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GIS Based Fire Emergency Response System

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Abstract: Urban fire is one of the most disturbing problems not only for developing countries but also for developed countries and, in Ghana very large amount of property and lives are unfortunately destroyed by fire annually. It was against this background that the Ghana National Fire Service (GNFS) was established to control fire outbreaks and, since its inception, it has embarked on programs and activities to educate the public on fire safety and prevention measures while fire stations were established in the major cities. In spite of the modern techniques of fire prevention and suppression, urban fires continue to damage properties. Thus, effective handling of these fires requires an effective planning response system on a regional scale. The objective of this paper is therefore to establish a GIS (Geographic Information System) based fire emergency response services where GNFS can identify the optimal route from its location to any fire incident. Since access to a fire incident and timely intervention play a crucial role in managing urban fire, the optimal route was modelled based on the distance of travel, time of travel, the slope of the roads and the delays in travel times. Besides using this analysis to timely respond to urban fire emergency services, GNFS could perform analysis on the number and spatial distribution of fire water hydrants. It is now possible to query the location of a fire water hydrant and its conditions, whether functioning, in high or low pressure or disconnected from water source. The developed fire information system could also be spatially joined to the building and cadastral parcel database for more comprehensive decision support system. However, it has been observed during the study that there are insufficient numbers of fire hydrants in the areas where fire is considered to be intensive and the distribution of these hydrants is not compatible with regulations.

Key words: Emergency Services, GIS, Network Analysis, Urban Fire, Fire Hydrant.

1. Introduction

Urban fire is one of the most common problems not only for developing countries but also for developed countries (Nisanci, 2010). Particularly in Ghana, a very large amount of property and lives are unfortunately lost through fire annually. For instance, in the year 2006, the Ghana National Fire Service (GNFS) recorded one thousand nine hundred and eighty six fire outbreaks that destroyed properties worth thousands of Ghana cedis (Aziz, 2007). The economic cost to the Nation is great since fire outbreaks tend to exacerbate the poverty level in the country. Emergency response service, especially in the area of fire disasters, is therefore important to save the country from losing scarce resources. This led to the establishment of the GNFS in 1963 to control fire outbreaks in the country and, since its inception, GNFS has embarked on programs and activities to educate the public on fire safety and prevention measures while fire stations were established in the major cities. These stations were equipped with modern techniques to preserve lives, property, and natural resources for the sustainable development of the people of Ghana. Even today, in spite of these modern techniques of fire prevention and suppression, fires continue to damage properties especially in the Central Business District (CBD) of Kumasi and effective handling of urban fires within the CBD involves an effective planning response system on a regional scale.

The objective of this paper is to establish a Geographic Information System (GIS) based fire emergency response services for GNFS where time plays a crucial role. In establishing fire emergency response database, emergency preparedness planning is an important issue that can impact people lives. If planned properly and implemented quickly, it can save hundreds or thousands of human lives and mitigate some of the economic losses in affected areas. However, if planned poorly or not implement in a timely manner, the consequence can be dire and could cost human lives (Nguyan, 2006).

According to ESRI (2011), there are five reflex time sequence for managing urban fire: (1) Dispatch time, which is the amount of time that it takes to receive and process an emergency call; (2) Turnout time, which is the time from when units acknowledge notification of the emergency to the beginning point of response time; (3) Response time, which is the time that begins when units are en route to the emergency incident and ends when units arrive on the scene; (4) Access time, which is the amount of time required for the crew to move from where the apparatus stops to where the emergency exists; and (5) the amount of time required for fire department units to set up, connect hose lines, position ladders, and prepare to extinguish the fire. It is against this background that the research was undertaken to develop a GIS based fire emergency response services for GNFS to help manage urban fire in the Kumasi Metropolis and to develop a cost analysis model in assisting the GNFS to identify the optimal route from its location to any fire incident within the Kumasi Metropolis. Modelling of this takes into account the distance of travel, time of travel, the slope of the roads and the delays in travel times. GNFS can also perform geospatial analysis on fire hydrants location. Spatial analysis on fire emergency response requires street network data, information on hazardous materials locations, and pre-fire survey information such as floor plans or hydrant location and capacity data (ESRI, 2011). As stated earlier, in this study, the city centre of Kumasi in Ghana was selected as the pilot area for the establishment of a spatial fire database based on GIS and as the basis of sample spatial queries in support of emergency fire response.

Of late attention has been given to the use of GIS network analysis in managing urban emergency services. In Nisanci (2010), the author used GIS through effective spatial data storage and query to produce dynamic fire maps. In the study, he established fire database based on GIS and also carried out an analysis of fire hydrant location. That he created fire information systems for urban area and highlighted the importance of this information system. This system was then used to determine the optimum distribution of hydrants, location of fire stations, classification of fire regions according to fire type and the creation of region specific early intervention plans. Similarly, Chevalier et al (2012) used an integrated GIS approach to locate fire stations in Belgium. The system was designed for an effective management of fire-stations locations and allocations. In their analysis, a multi-scale GIS which includes risk modelling approach was used to determine the optimal location and allocation model taking into account the queuing as well as staffing problems.

Also Pasha (2006) studied identified problems faced by emergency service providers on road network in Hyderabad city. In this research an integrated GIS based prototype system was developed for the routing of ambulance on road network such that it finds the accident location on the road network and locates the nearest ambulance to incident site using the real-time technologies (GPS/GSM). The system also creates the fastest route from nearest ambulance to accident site, and from there to nearest hospital. Using ArcGIS network analyst, congestion on roads during peak hours was considered, and the fastest route on both major and minor roads was created. Min and Wei-fang (2012) discussed the establishment of the roads spatial database in a GIS environment and also described the GIS network shortest path algorithm. They used Harbin urban roads map combined with building designs and photographs as primary data source. In a similar research, El houssaini and Badri (2012) developed a GIS-Based monitoring system for Road Network. Using information on road infrastructure and Dijkstra’s algorithm (as implemented in ArcGIS) optimal route based on minimum cost were identified.

The rest of the paper is organised as follows: Section 2 discusses the methodology which includes the description of the study area, data inputs and fire emergency response model parameters. In section 3, analysis including optimal path, spatial queries and also service area for fire hydrant are displayed. Results are presented and interpretation is illustrated by means of a case study in Section 3. Conclusions and discussions of future research works are also outlined in Section 4.

2. Modelling the Fire Emergency Response Service

This Section discusses the study area, data input, analysis (i.e. to find the optimal route, perform a buffer for fire hydrants) and data output. The materials that were used for the project were topographic map, GPS, parking inventory data and traffic data.

2.1 The Study Area

As stated in Togbi (2008), the CBD (Central Business District) of Kumasi is made up of Adum, Central market and Kejetia. The study area (Adum) is approximately made up of about 75% stores, 15% offices and 10% residential (Togbi, 2008) and this area was chosen as a pilot study because of the increasing and recurring cases of fire outbreaks and the degree at which properties worth millions of Ghana Cedis are lost when fire incident occurs. Adum is a part of the Subin constituency which is also under the Kumasi Metropolitan Assembly (Figure 1). Majority of trading and marketing activities in the Kumasi Metropolis take place here. It has the biggest open space market in Ghana and West Africa as a whole (Fiano, 2008). The current population figure is estimated to be 1,634,898 and with an estimated annual growth rate of 5.4 percent (Cobbinah and Amoako, 2012).

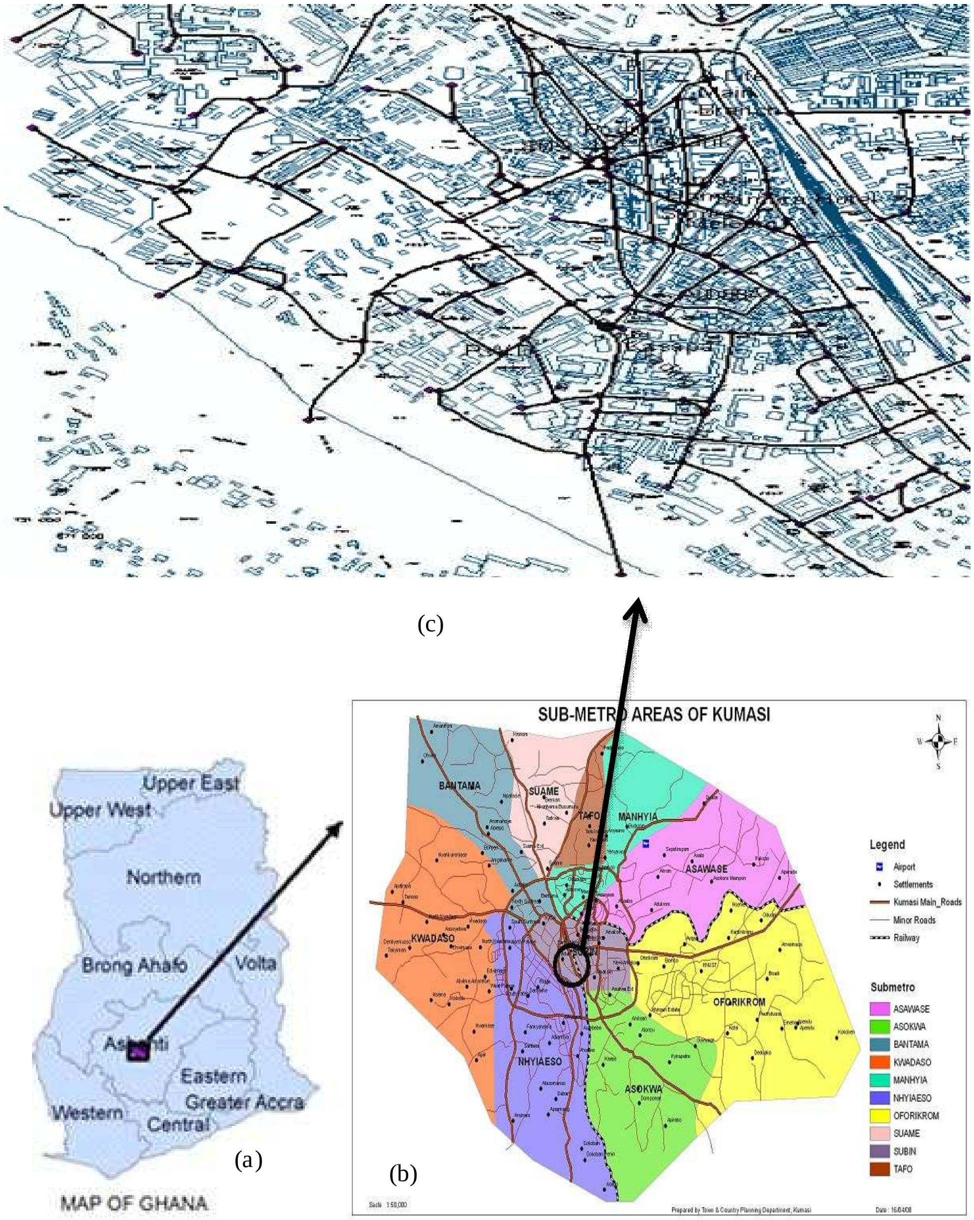


Figure 1: b) Geographic Location of the Kumasi Metropolis and b) the Study Area with Road Network (Source: Kumasi Metropolitan Town and Country Planning 2010)

2.2 Data Capture and Processing

Topographic map of the study area was digitized, projected, and geo-referenced in GIS environment. Detailed description of digitizing a topographic map (i.e., map quality, map scale, coordinate system, map units, grid intervals), distribution of GCPs (Ground Control Points), and map registration is available in Forkuo (2008; 2010). Street names and house addresses, which had not been updated for some time had to be updated. Global Position System (GPS) survey was conducted to coordinate the fire stations, fire water hydrants locations and buildings (such as residential, official facilities, factories, depots) in the study area. Attribute (i.e., non-spatial data) information such as the shape, the description of the location, status and the condition of each fire water hydrant was integrated into the geo-database development. The parking inventory data and traffic data was obtained from the Building and Road Research Institute (BRRI) where this inventory was conducted by consultancy services for urban transport planning and traffic management studies for Kumasi. Also, cost attribute information or impedances such as volume of traffic, type of road, width of road and speed limit, average time delay at road junctions and turns were obtained from a field survey conducted by BRRI. The distances of the various roads in the study area was derived from the digitized roads map.

2.3 GIS Network Analysis for Optimal Path

As one of the main functions of GIS, network analysis plays an important role in vehicle routing, traffic tourism, urban planning, electric power, communication and closest facility (Min and Wei-fang, 2012). This network (as implemented in ArcGIS) is used, among other things, to build an immediate, rapid and efficient emergency fire response system for the study area. Given the data of roadways and cost attributes, the network analyst can be used to analyze problems such as vehicle routing, closest facility and service area. In addition, network can be used to study problems when the facility of a location is already fixed. For instance if there is a fire incident (a house on fire), the GNFS could identify the optimal route from its service station to the fire incident and could also perform analysis to locate the closest fire hydrant. In network analysis, the most fundamental and the most critical problem is the computation of optimal route between different locations on a network (Zhang et al, 2009, Min and Wei-fang, 2012). The optimal route (also called the least cost path) in this paper is the path of lowest impedance or the lowest cost. This route takes into consideration all the impedances (discussed in Section 2.3) which include the distance, travel time, number signals and turns, slope, intersection delays, volume of traffic and parking.

ArcGIS network analysis uses the standard Dijkstra's algorithm to calculate the least accumulated cost between the destination node and every other node and details of this algorithm and its assessment can be found in (El houssaini and Badri, 2012; Nagib and Ali, 2011; Zhang, 2005; Zhan, 1997). The optimal path analysis has been studied and a range of models has been developed (Alivand et al., 2008, Min and Wei-fang). Peng and Huang (2000) used the optimal route finding algorithm for a web based transit network such as time-dependent services, common bus lines on the same street, and non symmetric routing. They developed a framework to categorize transit information system based on content and functionality. Advani et al (2005) also used GIS network analysis to determine the optimal routes from one origin to many destinations in Bhavnagar district area (as a case study) with an objective of minimizing travel distance and travel time of users. Similarly Zhan (1997) and Zhan and Noon (1998) have explored the use of optimal route algorithm on extensive road networks. Min and Wei-fang applied GIS network optimal path algorithm to Harbin urban roads. They used Dijkstra algorithm, as implemented in GIS network analysis, to find the optimal route in urban traffic roads based MapX and network topology establishment.

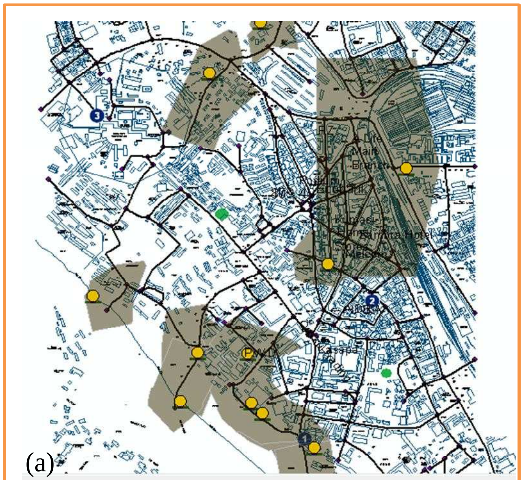
2.4 Impedance Factors

As previously stated, an optimal route in a network is the route of lowest impedance, also called the least-cost path. Impedance is a measure of the amount of resistance, or cost, required to traverse a path in a network or to move from one element in the network to another. Resistance may be a measure of travel distance, time, and speed of travel multiplied by distance. Higher impedance values indicate more resistance to movement, and a value of zero indicates no resistance. With this objective of optimizing travel time, the various impedance factors that play a significant role in deciding the travel time such as volume of traffic, type of road, road width, number of junctions, and turns are analyzed in determining the optimal route having the minimum travel time. The travel time used for the roads in the study area was based on the speed limits of the roads. With the speed limit and the distances known, the travel times for the various roads segments were then calculated. One way restrictions were also considered in this study. A field called “oneway” was added to the attribute table of the road feature class and was indicated according to the pattern of digitizing. Intersection delays at road junctions were also used as one of the impedances since some junctions in the study area are known to be very much congested at all times. These junctions were grouped into signalized (traffic controlled) and un-signalized (stop controlled) intersections. Standard delays with their Level of Service (LOS) were used to cost these junctions.

As mentioned earlier, on-street parking data was included in optimal route analysis due to the fact that parking lots in the CBD contribute to the delays in the travel times on the road in the study area. The number of parking lots available influences how busy a particular road can be during the active peak hours of the CBD. In determining the least cost route, another impedance factor, junctions and u-turns, were considered. Delays at the junction and u-turns can be very significant in the analysis. Turns are made at most road junctions where edges connect. Even at road junction with a single edge, it is possible to make one u-turn. Attributes of these u-turn movements through the road network was added to the geo-database. Common examples of attributes include the time required to make this movement and the restriction movement is restricted for a particular vehicle type. Standard or global turn times were used for this study which includes left, right, u-turn and straight movements. Visual Basic scripts were written to assign time values to the various turns. Again, slopes of the roads were also considered in estimating the optimal path from any fire station to a fire incident. The slopes of roads either steep or gentle affects the speed the fire tenders can move and therefore will affect the time of response. These slopes were calculated using the heights of the two ends of the digitized roads and their distances.

3. Results and Discussion

An urban fire information system has been developed for GNFS to indentify optimal route from their location to any fire incident. This system includes a geo-database of the fire hydrants (Table 1), and with this, queries could be made to locate fire incident on the GIS interface within a particular service area (Figure 2a). As can be seen in Figure 2a, proximity analysis such as spatial buffering could be performed to suggest possible locations and allocations of fire hydrants. Also, in Figure 2b, the fire service personnel can further make analysis to locate the closest fire hydrant (indicated as FHI) without having to memorize the location of these hydrants in the study area and in the fire incident scene (represented as FI).



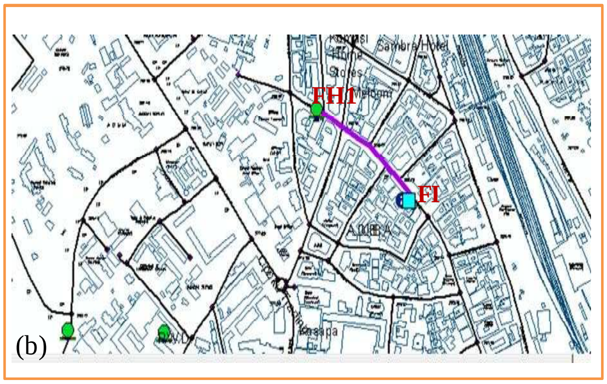


Figure 2: a) Screenshots of Locations of Fire Hydrants and b) the Closest Fire Hydrant

Table 1: Sample Geo-database of Fire Hydrants

Id	Shape	Location	x_Coord	y_Coord	Status	Condition
1	Port	KMA Fire Station	731507.471	673920.211	Underground with no outlet cap	very good
2	Port	New ECG Workshop	732708.358	672521.375	Above ground	excellent
3	Port	Pioneer Printing Press	733834.948	674084.388	Underground with outlet cap	excellent
4	Port	Roman Hil	735053.013	675032.881	underground with outlet cap	good
5	Port	PWD	732697.512	673125.831	Underground with outlet cap	very good
6	Port	Ghana Veneer Processing1	731941.541	673306.212	Underground with no outlet cap	excellent
7	Port	Ghana Veneer Processing2	732072.716	673165.336	Underground with no outlet cap	excellent
8	Port	Sultin River (Heatlh Edu.)	730726.188	673837.427	Above ground	excellent
9	Port	Sultin River (ECG)	732100.613	672310.801	Above ground	excellent
10	Port	Sultin River (Barracks)	733427.393	671261.407	Above ground	very good
11	Port	Sultin River (Zoo)	736904.270	673275.145	Above ground	good
12	Port	Sultin River (Doctors Flat)	736254.490	672664.560	Above ground	good

As access to a fire incident and timely intervention play a crucial role in managing urban fire, the shortest and fastest routes are analysed and the results presented in Figure 3. The shortest route (as in Figure (3b)) between a particular fire station (FSS) and a fire incident (FI) was calculated using geometric distances only. Similarly, the fastest route (Figure (3b)) however, was found considering only the travel time without the turns and the intersection delays. That is, this route does not consider the slopes of the roads and other impedances. In analysing the response time for emergency from a particular fire station to a fire incident, the slopes of the roads (slope only) and parking (parking only) were also considered. The roads with the least slope and less parking lots are shown in Figures (4a) and (4b) respectively.

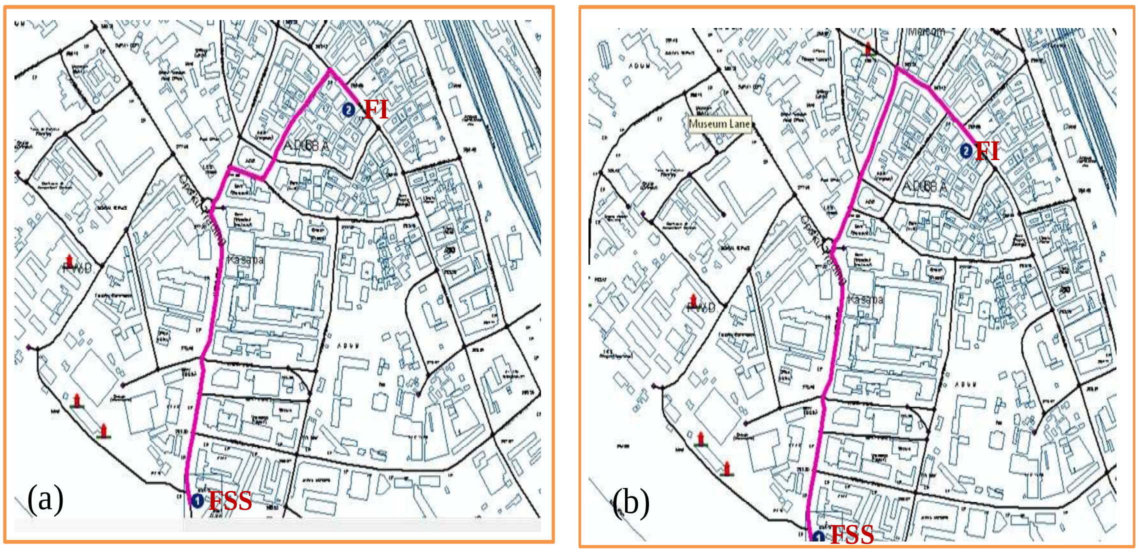


Figure 3: a) Screenshot of the Shortest and b) Fastest Routes from Fire Service Station to a Fire Incident

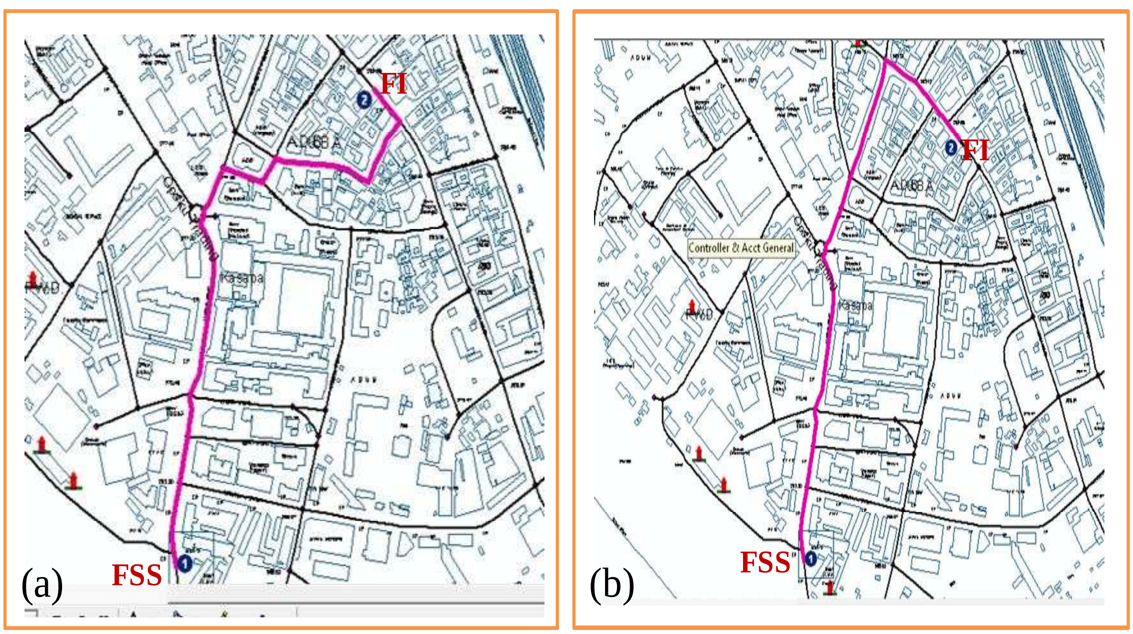


Figure 4: a) Screenshot of Routes using Slope only and b) Parking only from a Fire Service Station to a Fire Incident

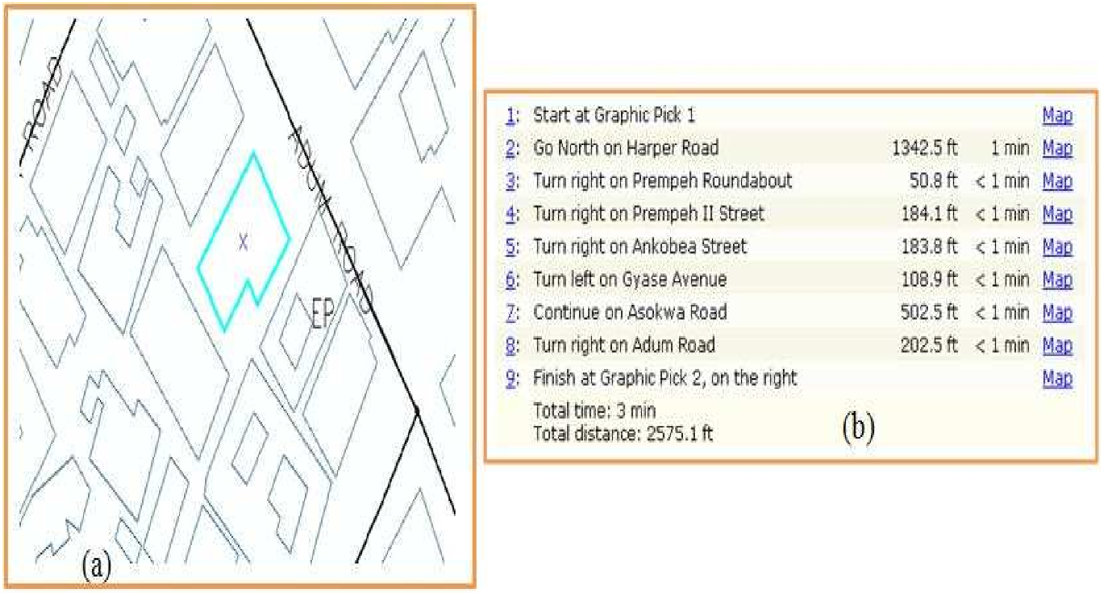


Figure 5: a) Displaying a Sample House on Fire and b) Directions window for effective communication

Moreover, fire departments upon receiving an emergency call for a fire incident can query the developed geo-database to find the location of that fire incident (Figure (5a)) and in addition to the graphical display of the location of the fire incident, a text description of the direction to this location (Figure (5b)) is also displayed. Integrating all the impedances, the optimal route is displayed in Figure (6a). This indicates the least cost route from the KMA fire station to any fire location upon an emergency call can be derived as indicated as FSS and FI. This path is the one with the lowest impedance within the road network in the study area or it is a path that the total amount of its weights is minimal. In addition, Figure (6b) shows the optimal path in conveying fire victims from the fire incident (indicated as FI) to hospital (indicated as H).

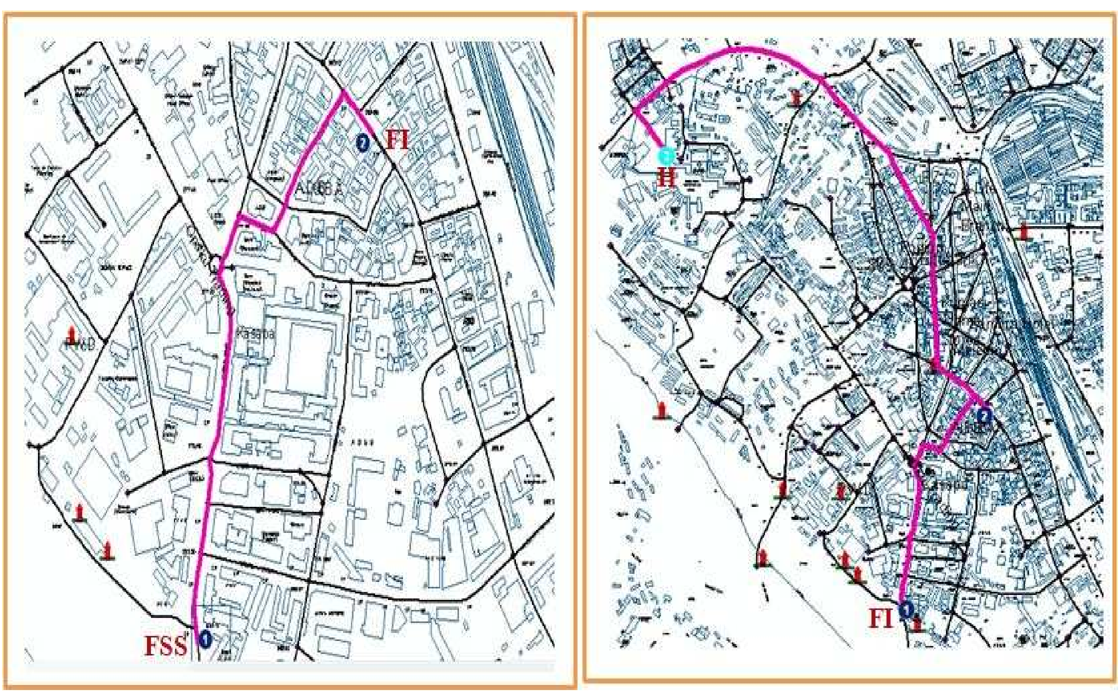


Figure 6: a) Optimal Route to Fire Location and b) Optimal Route in Conveying Victims to the Hospital from the Fire Location

Using different impedance values such as distance, speed, and parking, it has been observed that route with distance only (as shown in Figure (3a)) is similar to the optimal route indicated in Figure (6a). It is evident from the analysis that, route using slopes only of the roads from the study area of different instances do not give a good indication of minimising the cost of the fire service. The analysis also revealed that the integration of various impendence factors in modelling the optimal path would improve the operation of GNFS. Besides using this analysis to timely respond to urban fire emergency services (or to reduce cost of fire of urban fire fighting) GNFS could perform analysis on the number and spatial distribution of fire water hydrants. It is now possible to query the locations of the fire water hydrants and its conditions, whether functioning, in high or low pressure or disconnected from water source. Fire hydrant locations can be determined without difficulty and with high degree of precision in a digital environment. The developed fire service geo-database could also be spatially joined to the building and cadastral parcel database for more comprehensive decision support system. However, it has been observed during the study that there are insufficient numbers of fire hydrants in the areas where fire are considered to be intensive and, as stated in Nisanci (2010), the distribution of these hydrants is not compatible with regulations. It was also found out that the spatial information of fire water hydrant is deficient and the current data on their usability is not available (Nisanci, 2010). For effective urban fire management, it is therefore important that more fire hydrants be installed. Furthermore, it has been observed that the standards for spatial and attribute data with respect to GNFS fire records has not been developed.

4. Conclusion and Recommendations

A GIS based application for urban fire emergency response services has been developed to manage urban fire in the Kumasi Metropolis. It focuses on finding a way to quickly locate fire scenes using the residential addresses. Also a cost analysis model in assisting the GNFS to identify the optimal route from their location to any fire incident within the Kumasi Metropolis has been displayed. With this application, it is now possible to identify the optimal route in terms of the distance of travel, time of travel, the slope of the roads and the delays in travel times from a fire station to any fire location. In addition spatial database for fire hydrants was created to a perform geospatial analysis for suggesting new locations for fire hydrants and perform a buffer for them in the study area. It is also possible to query the locations of the fire water hydrants and its conditions, whether functioning, in high or low pressure or is disconnected from water source. The developed application provides a useful decision support system to determine the optimal route for emergency response and geospatial analysis on fire water hydrants. However, to facilitate a more comprehensive decision support system of the study area, database on cadastral parcels should be created and spatially joined to the existing database on fire records. Also, satellite imagery with high resolution will be useful to update the spatial data and attribute information. Future research will also concentrate on the investigation on the current distribution of fire water hydrants and the development of a digital metadata (for both spatial and attribute) standards for GNFS fire records.

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