Location–Allocation Model Applied to Urban Public Services: Spatial Analysis of Fire Stations in Mysore Urban Area Karnataka, India

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Abstract Prevention of fire occurrence is one of the most disturbing problems which damages life and properties to a great extent. Location-allocation model has been applied to find out the parts of the city having poor coverage. Potential sites were recommended wherefrom all demand points will be covered within a predefined impedance cutoff of time of five minutes as per the norms of Standard Fire Advisory Council (SFAC). The available sites to set up a fire station were identified using land use and land cover map that has been prepared from Landsat 8 Operational Land Imager (OLI) were from agricultural land, wasteland land, follow land having an area greater than 3 hectares were given as candidate (potential) sites. Within the travel time of five minutes the result indicates that 66.45 percent of the city population in the Southeast and Southwest is un-served. Two scenarios have been adopted to fulfill the requirements of such an emergency facility; by relocating the existing facilities and without relocating existing facilities. In both cases nine fire stations are required to cover the entire city effectively. The location-allocation model provides the solution for the spatial decision not only to find the optimal locations for locating the emergency service but also acts as a tool to determine where and how many facilities are in need to fulfill all requirements. Hence, it is advisable to adopt the second method that is, establishing six new fire stations without relocating existing three fire stations, which would be cost-effective.

1. Introduction

Today fire has an important place among the causes of loss of life and property. It should, therefore, be intervened as soon as possible to eliminate the destructive outcomes. The effectiveness of the intervention is directly linked with instant access to the fire accident spots. Information Technologies (IT) that have developed rapidly in recent years is being used in fire relief management and the application of Geographic Information Systems (GIS) specifically, in fire accident management can achieve efficient results. Since GIS can analyze exhaustive spatial and non-spatial data it is highly effective in responding to spatial queries. Physical accessibility for fire service in an urban area is exceptionally important despite the hindrances like transportation that reflects the ease of travel. Accessibility is a combination of two elements: the spatial location of a phenomena suitable destination, and the accessibility based on transportation network linking points on that surface (Vickerman, 1974). The distance, travel time, transportation, and the associated cost are the geographical dimension’s accessibility. Measures of access often focus on the spatial location of service “supply” and the population “demand” is based on time and space (Ghosh & Rushton, 1987). The location-allocation models have been applied to form structural form of services of facilities to fulfill the demands in an optimal way (Algharib 2011) Location-allocation model is the process in which distribution of demands are taken into consideration to selects the optimal location for facilities from a set of available locations (Drezner 1995).

The demand and supply are the basic determinants of the optimal location and allocation of facilities (Yeh and Chow 1997). The integration of GIS and location-allocation act as a tool for public facilities planning for developing a spatial decision support system (Valeo et. al., 1998). The location-allocation models can be helpful for the spatial planners to choose the optimal locations of public facilities (Rahman and Smith 2000). Location-allocation models are important in the location of new facilities as well as to evaluate and improve the efficiency of prevailing location decisions (Plastria 2001). There are methodologies designed to place a limited number of stations (Mon et. al., 1998) and others designed to place whatever number of stations necessary to address all demands (ReVelle and Swain 1970). Identifying and establishing fire station at an optimal location is one the important concerns of planners and researchers, especially in the cities where the population has been growing significantly (Aktas et. al., 1970; Catay 2011) To achieve an effective and reliable emergency response system, the location of rescue facility plays a major role, the fatalities and disabilities caused by natural and manmade disasters can be significantly reduced through an effecting planning of location (Basar et. al., 2012). It is important to assure that; the fire stations are not only located at the place from where it can serve large
areas but also strategically placed to minimize the response time to accident spots (Liu 2006). There are several methods have been used to identify the suitable location for establishing facility canters by researchers (Murray 2013; White et al., 1974) among them Geographical Information System (GIS) based assessment method is popular in recent days (Forkuo et al., 2013; Isa et al., 2016). GIS provides real-time simulation of transportation networks accompanied by a high level of accuracy as it uses actual travel distance, speed of vehicle, and time delays (Kazemi et al., 2013). A GIS-based analysis is likely to offer a straighter forward approach than conventional mathematical models (Park and Peter 2016). Hence, the present study adopted a GIS-based approach to assessing the location-based emergency service of an existing fire station in Mysore city, in which the service area of each fire station and unserved area is identified and suitable places for establishing new fire station and allocation of existing fire stations were assessed.

Mysore is one of the popular cities in southern Karnataka located from 12°18'N to 12°30'N latitude and 76°39'E to 76°65'E longitude, and has an average altitude of 770 meters (2,526 ft.), covering 89.71 sq. km area. According to the Census of India 2011, the city has been divided into 65 wards for administration purpose and the population of the city has been growing rapidly followed by spatial extension of settlements in all the directions. The city contains of three fire stations located at Saraswathi Puram, Bannimantap, and Hebbal to secure the population from the fire incidents. Fire outbreak is one of the major problems in the city which has been occurred often the number of fire incidences that occurred in the city has been increasing over the years from 246 in 2003 to 416 in 2016. The cost of property damage also has increased from 4.1 million in 2013 to 11.24 million in 2016. Hence, the result of the present study would help to understand whether the existing fire stations can cover the entire city, if not what are the necessary steps to have to be taken to protect the whole city.

2. The Methods

The methodology has been framed to examine three research questions as follows:

a) Which demand areas are not being served from existing facilities within the response time of 5 minutes?

b) Where are the optimal locations for placing an additional facility to address the unmet needs? And

c) What are the locations having appropriate building conditions, optimal distance, optimal time, population, facility capacity, optimal cost, etc. concerning fire station etc.

The present paper deals with the physical accessibility of fire stations to the different areas in the Mysore urban area. To attain the objectives of the study, fire incident data was collected from 2003 to 2016 related to the number/ prevalent of incidence. Road Network based Service area has been used to find out the parts of the city having poor coverage with the travel time of five minutes. Potential sites were recommended wherefrom all demand points will be covered within a
predefined impedance cutoff of time of five minutes as per the norms of Standard Fire Advisory Council (SFAC). The available sites to set up a fire station were identified using land use and land cover map that has been prepared from Landsat 8 Operational Land Imager (OLI) were from agricultural land, wasteland land, follow land having an area greater than 3 hectares were given as candidate (potential) sites. The demand points were generated by converting the settlement area into vector format and centroid of each polygon has been generated and their populations were assigned as weights. It is based on the assumption that the population within the ward is equally distributed. Two scenarios have been adopted to fulfill the requirements of such an emergency facility; by relocating the existing facilities and without relocating existing facilities. In both cases nine fire stations are required to cover the entire city effectively. The drive time was assumed depending upon the vehicular traffic supposed to ply on the respective roads, road hierarchy, land use in the vicinity, road width, nature of the road, traffic bottlenecks, etc. and does not take into consideration traffic signals, because of permission to emergency vehicles to pass off in traffic signal points. The drive-time is valid only in the normal traffic conditions and it does not apply in circumstances where unexpected situations of traffic jams, or other barriers such as tree falling, road accidents, road blockades, etc. occur. The Standing Fire Advisory Committee (SFAC) recommendations for area, population, and traveling time have been taken into consideration for the service area of the fire station.

3. Results and Discussion
The service area of existing fire stations in Mysore city was examined within the travel time of 5 minutes as indicated in Figure 2 and Table 1.

Figure 2. Service Area of Existing Fire Stations
Table.1 Service Area of Existing Fire Stations within 5 Minutes within Mysore Urban area

<table>
<thead>
<tr>
<th>Category</th>
<th>Population (%)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Served</td>
<td>33.55</td>
<td>57.91</td>
</tr>
<tr>
<td>Un-served</td>
<td>66.45</td>
<td>42.09</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100.00</td>
</tr>
</tbody>
</table>

The result of the service area depicts that the existing fire stations serve 33.55 percent of the population which is distributed over 57.91 percent area of the city within the time of 5 minutes. From the result it is obvious that the fire vehicle has to travel more than prescribed time to reach fire incidence in un-served areas, which may disastrous both in terms of life and property.

Location-allocation Analysis

As the result of the service area indicated that the existing fire stations do not cover the whole city area, therefore it is necessary to make a proper plan to protect the un-service area by establishing new fire stations. Two scenarios were used to establish new fire stations: Scenario 1 – establishing new fire stations by relocating existing fire stations and Scenario and 2 – establishing new fire stations without relocating existing fire stations. National Disaster Management Authority, Government of India 2012 guidelines (Basic Requirement for Setting Up A Fire Station, Annexure – 1B) has been followed to identify suitable sites to establish such facilities. In total, 81 sites were identified within the city limits which are suitable to establish fire stations.

Scenario - 1

This scenario was carried out to establish new fire stations without considering existing ones at available 81 sites and settlements polygon centroids were generated as demand points.

The result indicates that, among 81 potential sites 9 sites were chosen as suitable sites. These sites serve all the demand points within the travel time of five minutes. It was
Figure 4. Location-allocation based chosen facilities and their Service Area (Excluding Existing Facilities)

Table 2: A location-allocation model using travel time (in minutes) as impedance from proposed 9 fire station locations

<table>
<thead>
<tr>
<th>Name</th>
<th>Facility Type</th>
<th>Number of settlement Polygons</th>
<th>Demand Weight (Population)</th>
<th>Total Time Traveled (Min.)</th>
<th>Total Weight Time (Min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metagalli</td>
<td>Chosen</td>
<td>697</td>
<td>46022</td>
<td>2.76</td>
<td>1921.87</td>
</tr>
<tr>
<td>Rajendrarnagar</td>
<td>Chosen</td>
<td>1738</td>
<td>255219</td>
<td>3.14</td>
<td>5451.02</td>
</tr>
<tr>
<td>M.G Koppalu (Hebbal)</td>
<td>Chosen</td>
<td>559</td>
<td>10900</td>
<td>2.33</td>
<td>1302.15</td>
</tr>
<tr>
<td>Devaraja Mohalla (Sala Darshini)</td>
<td>Chosen</td>
<td>2386</td>
<td>358214</td>
<td>3.16</td>
<td>7530.40</td>
</tr>
<tr>
<td>Dattagalli</td>
<td>Chosen</td>
<td>498</td>
<td>17876</td>
<td>2.88</td>
<td>1433.93</td>
</tr>
<tr>
<td>Dattagalli South</td>
<td>Chosen</td>
<td>141</td>
<td>2510</td>
<td>2.79</td>
<td>394.04</td>
</tr>
<tr>
<td>Sriramapura (Madhuvana)</td>
<td>Chosen</td>
<td>1343</td>
<td>153623</td>
<td>2.92</td>
<td>3922.46</td>
</tr>
<tr>
<td>Kurubarahalli</td>
<td>Chosen</td>
<td>202</td>
<td>16434</td>
<td>2.80</td>
<td>566.33</td>
</tr>
<tr>
<td>Kurubarahalli East</td>
<td>Chosen</td>
<td>795</td>
<td>32264</td>
<td>2.73</td>
<td>2170.50</td>
</tr>
</tbody>
</table>
discovered that out of these nine potential sites (Table 2) Dattagalli South had the lowest allocated demand and Devaraja Mohalla(Jala Darshini) had the highest allocated demand.

**Scenario – 2**

The second scenario was implemented without relocating existing fire stations and to establish new facilities at available 81 sites to serve all the demand points.

The result shows among the available locations 6 locations were chosen for in addition to existing fire stations to cover all the demand points within the travel limit of five minutes. When the 6 additional (chosen) locations for the potential fire station facilities were included within the model, (Table 3) the results indicated that the potential site for the fire station in Dattagalli had the lowest allocated demand with just 240 settlement polygons and a total of approximately 4272 people allocated to it. It was discovered that despite the inclusion of the other 6 potential facilities the existing fire station of Saraswathipuram still had the highest allocated demand for its CKD healthcare service.

Both scenarios indicate that the city requires nine fire stations to serve all the demand points. Therefore it is advisable to adopt the second scenario i.e., to establish

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**Table 3 A location-allocation model using travel time (in minutes) as impedance from proposed 9 fire station locations without**

<table>
<thead>
<tr>
<th>Name</th>
<th>Facility Type</th>
<th>Number of settlement Polygons</th>
<th>Demand Weight (Population)</th>
<th>Total Time travelled (In Minutes)</th>
<th>Total Weight Time (In Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manasagangothri</td>
<td>Chosen</td>
<td>1168</td>
<td>100065</td>
<td>2.51</td>
<td>2930.72</td>
</tr>
<tr>
<td>Dattagalli</td>
<td>Chosen</td>
<td>240</td>
<td>4272</td>
<td>3.28</td>
<td>787.82</td>
</tr>
<tr>
<td>Srirampura Madhuyana</td>
<td>Chosen</td>
<td>1190</td>
<td>120844</td>
<td>2.80</td>
<td>3329.79</td>
</tr>
<tr>
<td>Kurubarahalli</td>
<td>Chosen</td>
<td>304</td>
<td>17368</td>
<td>2.58</td>
<td>785.41</td>
</tr>
<tr>
<td>Kalayangirinagar</td>
<td>Chosen</td>
<td>819</td>
<td>74260</td>
<td>2.59</td>
<td>2123.40</td>
</tr>
<tr>
<td>Gayathripuram</td>
<td>Chosen</td>
<td>2124</td>
<td>276614</td>
<td>2.49</td>
<td>5289.28</td>
</tr>
<tr>
<td>Hebbal</td>
<td>Required</td>
<td>761</td>
<td>22118</td>
<td>2.41</td>
<td>1833.82</td>
</tr>
<tr>
<td>Bannimantap</td>
<td>Required</td>
<td>751</td>
<td>108415</td>
<td>2.53</td>
<td>1901.99</td>
</tr>
<tr>
<td>Saraswathipuram</td>
<td>Required</td>
<td>1002</td>
<td>169106</td>
<td>2.89</td>
<td>2900.48</td>
</tr>
</tbody>
</table>
additional 6 new fire stations without relocating existing 3 fire stations, which would be cost-effective.

**Conclusion**

This paper proposed a method of gradual optimization of the urban fire station plan based on the GIS location-allocation model. The analysis revealed that the fire stations in the study area are less in number with the intent of its maximal coverage within the minimum impedance time concerned. Emergency services need to be planned in such a way that it caters to most areas/locations within the quickest possible time as the fire service mission is to protect life and property from fire. The main goal of the spatial planners around the world is the selection and finding the optimal site for facilities. The location-allocation model provides the solution for the spatial decision not to find the optimal locations for locating the emergency service facilities but also acts as a tool to determine where and how many facilities are in need to fulfill all requirements. The location-allocation model helps planners to locate facilities and also to support them in deciding where to locate facility or facilities inside a chosen location. The result of both analyses revealed that, a total of nine fire stations are required to cover the entire city within 5 minutes. Therefore, the present study suggests adopting the second method that is establishing 6 new fire stations without relocating existing fire stations which would be cost-effective.

**Acknowledgement**

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**References**

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