Implementation of a low-cost Ambulance Management System

FRANZ OKYERE[1], THEA MINNICH[2], MORITZ SPROLL[2], EDMUND MENSAH[3], LILIAN AMARTEY[1], CARLOS OTOO-KWOFIE[3] & ANSGAR BRUNN[2]

Abstract: Ambulance services are a critical component of health service delivery. The importance of a functioning and efficient management of ambulances to achieve the most gain of highly expensive resources cannot be overemphasised. Resources needed in health provision are expensive and commercially available management systems have high costs in installation and maintenance. In most deprived regions, the available ambulances to convey patients may not be smartly deployed. This is due to the lack of an effective fleet management system. Furthermore, poor road conditions only add insult to injury. Mobile health equipment takes advantage of the road network to make resource allocation and management optimal. We seek to develop a system that will reduce the cost of implementation of an ambulance management system. In this article, we present the implementation of a low-cost effective ambulance management system (EAMS) for Ashaiman, a large town in the Greater Accra Region of South Ghana and is the capital of the Ashaiman Municipal District. The solution is based on the principles of a geographic information system (GIS) and gives the operator clear acting paths. As part of planning, constant consultation with stakeholders was carried out making sure the basic user needs assessments were established. OpenStreetMap (OSM), a crowdsourced volunteered geographic information (VGI), data served as the source of spatial data for the system; thus the spatial database was linked to an open-source GIS desktop application. The OSM is used as well as cost-free Google satellite and Google hybrid as background map. Bespoke functionalities created within the custom application realise necessary processes; the functions were integrated into the software via custom python plugins. Moreover, communication of the requests for service from users to the ambulances and vice versa is done by email and messenger and Internet services. The operating system used was also free software with zero cost. We made use of software that can be installed at will on any computer void of the compatibility issues common with different computer platforms. The system has been installed in a clinic in Ashaiman (Ghana). The system has been tested by live simulation.

1 Introduction

In Africa, a higher proportion of individuals generally lack access to health facilities and emergency treatment. After an emergency, mortality is linked to income and a country's or region's overall degree of development (EGGER et al. 2018: 490). Meanwhile, Ghana has one of the worst emergency supplies in the world. In the entire country. There are only 56 ambulances in use, some

[1] KAAF University College, Kasoa, Ghana,
E-Mail: Franz.Okyere@kaafuni.edu.gh, LilianAmartey31@gmail.com
[2] University for Applied Sciences Würzburg-Schweinfurt, Würzburg, Germany,
E-Mail: Thea.Minnich@student.fhws.de, Moritz.Sproll@googlemail.com, Ansgar.Brunn@fhws.de
[3] Cape Coast Technical University, Cape Coast, Ghana,
E-Mail: Carlos Otoo-Kwofie: noraspinto@yahoo.co.uk, Edmund Mensah: eddiebeezy5@gmail.com

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of which are even not used at all due to technical difficulties. The few ambulances concentrate on the regional capitals (HUPP et al. 2019: 133). As a result, circumstances for rescuing individuals in medical situations are inadequate in Ashaiman, a city in Ghana's Greater Accra area (Accra metropolitan). These circumstances impact many, who live within the Ashaiman township.
Effective resource allocation and use will require a minimum of resources. But rather we find there are frequently insufficient cars available to evacuate sick people in critical conditions (HUPP et al. 2019: 132). It is vital to address these difficulties and improve the situation, especially of disadvantaged groups such as people living in informal settlements. The goal of this study is to see how well QGIS (previously Quantum GIS), an open-source geographic information system (GIS), can manage and help coordinate a fleet of ambulances. Additionally, we need to ensure efficiency in communication between the ambulance drivers and patients alike. With a stable server system, we should be able to track the ambulance or receive the position of an ambulance from external software. The health facilities should be located on a map and supplied with pertinent information in the application. This should ensure administrators or operators at the headquarters can choose the appropriate clinic in the case of an emergency. Furthermore, the system should be able to take over the ambulance's routing and send the driver information with the destination's coordinates or a predetermined route. To guarantee that the crises are documented, it is also critical that reports on the different activities be generated in the system.
This work aims to answer the following questions with the help of various plugins, settings and options in QGIS:

- To what extent can QGIS be used as a fleet management system?
- What adjustments need to be made?
- How can the appropriate geospatial data be integrated?
- How far can QGIS software be minimised to provide the user with a light version?
- How can communication with the ambulance take place?
- Which plugins are required for implementation?
- How can these components of the system be brought together in QGIS?

2 Study Region

The study region is the municipality of Ashaiman (Ghana) and neighbouring settlements, s. Fig. 1. Until 2008, Ashaiman was still part of the city of Tema and currently has an area of approx. 45 km². The area is characterized by a very high level of migration and unemployment. The population tripled between 1984 and 2000 (ARDAYFIO-SCHANDORF et al. 2012: 25). According to the statistical office in Ghana, Ashaiman had a population of about 235,000 in 2019. A high number of unreported cases can be assumed due to the high level of migration and the slums in the area. If you convert this statistical number of inhabitants to the area of Ashaiman, you get a population density of approx. 5200 people per km². The general location of Ashaiman in the Greater Accra Region, Ghana is 5°42′N 0°02′W and it is bounded by minimum longitude and latitude of 0° 3' 35.33" W and 5° 40' 41.16211" N respectively; and by maximum longitude and latitude of 0° 0' 46.80176" W, 5° 43' 23.100" N respectively.

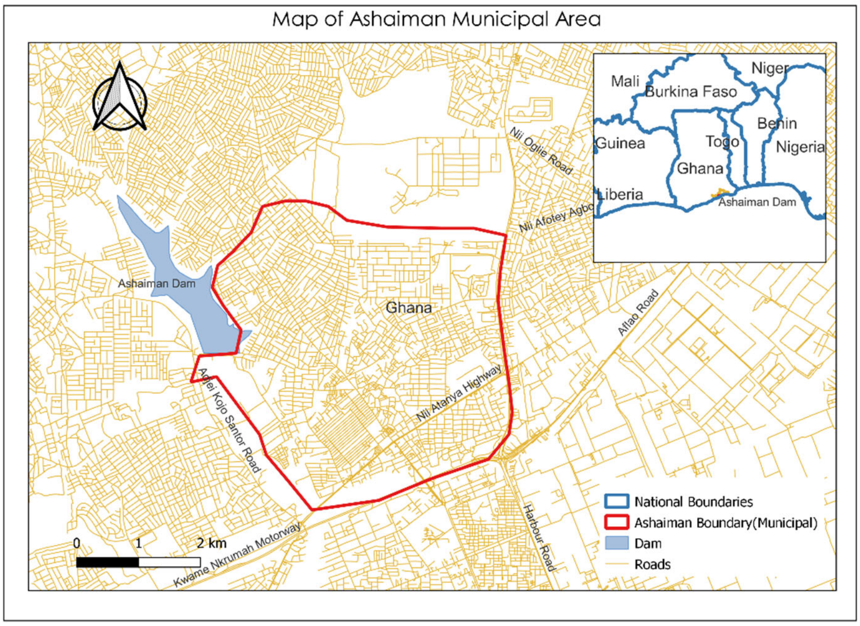

Fig. 1: Target Area Map

3 Problem Statement

The road infrastructure and condition of the roads in Ashaiman are inadequate. The few roads that exist are mostly not passable. A survey in 2012, in which 172 residents in Tulaku Township in Ashaiman were questioned, showed that more than half of the respondents said that a fire truck could not reach their home due to the poor road conditions (SARPONG 2013: 67). These survey results can be easily transferred to a scenario for medical transport since fire engines and ambulances usually have a similar requirement profile.

Strong environmental impacts, such as rain, have an impact on the roadways. During the rainy season, even paved roads in the region are vulnerable to flooding. The problem is exacerbated by the absence of drainage channels and the fouling of existing drains. The majority of Ashaiman's streets are not paved, making them even more vulnerable to the aforementioned influences: The streets are softened, and water collection holes are constructed. The fact that automobiles travel on these roads exacerbates the problem by allowing potholes to appear. Many of these routes are impassable during the rainy season as a result of these circumstances. During the project's duration, it's critical to determine which routes are accessible to an ambulance and which are not. To improve the route finding process, the latter might be eliminated from the routing. Traffic is also a major problem in Ashaiman. Concerning the size of the city, there are few street signs and speed bumps to regulate speeds and traffic (GUMAH 2015:12). As a result, accident rates in these locations are often high, necessitating greater medical care via ambulances. Traffic congestion is common, especially during the so-called "rush hour," due to insufficient infrastructure. Because of the absence of traffic organization and regulation, as well as the numerous traffic jams, motorized vehicles in metropolitan areas may only go at a speed of five to ten kilometres per hour on average.

As a result, getting a vehicle to a patient and a healthcare institution in the Ashaiman region takes a lengthy time. In an emergency, the ambulance management system should aid gain valuable minutes, which may frequently save a patient's life.

4 Related Works

Planning and administration are critical in hospitals or trauma centres for timely audit and treatment of trauma patients to prevent mortality caused by accidents and unforeseen events (AMINZADEH et al. 2017). As a result of this, we need to make use of effective systems that ensure timeliness in the transport of patients who may not be detained.

A sophisticated system developed by SANKAR et al. (2016)used a server, mobile applications, and GPS to track all ambulances, detect accident locations, send the nearest ambulance to the accident site, and ultimately, monitor the ambulance driver's performance. Google Maps layers were utilized to determine the best route.

RAABER et al. (2016)also employed prehospital geographical information systems (GIS) to handle the problem of overcrowding and handover. The use of GIS also influenced nurses' perceptions of GIS data as a tool for maximizing resource utilization and improving the quality of all patients' reception, whether they were critically or non-critically ill. Using traffic speed data, CHO & YOON (2015)proposed a GIS-based method to calculate the k-minute journey time contour to reflect the response coverage in Seoul, South Korea, considering time-of-day and day-of-week effects on travel time.

ESRI are producers of suites of commercial software for diverse problem domains. Esri® ArcLogisticsTM software provides a comprehensive solution for complicated routing and scheduling problems, allowing you to cut costs, increase productivity, and improve customer experience (ESRI 2010). We can also look at a prototype they developed in 2021. The functional requirements for the AJAX and Adobe Flex-based prototype fleet management application encompass- geographic coverage area, vehicle locations from an XML file, display of the vehicles location and related functions. The prototype makes use of the ArcWeb Services API family, which includes SOAP, REST, OpenLS, and Java ME, all of which are hosted by ESRI (GUP 2021). It is worth noting that a decade or more ago, PASHA (2006) already developed an Ambulance Management System prototype using GIS/GPS/GSM using ArcGIS9.1.

Hexagon Geospatial is also a commercial software company that provides extra features to their GeoMedia tiers' fundamental capabilities. Municipalities, airports, seaports, departments of transportation (DOTs), train firms, waterway agencies, and pipeline operations can use GeoMedia Transportation Manager to efficiently examine their transportation infrastructure. This includes the ability to track network data as well as execute specialized analytics (HEXAGON 2021).

KARKAR (2019) proposed a smart ambulance system based on GIS that can designate a route as an emergency route. It allows paramedics to transport patients to the hospital more quickly. The system, made up of three parts: the server program, the user emergency end-user application, and the paramedic end-user application.

As can be seen from the few works mentioned, the commercial approaches take centre stage when it comes to these systems. Attempts have, however, been made to use open source software to create EAMS. For example, Traccar is an open-source GPS tracking system that works with a variety of GPS tracker devices. The software was first released in 2009 by Russian developer Anton Tananaev and has been actively developed by developers all around the world since then. It is composed of the Jetty Java HTTP server, the MySQL database, and the Netty network pipeline architecture. Traccar server is only needed to control and record GPS tracker position (SENIMAN et al. 2020).

An open-source development environment, MapServer, was used to construct the mapping component of the fleet management system (MEDAGAMA et al. 2008). In this system, a webserver and mail server connected to GPS utilised an Oracle database. Oracle Database (commonly referred to as Oracle DBMS or simply as Oracle) is a multi-model database management system produced and marketed by Oracle Corporation (ORACLE 2017). So here we have a system that is not entirely free because of the use of a commercial database, Oracle.

5 Methods

5.1 Fleet Management

Managing ambulances requires knowledge of fleet management. This is vital for the optimal deployment of the vehicles. Fleet management, in general, includes the targeted disposition, management and control of a vehicle fleet, taking into account internal and external influencing factors (JUNG & VAN LAAK 2001**.** In the particular case of our customised system, we took into consideration the road network and to some extent the constraints that exist and can determine the availability of ambulances within the fleet of vehicles.

Fleet management systems should have certain requirements and capabilities and be tailored to specific application needs. The most important component for such a system is the tracking and tracing of the ambulance. Tracking is understood to mean the current position at the time of observation. In the case of tracing, on the other hand, position data from the past are included. The snapshots of the tracking are quasi strung together to make the change in position visible depending on the time (JUNG & VAN LAAK 2001: 34). The system developed in the EAMS, made it possible to track the vehicles permanently in real-time so that they could be dispatched as needed in an emergency. At the control centre, the computers or as is in the ideal situation, the server hosts the GIS application instance, database server; all of this connect to the internet for communication.

5.2 Geographic Information Systems

A Geographic Information System (GIS) is a computer-based system that provides the following four sets of capabilities to handle georeferenced data: data capture and preparation; data management, including storage and maintenance; data manipulation and analysis; data presentation.

We think of geographic phenomena as a collection of geographic objects when it isn't present everywhere in the research region but 'sparsely' populates it. Typically, such things are easily identified and named, and their location in space is determined by a combination of one or more parameters (HUISMAN & BY 2009). In this study, an ambulance management system is to be implemented in a GIS. This special case can be classified as a geographic information system in

transport and logistics (GIS-T). QGIS has been used at the core of the system to create our own GIS-T to manage the fleet of ambulances. The following plugins(functions) were developed - *Ambulance Location*, *Report Incident, GeoCoding*, *Location Help, Sending Mail*, *Information health facilities and Capture Coordinates.*
Qt designer was used for the user interface whiles python was used to write code that gave the controls functionality.

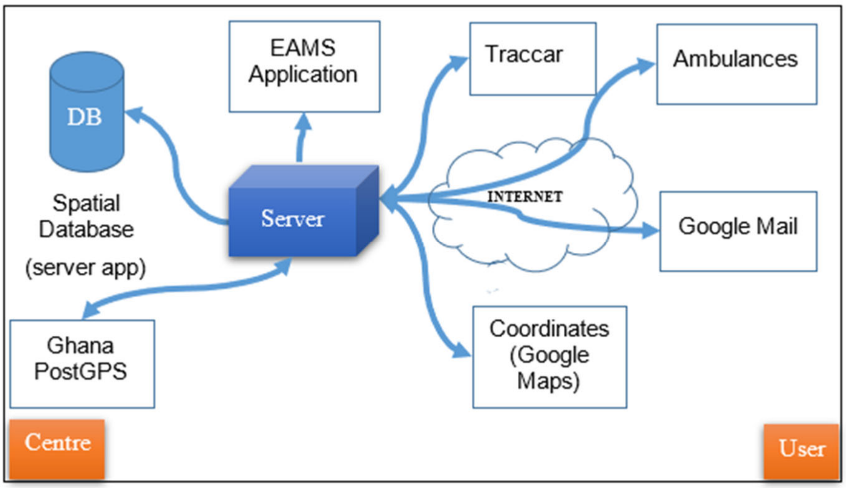

Fig. 2 System and Data Architecture

5.3 Components of an EAMS management system

The EAMS make use of several available components and new programmed Python code. All components of the system are shown in Fig. 2 and explained in the following sections.

5.3.1 Background Data layers

For the background data layer, the OpenStreetMap, Tileserver; Geofabrik geodata sources were used. Free geodata is extracted, filtered, and processed by the Geofabrik. Shapefiles, map pictures, tiles, and entire web map applications are among the services Geofabrik provide.
A tile server is a service that generates rendered images (tiles) from a database. Maps that are created with the help of such tiles are very efficient in terms of zoom and shift functions. The individual tiles on a map usually have an area of 256×256 pixels and are processed in PNG format. The tiles are cached on the server and client sides. Tile servers are superior to other technologies such as maps that have been loaded with the help of a WMS (Web Map Service) (GEOFABRIK GMBH 2020).
The standard OpenStreetMap (OSM) map is the first tile server to be integrated into QGIS. OSM dubbed the "Wikipedia of maps," is a free alternative to commercial map products that are backed by a big community of people who are interested in reproducing and comparing aerial images. In urban areas, the quality and timeliness of OSM data are even better compared to most commercial products. In contrast, the quality of the information in rural regions cannot always be judged to be good due to the small number of project supporters there (KEßLER 2015). In terms of coverage,

OSM data on roads are available for most parts of our study region but may not be guaranteed by parts characterised with informal settlements.

5.4 Open Source GIS Software Customisation - QGIS

It is possible to develop a complete application in a Python environment. Python in QGIS can be used to execute commands from the console, execute code automatically when QGIS starts, write custom expressions and actions, create new processing algorithms, create plugins and create standalone applications in QGIS (GANDHI 2020). The plugins were created to address the needs of the system by using the python programming language in QGIS.

5.5 Data Exchanges and Messaging Services

One of the most important factors in the project is the transmission of the ambulance coordinates to the control centre. It is essential that there are few failures as possible during the transmission and that an almost smooth process can be guaranteed. We need to ensure that the transmission works almost without errors. The three communication channels used by the control centre to interact with the ambulance, WhatsApp, Telegram, and Traccar, are integrated into the system via different interfaces. One of the application's requirements is that as many features as feasible be stored in QGIS. A link between the ambulance vehicles and QGIS was essential. Control panels were constructed with the Plugin Builder to integrate WhatsApp, Telegram, and Traccar with QGIS, allowing the platforms to be launched in external windows.

In addition to the live location from Traccar, there is the option of automatically importing the coordinates from WhatsApp into QGIS in case of a failure. It is important to update the current live position of the Google Maps Live location sent via WhatsApp and to centre the map as far as possible on the currently required ambulance.

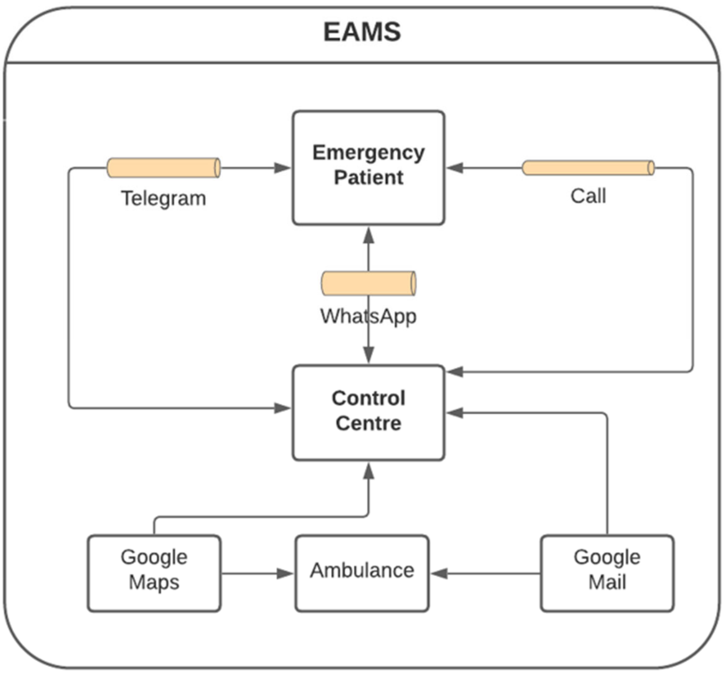

Fig. 3: EAMS Communication Network (Human)

Traccar is a GPS tracking system that is open-source. The software distinguishes itself by its flexibility, adaptability, and 'opensourceness'. Traccar enables you to track devices in real-time and view their coordinates at any time. Traccar has been set up on a DigitalOcean virtual private server (VPS) and can be accessed via a uniform resource locator (URL). A VPS is a virtual machine sold as a service by an internet hosting provider. This makes it possible for us to access an instance of Traccar server from anywhere in the world via an Internet protocol (IP) address.
Another task that must be completed as part of the project is to electronically convey information about an occurrence to the ambulance drivers. The Sending Mail plug-in was created as part of the project for this purpose.

5.6 Geocoding

Since the caller who wants to request help from an ambulance often does not know the coordinates of his accident/place of operation, it is essential to integrate a function for geocoding into the QGIS system. With geocoding, a text-based description of a place, e.g. an address or the name of a location, is entered and geographic coordinates, i.e. longitude and latitude, are returned to identify the location on the earth's surface.
The system uses the QGIS extension GeoCoding for geocoding, which makes it possible to use data from Nominatim, the geocoder from OpenStreetMap, or the Google Geocoder, within QGIS (NOMINATIM 2021). If the plug-in finds more than one place that fits the address or description, this extension shows several options in which the selection must now be made manually by the user.
In some countries, such as Ghana in this example, it is not uncommon that the street names are not known. For this case, the GhanaPostGPS system, which is common there, was additionally integrated as geocoding via API. In this system, there are unique codes for addresses in the form of squares with a side length of five metres.

5.7 Spatial Database and Routing

A database consists of a collection of data that are logically related to one another and organized by a database management system (DBMS). The data is saved according to predefined rules and is easily accessible. A programming language can be used to access the database and manage the data. By far the most important international database interface is SQL (Structured Query Language) (SCHICKER 2017).
Routing is a critical component of the system. The ambulance should be given the choice of routing to the individual in need and then to the nearest healthcare institution based on location data. There are numerous methods for routing and determining the shortest pathways between places. Edsger W. Dijkstra initially described and published the Dijkstra algorithm in 1959 (DIJKSTRA 1959: 269ff). In the initialization step, this method is given a coherent weighted graph (a network) with nodes and edges, as well as a beginning node from which the observation begins.
The A * algorithm is considered to be a generalization and extension of the Dijkstra algorithm. It is also known for searching for the shortest path, but in contrast to Dijkstra's algorithm, not only the path lengths are part of the calculations. With a database set up with which data about the hospitals can be displayed. For routing, the roads vector layer of Ashaiman was used together with

its routing system based on a database, leveraging on the QGIS shortest path (point to point) function.
A separate routing function has been integrated into the system. Road data from the project area was downloaded from the OpenStreetMap database and used for routing. The routing function uses the A* algorithm to find the shortest route from one point to another.
The system differs from other routing options in that the availability (free or occupied) of the ambulances is also included. To see which ambulance is currently occupied and which is not, the individual health facilities have been assigned geo-fences in Traccar. If an ambulance now receives a new order, its status changes to occupied. If the ambulance now enters the area of a health facility and delivers the patient there, the status is changed back to free and the dispatcher who operates the EAMS sees that the ambulance can accept a new order.

5.8 User Interface

The user interface of plugins in QGIS is created with the help of the Qt Designer. To achieve a reduction in the surface area, it is necessary to use the surface adaptation function in QGIS. All options on the graphical user interface that do not make sense for the application are hidden. Thus, the user is provided with a light version of QGIS tailored to the needs of an ambulance management system.

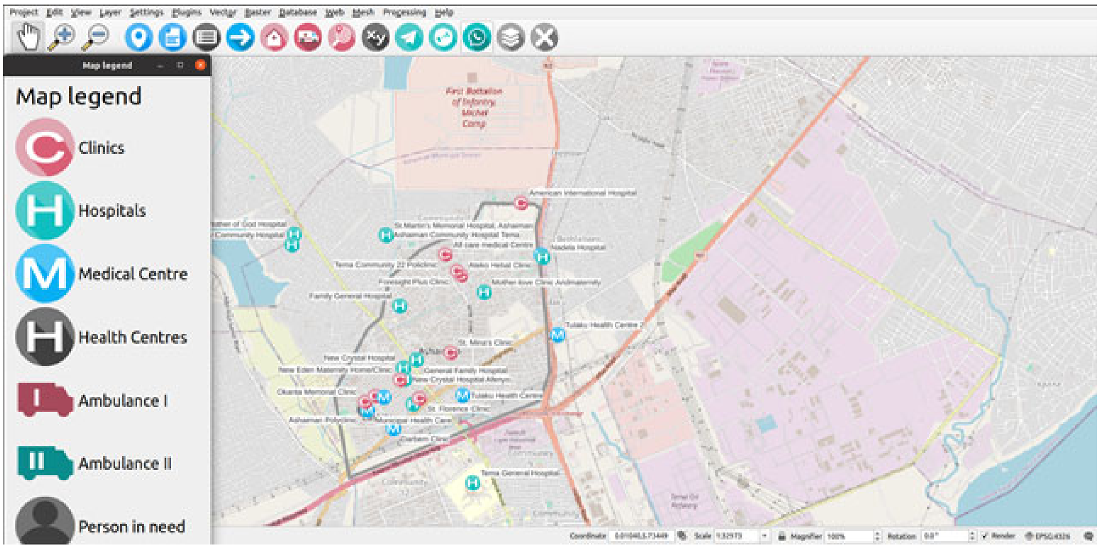

Fig. 4: QGIS Customised User Interface

6 Results and Tests

To test the developed application, the scenario of an emergency and an incoming emergency call was simulated. Concerning the functions of the system, the EAMS was developed with a local doctor in Ashaiman. He tested the developed functions and suggested improvements. As someone who has never worked with GIS before, the intuitiveness of the system and the practical application of the functions could be tested alongside the functions themselves.

On the integration of Traccar's functions into QGIS, no ambulances were available for testing purposes so far. However, their function could be simulated with faked GPS locations via a smartphone. This also made it possible to test Traccar's functions and their integration into QGIS. With regards to installation and subsequent use of plugins on another system, ZIP files can be set up using the *Install from ZIP* function in the QGIS plugin menu. This makes it possible to install and use the plugins on other computers. If a plugin uses add-ons such as browser history, it is also necessary to install them on the respective computer before using an extension.
Furthermore, the tests with the application show that QGIS is very well suited for the implementation of the project in Ashaiman. This geographic information system has the property of being highly configurable and adapting to any scenario with the help of plugins or other developments.
In the course of this work, a method was developed to automatically update the locations of the ambulances in the QGIS system in real-time, as is usual with a commercial fleet management system. The automatic receiving of the coordinates is done through a Python interface that was programmed. This reads the real-time coordinates of the ambulances from Traccar and passes them to QGIS. QGIS can then display this data directly. This interface automatically queries the location every 2 seconds.

7 Conclusions & Outlook

This study sort to find out the possibilities within the implementation of GIS for a fleet management system. The existing and available system for starters is almost free, low-cost and based on open-source software save the necessary but marginal cost of static IP address subscription to be used for the Traccar system. Nonetheless, there is the need to do adjustments and setting modifications and alterations to the open-source cost software to convert it to the semblance of a fleet management system or something closer. There is a need to consider certain factors concerning data integration – i.e. how do we bring data and integrate or make it a part of the system? We found out that the possibilities exist in making connections between the different components of the system; making use of the internet. So we have been able to achieve somewhat data integration and this was possible through the use of the interoperability between Traccar software, data server hosting PostgreSQL and the use of GPS data from mobile devices. To ensure that the application is useful and accessible to the user in the most portable way is to warrant that they could run the application without limitations. That is to say, the operating system and machine specifications do not hinder the installation process, for example. An ambulance system to work requires interconnected parts. We need to ensure these communication processes are functional and real-time, and we were able to achieve this by making use of the web applications that allowed effective and reliable communication. QGIS plugins are possible to create from scratch or customize. With the use of a programming language like Python, this was possible to do within the application and without much cognitive overhead – the development environment was amenable to allow for adaptation to meet user needs.
Furthermore, further tests with simulated incidents are being planned with ambulances on site, also for the training of new staff in the Control Centre and ambulances. It is also interesting for the use

of Traccar that, in addition to the live location of the ambulances, we also enable the geofences to display in QGIS which ambulance is occupied and, when entering the geofences of the assigned health facility, to display it is free again. More tests and analyses are possible and will reveal the effectiveness and accuracy issues with the current system.

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