Journal of Engineering Sciences and Information Technology (JESIT) • Vol 7, Issue 2 (2023) • P: 94 - 82
https://journals.ajsrp.com/index.php/jesit
ISSN: 2522-3321(Online) • ISSN: 2522-3321(Print)

A GIS-Based Streets Network Analysis in Al-Riyadh District, Al-Khartoum City

Dr. Sahar I. M. Abd Elrahman

Surveying Engineering Dept. | Sudan University of Science and Technology | Sudan

Received:
26/03/2023

Revised:
07/04/2022

Accepted:
11/04/2023

Published:
30/06/2023

* Corresponding author:
engsaharesmail@gmail.com

Citation: Abdelrahman, S. I. (2023). A GIS-Based Streets Network Analysis in Al-Riyadh District, Al-Khartoum City. *Journal of engineering sciences and information technology, 7(2),* 82 – 94.
https://doi.org/10.26389/AJSRP.M260323

Abstract: In light of the remarkable development and high population density, there are many questions regarding traffic problems and the possibility of reaching the event location in the shortest time. For all these inquiries, this paper aims to analyze the streets network of Al Riyadh district using Geographic Information Systems (GIS), represented in finding the optimal path between the home and the school based on time and length and finding another path in the event of an obstacle in the chosen path, clarifying the service area for an ambulance center, and also knowing the closest fire station to the place of the fire and the optimal path between them. To achieve these objectives, an ArcGIS 10.6 program was used, and many procedures were taken, a geographical database was created, a network dataset was built, and a lot of analyses were done by the network analyst toolbar. According to the findings of this study, was known the optimal path between two locations, the service area of an ambulance center and the closest fire station to the fireplace, to be able to perform the required service in the shortest possible time. This work is a real contribution to the development of societies, as it is difficult to reach these results without using the capabilities of GIS. Therefore, it is recommended to implement all the analysis tools for the streets network within the GIS program.

Keywords: Sudan, GIS, Network Dataset, New Route, New Service Area, New Closest Facility.

تحليل شبكة الطرق مبنية على نظم المعلومات الجغرافية
(دراسة حالة: منطقة الرياض، مدينة الخرطوم)

الدكتورة / سحر إسماعيل محيي الدين عبد الرحمن

قسم هندسة المساحة | جامعة السودان للعلوم والتكنولوجيا | السودان

المستخلص: في ظل التطور الملحوظ والكثافة السكانية العالية، هناك العديد من التساؤلات حول مشاكل المرور وإمكانية الوصول إلى موقع الحدث في أقصر وقت ممكن بالاستفادة من التقنيات المتوفرة. لجميع هذه الاستفسارات، تهدف هذه الورقة إلى تحليل شبكة شوارع منطقة الرياض باستخدام تقنية نظم المعلومات الجغرافية (GIS) متمثلة في إيجاد المسار الأمثل بين المنزل والمدرسة بناء على الزمن والطول وإيجاد مسار اخر في حالة وجود عائق في المسار المختار، توضيح نطاق الخدمة لمركز إسعاف وأيضا معرفة أقرب محطة إطفاء لمكان الحريق والمسار الأمثل بينهما. لتحقيق هذا الأهداف، تم استخدام برنامج ArcGIS 10.6، وتم اتخاذ العديد من الإجراءات داخله حيث تم إنشاء قاعدة بيانات جغرافية تضم بداخلها كل البيانات المكانية والوصفية الخاصة بالدراسة، وتم إنشاء مجموعة بيانات الشبكة حتى يتم التعامل معها كوحدة واحدة، وتم إجراء الكثير من التحليلات بواسطة شريط أدوات محلل الشبكة. تم التوصل إلى معرفة أفضل مسار بين موقعين مزودا بالبيانات الوصفية الخاصة به، منطقة الخدمة لمركز الإسعاف وأقرب محطة إطفاء إلى مكان الحريق حتى تتم الخدمة المطلوبة في أقل زمن ممكن لتفادي الخسائر المتوقعة بقدر الإمكان. يعتبر هذا العمل مساهمة حقيقية في تنمية المجتمعات، حيث يصعب الوصول إلى مثل هذه النتائج دون استخدام إمكانيات نظم المعلومات الجغرافية. لذلك يوصى بتطبيق كل أدوات التحليل الخاصة بشبكات الطرق داخل برمجية نظم المعلومات الجغرافية.

الكلمات المفتاحية: السودان، نظم المعلومات الجغرافية، مجموعة بيانات الشبكة، مسار جديد، منطقة الخدمة الجديدة، أقرب مرفق جديد.

1. Introduction

GIS technology is more beneficial for managing tasks and decision support systems, which are more beneficial for the urban planning process (Rai, Singh, Singh, and Mohan 2013). Analyzing urban networks using geographic information system techniques is essential for understanding the complex dynamics of urban areas. GIS is a powerful tool that allows researchers to collect, store, analyze, and visualize large amounts of spatial data. Urban networks, such as transportation and communication systems, are crucial components of cities that affect social, economic, and environmental outcomes. Overall, GIS techniques are crucial for analyzing and understanding the complex dynamics of urban networks. By using GIS to analyze urban networks, researchers can gain insights that can inform policies and interventions that promote sustainable development and social equity.

A GIS-based streets network analysis involves using geographic information systems to analyze the characteristics and connectivity of streets in an urban area. This type of analysis can provide insights into transportation patterns, accessibility, and urban design. Here are some steps involved in conducting a GIS-based street network analysis:

Data collection: The first step in a GIS-based streets network analysis is to collect data on the street network. This includes information on streets names, road classifications, speed limits, and other attributes. The data can be collected from public sources, such as municipal databases, or private sources, such as GPS tracking devices.

Data processing: The collected data is then processed to create a spatial database that can be used for analysis. This involves geocoding the streets network data, which involves assigning latitude and longitude coordinates to each street segment.

Network analysis: The next step is to perform network analysis on the streets network data. This involves identifying the connectivity between different streets segments, calculating travel times and distances between different points in the network, and identifying any bottlenecks or congestion points.

Visualization: Once the network analysis is complete, the results can be visualized using GIS software. This allows researchers to map out the street network and identify any patterns or trends that emerge from the analysis.

Interpretation: The last step is to interpret the results of the analysis and draw conclusions about the streets network. This could include identifying areas of high traffic congestion or poor accessibility, assessing the impact of road closures or construction projects, or identifying opportunities for urban design improvements.

1.2 Research Problem

The infrastructure of any country plays the main role in developing and distinguishing it, especially the roads network because of the many facilities it provides, for example, but not limited to, it plays the main role in the ease and smoothness of movement for the population and their needs, and this entails many benefits and advantages. Therefore, there was an urgent need to analyze the roads network to reach results that are difficult to obtain by traditional methods, and here it was necessary to mention the use of geographic information systems in this field and enjoy its effective capabilities, this reflects the necessity to point out the paramount importance of using GIS and benefiting from its capabilities in the needs of daily life and community service, where there are many advantages and capabilities that GIS enjoys, from here the idea came to take advantage of GIS techniques in the analysis of streets network.

1.3 Research Objectives

This paper aims to analyze the streets network of the Al Riyadh district using GIS technology, where the study area lacks a digital database of the streets network, in addition to the traffic congestion, so this paper focused on the objectives below:

1- Finding the optimal path between home and school, for access to school in the shortest possible time.
2- Knowing the service area of an ambulance center, to identify the time when the ambulance came to the place of the event.
3- Identify the closest fire stations, to be chosen to reach the place of the fire in the shortest possible time.

1.4 Literature Review

The convenience and efficiency of people's daily lives are dependent on the city's traffic system. Understanding the interrelationships between the urban street network and traffic flow can aid the urban system design process (Wu, Hu, Jiang, and Hao 2021).

As one of the world's oldest transportation infrastructures, street networks have played an important role in modernization, sustainable development, and human everyday activities in both ancient and modern times (Jiang and Okabe 2014).

The application of the network approach to the urban case raises several issues, including how to deal with metric distances, what type of graph representation to use, what types of measures to investigate, how to deepen the correlation between network structure and network dynamics, and what contributions from the geographic information systems community are possible (Porta, Crucitti, and Latora 2006).

Traffic emergencies are situations that pose a significant risk to people's lives and the development of human society. The incidence of road accidents is linked to people's behavior, population density, machine behavior, and infrastructure layout. Ordinary automobiles, ambulances, and police or firefighters are all capable of responding to any collision. The response time must be as short as feasible. This response time is determined by the condition of the emergency response vehicle as well as any potential roadblocks or prohibitions (Nicoară and Haidu 2014).

After experiencing severe concerns or problems such as traffic congestion, delay, pollution, increasing vehicle operating costs, and road accidents, society now demands an efficient road network unobstructed (Das, Ojha, Kramsapi, Baruah, and Dutta 2019).

Complex road networks necessitate analysis to better the movement of people, products, services, and resources.

Graph theory is the most frequent method for modeling physical roadway networks on a local, regional, or national scale. Typically, two types of components are used in the analysis, street segments as edges and street intersections as nodes (Telega 2016).

Since the early years of GIS, specific programs dedicated to directed graphs and the problem of finding the best route through a city have been developed.

For example, the shortest path in a road network between two sites is defined as a directed simple path between them with the property that no other such path has a lower weight.

GIS Network Analysis assists in determining the best places for services to be offered. Roads, railways, rivers, infrastructure, and utilities are all examples of linear networks that may be studied using network analyses (Comber, Brunsdon, and Green 2008).

1.5 Previous Studies

Nicoară and Haidu (2014) conducted a study to develop a system based on GIS technology, and apply it to the city of Cluj-Napoca, Romania, one can model the shortest path and closest facility for an ambulance to travel through a streets network.

Comber, Brunsdon, and Green (2008) wrote a paper showing how the equality of access to community goods and services can be examined using a GIS-based streets network analysis along with statistical analysis of socioeconomic data. They concluded that the outcomes can be used to guide local planning efforts, and the GIS method can be applied to other local government spheres.

The author agreed with previous studies in analyzing the streets network using geographic information systems, but she obtained more comprehensive results because they found the best route between two locations, suggested another path in the event of barriers, and conducted an analysis of new service areas and new closest facilities. While Nicoară and Haidu (2014) limited their study to identifying the shortest path and closest facility in the medical field, Comber, Brunsdon, and Green (2008) addressed in their study the determination of the accessibility to community goods and services. As a result, the study is a valuable addition that offers additional information and methods that were not covered in the previous studies.

2. Methodology

Since the main objective of this study is to analyze the streets network of the district of Al Riyadh, a lot of work was carried out using the ArcGIS 10.6 program, the attribute data were inserted, and the relevant network dataset was created. The methods of the network analysis were done using the network analyst toolbar, represented in New Route, New Service Area, and New Closest Facility tools.

2.1 Study Area

The district of Al Riyadh was selected as a study area. It is located in the southern part of Khartoum, the capital city of Sudan. The district is primarily made up of residential areas, with some commercial and retail spaces. It is a relatively new district developed in the late 1990s and early 2000s. Lies between longitudes 39°26´51″.025 and 21°05´49″.021 E as well as the latitudes 23°42´15″.172 and 08°07´47″.419 N, a Riyadh district area is approximately about 3415.517 Km^2. It is considered one of the neighborhoods with high traffic congestion due to its many facilities of interest to citizens, such as restaurants, parks, hospitals, schools, mosques, shopping centers, etc. The district is located near several major roads, including the Khartoum Airport Road and the Southern Circular Road, making it easily accessible from other parts of the city. Overall, Al Riyadh is a peaceful and thriving district, with a growing population and a strong sense of community. Therefore, there was a need to analyze its streets network to avoid the problems that may result from traffic congestion and to facilitate movement in general, and this was the reason for choosing it as a study area.

2.2 Test Data

The primary source data, a satellite image of the study area with the placemarks as control points (Figure 1), was obtained from the Google Earth Pro program, and the attribute data of the street layer was collected from the field to build the database on which the analysis will be carried out.

Figure 1: Satellite Image of Study Area (Google Earth Pro program, 2022)

2.3 Procedures

There are many ways to get the streets layer, either by downloading it from open-source sites directly (for example, but not limited to the site of BBBike Extracts OpenStreetMap) or from within the ArcGIS program itself from the base map of an open street map or the Quantum GIS (QGIS) program or Google Earth Pro program or creating it manually or other ways, it should be noted that some of these methods give you most of the desired area spatial data not only streets layer in addition to the most of relevant attributes data, in this study, but the streets layer will also be created manually.

There are many procedures were carried out in ArcGIS 10.6 program (Figure 2) to obtain the results of the streets network analysis and use them to facilitate the requirements of daily life, where it is difficult to obtain such results from other applications such as Google Maps because they do not support the ability to provide the beneficiary with attributes data along with spatial data to assist him in making decisions, and the author made a lot of effort to obtain this attribute's data along with the spatial data and then used it to create a geodatabase on which the analysis is based.

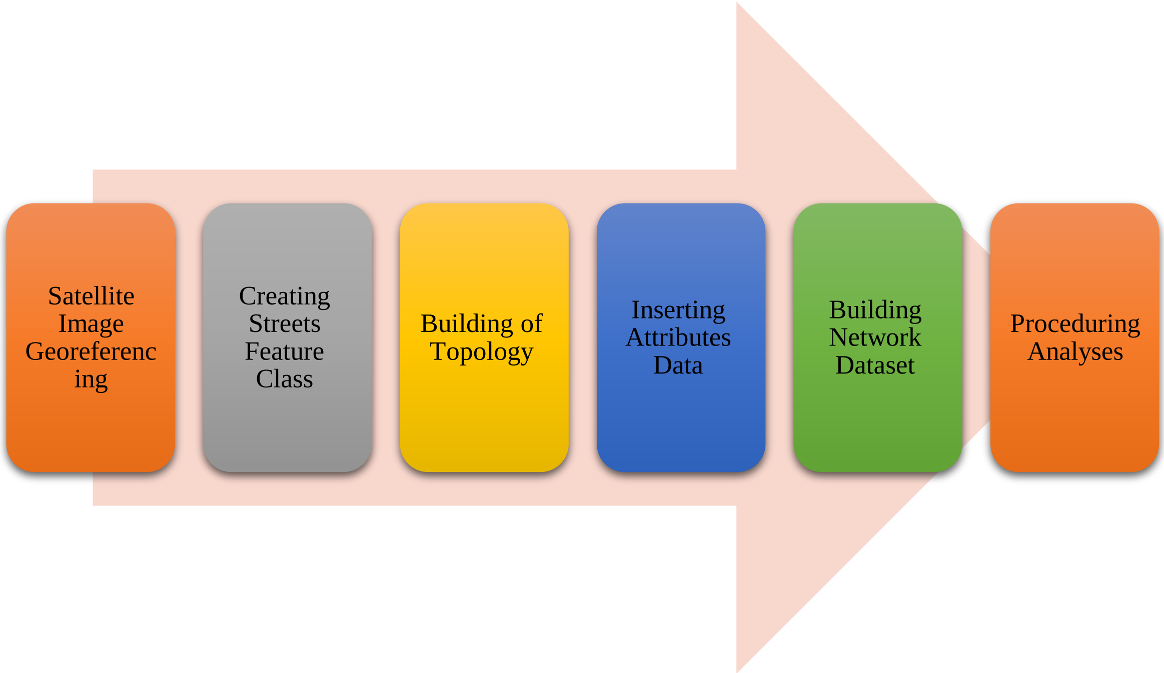

Figure 2: Work Steps

2.3.1 Data Acquisition and Management

The test data was collected, acquired, and managed by different means and from various resources. The satellite image which covers the study area was obtained from the Google Earth Pro program with placemarks for use in georeferencing. All attributes data required were collected from the field, represented in the name, type, one-way, distance, speed, and time in seconds for every road.

The layer for the streets was created based on the satellite image of the study area, and then was worked the topology on it, where the errors resulting from the creation process that hinder the analysis process were corrected.

A geographical database was created for the streets of the city of Riyadh, where the relevant attributes data were inserted in fields of the attribute table, and thus it can be said that the spatial and attribute data have been linked.

2.3.2 Building a Network Dataset and Perform Analysis

The network dataset of the streets under study was built and a lot of analyzes were carried out on it. A New Route analysis was done where the optimum path was found between two sites, where the chosen path is the optimal and best path in terms of speed of access and low cost. The analysis of the New Service Area was done, which helps in knowing the ranges that the vehicle reaches at a certain time. Also, a New Closest Facility analysis was done, which helps in quick access to the scene of the accident, for example, an ambulance or fire engine, or so on.

3. Results, Analysis, and Discussion

Many tasks were performed within the ArcGIS 10.6 program environment that would have been difficult to perform without the program.

3.1 Creating a Geodatabase

The WGS 1984 UTM Zone 36N was chosen as a coordinate system, a satellite image of the study area was called within the ArcGIS program and was worked georeferencing for it by making use of the placemarks obtained from the Google Earth Pro program after they were converted from a Keyhole Markup Language (KML) to layer by the conversion tools.

The file geodatabase, feature dataset, and feature class were created of the streets under study and within it, the streets under study were created, and thus a map was obtained (Figure 3).

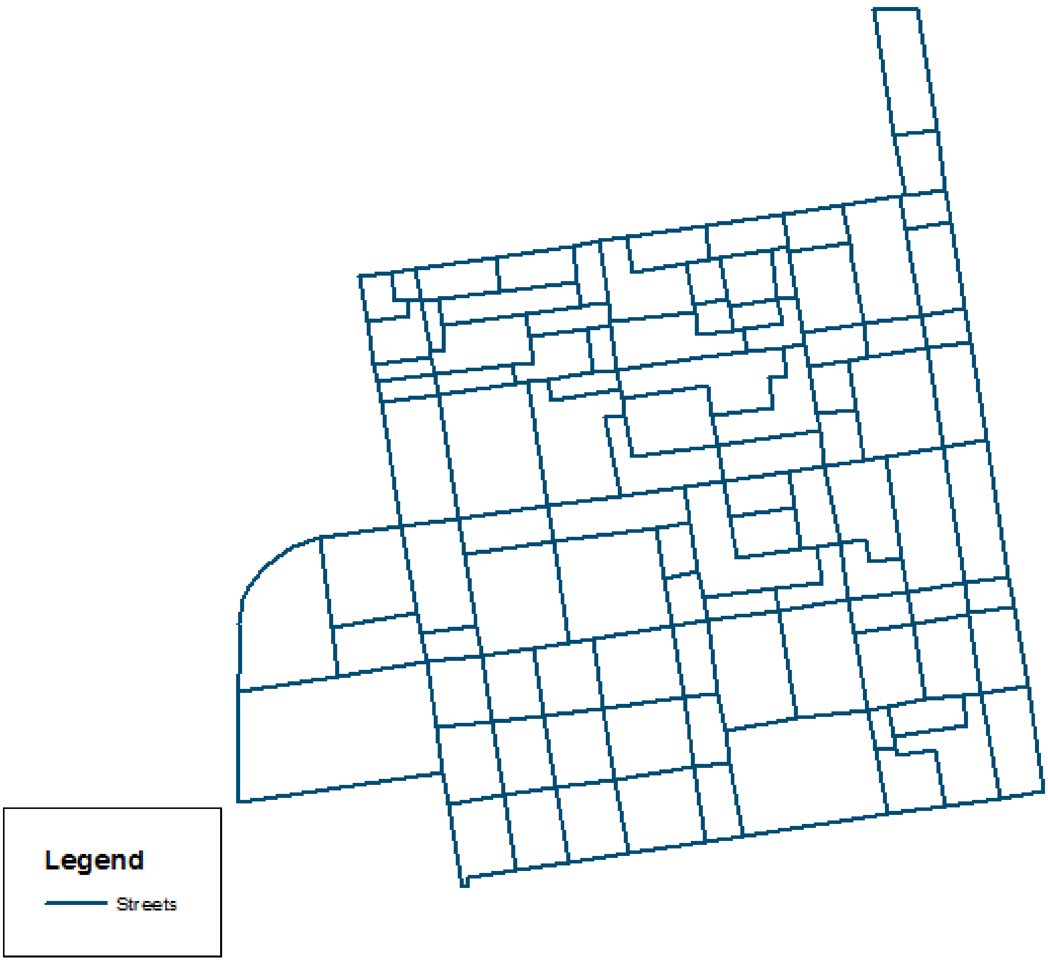

Figure 3: Map of Al Riyadh Streets

To analyze the streets network dataset that will be established later, a topology work must be done, where errors must be corrected so that there are no overlapping or intersecting streets, this was done based on the streets feature dataset.

All previously collected attribute data were inserted in the streets layer attribute table (Figure 4).

Streets

OBJECTID *	SHAPE *	SHAPE_Length	Name	Type	One Way	Distance	Speed	Seconds
1	Polyline	173.93439	Sixty Street	Asphalt Street	F	173.93439	25	6.957376
2	Polyline	115.876823	Sub Street	Dirt Street	F	115.876823	8	14.484603
3	Polyline	174.689497	Sub Street	Asphalt Street	F	174.689497	8	21.836187
4	Polyline	110.660658	Omak Street	Asphalt Street	F	110.660658	17	6.50945
5	Polyline	365.389461	Sub Street	Asphalt Street	F	365.389461	8	45.673683
6	Polyline	355.488904	Sixty Street	Asphalt Street	F	355.488904	25	14.219556
7	Polyline	117.860715	Sub Street	Asphalt Street	F	117.860715	8	14.732589
10	Polyline	257.980106	Sub Street	Dirt Street	F	257.980106	8	32.247513
11	Polyline	225.862304	Al Juraif Street	Asphalt Street	F	225.862304	14	16.133022
12	Polyline	245.534641	Makkah Street	Asphalt Street	F	245.534641	14	17.538189
13	Polyline	270.953187	Makkah Street	Asphalt Street	F	270.953187	14	19.353799
14	Polyline	238.550454	Sub Street	Dirt Street	T	238.550454	8	29.818807
15	Polyline	251.024257	Obaid Khatam Street	Asphalt Street	T	251.024257	19	13.211803
16	Polyline	83.447526	Obaid Khatam Street	Asphalt Street	T	83.447526	19	4.391975
17	Polyline	549.249752	Al Juraif Street	Asphalt Street	T	549.249752	17	32.308809
18	Polyline	141.020487	Sub Street	Dirt Street	T	141.020487	8	17.627561
19	Polyline	319.889498	Al Juraif Street	Asphalt Street	F	319.889498	17	18.817029
20	Polyline	561.816675	Riyadh Park Street	Asphalt Street	F	561.816675	14	40.129763
21	Polyline	189.180895	Obaid Khatam Street	Asphalt Street	F	189.180895	19	9.956889
23	Polyline	214.17907	Badr Street	Asphalt Street	F	214.17907	14	15.298505
24	Polyline	134.63431	Abdullah Al-Tayeb Street	Asphalt Street	F	134.63431	17	7.919665
25	Polyline	211.908138	Obaid Khatam Street	Asphalt Street	F	211.908138	19	11.15306
26	Polyline	28.005955	Obaid Khatam Street	Asphalt Street	T	28.005955	19	1.473998
27	Polyline	17.999481	Obaid Khatam Street	Asphalt Street	T	17.999481	19	0.947341
28	Polyline	26.671837	Obaid Khatam Street	Asphalt Street	T	26.671837	19	1.403781

Figure 4: Part of the Streets Layer Attribute Table

3.2 Building a Network Dataset

From within the catalog from the streets feature dataset, the streets network dataset was built, in which length and seconds were defined as cost and one way as a restriction.

Through the network analyst toolbar, many analyses on the streets network were been carried out.

3.2.1 New Route Analysis

To find the optimal path from my home to my son's school, from the network analyst toolbar, a New Route was chosen, and from the Create Network Location Tool the points representing my home and my son's school were marked and a Solve was pressed depending on the time (Figure 5).

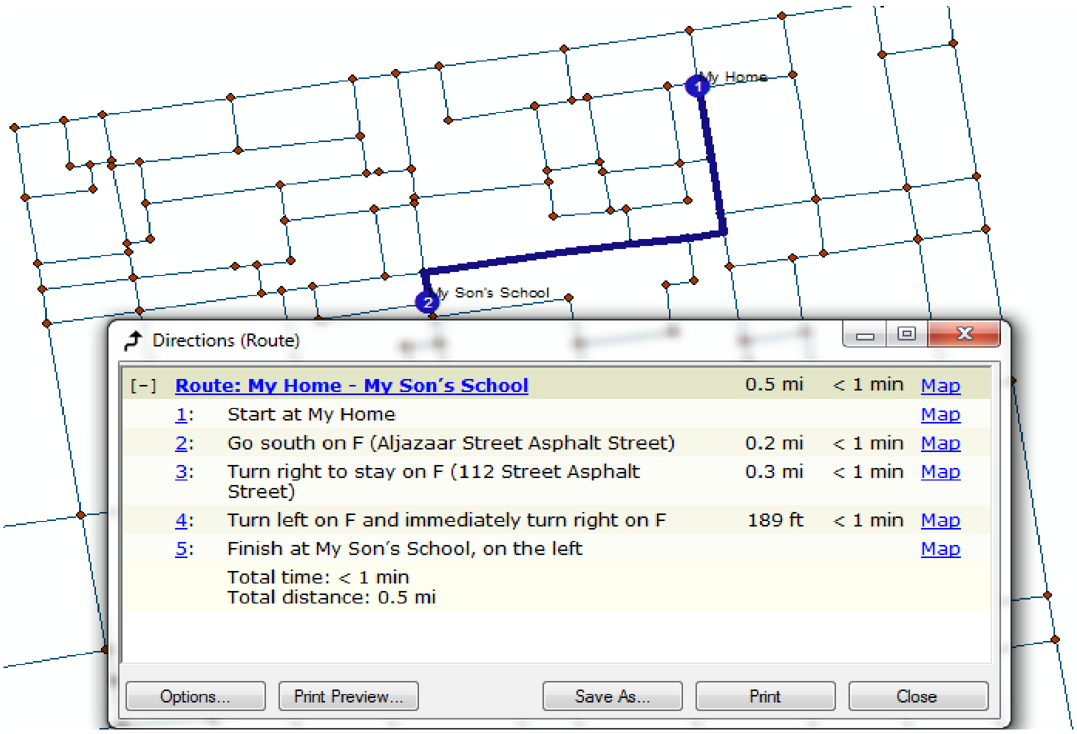

Figure 5: The Optimal Path depending on the Time

In the case of searching for the optimal path, depending on the length, the route changes (Figure 6).

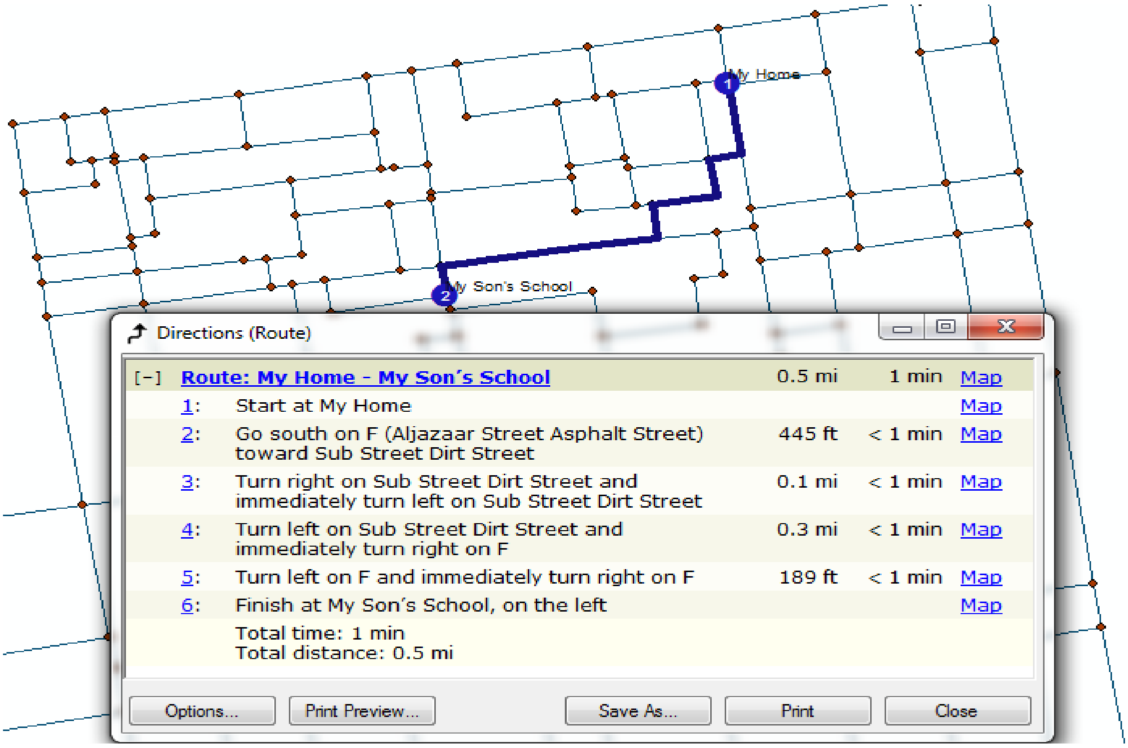

Figure 6: The Optimal Path depending on the Length

If there is an accident in the path obtained depending on the length, another path was found (Figure 7) where the Barrier was placed in the place of the accident and then the Solve was pressed.

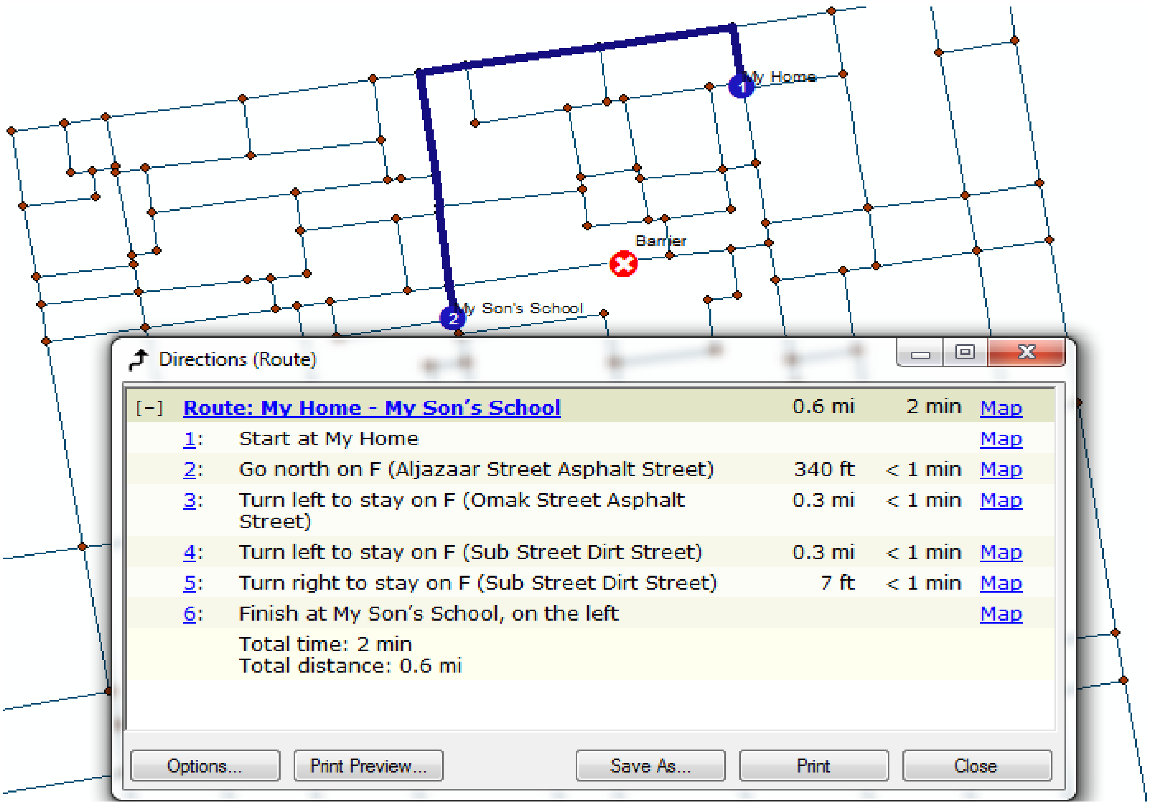

Figure 7: The Optimal Path in the Event of a Barrier

Forms 5, 6, and 7 show, respectively, the optimal path from home to school in terms of time and length and also the optimal alternative path if there is a barrier on the chosen path. This is important for reaching the school in the shortest possible time and at the lowest possible cost. These forms dealt with three analysis methods, whereas previous studies were limited only to choosing the optimal path based on time.

3.2.2 New Service Area Analysis

In the second analysis, we wanted to know the service area of an ambulance center, from the network analyst toolbar, the New Service Area was selected, and the Create Network Location Tool was placed on the ambulance center, the service scope was chosen based on the time every 2, 4, 6, and 8 minutes and the Solve was pressed, the service area was selected, where the darker color represents the access area with least time (Figure 8).

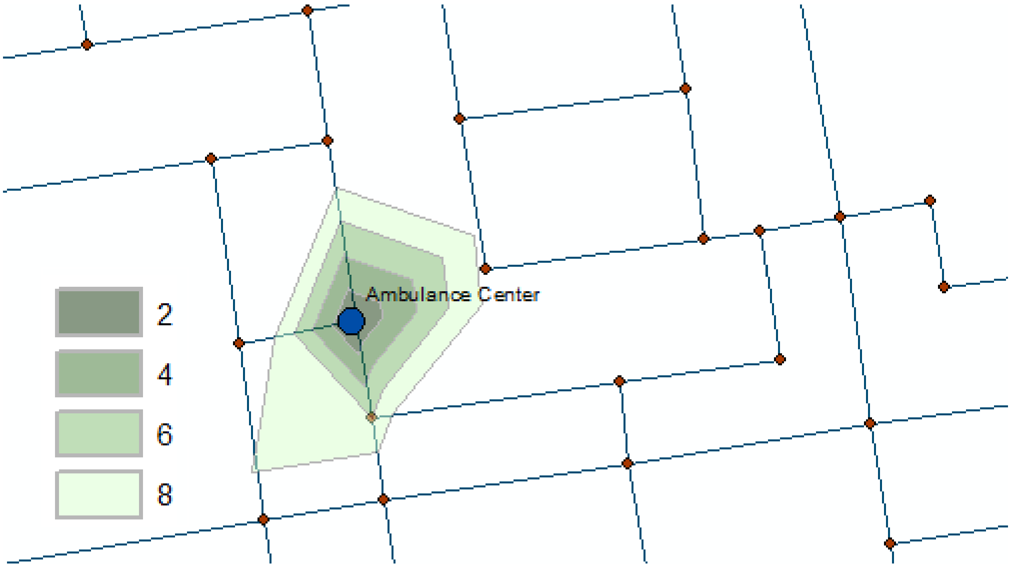

Figure 8: Service Area of the Ambulance Center

Form 8 shows the ranges in which the ambulance is every 2, 4, 6, and 8 minutes so that the ambulance can be tracked and the time of its arrival at the event scene can be known, which contributes to saving lives. This form is considered a real addition because it has not been addressed in previous studies.

3.2.3 New Closest Facility Analysis

There is a group of fire stations and fire happened somewhere, we want to know the closest fire stations in terms of time to the fireplace, this was done through the network analyst toolbar from the New Closest Facility which determined the locations of fire stations and the fireplace by the Create Network Location Tool, a Solve was pressed, the program determined the closest fire stations and its path to the fireplace (Figure 9).

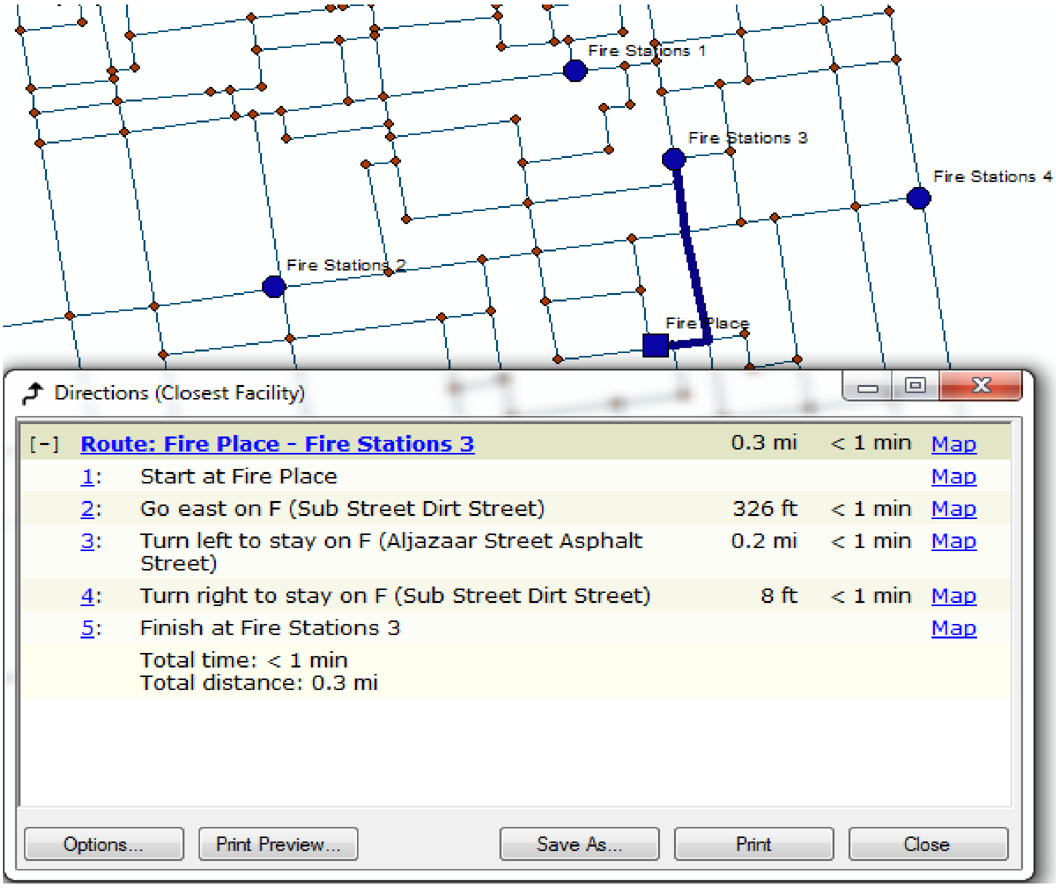

Figure 9: The Closest Fire Station to the Fire Place

Form 9 shows that in the event of a fire occurring in a place where there are a group of fire stations, the fire station closest to the place of the fire in terms of time was determined, and the optimal path was also determined. This assists with quickly putting out the fire, decreasing the destruction it causes.

4. Discussion

This study reached substantial, distinct, and numerous results and it is considered a real addition, where Ahmed et al (2017) reached in their study to find the best route between two locations and the closest facilities to the location of an incident, and Rai et al (2013) in their study reached to find the shortest route from one location to another location at the emergency time and shortest route from an accident spot to a hospital, while the author reached more detailed results as reached the best route depending on time and also depending on the length and also suggested another path in the event of barriers and also reached additional results where latency ranges time of an ambulance center are defined depend on the New Service Area analysis.

Therefore, it is recommended to apply this study to make maximum use of all the results that have been reached, and also take advantage of all the capabilities of geographic information systems in support of decision-making.

5. Conclusion

Based on the goal for which the paper was made, to benefit from the capabilities of GIS in the analysis of the streets network in the city of Al Riyadh, the paper concluded the possibility of benefiting from the streets network dataset that was built within ArcGIS 10.6 program in many inquiries, where it is difficult to carry out these analyses and inquiries manually or by using the traditional methods because of the effort, time and cost that it takes, when talking about the cost of this work, we find that there is a cost in creating geodatabases, but now the relevant authorities do this, only, there must be awareness and guidance to update these geodatabases constantly and make them comprehensive, and then the main point is to use them to conduct such analyses until these geodatabases are not trapped in the devices, and here lies the essence of benefiting from this paper. From these advantages:

1. Create a geodatabase for the area under study (Figures 3 and 4).
2. Selecting the optimal path between two locations or more depending on time (Figure 5) or length (Figure 6), and finding another path in case of a barrier in the chosen path (Figure 7).
3. Determining the service area of some centers to know the arrival time ranges (Figure 8), the analysis shows the time ranges for the mobile ambulance to arrive at the injured from the ambulance center, this allows for estimating how long it will take the ambulance to arrive at the accident location.
4. Knowing the closest facility to someplace and the path between them (Figure 9), the fireplace was used as an example, where the analysis assists in determining the closest fire station to the fireplace and therefore reducing the risks that may arise if the fire cannot be managed fast.

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