GIS Based Fire Emergency Response System for Mandalay

San Hay Mar Shwe, Htet Ne Oo

Abstract*—Urban fire plays one of the most important problems that causes disturbing conditions not only for developing countries but also for developed countries. In spite of the modern techniques of fire prevention and suppression, urban fires continue to damage properties and lives. It is required to develop an effective response system on a regional scale to tackle this problem. Therefore, this system intends to establish a system that can identify the best route from any fire incident to the nearest or closest rescue places such as fire emergency services, hospitals, police stations and so on. In this system, GIS-based technology applies for finding the best route by considering traffic data. Both graph theory and network analysis tools in GIS are supplied for modeling and analyzing transportation networks. A transportation network is a valued graph that contains a set of vertices, and edges. To compute the length of the shortest path from the source to each of the remaining points in the graph, the system uses Dijkstra's algorithm. Comparing to other simple shortest route, the algorithm in this system can provide an optimal route that consumes less time but the average speed is higher.

***Keywords*— Dijkstra's algorithm, geographic information systems (GIS), network analysis, optimal route, traffic data**

I. Introduction

Nowadays, there are various kinds of disasters such as earthquakes, landslides, floods, fires, and so on. So, it is needed to handle that emergency cases effectively. The emergency is a course of events that endangers or adversely affects people, property, or the environment. Therefore, disaster management information system **(**DMIS) and decision support system for emergency response (DSSER) is needed to reduce these damages and losses by these. Disaster management is a system that applies the rules and professions on science, technology, planning, and management when extreme events happen. Disaster management activity can be divided as four phases like: Planning, Mitigation, Preparedness, Response (to know accurate information of exact location when an emergency situation occurs, to save time during the determination of trouble areas (Quick Response) and to use as floor guide for evacuation routes) and Recovery. This paper intends to provide emergency system as the response phase of disaster management. In this phase, GIS performs making detailed pictures of the event tracking and the evacuation plans**.** This system provides a useful decision support system to determine the best route for emergency response.

GIS is an automated information system that is used to do decision making of planning and management about environment, transportation, land use, natural resources, urban facilities, and so on. GIS incorporates a way of capturing, analyzing, and visualizing geo-relevant phenomena. GIS is used to analyze the features that present on the earth surface and the events that take place on it. Also, it is also efficient for determining emergency vehicle routing and solving the emergency vehicle shortest path routing problem. In case of any emergency, it needs to reach the location on a priority basis, and even a minor delay may cause uncontrollable conditions.

The path finding solutions are becoming a major role for many GIS applications. Shortest path analysis helps in such critical situations by calculating the shortest path or most optimal route. The shortest path refers to as the fastest, or most optimal one depending on the type of cost. In the research, it will be calculated depending on traffic data, which sometimes means the smallest distance route can consume more time than longer route if there is a traffic jam. Traffic data give information about changing travel speeds on specific road segments according to time. It is a major role in network analysis because of affecting travel times that in turn change results. If no traffic data, the expected travel and arrival times could be far from accurate. Besides this, it provides the routing opportunities to avoid the slower, more congested roads, which can save time. This system can find the fastest route to reach the destination by avoiding traffic jam. To do this, GIS offers powerful capabilities for network analysis and management of urban traffic network. There are two spatial data models being used in GIS today: vector and raster. This system applies vector data model with three basic types: points, lines, and polygons. In case of any incident, an emergency responder needs a smart decision support system to reach the incident location as soon as possible. The fastest possible response is required to the disaster related places. GIS helps to provide geographical inquiry and especially, spatial decision making. This research intends to find the most optimized route by considering traffic data and representing this valuable spatial information to end-users in an efficient way using GIS

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software.

II. Related works

In [1], an enhanced GIS-based network analysis was performed and applied to the Greater Cairo road network. It focused on finding the best route between two locations on the road network and finding the nearest healthcare service providers to an incident location based on the travel time and used historical traffic data in the analysis. The Dijkstra's routing algorithm built into the ArcGIS Network Analyst Extension is used for implementing the network analysis. It shows an improvement in the travel time with 20% to 22%, according to the travel distances. However, the system did not consider the other factors that cause a delay when traveling through the road network.

In [2], the authors choose the study area of Aurangabad city, Maharashtra State, India to find a specialized hospital from the user's location and its shortest path to reach it. They also used the ArcGIS software and Dijkstra's algorithm. The calculations were only basing on road distances; not considering other conditions like traffic congestion and state of the roads.

In [3], the authors developed a GIS-based application for healthcare services as ERS in the ALMOKATAM Zone in the south of Cairo, Egypt. It includes integrating data acquisition from databases and plotting the location-based features of satellite image through a web-based interface which gives access to all different tasks by different end-users to be a decision-maker in system management. However, they didn't consider the distance rather than other factor.

In [4], the authors focuses on to solve the shortest path to reach a specialized hospital in Aurangabad city, Maharashtra State, India. This system was also the same consideration as in [2]. The calculations of the shortest path were based on road distances; traffic congestion and state of the roads were not considered.

In [5], the authors based on GIS in Delhi, India to develop a desktop-based emergency response management system. In this system, a detailed transportation network and real-time traffic data were maintained and integrated. GIS capabilities, such as network analysis, Origin–Destination (OD) cost matrix, proximity analysis, and buffer analysis were also performed.

III. System methodology

A. Graph Theory and Network Analysis

There are classical problems presented as graphs such as shortest path, longest path, travelling salesman problem. From the view of an emergency response system, it is an important issue to reduce the transmission time through the network by analyzing the spatial network with search procedure. Finding the shortest path from rescue sites to accident point through a road network is crucial for emergency services. To take prompt actions in an accident, it is important to construct an appropriate transportation network. The graph theory is used intensively in operations research, discrete mathematics, combinatorial optimization, and network analysis [6]. Graphs provide a powerful tool to model objects and relationships among objects. Graphs are defined by a set of vertices and a set of edges, where each edge connects two of its vertices. Graphs are further classified into directed and undirected graphs, depending on whether the edges are directed [7]. A graph structure can be extended by assigning a weight to each edge of the graph. Graphs with weights, or weighted graphs, are used to represent structures in which pairwise connections have some numerical values. For example, if a graph represents a road network, the weights could represent the length of each road [8]. A graph G consists of a set V of vertices and a set E of edges such that each edge in E joins a pair of vertices in V. Graphs can be finite and infinite, when V and E are finite then G is also finite.

Network analysis has many practical applications, for example, to model and analyze traffic networks. A traffic network represented by a directed graph consisting of a finite set of nodes and a finite set of the path which is connected. Each path in the traffic network has an associated generalized cost which could be a combination of travel time, direct cost, and travel distance. The length of a path is the sum of the weights of the edges on that path. The shortest route is a classical problem in network analysis, and it is mandatory for GIS. It has multiple realizations and is highly dependent on the nature of the transportation network and the distance between origin and destination.

GIS is designed to capture, analyze, represent spatial data in a way that user can easily understand by geographically referencing graphs, and each vertex has well defined absolute coordinates related to earth. Network analysis problems firstly make modeling as graph problems based on the underlying graph model of networks. The optimal route in the networks is an optimization problem that finds the optimal minimum value path among many alternatives.

B. Dijkstra's Algorithm

Basing on graph search, the edge, and vertex, dijkstra's algorithm can search the shortest path between two vertexes. For a given source vertex (node) the graph, the algorithm finds the path with the lowest cost (i.e., the shortest path) between that vertex and every other vertex. It can also be used for finding costs of shortest paths from a single vertex to a single destination vertex by stopping the algorithm once the shortest path to the destination vertex has been determined [9].

The algorithm is represented in brief as below:

$$G = (V, E)$$

where V is a set of vertices and E is a set of edges.

Dijkstra's algorithm keeps two sets of vertices:

S = the set of vertices whose shortest paths from the source have already been determined.

V-S = the remaining vertices.

The other data structures needed are:

D = array of best estimates of the shortest path to each vertex

Pi = an array of predecessors for each vertex

The basic step of operation is:

1. Initial is **d** and **pi**,
2. Set **S** to empty,
3. While there are still vertices in **V-S**,

a. Sort the vertices in **V-S** according to the current best estimate of their distance from the source,

b. Add **u**, the closest vertex in **V-S**, to **S**,

c. relax all the vertices still in **V-S** connected to **u**

Pseudo code for Dijkstra's Algorithm:

Distance [s] ←0 (distance to source vertex is zero)

for all v ∈V–{s}

do distance [v] ←∞ (set all other distances to infinity)

S←∅ (S, the set of visited vertices is initially empty)

Q←V (Q, the queue initially contains all vertices)

while Q ≠ ∅ (while the queue is not empty)

do u ← min distance (Q, distance) (select the element of Q with the min. distance)

S ← S ∪ {u} (add u to list of visited vertices)

for all v ∈ neighbors[u]

do if distance [v] > distance [u] + w(u, v) (if new shortest path found)

then d[v] ← d[u] + w(u, v) (set new value of shortest path)

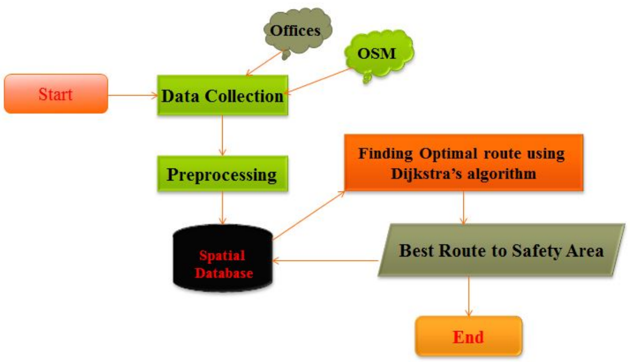
(if desired, add trace back code)

return dist

IV. EXPERIMENTAL RESULT

A. *Proposed Approach*

The flow chart of the proposed system is, as shown in Fig.1 This system collects data such as street network, recuse sites from Open Street Map (OSM), offices, etc. The resulted data is preprocessed to discover whatever errors in the data and correcting them to get better analysis and results. And then, it searches the shortest route between the incident location and recuse sites by applying Dijkstra's algorithm within Mandalay city network.



. Fig.1. Flowchart for Proposed System

The following Fig.2 shows the detailed process for finding the shortest path and closet facilities.

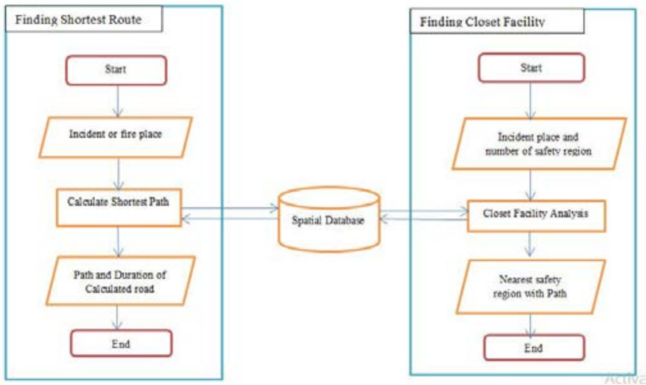


Fig.2. Detail Process for Proposed System

B. *Study Area*

The study area, Mandalay city, is the second-largest city and former royal capital in Myanmar. It is economical, industrial, transportation, and educational center. It locates in the central part of Myanmar with Latitude and longitude coordinates: **N21.954510, E96.093292.** The population is around one and a quarter-million people. The total area covers 29,686km^2, and consists of 28 townships. 29% of the population lives in urban areas, and the remaining 71% in rural areas [10]. Fig.3 represents the map of the current study area.

Fig.3. Study Area

C. *Data Preparation*

This phase includes collecting the study area base map, preparing the road network data, specifying safety area regions. Open Street Map (OSM) provides the service to download the base map of. It also gives accessed as an ArcGIS Online Service to ensure free read-only access to

Open Street Map as a base map for GIS work in ESRI products such as ArcGIS Desktop. The road network data are created with attributes such as name to store the name of each road segment, meters for the length of each road segment, direction for each segment direction and TF_Minutes & FT_Minutes for the time required to travel over each road segment in both directions. Safety area data are with attributes such as name for each safety region and another attribute to store the type of this safety region.

Fig.4 and Fig.5 shows the base map and road network of Mandalay region. The last step is to prepare traffic data on road network. Traffic data can be modeled with two different modes such as: historical and live traffic. This research uses historical one. It is used to model the time-dependent speeds of traveling on roads. And, it creates a series of costs (traffic speeds at different times of the day) for each edge. In order to perform analysis with this traffic data, it needs to create daily profiles table and street-daily profiles table.

Fig.4. Base Map of Mandalay (from OSM)

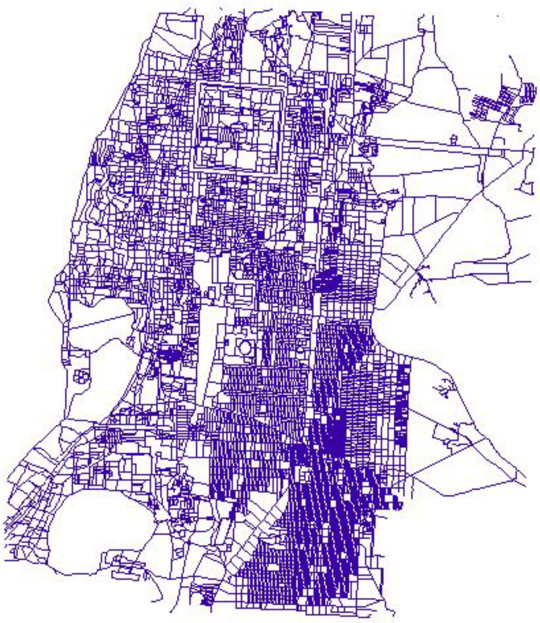


Fig.5. Mandalay Road Network

D. *Creation of Geo-database*

A geo-database is a useful one to store GIS related information in one large file, which may contain multiple points, polygon, and polyline layers. It can organize data than having multiple shape files [11]. In this system, using the Mandalay City Map as the base map, vectorization of roads and other surface features are done. In the next step, it generates the vector files of main features and streets, and establishes geo-database including feature dataset and many feature classes (including road network data, safety region, and traffic tables) with spatial and non-spatial data. The line feature classes within a feature dataset represent streets. There are also two tables to store speed profiles, and the relationships between the streets and speed profiles. Each record in this table has a unique identifier and several fields for storing the free-flow scale factor at a different time of the day. Then, it needs to split the time of the day into time interval or time slices, which must be same duration and thus split a 24 hour into the equal partition as 1-hour interval. In daily profiles table, calculating Free-flow scale factor is as follow:

$$speed = distance / time$$

$$free\text{-}flow\ speed = speed / defined\ speed\ for\ each\ road$$

Google Map provides the information for different time intervals to collect the distance and time for each road. In street-daily profiles table, it identifies street features, their free-flow travel speeds, and their related traffic profiles for each day of the week. Each street feature has a unique identifier: the ObjectID value. This table relates streets to their various traffic profiles through the unique identifier. Fig.6 shows the relation of graphical data and attribute data, and the information of the location of each recuse site and street name. And also Fig.7 and Fig.8 describe daily profiles table and street-daily profiles table, respectively.

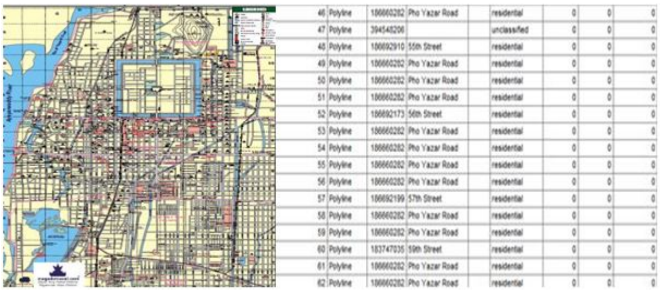


Fig.6. Relationship between Graphic Data and Attributes

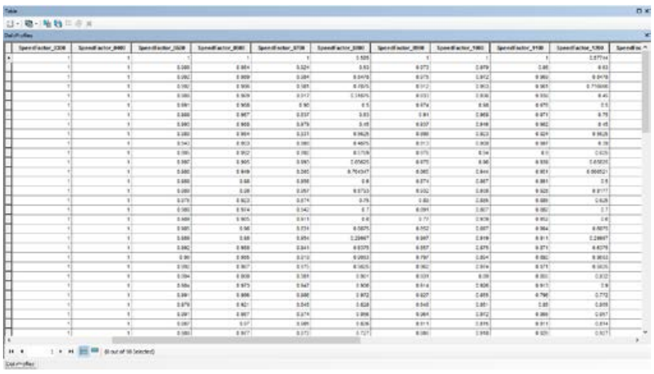


Fig.7. Daily Profiles Table

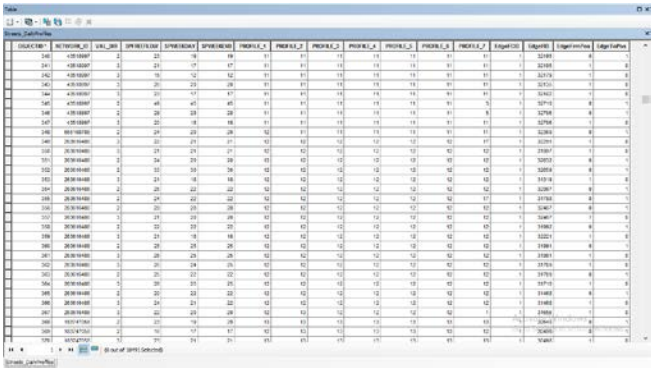


Fig.8. Street-Daily Profiles Table

E. Building Network Dataset

A network dataset is a GIS dataset that is designed to support network analysis. Building network dataset includes the step by step such as creating network elements, establishing connectivity, and assigning values to the defined attributes [12]. After creating geo-database in the previous step that contains a line feature class, and safety regions and two traffic tables, network dataset is built and then that is ready for use in the network analysis. In this system, it creates geo-database network dataset with attributes such as hierarchy, meters, minutes, one way, road class, travel time, and so on. As a result, Fig.9 shows the network dataset of study region with 11613 junctions and 34314 edges for 17157 road segments.

Fig.9. Network Dataset Results

F. Performing Network Analysis

The network analysis is performed by using network analyst solvers within the ArcGIS network analyst extension namely the Route, Closet Facility, and OD Cost Matrix solvers that basing on the well-known Dijkstra's algorithm for finding shortest paths. The classic Dijkstra's algorithm solves the shortest path problem with an undirected, nonnegative, weighted graph. However, real-world transportation data needs other modifications on it with user settings such as one-way restrictions, turn restrictions, junction impedance, barriers, and slide-of-street constraints while minimizing a user-specified cost attribute. Based on this well-known Dijkstra's algorithm, there are two types of network analysis: best route analysis and closet facilities analysis.

1) Best Route Analysis

It generates the best route based on travel time which depends on the traffic conditions with parameters such as travel time, a start time of traveling, road directions, etc. GIS intends to find the optimal route between the given origin and destination involving shortest distances as well as shortest travel time. Finding the optimal path means that selecting either the shortest path or the path having minimum travel time [13]. The following Fig.10 and Fig.11 illustrate the best path between the ambulance location (Yi Yi store as the origin) and the nearest fire station(central fire station as the destination). This result is generated by processing suitable landmarks (i.e., identifiable buildings, round turns, road junctions, etc.) that have been identified and located along each road to reach the accident spot.

As a direction result shown in Fig.11, from the origin, it must first go north on 31st street and then toward to 81st one. Then, it finds the central fire station as the destination. Its total distance is 2.5 miles and the whole time takes 3 minutes.

Fig.10. Best Route Analysis Result

Fig.11. Best Route Direction Result

2) Closet Facilities Analysis

Analyzing closet facilities needs to perform with parameters such as impedance factor, start time, period to reach closet facilities, number of facilities to find, the direction of travel.

To perform such analysis, it is required to make a closet facility analysis layer and its analysis properties. This layer is useful in determining the closet facility or facilities to an accident based on a specified network cost. Fig.12 shows safety regions layer as the closet facilities for this system. It finds the closet facilities that can reach in a specific period from an incident location based on travel time and distance information available.

Finding such emergencies helps to reduce time, effort, resources and saving people life [14]. The following figures demonstrate finding the closet facilities within 5 minutes for incident location (at the corner of 27*83). The three closet facilities as Aye chin Tar hospital, Mandalar clinic, and central fire station are the results of analysis within two, three, four minutes with their corresponding mile values. The detailed result can be seen in Fig.13 and 14.

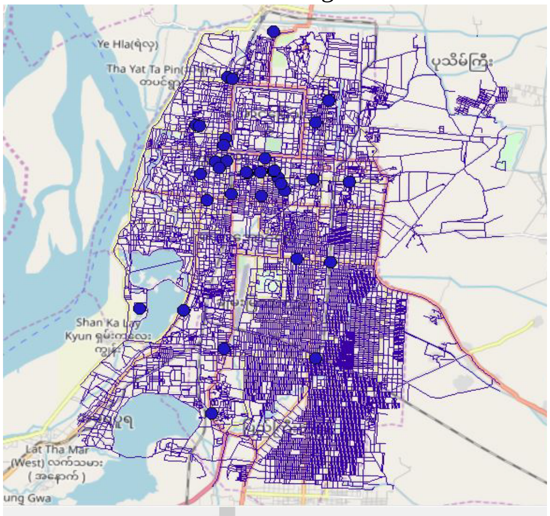


Fig.12. Map of Hospital and Fire-station Locations as Closet Facilities

Fig.13. Closet Facilities Analysis Result

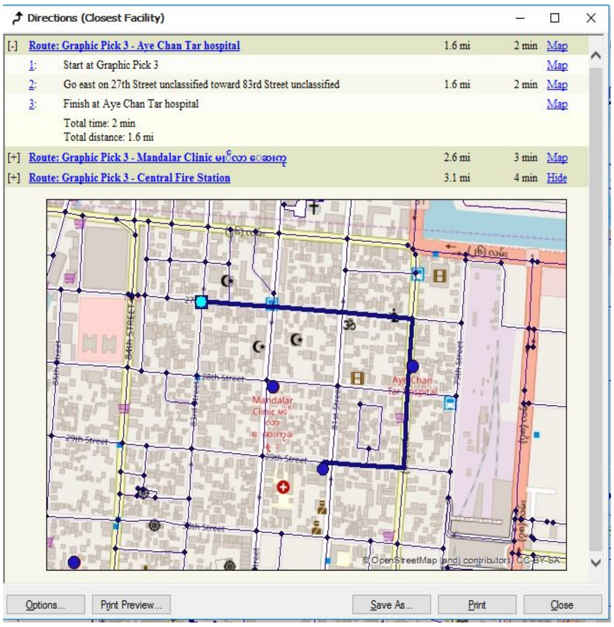


Fig.14. Closet Facilities Direction Result

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The following figures (incident occurs on 33 street, near 76) show the difference between the results of using traffic data or not to reach the closest recuse site. Without considering traffic data, it can go Gangaw hospital with 5 minutes as in Fig.15, but with traffic, it generates different route driving direction with less time (4 minutes). Fig.16 shows this result.

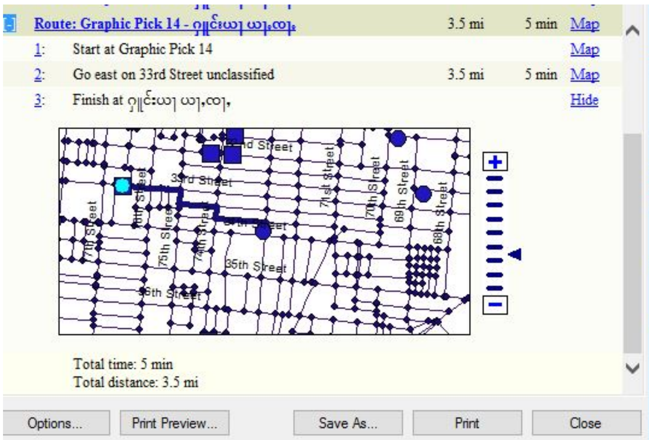

Fig.15. Best Route Direction Result without Traffic

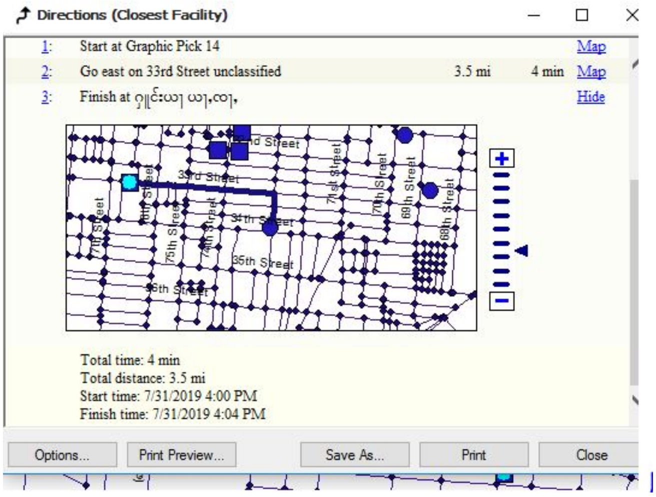

Fig.16. Best Route Direction Result with Traffic

V. Conclusion and Future Works

In this paper, GIS-based network analysis was implemented and applied to the Mandalay road network. It emphasizes on selecting the best route direction between two given locations on the road network data and finding the nearest emergency service providers and fire stations to an incident location based on the traffic conditions. Also, the proposed method Dijkstra routing algorithm built is the best one in performing network analysis, especially in the crowded city such as Mandalay. In future work, other cities rather than Mandalay can apply to find the optimized route with this system.

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References

[1] S. Ahmed, R. F. Ibrahim, and H. A. Hefny, "GIS-Based Network Analysis for the Roads Network of the Greater Cairo Area", In: Proc. of 2nd International Conference on Applied Research in Computer Science and Engineering, 2017.

[2] *AmrapaliDabhade, Dr. K. V. Kale, Yogesh Gedam, "Network Analysis for Finding Shortest Path in Hospital Information System", IJARCSSE, Vol.5, No.7, July 2015, pp. 618-623.*

[3] A. Gubara, A. Amasha, Z. Ahmed and S. El Ghazali, "Decision Support System Network Analysis for Emergency Applications", Informatics and Systems (INFOS), 2014 9th International Conference on, Cairo, 2014, pp. ORDS-40-ORDS-44.

[4] A. Dabhade, K. V. Kale, and Y. Gedam, "Network Analysis for Finding Shortest Path in Hospital Information System", International Journal of Advanced Research in Computer Science and Software Engineering, Vol.5, No.7, pp.618-623, 2015.

[5] A.Bhagat and N.Sharma, "GIS-Based Application for Emergency Preparedness and Management Accelerating Response System through GIS", In: Proc. of the 14th Esri India User Conference, pp.1-7, 2013.

[6] Samir Khuller, Balaji RaghavachariI. Graph and Network Algorithms. ACM Computing Surveys. 1996.

[7] Graphtheory.http://en.wikipedia.org/wiki/Graph_theory.

[8] https://www.geospatialworld.net/article/optimal-route-analysis-using-gis

[9] R. Somalia and M. B. Potdar, "Shortest path algorithms on GIS dataset using geotools ", International Journal of Scientific & Engineering Research, Volume 4, Issue 10, October-2013 637 ISSN 2229-5518.

[10] Anonymous: https://en.wikipedia.org/wiki/Mandalay.

[11] https://helpwiki.evergreen.edu/wiki/index.php/ArcGIS_10:_What_is_a_Geodatabase%3F.

[12] http://wiki.gis.com/wiki/index.php/Network_dataset.

[13] Mohamed A. Eleiche. Network Analysis Methods for Mobile GIS. University of West Hungrary. 2011.

[14] https://helpwiki.evergreen.edu/wiki/index.php/ArcGIS_10:_What_is_a_Geodatabase%3F.