GIS based Fire Emergency Response System for Mandalay

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Abstract- Urban fire is one of the most disturbing problems 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. To tackle this problem, it is required to develop an effective response system on a regional scale. The objective of this paper is therefore to establish a system that can identify the best route from any fire incident to the nearest or closest rescue places such as urban fire emergency services, hospitals, police stations and so on. GIS-based technology is applied in this system for finding the best route by considering traffic data. Both graph theory and network analysis tools in GIS are applied for the purpose of modeling and analyzing transportation networks. A transportation network can be referred to as a valued graph consisting of a set of vertices and a set of edges. In order to compute length of the shortest path from the source to each of the remaining points in the graph, Dijkstra's algorithm can be used. Comparing to the normal shortest route, the algorithm in this system can provide an optimal route selection, which costs less time and has a higher average speed.

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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. Emergency is a course of events that endangers or adversely affects people, property, or the environment. To reduce these damages and losses by these, disaster management information system (DMIS) and decision support system for emergence response (DSSER) is needed. Disaster management can be defined as the discipline and profession of applying science, technology, planning and management to deal with extreme events. Disaster management activity is divided into the following phases as: Planning, Mitigation, Preparedness, Response (to provide accurate information on exact location of an emergency situation, 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 can be used to making the 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.

Geographic information system is an automated information system that is used to support decision making for planning and management of land use, natural resources, environment, transportation, urban facilities and so on. GIS incorporates an elaborate 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 an effective tool for determining emergency vehicle routing and solving the emergency vehicle shortest path routing problem. In case of any emergency, it is important to reach the location on a priority basis and even a minor delay may cause major problems. Path finding solutions are becoming a major path of many GIS applications. Shortest path analysis helps in such critical situations by calculating the shortest path or most optimal route. Depending on the type of cost, the shortest path can be referred to as the shortest, fastest, or most optimal path or route. In the research, the fastest route will be calculated depending on traffic data that means sometimes the shortest route can consume more time than more longer route if there is traffic jam. Traffic data are given information about how travel speeds on specific road segments change over time. In network analysis, traffic is important because it affects travel times, which in turn affect results. If traffic routing from one location to another is not considered, the expected travel and arrival times could be far from accurate. Another reason to account for traffic is that it gives the routing opportunities that avoiding the slower, more congested roads, which saves time. This system can find the fastest route to reach destination by avoiding traffic jam. To do this, GIS offers powerful capabilities for network analysis and management of urban traffic network. There are two common spatial data models being used in GIS today: vector and raster. In this system, vector data model is applied 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 needed to dispatch the emergency services to the location of disaster. GIS was designed to support geographical inquiry and ultimately, spatial decision making. The main objective of this

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research is 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 software.

II. Related Works

In [1], an enhanced GIS-based network analysis was performed and applied on the Greater Cairo road network. The focus was 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. The proposed method has integrated historical traffic data to be used in the analysis. The authors have used The Dijkstra's routing algorithm built into the ArcGIS Network Analyst Extension for implementing the network analysis. The proposed method has improved the travel time with 20% to 22%, depending on the travel distances. The authors did not consider the other factors that impose a delay in travelling through the road network.

In [2], the authors tried to solve the problem of finding a specialized hospital and its shortest path to reach in Aurangabad city, Maharashtra State, India. They used the ArcGIS software and Dijkstra's algorithm that provide the shortest path from one location to another for finding the nearest location of the hospitals from user's location. The calculations of the shortest path were based on road distances; traffic congestion and state of the roads were not considered.

In [3], the authors developed a GIS based application for healthcare emergency response system services to manage healthcare in the ALMOKATAM Zone in the south of Cairo, Egypt. The optimal route was modeled based on the distance to the closest healthcare service providers. The system integrated data acquisition from databases and plotted the location-based features of satellite image through a web base interface which gives access to all different tasks by different end users to be a decision maker or policy makers in system management. They didn't consider any factor other than the distance.

In [6], the authors have used the ArcGIS software and Dijkstra's algorithm to solve the problem of finding the shortest path to reach a specialized hospital in Aurangabad city, Maharashtra State, India. The calculations of the shortest path were based on road distances; traffic congestion and state of the roads were not considered.

In [7], the authors have developed a desktop-based emergency response management system based on GIS in Delhi, India. In this system, a detailed transportation network was maintained and integrated with real-time traffic data provided by NAVTEQ in India, which was used in analyzing the best routes to an incident location. Various analyses were performed in this system using GIS capabilities, such as network analysis, Origin–Destination (OD) cost matrix, proximity analysis, and buffer analysis.

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. In order to take prompt actions on a serious 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 [9]. 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 [10]. 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 pair wise connections have some numerical values. For example if a graph represents a road network, the weights could represent the length of each road [11]. 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 path which is connected to each other. 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 the path. The shortest path is a classical and main problem in network analysis and it is mandatory for GIS. It has multiple realizations and is highly dependent on the nature of transportation network and the distance between origin and destination.

GIS are designed to capture, analyze, represent spatial data in a way that user can easily understand. The graphs in GIS are geographically referenced, and each vertex has a well defined absolute coordinates related to earth. Network analysis problems are modeled as graph problems based on the underlying graph model of networks. Since there can be more than one path between two vertices, there is then the

problem of finding a path with the minimum cost between these two specified vertices. The optimal path in the networks is an optimization problem that finds the optimal minimum value path among many alternatives.

b) Dijkstra's Algorithm

Dijkstra's Algorithm is based on graph search, the edge and vertex, gives the shortest path between two vertex. For a given source vertex (node) the graph, the algorithm finds the path with 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 [5].

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 shortest path to each vertex

Pi = an array of predecessors for each vertex

The basic mode 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 figure 1. Data such as street network, recuse sites is collected from Open Street Map (OSM), offices, etc. The resulted data is preprocessed to discover whatever errors in the data and correcting them in order to get good analysis and results. And then, the shortest route between the incident location and recuse sites can be searched by applying Dijkstra's algorithm within Mandalay city network.

Fig. 1: Flowchart for Proposed System

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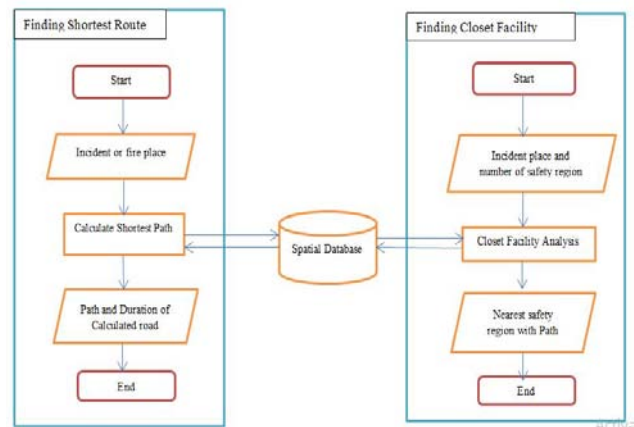

Fig. 2: Detailed process for proposed system

b) Study Area

The study area, Mandalay city is the second largest city and former royal capital in Myanmar. It is economic, industrial, transportation, and educational center It is located in the central part of the Myanmar with Latitude and longitude coordinates: N21.954510, E96.093292. It is bounded by Sagaing, Shan, Kayin, Bago, Naypyitaw and Magway. The population is around one and a quarter million people. 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[4]. Figure 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. The base map of Mandalay was downloaded from open Street Map (OSM). OSM can be accessed as an Arc GIS Online Service that provides free read-only access to Open Street Map as a base map for GIS work in ESRI products such as Arc GIS Desktop. The road network data are created with attributes such as name to store name of each road segment, meters for length of each road segment, direction for each segment direction and TF_Minutes & FT_Minutes for time required to travel over each road segment in both directions. Safety area data are with attributes such as name to store for name of each safety region and another attribute type to store the type of this safety region. Figure 4 and figure 5 shows the base map and road network of Mandalay region. The last step in the data preparation phase is the preparation of the road network traffic data. Traffic data can be stored using two different models: historical and live traffic. In this paper, traffic data were stored as historical traffic data. It is used to model the time dependent speeds of travelling on roads. And, it creates a series of costs (traffic speeds at different times of the day) for each edge. To perform analysis with this traffic, daily profiles table and street-daily profiles table are created.

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

Fig. 5: Mandalay Roads Network

d) Creation of Geo-database

A geo-database is an alternate way to store GIS information in one large file, which can contain multiple point, polygon, and/or polyline layers. It can organize data than having multiple shape files[14]. 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, the vector files of main features and roads are generated and geo-database is established 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 represent streets, which must be stored in a feature dataset. The speed profiles are stored in one table, and the relationships between the streets and speed profiles are stored in the other table. Each record in this table has a unique identifier and several fields for storing the free-flow scale factor at different time of the day. The time of the day are split into time interval or time slices, which must be equal duration and thus split a 24 hour into equal interval as 1 hour interval. In daily profiles table, Free-flow scale factor is calculated as

$$\text{Speed} = \frac{Distance}{Time} \quad \text{and}$$

$$\text{Free-flow speed} = \frac{speed}{Defined\ speed\ for\ each\ road}$$

The distance and time for each road are collected from google map for different time intervals. 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 Object ID value. This table relates streets to their various traffic profiles through the unique identifier. Figure 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 figure 7 and 8 describe daily profiles table and street-daily profiles table respectively.
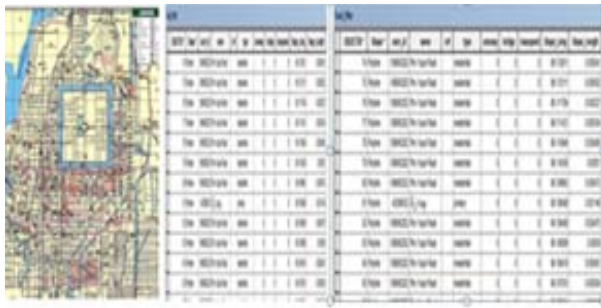
Fig. 6: Relationship between Graphic Data and Attribute Data

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. When creating a network dataset or edit an existing network dataset, it must be built. Building is a process of creating network elements, establishing connectivity, and assigning values to the defined attributes[13]. After creating geo-database that contains a line feature class and safety regions and two traffic tables, network dataset is built and then that is ready for using in the network analysis. In this system, geo-database network dataset is created with attributes such as hierarchy, meters, minutes, one way, road class, travel time and so on. As a result, figure 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 are based on the well known Dijkstra's algorithm for finding shortest paths. The classic Dijkstra's algorithm solves a shortest path problem on an undirected, nonnegative weighted graph. To use it within the context of real-world transportation data, user settings such as one-way restrictions, turn restrictions, junction impedance, barriers, and slide-of-street constraints can be modified 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.

Best route analysis generates best route based on travel time which depends on the traffic conditions with parameters such as travel time, start time of travelling, road directions, etc. GIS can be used to address the objectives of finding the optimal route between the given origin and destination. It can be used to find out the routes involving shortest distances as well as shortest travel time. To find optimal route between two given points, either the shortest path between them or the route having minimum travel time is to be selected[12]. The following figure 10 and figure 11 illustrate the best route 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 in order to specifically reach the accident spot.

Fig. 10: The Best Route Analysis Result

Fig. 11: The Best Route Direction Result

As a direction result, from the origin, it must first go north on 31 st street and then toward to 81 st street. Then, it find the central fire station as the destination. It's total distance is 2.5 miles and total time takes 3 minutes.

Closet Facilities Analysis The closet facilities analysis is performed with parameters such as impedance factor, start time, period to reach closet facilities, number of facilities to find, direction of travel. To perform closet facilities 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. The safety regions layer (especially fire stations, hospitals, schools) as the closet facilities for this system can be seen in the following figure 12.
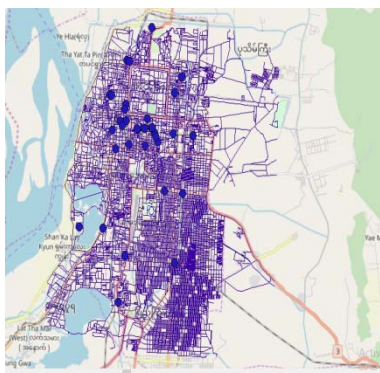
Fig. 12: Map of hospital and fire-station locations as closet facilities

It finds the closet facilities that can be reached in a specific period from an incident location based on travel time and distance information available. This helps in emergency situations to know the closest facilities that can be reached from the incident location, which in turn reduces time, effort, resources and saving people life [8]. The following figures demonstrate finding the closet facilities within 5 minutes for incident location (at the corner of 27*83). As a result, the three closet facilities as Aye chin Tar hospital, Mandalar clinic, and central fire station can be found within two, three, four minutes with their corresponding mile values. This can be seen detail in Figure 13 and 14.
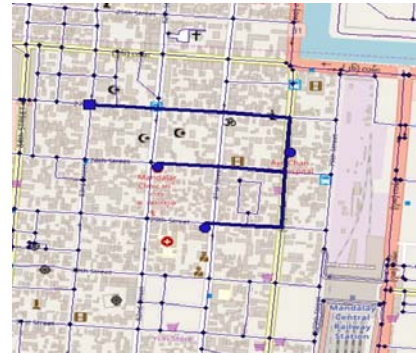

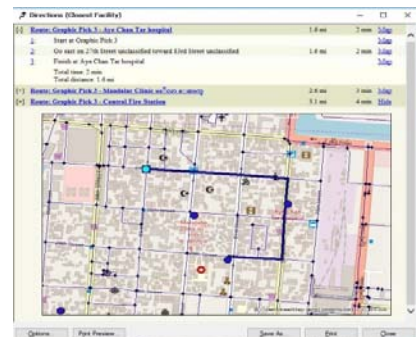*Fig. 13:* The Closet Facilities Analysis Result

Fig. 14: The Closet Facilities Directions Result

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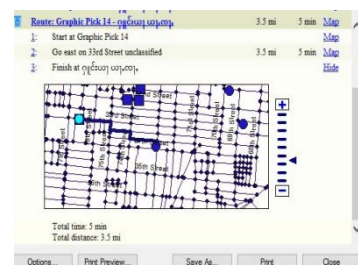

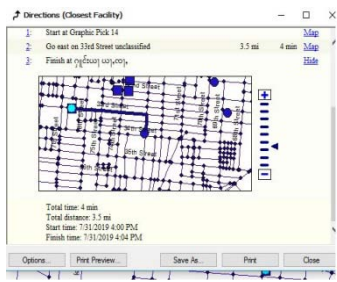*Fig. 15:* The Best Route Direction Result without traffic

Fig. 16: The Best Route Direction Result with traffic

V. Conclusion & Future Works

In this paper, GIS-based network analysis was implemented and applied to the Mandalay road network. It focuses on finding the best route between two locations on the road network and finding the nearest healthcare service providers and fire stations to an incident location based on the traffic conditions. Also, the proposed method Dijkstra best routing algorithm built is the best method for the network analysis, especially in the crowded city such as Mandalay. In the future work, this system can be applied in other cities rather than Mandalay.

Acknowledgments

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