Analyses of implementation data from a low-cost ambulance service in Ghana

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SUMMARY

The allocation of ambulances to support healthcare services within the Ashaiman municipality represents a promising development for the region. However, the challenges faced by neighbouring deprived areas, which are characterized by poorly maintained roads, pose a significant obstacle to efficient service delivery. While this challenge cannot be resolved immediately, it requires further investigation. In our study, which focuses on the implementation of ambulance projects in Ashaiman, Ghana, we seek to minimize uncertainties associated with implementation by carefully considering the data generated in the system's initial phase. This requires simultaneous consideration of both system operation and spatial data analysis, as ambulances must be strategically deployed to transport patients to healthcare facilities and back.

To achieve this objective, we analyzed ambulance data against the road network dataset to support the operational needs of the current low-cost ambulance management system. Our study region is the municipality of Ashaiman and Tema (Ghana), with a focus on the service areas of the ambulances. We incorporated road network data and other relevant data layers into a geodatabase and used geographic information system (GIS) software to conduct location-allocation, service area, and closest facility network analysis. The location of ambulances was obtained from tablets installed in the ambulances with in-built Global Positioning System (GPS) receivers. The results show that more than 30000 demand nodes that represent households are only served by a few ambulances. The allocation-allocation analysis for 3 randomly chosen facilities by the algorithm shows that intuitively we could have different allocations based on the parameters used. The number of emergency cases when varied will affect the allocation at any point in time. Service areas based on travel distances of 1 to 3 kilometres implied a travel time of fewer than 5 minutes. Furthermore, network connections greatly affected the closest facility's output routes.

Geovisualization of geographical data has revealed interesting patterns for phenomena such as networks. We generated 2D maps displaying the geovisualisation of the geodata and network analysis, such as location-allocation of health facilities. These maps can support health facility managers, local government agencies, and paramedics in the study region. We expect that the results from this initial operational phase of the project will inform a general improvement of the system.

1. INTRODUCTION

Most of the world's documented deaths occur in the developing world or the global south because of a lack of basic infrastructure. It is not enough to provide resources to help with the situation but effective implementation of a decision support system will lead to a sustainable operation. Future expansion of ambulance fleets equipped to handle medical crises presents the risk of abuse if not closely managed. Uneven population and healthcare provider distributions result in geographic disparities in patient accessibility and varying workloads for hospital and clinic staff (Wang, 2020). There are several ways that emergencies are handled based on availability and geography but the general idea has been described by Reuter-Oppermann et al (2017). The emergency service (EMS) provider in a typical EMS system is responsible for two main tasks: emergency calls and patient transports. Emergency medical dispatchers use complex algorithms to prioritize each ambulance call: The category of EMS tasks and response varies from country to country (Reuter-Oppermann et al., 2017).

Ghana is a developing nation that values emergency care to reduce acute illness and harm. As it seeks middle-income status, investments in emergency medicine demonstrate the need for this approach in communities where medical care is sought in emergencies (Yiadom et al., 2021). With the accompanying lack of infrastructure, the annual toll of casualties will rise. The lack of proper resource management should reduce the effectiveness of any human or physical medical resource. Even the absence of inadequate infrastructure can lead to chaos at many facilities. The need for rescue workers, for example, increases in proportion to the pace of population growth in any given location even globally. Internationally, the prevalence of medical emergencies is very high. While the global health agenda is always shifting, emergency medical services remain largely unfunded and unsupported (Chipendo et al., 2021). Additionally, aggregated numbers of emergencies lead to overcrowding (Acuna et al., 2020). This trend is worrying because one of the most pressing problems in the medical field is getting aid to the patient as quickly as feasible once the initial intervention has been performed, and then getting the patient to the hospital as soon as possible after that. If something goes wrong at this pivotal point, the patient could die (Akca et al., 2020). The study area's deployment of low-cost ambulance service entails more than just installing the necessary software and systems; it also requires a thorough examination of the service's operational facets. We understand that more ambulances would need to be added to the system over time, but that it would also be important to monitor and ensure the optimal allocation of households to health facilities. The routes used by the ambulances need to be the one that minimizes cost. To achieve the objective of dispatching ambulances along the least-cost route, a decision support system is useful. For instance, if facilities are kept in their most fuel-efficient locations, the cost of operating ambulances will be minimized, leading to the realization of a long-lasting and reliable system. There is a need to deal with the EMS station location, ambulance allocation, and ambulance routing problems (Shetab-Boushehri et al., 2022). Only statistics relevant to the area of interest will allow us to gauge the effectiveness of the current system, but how can we keep track of these numbers? Finding out how many additional ambulances will be required to meet demand, and where they are located, is crucial information. In what way do we realize this?

Therefore this paper aims to apply network analysis to the real data of patients and ambulances based on Effective Ambulance Management System (EAMS) as described in

Okyere et al. (2022) to ascertain the possibilities of improvement to the current system. By making use of Geographic Information Systems and opensource data this study will assess the optimal allocation of ambulances available in the study region. By employing the network analysis algorithms we hope to generate the allocation of health facilities and centroid of households as demand nodes and to look at location scenarios and their possible outcomes. Geovisualisation of the routes used by ambulances and the entire road network will support the effective ambulance management system (EAMS) (Okyere et al., 2022).

2. PREVIOUS WORK

2.1 Ambulance Management Systems using GIS

The use of geographic information systems (GIS) is critical in resolving the problem of ambulance relocation because it allows for the acquisition of reliable information in real-time. Since the 1960s, many problems arising from the management of EMS systems have been studied by operations research scientists, EMS planners, and healthcare practitioners because of the importance and sensitivity of decision-making in the EMS field (Aringhieri et al., 2017). To demonstrate the usefulness of this system, Alaeddinne (2012), using GIS carried out a simulation procedure between the various study instances and provided the results as scenarios. Also, Yunus and Abdulkarim (2022) utilized Network Analysis (shortest and nearest route) to determine the best and shortest travel distance of ambulances to incident locations, from incident locations to the closest emergency healthcare facilities, and the shortest route and closest facility within the city. They also used a location-allocation study to find new places where more ambulances may be stationed.

Akca et al. (2020) used an application they developed to find the quickest route for ambulances. The time spent on tasks like finding the quickest route was kept to a minimum. They scoured the database for nearby medical facilities and compiled a list of the best options, including directions. The haversine formula was used during these computations.

2.2 Network analysis of ambulances

Baloyi et al (2017), carried out response time analysis (journey time), sufficiency analysis (capacity and distance for population scenarios), and travel time was utilized to create density maps and travel time maps, respectively. Location allocation is a twofold problem that simultaneously locates facilities and allocates demand points to the facilities. By picking a set of locations for facilities and assigning sets of demands to these facilities, Maghfiroh et al (2017)'s location-allocation model simultaneously address the problem, optimizing the system to maximize patient coverage while minimizing response time or the number of vehicles.

The purpose of location allocation analysis is to find the best possible location of facilities to achieve a goal while satisfying all relevant constraints. There exist various algorithms used to find the optimal allocation of facilities to demand points. An example is the *p-median* problem which seeks to minimize the total weighted distance that users must travel to reach a given set of facilities. The location set covering problem (LSCP) seeks to minimize the number of facilities required to cover all demand, and the maximum covering location problem (MCLP) seeks to maximize the demand covered within a desired distance or time threshold by locating a given set of facilities. Emergency Medical Technicians (EMTs) utilize a set number of ambulances spread out in key locations across the territory they cover to provide a sufficient level of service to the population. The goal of the static ambulance location problem is to determine how many ambulances should be stationed at each backup location and which backup locations to use (Bélanger et al., 2019).

There was an earlier floating catchment area method, which catches the area twice based on population demand and health care supply, which was improved by the two-step floating catchment area method (Kanuganti et al., 2016). It is a physician-to-population ratio and it is better explained by Kanuganti et al. (2016). On the other hand, the two-step floating catchment area method by Luo and Wang (2003) and Luo & Qi (2009) has been used the most often because it takes into account both how close service providers are and how often they are available.

2.3 Accessibility mapping and emergency ambulance services in Ghana

Not much research has gone into GIS applications and the use of such systems in health facility management in Ghana. In their research, Okyere et al. (2022) describe an effective ambulance management system built on open-source software with integrated python plugins. The system uses Traccar software to determine the location of the ambulances whiles a uniform resource locator (*URL)* embedded in emails generated based on user requests provides google maps optimized routes. A few studies do not leverage road network analysis. For example, Agbenyo et al (2017) assessed communities' access to healthcare services in rural Ghana but only limit their research to basic GIS operations to meet their aim of mapping health facilities. In doing so, they analyzed the spatial distribution of health facilities in Wa West District as a case, using ArcGIS 10.2. The findings by Adamtey et al.(2015) regarding the means of transporting patients in need of emergency care to health facilities highlight the importance of effective planning of ambulance and emergency services in planning healthcare delivery at the district and rural community levels.

3. METHODOLOGY

3.1 Study Area

Our study area includes two adjacent cities of Tema and Ashaiman as shown in the study area map (Figure *1*). The study area includes Tema city since the Tema General hospital and other medical facilities may not exist in a generic clinic or medical centre in Ashaiman. Tema is a city on Ghana's Atlantic and Bight of Benin coasts. It is 25 kilometres (16 miles) east of the capital city, Accra, and is the capital of the Tema Metropolitan District. It is in the area of Greater Accra. Tema is the eleventh most populous town in Ghana, with about 161,612 people living there in 2013. This is a big drop from 2005 when 209,000 people were living there.

The two ambulances at the heart of the research are stationed at a control centre at approximately the centre of Ashaiman. Up until the year 2008, Ashaiman was still considered to be a part of Tema, and its present area is approximately 45 km^2 in size. The region is distinguished by exceptionally high rates of both migration and unemployment. The population increased by a factor of three between 1984 and 2000 (Ardayfio-Schandorf et al., 2012). The Ghanaian statistical office estimates that approximately 235,000 people were living in Ashaiman in the year 2019. Because of the high rate of migration and the slums in the area, it is reasonable to presume that there is a significant number of instances that have not been reported. When applied to the territory of Ashaiman, this statistical number of residents results in a population density of approximately 5200 persons per km^2, giving Ashaiman a total population of approximately 110,000 people. The general location of Ashaiman in the Greater Accra Region of Ghana is 5°42′ North and 0°02′ West. It is bounded by minimum and maximum longitude and latitude of 0° 3' 35.33" West and 5° 40' 41.16211" North, respectively; and by minimum and maximum longitude and latitude of 0° 0' 46.80176" West and 5° 43' 23.100" North, respectively.

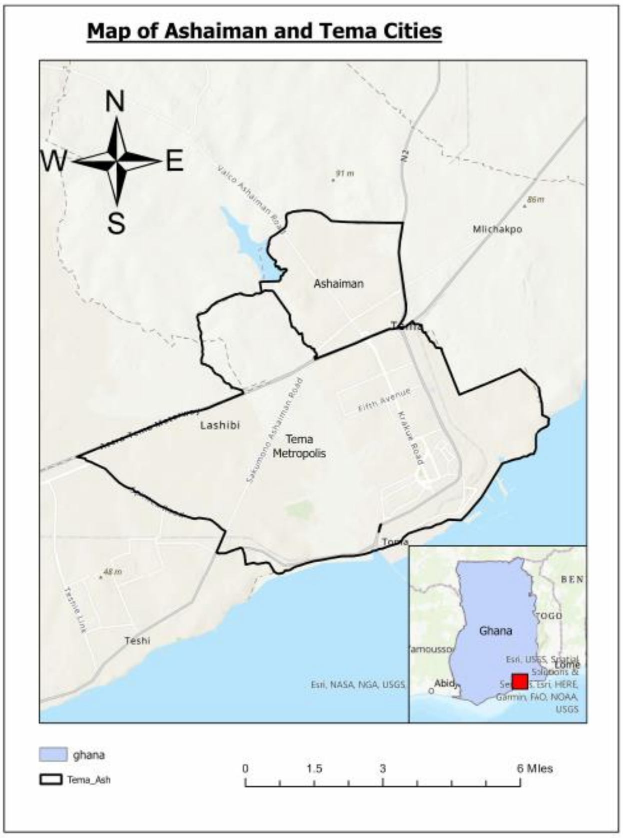

Figure 1: Study area map.

3.2 Data sources

Data from a variety of sources were used in the analysis and were mostly open-source. Here we briefly describe the datasets used in this study.

Demand Points – Building centroids

In this study building, centroids obtained from OpenStreetMap served as demand nodes. We assumed that patients live in all buildings captured by OSM. Even though this is a precarious assumption this is not an extreme within a built-up area. It is assumed that every building is inhabited.

GPS Routes of Ambulances

The primary data source for the ambulance is the Global Navigation Satellite System (GNSS) coordinates generated by the receiver, a tablet with GPS and internet enabled within the ambulance.

Spatial data scraping - Google Maps Sourced Health Facility Locations

One of the most vital steps in any GIS project is gathering reliable secondary data. Therefore, it helps greatly if we make use of the web services and tools that exist to help us extract publicly available data. We have relied on a web service called *Octoparse* (Octoparse, 2023) in this project. This service offers a graphical user interface (GUI) for configuring search terms and building data extraction templates for use when mining the web for information. Our primary focus is on using publicly available Google Maps, from which we were able to obtain a map template that extracts both non-spatial data and geographic coordinates. The clinics, hospitals and diagnostic centres were extracted from a database of health facility geolocations using an as-built data scraping technique. Furthermore, the following query was used to extract the relevant hospital locations: "Category" = 'Hospital' OR "Category" = 'Medical Center' OR "Category" = 'Private hospital' OR "Category" = 'Public medical centre' OR "Category" = 'Government hospital'

OSM Road Network and Building centroids (Demand Points)

The road network data from Open Street Map was used in this study. The raw data contains topological errors that are common to digitising errors. Here the topological rules were set and used to clean up the dangling nodes and duplicate lines for example. This HOTOSM project's goal is to fix gaps in the major road network in Ghana by adding missing roads and missing connections, relocating roads that may be misaligned according to GPS traces, and correcting inaccurate road classifications. Other goals include connecting or fixing roads that are not connected to anything else (Minghini & Commission, 2017). The purpose of the Tasking Manager is to divide a large mapping project into smaller tasks that can be completed rapidly and collaboratively, with many people contributing to a collective project goal (HOTOSM, 2023).

In this study building, centroids derived from OpenStreetMap building polygons served as demand nodes. We assumed that patients live in all buildings captured by OSM. Even though this is a precarious assumption this is not an extreme within a built-up area. It is assumed that every building is inhabited.

3.3 Software

In a *python* environment, it is possible to build a full application. Python can be used in QGIS to run commands from the console, run code automatically when QGIS starts, write custom expressions and actions, create new processing algorithms, make plugins, and make standalone applications (Gandhi & Ujaval 2020). The plugins were created to address the needs of the system by using the python programming language in QGIS.

It must be noted that QGIS and Grass are Free and Open Source Geographic Information Systems (QGIS, 2023). Grass GIS was used to handle some aspects of topological errors in the raw network data from HOTOSM. ArcGIS Pro is the latest version of a commercial off-theshelf GIS suite of software for handling geographic information and it is utilised because of the rich set of tools for network analysis and free license at the time of this research. When it comes to network analysis QGIS is limited in its tools and functionality. One available plugin in QGIS is QNEAT3. It has more complex algorithms for network analysis, like Isochrone Area (also known as service areas or accessibility polygons) and OD-Matrix (Origin-Destination-Matrix) computation, that can do things like find the shortest path between two points.

3.4 Methods

Figure *2* shows a process where data from the EAMS is used to create a geodatabase in ArcGIS software. The EAMS data includes ambulance pick-up locations for patients. The raw data is extracted and converted into GPX format, then into the shapefile format. Octoparse software is used to scrape Google Maps data and gather spatial and non-spatial data for health facilities in the study area. GPS locations for ambulances and HotOSM data are imported into the geodatabase, which is organized into a feature dataset. Network analysis algorithms are applied to the network dataset built from topologically-corrected road network data (from HOTOSM), and the resulting outputs are stored in the same geodatabase. Finally, the geovisualisation of the EAMS-generated data is achieved using ArcGIS software by creating maps and applying overlay GIS operation of the dataset as seen in Figure *3*.

Building a Network Dataset

One or more locations in "Demand Points" could not be reached by one or more locations in "Facilities". The network may have areas that are disconnected, unbuilt, or disconnected due to turn restrictions, restriction attributes, or barriers. Incomplete network connectivity may result in a non-optimal solution (ArcGIS Pro: ESRI, 2023).

Location-Allocation Network Analysis Algorithm

Though several options exist for allocating a facility to a set of demand nodes, the most appropriate is to cater for health facility accessibility to the public. The optimisation criteria can be any of the following: *Minimise Impedance, Maximize Coverage, Maximize Capacitated Coverage, Minimize Facilities, Maximize Attendance, Maximize Market Share* and *Target Market Share*. The Minimise Impedance problem is also known as the p-median problem.

P-median problem: Facilities are positioned in such a way as to reduce the total of all weighted costs incurred in travelling between demand points and solution facilities. The fact that allocation is determined by the distance between each demand point is brought attention to by the arrows in the following image.

The *minimize Impedance* algorithm selects facilities in such a way as to minimize the total weighted impedance, which is calculated by multiplying the demand that is assigned to a facility by the impedance that it faces. Because it can lower the overall transportation costs of delivering goods to outlets, this issue type has typically been utilized in the process of determining the locations of warehouses. The *minimize impedance problem* without an impedance cutoff is typically considered to be more equitable than other problem types when it comes to the placement of certain public-sector facilities such as libraries, regional airports, museums, department of motor vehicles offices, and health clinics. This is because minimising impedance reduces the overall distance that the general public needs to travel to reach the chosen facilities.

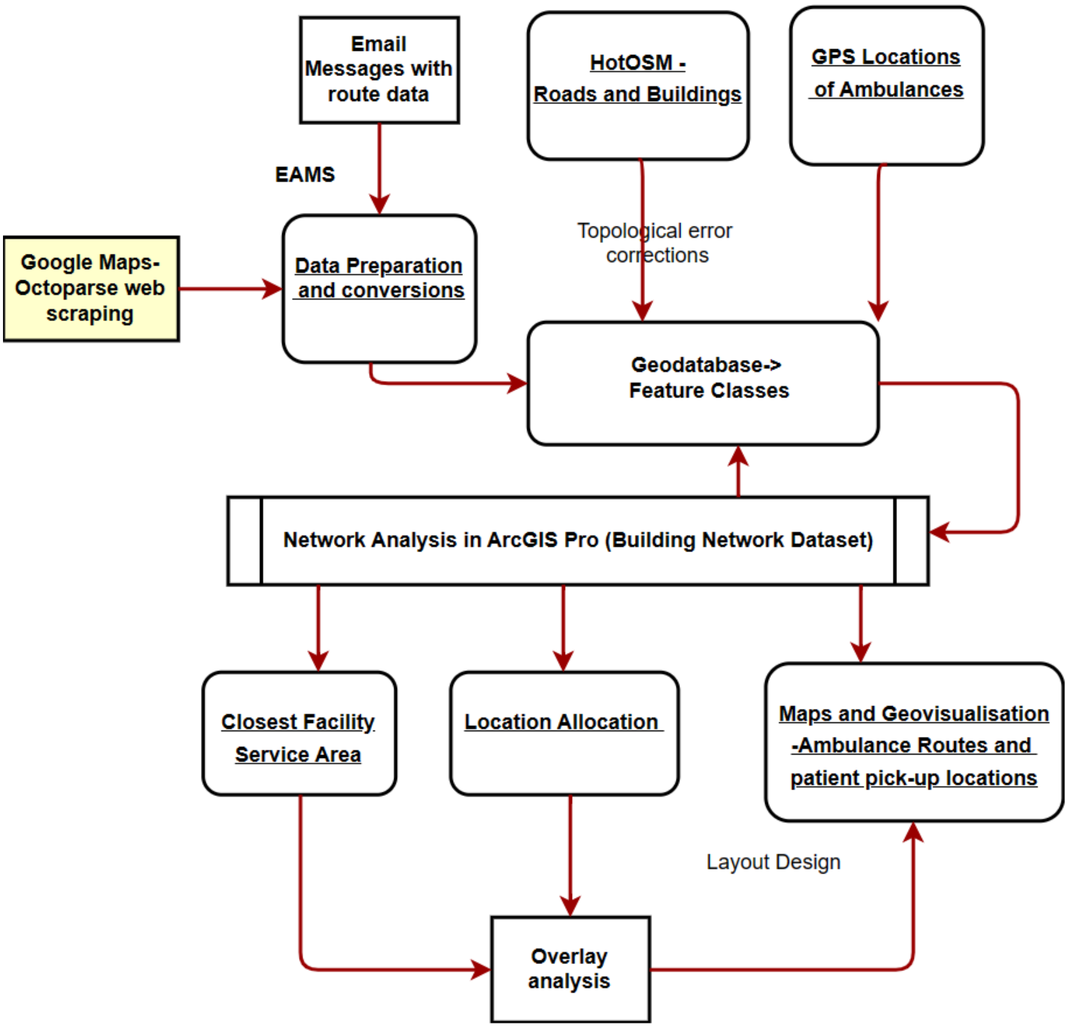

Figure 2: Flow chart of methodology.

This is how the minimize impedance problem type deals with demand: If an impedance cutoff is established, any demand that is more than the impedance cutoffs of all the facilities will not be allocated. When a demand point is placed inside the impedance cutoff of a single facility, that facility receives the entirety of the demand point's demand weight. When a demand point is located inside the impedance cutoff of two or more facilities, that point's entire demand weight is only distributed to the facility that is geographically closest to it.

The closest facility solver identifies one or more facilities that are the closest to an incident based on travel time or distance and outputs the best routes as driving directions between the incident and the selected facilities.

A network service area encompasses all streets that can be reached within a specified distance or amount of time from one or more facilities. For example, a facility's 10-minute service area includes all streets that can be reached within 10 minutes in the case where travel time is factored into the network dataset.

4. RESULTS

Results for the study encompass location-allocation, network service area and closest facility as shown in Figure 3 and explained in the following sections.

Location allocation for 3 hospitals or medical centres:

Out of a total of 93 facilities, 3 were chosen to service 30, 815 demand points. The attributes used in the analyses exclude *FT_Minutes*, *TF_Minutes* and without travel time inputs. *Meters*, and one_way were set as impedance. Speed limits of 200km/hr in the *Spd_km* (Adamtey et al., 2015). The *F_ZLEV*, *T_ZLEV*, *PAVED*, *AR_PEDEST*, *AR_BUS*, *AR_AUTO*, *DIR_TRAVEL*, *TF_HeightLimit_Meters*, *FT_HeightLimit_Meters* were are ignored in the computation. The location-allocation shown in Figure *3*B algorithm set the direction of travel to facilities and not from the facilities. A search tolerance of 800m was set. The centroid of building polygons is used as demand points in the determination of allocated facilities.

Service area with 1000, 2000 and 3000m cut-off areas from the control centre:

Results from the network service area show possible areas that can be reached based on distance as seen in Table 1. Adamtey et al. (2015)'s study indicates that ambulances in Ghana can travel up to a maximum of 200 km/hr. That said traffic data has not been included in our analysis so assuming 60 and 40 Km/hr as the worst-case scenario, gives us an idea of the time it takes to reach the facility.

Table 1 Sample speed limit(Spd) (60Km/hr and 40km/hr) and travel time to reach service areas

Spd (km/hr)	Dist (km)	Time (hrs)	Minutes	Spd (km/hr)	Dist (km)	Time (hrs)	Minutes
60	1	0.016667	1	40	1	0.025	1.5
60	2	0.033333	2	40	2	0.05	3
60	3	0.05	3	40	3	0.075	4.5

Closest facility analysis for ambulance centre:

The proximity of ambulances to the control centre was computed based on a single facility serving several demand points (households) with a search tolerance of 5000m.

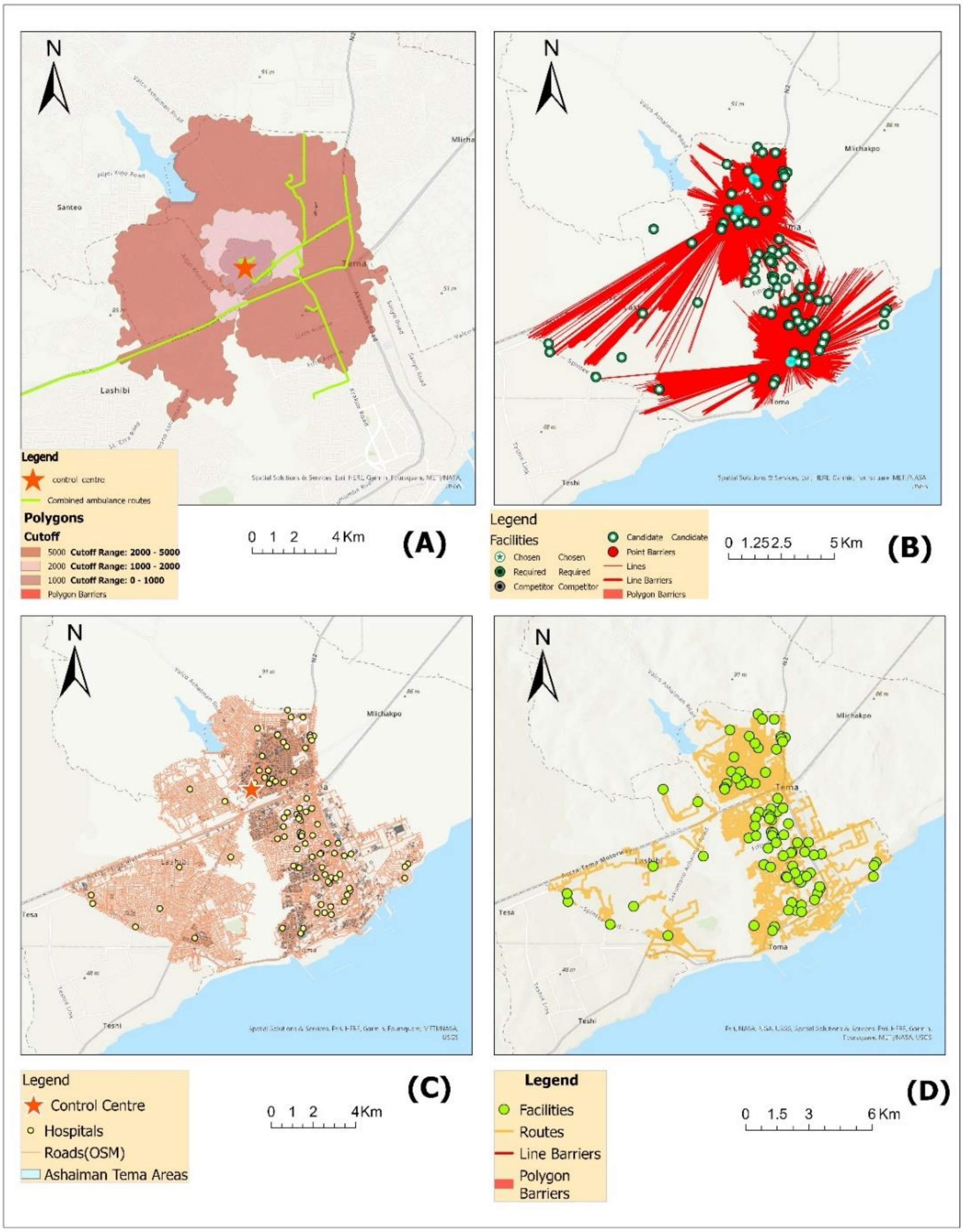

Figure 3: Network analysis and overlay analysis in ArcGIS Pro. (A) Service area (B) Location-Allocation of 3 hospital facilities (C) Overlay of combined ambulance routes (D) Routes leading to closest hospitals.

5. DISCUSSION AND CONCLUSION

It is revealing to overlay the real ambulance route taken on the resultant network analysis results. The closest facility, service areas and location-allocation problems confirm the need for the utilisation of more concise data; the results are not arbitrary but can be improved with more parameters provided. We find it interesting how facility locations tend to coalesce or cluster around the destination of transported patients (facility). The route, as shown in Figure *3*(A), was determined solely based on the shortest route algorithm by *Google Maps*. The control centre serves as the default location (home or station) for ambulances used for the EAMS located at the northern ends of the Ashaiman area. In this study, the GIS software helps us to geovisualise existing hospital facilities as an overlay. Hospitals are more likely to have the required Emergency Department (ED). Since the system uses *Google Maps* traffic-generated network routes to direct the ambulance driver, the paths found are optimal.

According to the findings, only a few ambulances serve more than 30000 demand nodes, which represent households. The allocation-allocation analysis (Figure *3*(B)) for three randomly selected facilities reveals that, intuitively, we could have different allocations depending on the parameters used. When the number of emergency cases changes, the allocation will change. Service areas as shown in Figure *3*(C) with travel distances of 1 to 3 kilometres implied a travel time of fewer than 5 minutes. Furthermore, network connections had a significant impact on the output routes of the closest facility as indicated by the map display at Figure *3*(D).

Resolve Medical Services located at 823,659.99E 623,724.94N m, seem to be disconnected from the larger network of roads. This could be attributed to the lack of mapping by the OSM as can be visualised by an overlay of the world topographic map which is only available as a web map service.

It is recommended that in future studies a database is built to collate more analysis-ready data. The right attributes are selected to meet the sole purpose of monitoring based on time. The monitoring of the Ambulance management system should go beyond a limited set of algorithms that support visualization of the facility and road network data. For example, for proper evaluation, it is required that response time and location are analysed in tandem.

Nonetheless, the current system is disjoint and not seamless. The *Traccar* software is independent of the actual allocation which is also not intuitive. It tells the user which ambulance is free using geofences but not programmatically.

Carrying out network analysis using commercial GIS software allows several network analysis procedures and algorithms to be used without much stress but at a cost. ArcGIS is used for this study and yet the original native algorithm for location-location has not been built into the system yet, so in the future, we hope that this functionality can be added to it seamlessly.

. Comparisons to using open-source software need to be on the agenda. The results from this study can be compared with a plugin purposely written to add network analysis to the QGIS interface. Free and open-source software can only go as far as the available plugins can take us. It is recommended that more open-source ideas are used to extend the existing system.

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