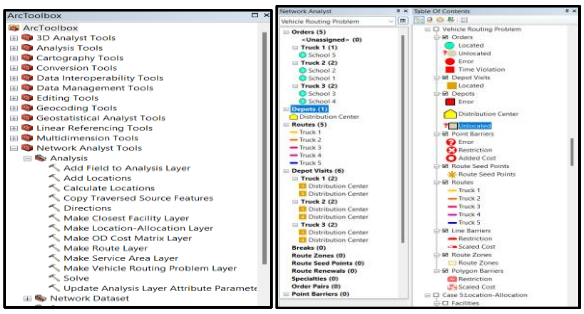

Fig. 10. (Left) ArcTool box for Network Analysis, (Right) VRP Analysis

3. RESULTS AND DISCUSSION

3.1 Route Analysis

Figure 11 illustrates the route from the distribution center to the camps. The route begins at the distribution center and proceeds to the nearest camp first. From there, it continues to the next closest camp, sequentially, until reaching the final destination.

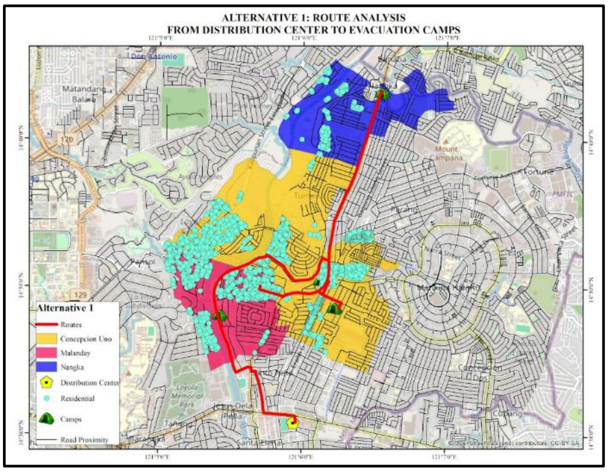

Fig. 11. Route Analysis

3.2 Closest Facility

Figure 12 illustrates the routes from the distribution center to each camp. Camp 1 has a total distance of 2.1 km with an estimated driving time of 4 minutes. Similarly, Camp 2 covers a distance of 2.7 km, requiring approximately 5 minutes of driving time. Camp 3 is 2.0 km away from the distribution center, with a total driving time of 4 minutes. Camp 4 involves a 2.5 km drive, taking around 5 minutes. Lastly, Camp 5 has the longest route, covering 4.6 km and taking an estimated 9 minutes to reach.

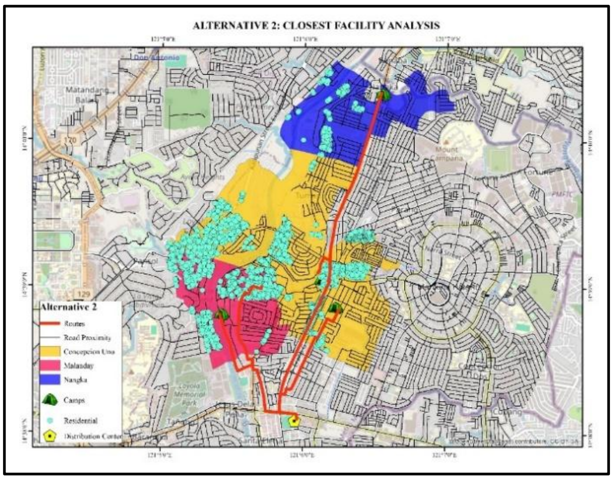

Fig. 12. Closest Facility Analysis

3.3 OD Cost Matrix

Figure 13 illustrates the results of the OD Cost Matrix analysis from the distribution center to the various camps. The camps were ranked based on the length of the roads traveled. Camp 3 ranked first, followed by Camp 1, Camp 4 in third, Camp 2 in fourth, and Camp 5 in fifth.

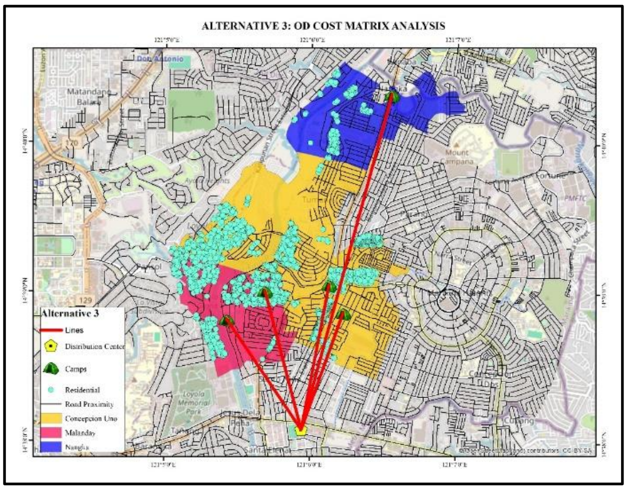

Fig. 13. OD Cost Matrix

3.4 Vehicle Routing Problem

Three trucks, each with a capacity of 2,500 relief packs, were assigned to distribute supplies to various camps. Figure 14 illustrates the designated routes for each truck. Truck 1 was assigned solely to Camp 3, covering a total distance of 4.1 km with a driving time of 1 hour and 8 minutes. Truck 2 catered first Camp 4 and then headed to Camp 1, traveling a total distance of 5.4 km with a driving time of 1 hour and 11 minutes. Meanwhile, Truck 3 delivered supplies to Camp 2 followed by Camp 5, covering a total distance of 9.8 km with a driving time of 1 hour and 20 minutes.

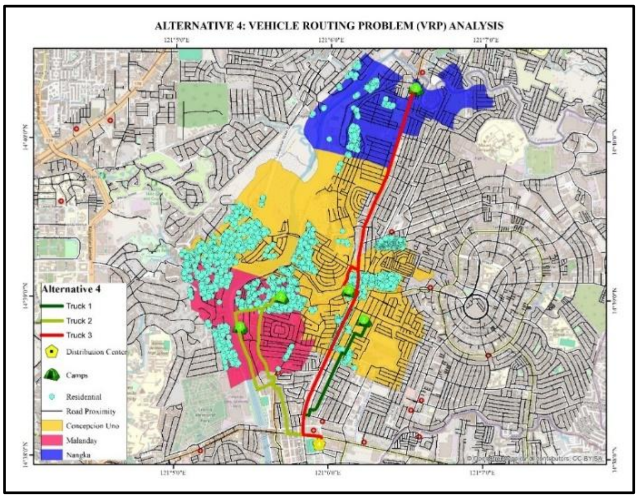

Fig. 14. Vehicle Routing Problem (VRP)

3.5 Summary of Results

Table 2 provides a comprehensive summary of all the alternatives used in determining the optimal route for distributing relief goods during flooding disasters in three selected barangays in Marikina City. This analysis, which evaluated various routes and parameters, identified vehicle routing problem analysis as the most effective technique. This method accommodates five camps and incorporates economic considerations by factoring in the capacity of trucks, demand per camp, driving time, and travel distance.

Table 2. Summary of Results

Alternatives	Total Length	Time	Pros	Cons
1. Route Analysis	9.8 km	20 mins	- Can pass all the camp areas in one path. - Fastest Route	- No information on how many trucks to be deployed. - No direction on how back to the distribution center
2. Closest Facility Analysis	13.9 km	27 mins	- Enhances emergency response times by identifying the nearest facilities.	- No information on how many trucks to be deployed. - Only consider proximity. - No direction on how to get back to the distribution center.
3.OD Cost Matrix Analysis	13.86 km	N/A	- Clear insights into travel costs between the origins and destinations	- Based on static data, not accounting for real-time. - No road information
4. VRP Analysis	19.3 km	3 hrs 39 mins	- Optimizes routes for multiple vehicles, reducing overall transportation costs.	- Real-time changes (Traffic, delays) can complicate routing, requiring dynamic adjustments.

4. CONCLUSION AND RECOMMENDATIONS

This study has demonstrated the significant potential of Geographic Information Systems (GIS) and network analysis techniques in optimizing relief goods distribution during disaster scenarios in Marikina City. In conclusion, this research project has successfully achieved its objectives of determining the parameters necessary for the optimal distribution of relief goods and generating maps using Geographic Information System (GIS) to illustrate these routes in Barangay Nangka, Barangay Concepcion 1, and Barangay Malanday in Marikina City, Philippines. The results of the study revealed that various route analysis techniques produced different outcomes in terms of total length and driving time. Among the methods evaluated, the Vehicle Routing Problem (VRP) Analysis emerged as the most effective solution.

In evaluating and optimizing the network analysis, decision criteria were essential. These criteria included Road Conditions, Building Footprint, and Demand, each with their respective sub-criteria. Road Conditions encompassed factors such as road quality, congestion, and accessibility, while Building Footprint considered the distribution of buildings and structures along the routes. Demand referred to the quantity and location of relief goods needed in different areas, influencing route prioritization and allocation. However, a limitation was identified during the validation process. The absence of historical data on road blockages during floods in Marikina City may affect the reliability of the maps generated. This highlights the importance of continually updating and refining data inputs to enhance the accuracy and reliability of GIS-based decision support systems in disaster management scenarios.

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